The Goddard Earth Sciences and Technology Center
Annual Report

May 11, 2009 - May 10, 2010

University of Maryland, Baltimore County
Howard University
Hampton University
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GEST
GODDARD EARTH SCIENCES AND TECHNOLOGY CENTER

Goddard Earth Sciences and Technology Center (GEST)

Tenth Annual Report

10 May 2010

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INTRODUCTION

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INTRODUCTION

Turning the Corner on the Decade

This year marks GEST's tenth anniversary as a Cooperative Center with NASA. Decades make you look forward ten years to see where you will be in 2020. It is also a time of critical reflection to see how far you've come. As GEST was awarded for a ten year period, we know that this will be a critical year for the Center to make its case for continuance with NASA and we are confident that we will have a renewed vision and outlook for the Center by this time next year. What has GEST meant to UMBC?

GEST brings nearly $17M in research revenue to the University and this represents 20% of the entire UMBC research portfolio. The 168 faculty and staff who are associated with GEST are about the same percentage of UMBC's research faculty and can be compared to UMBC's 400 or so tenure-track faculty positions. Without exaggeration, and to quote the Vice President of the United States, GEST "is a big (bleeping) deal!" UMBC's support for the Center is unwavering and while these are very difficult times for the State of Maryland and the nation, UMBC is steadfast in advocating for the joint research centers with GSFC in the strongest terms.

The challenges are difficult. Faculty and staff at the University have undergone their second year of austerity measures that freeze salaries and apply furloughs to even the most junior of staff. Tenure-track faculty are generally taking 9-10 days of furlough in addition to the salary freeze. Because of the advocacy of the Vice President for Research, the Provost and the President, GEST research faculty escaped having furloughs applied, as long as they were supported by non-State funds. This year, the University System of Maryland will allow salary increases to retain the most junior faculty, the Ph.D. Research Associates. This is helpful in retaining faculty. But both research and teaching faculty continue to find opportunities elsewhere and this drain is a concern to the University and to Maryland. In 2010-11, UMBC will commit to aggressively attempt to retain faculty within the UMBC family.

However, unlike other Universities that are cutting faculty and programs, UMBC continues to thrive. We were named AGAIN the "#1 Up and Coming University in the Nation" by *US News and World Report* for the second straight year. The *Princeton Review* and the *Kiplinger Report* both named UMBC a "Best Value University". *CNNReports* recognized UMBC for its excellence in undergraduate research and teaching. GEST and its sister centers, JCET and CRESST, have had a strong influence on the trajectory of this young campus. It is a record of which GEST faculty and our NASA partners should be very proud. We are eagerly looking forward to the chance to continue our partnership with NASA in the Earth System Sciences.

Our tenth anniversary coincides with the tenth anniversary of the Terra satellite and Jen Shoemaker of our Earth Science production staff produced a review video this year to celebrate Terras's birthday (http://svs.gsfc.nasa.gov/vis/a010000/a010500/a010514/Terra10.mpg). The reader may have heard about the rapid sea ice changes in Antarctica, but the visualization by Trent Schindler clearly shows the changes in the Larsen B ice shelf over the last ten years, including the record 2005-6 breakup of state-sized icebergs (http://svs.gsfc.nasa.gov/vis/a000000/a003800/a003803/larsen.mp4). And, at the risk of being parochial, the same group provided coverage of UMBC's Smog Blog with yours truly as narrator (http://svs.gsfc.nasa.gov/vis/a010000/a010600/a010612/G2010-057_Smog_Bloggers_appletv.m4v). The outreach capabilities of our Earth Sciences and Heliophysics production staff is of tremendous value to UMBC's public image.

GEST scientists continue to receive accolades for their work. Dr. Shin-Chan Han had a wonderful year receiving three prestigious items of recognition. He was given a NASA Career Fellowship, awarded to outstanding young scientists. He was given the American Geophysical Union's Geodesy Section Award.

And third, he was given the Robert H. Goddard Exceptional Achievement in Science Award. That was an outstanding year for Shin-Chan.

Nickolay Krotkov was given the Robert H. Goddard Exceptional Achievement in Science Award for 2009 as well. It truly is an honor to have two of our young scientists gain the same award in the same year. In the Laboratory for Atmospheres at GSFC, Xiaowen Li won the Best First Author Publication Award, Huisheng Bian won the Outstanding Performance Award in the Science category, Toshihiru Matsui won an award for outstanding scientific research in the development and application of multi-sensor satellite simulators, and Kai Yang was given the Software Development Award for the sulfur dioxide algorithm on the Ozone Measurement Instrument. In the Laboratory for Heliophysics, Jan Merka won the Peer Award, given by his colleagues to the outstanding scientist in their Division. In all, this was a very good year for awards for GEST Faculty.

The Center continues to attract Goddard Visiting Fellows from around the world. Dr. Wenge Ni-Meister, an Associate Professor at the City College of New York was able to spend her sabbatical in the program this year. From the National Center for Atmospheric Research in Boulder, Colorado, Dr. Dezheng Sun came to do a sabbatical visit in the Global Modeling and Assimilation Office. Professor Chien Wang of the Massachusetts Institute of Technology was able to spend four months in the Climate and Radiation Branch. And Mr. Kurtulus Ozturk completed his one-year sabbatical from the Turkish Meteorological Service and returned home after working on validation for the upcoming Global Precipitation Mission. This was truly an impressive group of visitors who were able to spend sabbatical time at GSFC and UMBC.

In this report, you will see why we are so proud of the accomplishments of the GEST faculty members. I have been a member of the NASA Earth System Science Subcommittee for two years now and was recently appointed as Chair of the NASA Applied Sciences Advisory Group. Both of these roles helped the Earth Sciences Directorate review research and applications leading to NASA's strategic goals. In most of the "significant achievements" in the Earth Sciences I see signatures of GEST faculty. Our research runs like a very thick thread through NASA’s core mission and ties us strongly to the future of the agency. I hope you will take the time to read this report and see how GEST's achievements are interwoven into NASA's research portfolio.

Raymond M. Hoff
Director

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EXECUTIVE SUMMARY

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Executive Summary

The Goddard Earth Sciences and Technology (GEST) Center has now completed its first decade and continues to grow. GEST is up to 162 research faculty and staff (from 134 last year) plus an excellent administrative staff of 12 professionals. GEST's growth attests to the excellent scientific research environment it brings to GSFC and UMBC. Our faculty have the opportunity to work with leading researchers at the Goddard Space Flight Center as well as to interact with the faculty and students of a quickly growing medium-sized research intensive university. GEST researchers work in seven research groups organized by their respective affiliations within Goddard and their areas of scientific interest.

We continue to build new linkages between our partners Hampton University, Howard University, Caelum Research Corporation and Northrop-Grumman Corporation. In the last year, two tasks with Northrop-Grumman advanced planning on the Atmospheric Chemistry Experiment (ACE) mission and its radar design. We continue to build linkages with the Beltsville Campus of Howard University and new infrastructure capability is being added at the Campus so that more state-of-the-art instrumentation can be added.

This Annual Report gives brief one or two page discussions of the research focus and yearly results for GEST faculty and staff. In addition, there are short objectives for each task that define the work to be conducted in the next year and form the basis of our Annual Research Program Plan (ARPP). We report on 152 separate Tasks or Grants of GEST faculty researchers and visiting fellows. Each report lists the name of the Task or Grant by which the research is funded, the names of collaborators, accomplishments during the past year, and a plan for work during the forthcoming year. The Appendices consist of cumulative lists of GEST publications in monographs, professional journals, conference proceedings papers, and other presentations/reports. During this past year, our GEST faculty authored, published or had accepted 190 refereed journal publications and 62 other publications. Additionally, 452 presentations and posters were selected for inclusion at numerous conferences and meetings during this same period. The Introduction listed important peer and society awards that recognized the quality of the work of the faculty. Best First Author Papers were recognized for GEST faculty throughout GSFC Earth Science Directorate. GEST continues to show a remarkable success rate of the research proposals submitted: out of 158 applications for grant funding reported by our faculty participating either as the PI or as a Co-I, 95 have been awarded with another 44 still pending a decision. These submissions by our faculty went to NASA, NSF, and other agencies in collaboration with their colleagues at GSFC and elsewhere.

The Goddard Visiting Fellows Program had four candidates come to Goddard during the past year for varying lengths of time. The Visiting Fellows continue to be predominantly faculty from other universities who wish to spend sabbatical arrangements at GSFC. The candidates' activities while at Goddard are reported as contributions within their respective research groups.

In terms of Educational Programs, GEST continues to administer the Graduate Students Summer Program, with nine students participating in 2009. All participants were paired with scientists as mentors to work on projects within the Earth Sciences. GEST also hosted eleven students as Student Summer Interns in the Earth Sciences Summer Institute and an additional eight self directed summer interns. The GEST Graduate Fellowship in 2009-10 was awarded to Mr. James Travis of the Mathematics/Statistics Department.

As part of the cooperative research program with GSFC, GEST facilitates collaboration between scientists based at Goddard and in organizations outside the Center who must work for short periods of time at GSFC, at field research locations, or at external conference sites. This year, we had 107 visitors participate in this program from U.S. universities and institutions, as well as international federal laboratories and universities. An additional 47 travelers were sponsored to attend four meetings for

GEWEX, GMAO, and educational outreach programs. Some of these visitors came to Goddard on more than one occasion. The list of visiting scientists and their home institutions are presented in the appendix.

The leadership of the International GEWEX Project Office (IGPO) continues to reside in GEST. This office provides management, service and coordination functions for more than 1500 scientists from over 45 countries who are working on the water and energy cycle science. It supports the information and management needs of the World Climate Research Program (WCRP). Dr. Peter van Oevelen is Director of the IGPO. In another important area of influence, Dr. Lars Peter Riishojgaard, GEST Senior Research Scientist, continues as Director of the Joint Center for Satellite Data Assimilation. Dr. Robert Curran, Senior Research Scientist, continues to work at the Climate Change Science Program Office producing "Our Changing Planet". In addition, GEST sponsors a number of Intergovernmental Personnel Assignments who are working at NASA Headquarters and at the NPOESS Integrated Program Office.

This summary just briefly touches the accomplishments of GEST during the past year and I hope it gives the reader an interest in reading the details of the research accomplished by the GEST Faculty, in cooperation with collaborating scientists at GSFC.

Raymond M. Hoff

Director

Office of the Director and AETD
(Code 100-500)

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GEST Highlight: Global Map of Average Sea Surface Density

Helen-Nicole Kostis

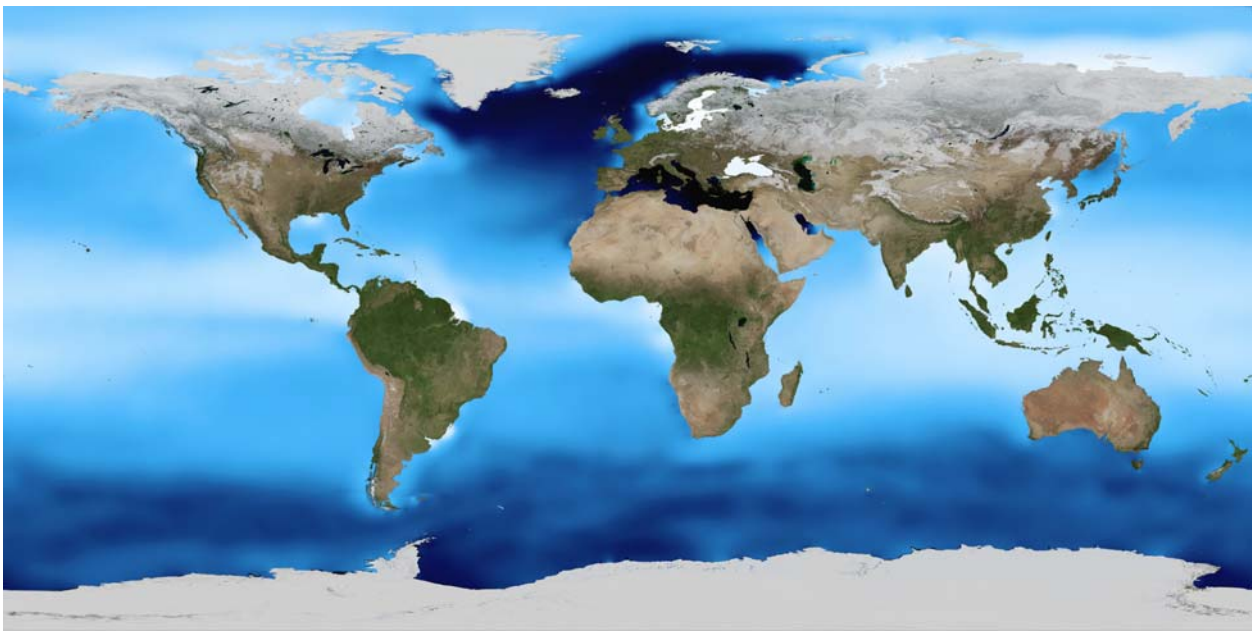

Figure: The average density of sea surface water can be calculated from the average sea surface temperature and salinity using the state equation for seawater. This still shows the long-term average sea surface density, with light blue regions having the least density and dark blue regions having the greatest density. The sea surface density variations are actually very small, less than 3% overall, but the variation is very important. There are three stable, dense regions in the ocean's surface, one in the sea around Iceland, Greenland, and Scandinavia and the other two near or under major Antarctic ice shelves. In these regions, the surface water becomes dense enough to sink and join the deep ocean currents. In fact, this sinking is thought to drive these deep currents as part of a system called the Thermohaline Circulation. This circulation has a strong effect on the Earth's climate, influencing the Gulf Stream, El Niño events, and both past and future Climate Shifts.

NASA/Goddard Space Flight Center Scientific Visualization Studio

Reference DEM data provided by Jay Friedlander

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Task 130-67-234: **GSFC Earth Science and Education Multimedia and Visualization Production**

GEST Investigators: Jefferson Beck, Ryan Fitzgibbons, Maria Frostic, Helen-Nicole Kostis, Stefanie Misztal, Silvia Stoyanova, Jennifer Shoemaker, Scott Wiessinger (Sponsor: Wade Sisler, GSFC 130)

GEST Media Specialists: Rob Garner, Katherine Lewis, Laura Motel, Trent Schindler, Ernest Wright

Description of Work

Goddard's Earth Science Multimedia group excels at translating complex scientific concepts into a suite of public outreach and educational media products. The team creates satellite media tours, video podcasts, and other multimedia products to support NASA GSFC science missions. They produce scientific data visualizations and conceptual science animations, and acquire a broad range of high definition video footage. In addition, the GEST media group supports GSFC TV with camera operation in covering live press conferences, media events, and other live shot campaigns. The group continues to break new ground with new formats and outlets for their work, including a variety of social media platforms and high-end productions in 3D and for the Science on a Sphere. They also provide audio/visual support for the Digital Learning Network and live Internet broadcasts.

Accomplishments during the Reporting Period

Video Production

Media Specialist Laura Motel produced nine live TV interview campaigns on topics such as the Hubble servicing mission, the ozone layer, and Arctic sea ice. Reaching an average of 20 TV stations per campaign, they brought news of NASA missions and science to viewers across the country. She also produced longer form live TV and web broadcasts, NASA TV video files, reporter packages, and other short videos. Motel promotes Goddard video and multimedia releases to the broadcast news media, bloggers and other communications outlets through media advisories and breaking news tips, and personally pitches stories to key broadcasters. She currently supports the Climate@Home project, which invites users around the world to donate idle processing power on desktops and laptops to compute global climate models.

Michelle Williams spent her first year with GEST producing a suite of multimedia products in collaboration with the larger Earth science team. She produced a video commemorating the 10th anniversary of NASA's Earth Observatory, planned and produced media for the public event "Earth System Science at 20" symposium, produced a video about the water cycle for Earth Science Week 2009, and spearheaded the *Science for a Hungry World* podcast series that reached over half a million viewers. She also organized the timely Climate Essentials gallery on the Scientific Visualization Studio website.

Since joining GEST in May, Jennifer Shoemaker has produced, written, and edited eight Earth science videos, together totaling over a half-hour of finished content that has drawn over 56,000 YouTube views. She has also conducted thirteen on-camera interviews, written or edited several other videos, produced a popular web image gallery, written news feature items, supported live shots, and contributed an extensive amount of new footage to the footage library. As primary producer for Landsat, she developed a media plan leading up the 2012 launch of the Landsat Data Continuity Mission and provided media support for several events.

Scott Wiessenger joined the team in September as the primary Heliophysics and Astrophysics producer at Goddard. He has already assisted several projects including an LRO press event, Earth Science Week, and the Cosmic Background Explorer. He has produced or co-produced visuals for the IBEX (Interstellar Boundary Explorer) press conference, the video Einstein's Cosmic Speed Limit for the Fermi Gamma-ray Telescope group, and the video

Suzaku: Intergalactic Prospector. Wiessinger has begun work on a short blazar video, a supernova video, visuals for Acceleration Reconnection and Turbulence and Electrodynamics of the Moon's Interaction with the Sun, and a video on dark flow. He is also supporting the SDO (Solar Dynamics Observatory) mission with a video file, a series of older DVDs, and visuals for the pre-launch press conference.

Ryan Fitzgibbons continued as the lead Education Producer, focusing on school-targeted webcasts, special Digital Learning Network events, and the development of new content for future DLN modules. Live program and packaged material content included a special performance by artist/musician Kenji Williams for Earth Day, a look at the newest Hubble images with scientist Eric Smith and SM4 astronauts Johnson and Altman, and a series of ocean-focused webshorts and live webcast during Earth Science Week. Fitzgibbons worked closely with Dr. Marci Delaney and Shane Keating to expand the breadth and reach of the DLN, including a simulcast through the social media-friendly broadcasting site UStream.tv. Fitzgibbons is currently developing a new series of webshorts focusing on the legacy of Hubble science.

This year Jefferson Beck assumed the role of team lead for the Earth Science Producers, helping to manage workloads and representing the team externally. He produced videos on topics including NASA and Agriculture, Earth Science Week, Arctic sea ice, and a return to Pine Island Glacier. He has also continued work on a podcast for the Aqua satellite and now leads a campaign on the Global Hawk's Pacific atmospheric chemistry mission and a campaign on visualizing sea level rise. In the leadup to the Copenhagen climate change conference, Beck presented NASA Earth science visuals to a multi-agency working group at the U.S. State Department.

Silvia Stoyanova provided full-time multimedia and research support for three critical NASA/NOAA missions including a suite of multimedia products for the GOES-O mission, continued support of the IBEX mission, and a prelaunch campaign for the NOAA-N Prime mission. In addition to conducting extensive research on the projects, she wrote, directed and produced six short videos and several live media campaigns, traveled and covered the launch of the GOES-O mission, and wrote and designed multiple print materials for the projects. After completing a number of tasks for the GOES-P mission, she will be supporting NPP during 2010.

While the team said goodbye this year to Maria Frostic and Stefanie Misztal who moved on to other worthy pursuits, they remain grateful for their legacy of work. Besides continuing to advance Goddard's social media presence, this year Misztal provided all-around editorial support to the greater team, including assisting Maria with a substantial body of work on NASA's Glory mission set to launch this spring. This year Misztal and Frostic also produced and edited videos for Earth Science Week and the NASA and Agriculture campaign.

Scientific Visualization Studio Production

Ernest Wright supports Lunar Reconnaissance Orbiter (LRO) education and public outreach, creating or contributing to more than a dozen visualizations of the spacecraft's flight path and data gathering. He animated the orbital tracks of all 63 of Jupiter's moons for the Science on a Sphere production "Largest." His visualizations of the Lunar Crater Observation and Sensing Satellite (LCROSS) impact site, initially created for ground-based observation planning, were also used for target selection, mission operations simulations, real-time graphics for the live TV coverage of the impact, and in press briefings by both NASA/Ames and NASA/Goddard. In the coming year, he will continue to support LRO.

Trent Schindler created visualizations of satellite data from NASA earth science missions and worked to develop new techniques for visualizing volumetric and 3D datasets, writing custom software in the IDL, RSL, and MEL languages for use within Maya and Pixar's Renderman. Highlights of his work this year include a 3D flyover of the Galapagos Archipelago, incorporating visual imagery, sea-surface productivity data and temperature data,

illustrating the influence of geography, current, and temperature on the biosphere; a visualization of the relationship of atmospheric CO_2 to the seasonal cycles of greening of the planet; and, a collection of volumetric visualizations of atmospheric variables from the MERRA long-term analyses of weather and climate, incorporating stereo 3D techniques.

This year Helen-Nicole Kostis developed a variety of stereoscopic visualization media in support of NASA science missions, including Earth Science visualizations that showcase dynamic changes in arctic Sea Ice, global biosphere data from the last decade, and visualizations for the LRO mission. In addition, she produced visualization media that showcase Sea Surface Temperature, Ocean Salinity and Density for the Earth Science Week 2009 and material to support the Terra 10 anniversary video released during the AGU conference. As a member of the Information Science and Technology Committee, she invited experts from the fields of computer graphics and organized colloquia for NASA/GSFC employees. Upcoming projects include creating a wide collection of Earth Science visualizations for various display systems and providing support for breaking news and stories for NASA scientists and public outreach.

GSFC Web Production

In his role as Web Team lead, Rob Garner manages the team's workloads and priorities and acts as chief liaison to Goddard PAO and NASA HQ. This past year, he has implemented streamlined content-intake and publishing practices, greatly increasing the team's overall efficiency. Garner additionally oversees team projects, managing a web traffic tracking plan to better gauge the success of recent stories, implementing RSS, and increasing Goddard's presence on Facebook and Flickr. His team continues to support Hubble, LRO, SDO, STEREO, hurricane and other NASA Web sites.

Katherine Lewis continues to develop her role as interactive web producer, using Flash to create online interactive features, including a video lecture on Goddard's John Mather, a rotating homepage slideshow, and a website for Science on a Sphere's *Frozen*. She also developed a customized Flash slideshow for the Goddard home page designed to increase the viewership of the best news coming out of Goddard. Day to day, she has been responsible for editing and posting feature stories, mission news, aggregation pages, images, and video to NASA.gov. In 2010, Lewis will be developing a JWST 3D-rotation feature and the Goddard Virtual Tour, a large-scale, interactive overview of the center.

Selected 2009 highlights

Galapagos Islands Flyby, Trent Schindler
http://svs.gsfc.nasa.gov/goto?3628

Sea Surface Temperature, Salinity and Density, Helen-Nicole Kostis
http://svs.gsfc.nasa.gov/goto?3652

Lunar Topography in Natural Color, Ernest Wright
http://svs.gsfc.nasa.gov/goto?3594

Terra@10: Terra 10th Anniversary Video, Jennifer Shoemaker
http://svs.gsfc.nasa.gov/goto?10514

Melting Ice, Rising Seas, Jefferson Beck
http://svs.gsfc.nasa.gov/goto?10503

Science For a Hungry World: Introduction, Michelle Williams
http://svs.gsfc.nasa.gov/goto?10490

Salt of the Earth, Ryan Fitzgibbons
http://svs.gsfc.nasa.gov/goto?10504

GOES-P: Mission Overview Video, Silvia Stoyanova
http://svs.gsfc.nasa.gov/goto?10575

The Story of the Universe by John Mather, Katherine Lewis
http://www.nasa.gov/externalflash/mather/

Objectives for the Coming Year

The Earth Science and Education Multimedia Production team will continue to produce a suite

of multimedia products and explore new approaches to the ever-changing media landscape. The team will support a range of current NASA missions, with specific attention to Landsat, the Hubble Space Telescope, and the Aqua satellite, while also providing support to emerging missions such as the Glory, Aquarius, and Landsat Data Continuity Mission satellites and provide comprehensive support to new field campaigns such as the Operation Ice Bridge and the Global Hawk unmanned aircraft missions. They will also work to strengthen the connections made over the previous year with the cross-center Earth Science Storytelling Team to produce major thematic campaigns on topics like drought and sea level rise. The visualization team will significantly enhance their stereoscopic portfolio and produce major products on the A-Train suite of satellites, while the web team will take the lead in producing an interactive virtual tour of Goddard Space Flight Center.

Task 606-73-250: **Broadening the NAI-MIRS Program and Astrobiology Research Collaborations for underrepresented communities**

GEST Investigator: Benita Bell

Collaborators: George Cooper (PI, NASA Ames Research Center), Todd Gary (Tennessee State Univ.), Wence Lopez (Polytechnic Univ. of Puerto Rico)

Description of Research

The goal of this project is to develop new initiatives to support the NASA Astrobiology Institute Research Support Program (NAI-MIRS) and strengthen existing initiatives in the field of astrobiology for underrepresented communities. Astrobiology by its very nature crosses disciplines, which serves to bring faculty and students from diverse cultures together to address key scientific questions regarding life in the universe. The focus has been identifying colleges and universities within the U.S. with faculty interested in broadening their research capacity and enhancing curriculum development. By integrating interdisciplinary models into their science programs, faculty members have found an effective tool for recruitment and retention. EPO activities also have been developed through these collaborations, including Astrobiology in the Secondary Classroom. Through their partnership with the NAI Lead Teams, these research faculty members from minority institutions have generated numerous publications. Bell has been a key NAI-MIRS team member, assisting in recruiting faculty and developing joint projects. Since the inception of the NAI-MIRS program, ten faculty members have been recruited and selected as Fellows. NAI-MIRS Faculty have been recruited and selected from Hispanic Serving Institutions, Historically Black Colleges and Universities and Native American Institutions. Colleges and Universities include Howard University, University of Puerto Rico, South Carolina State University, Tennessee State University, Colorado State University at Pueblo and the University of Montana. Additionally, the first Native American Research Laboratory (NARL) was developed under the construct of Native American Professor Michael Ceballos at the University of Montana during his tenure as a NAI-MIRS Fellow.

Accomplishments during the Reporting Period

Bell served as an organizing team member for the first Minority Institution Workshop held at NASA Ames, where the goal was to develop strategies and determine best practices to assist NASA at large in its effort to attract and recruit a diverse workforce. Several NAI-MIRS Fellows were selected to attend the workshop to discuss their research and to share the impact of their research partnership experience. The NAI-MIRS Program and MIAC continue to be two significant programs that are leading a national effort to engage the minority community in astrobiology. Bell also continues to serve as Co-Director of MIAC along with Dr. Todd Gary of Tennessee State University. Initiated through the

MUSPIN Program at NASA Goddard Spaceflight Center, the Minority Institution Astrobiology Collaborative (MIAC) is a virtual collaboration of minority universities with the goal of generating research opportunities for faculty and students in the field of astrobiology.

Bell developed a partnership between the NAI-MIRS Program, the NASA Science and Technology Institute (NSTI) and the United Negro College Fund Special Programs Corporation (UNCFSP) for joint recruiting of faculty and students for summer internships and fellowships. At an upcoming annual astrobiology conference (ABSciCon) in April 2010, Bell and Todd Gary will host a session, along with poster sessions and presentations, for MIAC and NAI-MIRS.

Bell also developed a proposal concept between MIAC and the Polytechnic University in Puerto Rico (PUPR) that links astrobiology with the field of robotics. She collaborated with Professor Wence Lopez, Director of the Center for Robotics and Industrial Controls. This research concept will involve the application of advanced robotic technologies to conduct scientific analyses (*i.e.* chemical reactions, sample prep and analyses, etc.) on projects that relate to the study of MARS. The research concept will allow numerous identified extrasolar compounds such as meteorites, asteroids, various rocks, soils and other compounds to be studied. In an effort to provide greater community awareness to astrobiology, Bell conducted workshops for K-12 (one of which included a Digital Learning Workshop with middle schools from Connecticut), the NASA SEMAA K-12 Science Program at Tennessee State University, the Boys and Girls Club, and various Native American outreach activities. Bell developed a K-12 partnership with the Polytechnic Institute of Robotics.

Other activities during the past year included Bell's assistance in developing the HBCU Partnership Exploration Workshop held at NASA Goddard, and her work as a peer reviewer for the NASA URC (University Research Centers). She also continued her ongoing work with Dr. George Cooper at NASA AMES Research Center on the analysis and characterization of organic compounds in carbonaceous meteorites, and her work with Dr. Cooper to expand research to include international partners.

Objectives for the Coming Year

Bell plans to establish a new initiative to expand astrobiology through an astrobiology seminar series that will involve NAI-MIRS Fellows, targeted for but not limited to minority universities. Bell also will assist in recruiting additional NAI-MIRS Fellows. She will continue with her work with Dr. Cooper as well.

Task 130-84-296: **NASA's Best Students (Beginning Engineering, Science and Technology)**

GEST Investigators: Marcianna Delaney, Susan Hoban and staff: Laurie Cook and Brittany Hamolia

Collaborators: Carmel Conaty (GSFC 130), Robert Gabrys (GSFC 130), Maureen McMahon (Anne Arundel County Public Schools), Richard Cerkovnik, (Anne Arundel County Public Schools), Michelle Graf (consultant)

Description of Research

The NASA's BEST Students project involves the research, development and application of educational technologies to communicate NASA science and engineering concepts to educators and students. The NASA's BEST Students team provides professional development for educators and curriculum support resources with a space exploration theme for elementary and middle school students' engineering clubs and for high school students' robotics clubs. The project also hosts engineering challenges and two-week summer bridge programs, centering on lunar exploration for middle and high school students. More information may be found on the web: http://userpages.umbc.edu/~hoban/BEST/.

Accomplishments during the Reporting Period

Highlights

Some highlights from the past year include the fact that the NASA's BEST Students project was awarded three-years of follow-on funding in 2009 after a one-year pilot. Additionally, the Saint Michael School in Hudson, MA implemented the BEST Engineering Club after school in Fall 2009, and the response from students and parents was so overwhelming that the BEST curriculum has now been incorporated into the school day.

The main objective for the NASA's BEST Students project for 2009 was to broaden the dissemination of professional development and curriculum support. The BEST team attended the ESMD Project Managers Meeting, February 24-27, 2009, at NASA Kennedy Space Center to present project achievements and goals for the coming year.

Educator Professional Development

Early in the year, an online professional development series was designed and delivered. The BEST team made a presentation to the MSDE Elementary Technology Coordinators on May 7, 2009 at the Baltimore Museum Of Industry, which resulted in an invitation to deliver professional development to educators from across the state at the Technology Education Association of Maryland (TEAM) Conference on October 16, 2009. Professional development was also provided at "100 Hours of Astronomy" at NASA GSFC, April 3 and 4, 2009 (Informal educators and Teachers Night).

Student Programs

In Spring 2009, the BEST Team provided a workshop entitled "Nice Ride: Design and Build a Lunar Rover" for 24 middle school students (23 girls and 1 boy) at the workshop for middle school students at the Sally Ride Festival on April 18, 2009, held at the Fairfax Campus of George Mason University.

Three summer bridge activities were implemented: Lunar Robotics for MSDE Gifted and Talented Students, co-funded by NASA and the Maryland State Department of Education for 20 rising 8th and 9th graders from across the state; Lunar Robotics for Rising 9th Graders in STEM Magnet High Schools in Anne Arundel County; and STEM Systems (Modeling the Physics of Rocket Motion) for Rising 10th Graders in STEM Magnet High Schools.

A Problem-based Learning course was designed and piloted with thirty-two 10th grade students in the South River STEM Magnet High School in Anne Arundel County in Fall 2009.

Additional Activities

A stakeholders' workshop in the area of STEM Systems was held in collaboration with Anne Arundel Community College in March. As a result of this workshop, a successful proposal to the NASA Teaching from Space program was submitted entitled "Rockets As Systems: A Professional Development Course for Middle and High School Educators."

A new research study on the effectiveness of electronic professional development for STEM educators was initiated this year. A draft of a technical report was completed, and the design of the data collection phase has begun.

The BEST team began to collaborate with Blended Schools to place the BEST curriculum online. Also, discussions with Science Kit, Inc. have resulted in the development of a kit that contains the materials for an after-school BEST engineering club. These kits will be finalized next year and schools will be able to purchase them.

Objectives for the Coming Year

The addition of a consultant on the West Coast will enable the expansion of professional development activities in the western part of the United States. In addition, the NASA's BEST Activity Guides will be finalized in 2010, and the NASA's BEST portal website will go live in 2010. The Teaching from Space project that was awarded in 2009 will begin, and a pilot hybrid course will be offered in 2010. Also, the research on electronic professional development will be submitted for publication.

Task 550-74-257: **Development of Active and Passive Sensors for Remote Sensing Applications**

GEST Investigator: Elena Georgieva

Collaborators: William Heaps (GSFC 613.3), Elizabeth M. Middleton (GSFC 614.4), Petya K. E. Campbell (JCET/UMBC), Emily Wilson Steel (GSFC 554), Wen Huang (SSAI, GSFC 613.3), Huguens Jean (GSFC 554)

Description of Research

This research focuses on developing passive and active sensors for remote sensing determination of various atmospheric trace gases. The objective for the active sensor work is to build up a unique airborne laser system for measuring carbon dioxide changes in the lower atmosphere using as its detector a section of the Fabry-Perot (FP) Interferometer constructed as a passive sensor during previous years. One advantage of this new approach is that it reduces the number of lasers required for the measurement; by reducing the risk for a space-borne system, much of the responsibility for wavelength control is placed on the detector rather than the laser, eliminating one of the difficulties presently facing proposed laser systems. It also provides a straightforward path to space since the majority of components involved in the construction of the system have already flown on satellites. The work in the laboratory includes building and testing the new laser transmitter for CO_2 measurements using a superluminescent light-emitting diode (SLED), Nd:YAG (neodymium-doped yttrium aluminium garnet) laser, and an Optical Parametric Amplifier (OPA).

Georgieva also continued her work on improving the passive sensor for methane measurements on Mars and is participating in a preliminary proposal for the SALMON ExoMars Trace Gas Orbiter Instruments Investigation. In addition to the experimental optical engineering work in the lab, Georgieva continues to work on data analysis and modeling, using IDL routines.

Accomplishments during the Reporting Period

Georgieva is in the process of developing a lab prototype of a new active sensor for CO_2 measurements. The preliminary system consists of a source formed by a SLED operating in the 1560-1580nm range followed by an OPA and a small telescope used to collimate the transmitted beam. A Nd:YAG laser is used to pump the OPA. The receiver consists of a larger telescope (diameter on the order of 30-50 cm) fiber coupled to the existing passive Fabry-Perot instrument channel, which is used as a detector.

Georgieva has focused on the calibration study of SLED power to be used in the lidar system for atmosphere CO_2 concentration measurement. The concentration level for CO_2 in atmosphere is about 385 ppm. In order to achieve sensitivity at ppm level for CO_2 content variation, the signal-to-noise ratio of the system is expected to be well below 1%. A careful design is required in order to calibrate any fluctuation or system drift during the measurement. The error sources include the SLED power, optical transmission, detector and electronics. The OPA is used for the SLED amplification process because it is capable of producing a pulse 100 times shorter in duration than an EDFA. This has the effect of reducing the error arising from solar background light by a factor of 100.

The current laboratory lacks access to the outside atmosphere; therefore, fibers (over 20 meters) are used to transmit the light to the roof telescope setup. The use of long fiber has created a large fluctuation in the measurement, typically by a small percent in the signal-to-noise ratio for long-term measurement (*e.g.*, overnight). This fluctuation is the result of the wavelength dependence of fiber coupling and

transmission loss due to the use of long fibers. The in-lab test using short fibers has proven that a signal-to-noise ratio better than 0.5% can be achieved over a three-day period. The PI is in the process of moving to a new laboratory, relocating, arranging and aligning the equipment in a new space.

Georgieva presented the results of her research at the SPIE and AGU 2009 fall meetings. She is also a first author on a paper published in *SPIE* and a co-author of a paper titled "Development of a miniaturized, low-power, low-cost gas correlation radiometer", submitted to *Measurement Science & Technology*.

She is a co-investigator on two proposals submitted to NASA ROSES Research opportunities. Georgieva collaborated with Dr. Middleton and Dr. Campbell on a study for a fluorescence measurement system using the Fabry-Perot technique. She also worked on a proposal titled "Differential Radiometer Using Fabry-Perot Interferometric Technique for Precise Remote Sensing Determination of CO_2, O_2, H_2O and CH_4 Column Concentration", submitted for NASA, (ROSES), Airborne Instrument Technology Transition. She also collaborated with Dr. Emily Wilson and Huguens Jean (Code 554) on research for a Hollow-Fiber Gas Correlation Radiometer for Column Measurements of Formaldehyde, Methane, and Water Vapor on Mars. She is a Co-I on a proposal titled "Development of a miniaturized, low-power, low-cost gas correlation radiometer instrument for mapping multiple trace gases on the 2016 Mars Science Orbiter", which was submitted to the Planetary Instrument Definition and Development Program.

This past year, Georgieva taught a graduate course at UMBC, "Fundamentals of Polarimetric Remote Sensing and Gas Absorption", as a part of a PHYS 721: Atmospheric Radiative Transfer Course with Dr. J. Vanderlei Martins (JCET).

Objectives for the Coming Year

Georgieva's principal goal is to demonstrate the ability of the Fabry-Perot Interferometer technique to be used to make ultra-precise determinations of the total column abundance for CO_2 and O_2.

The first activity will be to construct and test a lidar system for CO_2 measurements. She expects to have a lab version operational in 2010 and to design a flight version to be tested on NASA DC-8 flying laboratory in late 2010. Associated with this will be the calibration of both ground and flight versions.

She will continue to develop the methane instrument for Earth and Mars applications by building a prototype and testing it from airborne platforms. Instead of using the solid Fabry-Perot etalon, she and her team are optimizing the design by using air gap and liquid crystal etalons. The second activity will be to calibrate the CH_4 instrument. This involves laboratory experiments using a gas pressure cell in which known amounts of CO_4 can be added to the optical path viewed by the instrument.

Finally, the researchers will continue to refine the precision of the CO_2 system as a ground-based and airborne system particularly for use in the validation of GOSAT.

Task 690-07-243: **Planetary Data Systems**

GEST Investigator: Susan Hoban

Collaborators: Nand Lal (GSFC); Ed Grayzeck (GSFC)

Description of Research

Work under the Planetary Data System task includes investigating information science and educational technology for the use of data from NASA's planetary missions to advance education in science, technology, engineering,

and mathematics. Hoban is working with Goddard collaborators to design and implement an educational program that will encourage college students to pursue Planetary Science through the use of data from these missions.

Accomplishments during the Reporting Period
NASA's Planetary Data System is the ultimate repository for all data from NASA's planetary science missions. Along with the Goddard collaborators, the GEST PI is working to design and implement the NASA Planetary Data System College Student Investigator (CSI) initiative. During 2009, the second cohort of four college student interns at Planetary Data System nodes was funded to design and conduct research projects based on data from NASA's planetary missions. The first two students presented their research proposals in January, and the PDS Management Council accepted these proposals. Hoban and the students presented two poster papers at the 41st Annual Division of Planetary Sciences of the American Astronomical Society Meeting in Fajardo, Puerto Rico.

Additionally, Hoban attended quarterly meetings of the PDS Management Council to report on the CSI Initiative.

Objectives for the Coming Year
Half of the CSI cohort will graduate in the spring, so the researchers will be recruiting new students for the fall. At least one CSI student will present his research proposal in 2010. Hoban will collaborate with the Goddard sponsor to develop a hybrid PDS tutorial for the 42nd Annual Division of Planetary Sciences of the American Astronomical Society Meeting to be held in Pasadena, CA. Also, she will attend PDS Management Council meetings and provide support as needed.

Task 555-71-245: **Airborne Instrument Technology Transition (AITT) Program: Radio-Frequency-Interference (RFI) Detection**

GEST Investigator: Priscilla Mohammed

Collaborators: Simon Yueh (PI, JPL), Jeffrey R. Piepmeier (Co-I, GSFC 555), Joel T. Johnson (Co-I, The Ohio State University) and Christopher S. Ruf (Co-I, The University of Michigan).

Description of Research
Radio frequency interference (RFI) is a recognized problem for airborne and space-borne microwave radiometers. With the increasing use of active services near measurement frequencies, it is significant to address issues pertaining to RFI detection and mitigation. The double detector (DD) system developed at GSFC is a combination of detection hardware and algorithms designed to address this problem. The DD, which uses the kurtosis statistic to detect non-Gaussian signals, has been previously used in ground-based campaigns demonstrating RFI detection in microwave radiometers. An airborne campaign, conducted in the fall of 2008, included RFI detection back-ends from the Ohio State University and the University of Michigan in addition to the DD. The airborne campaign was conducted to demonstrate RFI detection for L-band microwave radiometry whose results will also improve the knowledge of the L-band environment. Understanding the L-band RFI environment will have a major impact on the SMAP (Soil Moisture Active Passive) mission.

The focus of research this past year included data analysis from the airborne campaign, which was part of the SMAPVEX08 (Soil Moisture Active Passive Validation Experiment 2008) Experiment Plan.

Accomplishments during the Reporting Period
Three RFI detection back-ends simultaneously observed the IF signals from the L-band radiometer of the Passive Active L-band Sensor (PALS) on board a Twin Otter aircraft. The backend systems included the L-Band Interference Suppressing Radiometer (LISR) from the Ohio State University and the Agile

Digital Detector (ADD) from the University of Michigan as well as the DD. Existing Matlab code was modified to process approximately 67 hours of raw data collected by the DD. The high rate data was integrated to produce SMAP-like data and used in an RFI detection algorithm, which incorporated the pseudo-kurtosis. Pseudo-kurtosis time series plots were used to demonstrate the usefulness of the statistic to detect and classify different types of RFI. A short paper was written on these results, which showed that the DD can detect CW RFI that goes undetected by conventional pulse blanking using high rate data, and two types of RFI (CW and pulsed) are studied, comparing theoretical to experimental results. This paper will be submitted for publication this year. Additional flights occurred in February and March of 2009. Similar processing described above was conducted for the 27 hours of additional data. Results from the data analysis provided better understanding of the RFI environment to be encountered by SMAP.

Mohammed managed a summer intern who helped in the calibration of the airborne data. The intern worked on a model for the geolocation of the PALS footprint, solved the issue of synchronization between navigation and RFI data timing, and calibrated data, converting raw data or digital counts into brightness temperatures.

The research under the AITT program was transitioned to SMAP. The GEST PI became the team lead for the level 1B science algorithm team. A first draft of the algorithm theoretical basis document (ATBD) was submitted to the SMAP Science Definition Team (SDT) at JPL. A workforce plan and preliminary schedule was completed and support was provided at meetings and telecons. Mohammed presented work on the RFI challenge facing SMAP at a Digital Signal Processing (DSP) peer review at GSFC, which included work on RFI detection algorithms to be included on SMAP as well as the results of SMAP simulations using the aircraft data described above.

She also designed a cavity resonator for conductivity measurements in support of the GMI (Global Precipitation Measurement-Microwave Imager) mission. These measurements are used to characterize loss of the antenna reflector, which in turn is useful for verifying requirements and for radiometric calibration.

Objectives for the Coming Year

The short paper written on the results of the aircraft data will be submitted for publication to the *IEEE Geoscience and Remote Sensing Letters.* As team lead for the SMAP level 1B science algorithm team, Mohammed will continue to provide support at meetings, teleconferences and workshops, and complete the second draft of the ATBD. Primary responsibilities include developing code in Matlab for the RFI mitigation algorithms as well as radiometric calibration. Written responses to comments from the first DSP peer review will be provided in preparation for a second DSP peer review.

There are plans for more flights of the PALS instrument on the Twin Otter aircraft, which will include the three RFI backends mentioned above (including the DD from GSFC.) Depending on the flight paths, the data will provide additional coverage of the L-band RFI environment or provide insight into its evolution.

Task 902-00-005: **Climate Change – GCRP - Global/Water Energy Cycle; GEO/GEOSS**

GEST Investigator: Sushel Unninayar

Collaborators: Lola Olsen (PI, GSFC)

Description of Research

NASA Headquarters assigned this task to GEST through the Global Change Data Center (GCDC) in GSFC's Earth Science Directorate. It provides the necessary scientific, technological, and research leadership support required by the White House's Office of Science and Technology Policy (OSTP)'s Committee on Environment and Natural Resource's (CENR)—in particular, the CENR Sub-Committee on the US Global Change Research Program (USGCRP). The task also supports NASA HQ in a variety of other NASA/SMD's internal, interagency, and international programs, such as the Global Water and Energy Cycles Program (GWC and GEWEC); U.S. participation in the GCOS, as called for by the Conference of Parties (COP) to the UNFCCC; the science assessments of the IPCC; the international WCRP/GEWEX program; the international Group on Earth Observations (GEO) of the Global Earth Observing System of Systems (GEOSS), the international Integrated Global Observing Strategy (IGOS) and the activities of the Committee on Earth Observation Satellites (CEOS), among others.

Accomplishments during the Reporting Period

The GEST PI is responsible for the science integration/coordination for the Interagency Working Group on the Global Water Cycle and the analytical science development of the international survey on requirements for the "Water" Societal Benefits Area (SBA) of the Group on Earth Observations (GEO) by coordinating the implementation of the Global Earth Observing System of Systems (GEOSS). Unninayar's work over the reporting period involved continued and extensive interactions with all science elements of the U.S. Global Change Research Program (GCRP) regarding the development and implementation of the long-term strategic science plans as directed by OSTP and OMB. The GCRP also represents, *de facto*, the U.S. response to the UN Committee of Parties (COP) dealing with UN Convention on Climate Change (UNFCCC). Additionally, he organized and reported on the multi- and inter-agency activities of the global water cycle program and its sub-elements, such as observations, modeling, process studies, field campaigns and various applications projects. He wrote and finalized the GCRP Chapter on the global water cycle in *Our Changing Planet—FY11*, a program and budget planning report submitted to the OMB and OSTP as a part of the Presidents national program and budget plans. The GEST PI developed and was lead author of decade-long integrated priority programs and projects (Interagency—GWC) for FY09 and FY10, and developed strategic science and applications, "Building Blocks", for the GWC as part of the GCRP-Principals initiative to define goals and objectives for an expanded (in scope) US-GCRP as called for by the new Administration. Unninayar also proposed new science strategies to accelerate the interagency implementation plans of the GWC focusing on 5 integrating themes, involving the GWC Science Steering Group (SSG) and the external research and applications communities. These activities begin a new focus on end-to-end support for observations/research, modeling/predicting, applications/decisions as required to meet emerging requirements to incorporate research to transitioning applications, leading to societal benefits. The new focus areas placed on the GCRP by the GCRP-Principals, OSTP, and OMB also highlight the accelerated development of the science required for mitigation and adaptation measures in the context of the increasing concerns on the impacts of global climate change. Furthermore, Unninayar was called upon by NASA-HQ in the role of chief science "analyst," for the Societal Benefits Area (SBA)-Water under the rubric of the User

Interface Committee (UIC) of the GEO that oversees the implementation of the GEOSS. Other accomplishments included participation in several programs of NASA GSFC's educational DLN video podcast series on climate change, including one special hour-long discourse with groups of high school teachers invited by GSFC to participate in various NASA education programs.

Objectives for the Coming Year

Unninayar will implement the FY10/FY11 Interagency's (GWC) priority goals and objectives and also continue with the drafting of a new strategic plan for the GCRP/GWC as called for by the OSTP and the US Government. Implementation activities will include the continuation of those priority projects initiated in FY09/FY10 with the selection of an appropriate set of observational sites cutting across different climatic/hydrological regimes in the continental US with the objective of enhancing existing infrastructures to enable improved observations and models to address "closure" and "scale interaction" issues pertinent to the global and regional water cycle in the context of climate change. Planning will begin for the implementation of the FY10/FY11 global water cycle priorities to address one of the major challenges facing the climate change science program, namely developing the methodology to reliably downscale the global climate change assessments of IPCC-AR4 to space/time scales relevant to water resources management. Strategic concepts for the GWC FY11 priority activities will be designed and finalized. The articulation of a new GCRP Global Water Cycle (GWC) program as called for by the new Administration (through OSTP, OMB) will be developed with goals and objectives for the next decade, including strategies aimed at national assessments of the impacts of climate change and adaptation/mitigation measures. Finally, the PI will continue to analyze and present multi-disciplinary science and applications user requirements for global-to-regional-local observations and analyze products for various programmatic purposes, such as the water cycle SBA (Societal Benefits Area) of the international GEO/GEOSS, the international IGWCO (Integrated Global Water Cycle Observations theme of IGOS-P, and various UN programs, including the WMO and Unesco. The PI will also contribute to the analytical results to meet the needs of the USGCRP.

In general, Unninayar will continue scientific coordination and integration of the interagency GCRP Global Water Cycle Working Group (GWC/IWG) and interlinks with Atmospheric Chemistry (AC), Climate Variability and Change (CVC & US-CLIVAR), Carbon Cycle (CC), Land Use and Land Surface Change (LULC), Ecosystems (Eco), Human Contributions and Decision Support Systems (HCR/DSS); among other national and international programs (*e.g.*, WCRP, IGBP, HDBP, GEWEX, GCOS, IPCC, GEOSS, CEOSS, and others).

Task 130-82-283: **Imaging Research Center (IRC) at UMBC, Earth Science Animation**

GEST Investigator: Megan Willy (IRC at UMBC), Ivy Flores (IRC at UMBC)

Collaborators: Dan Bailey (IRC at UMBC), Wade Sisler (GSFC 130)

Description of Research

Recognizing imaging as a process that is rooted in art and design, that incorporates science and technology, and that vividly describes ideas, the University of Maryland, Baltimore County's Imaging Research Center (IRC) is a recognized center for interdisciplinary collaboration among artists, researchers, industry partners, and students in creating technologically advanced media works that communicate to and resonate with the general public. In collaboration with NASA Goddard's television and web media production team, the IRC creates high-quality technical and conceptual science animations and interactives used for educational purposes on television, on the web, and in the classroom.

Accomplishments during the Reporting Period

Earth Science Week

Earth Science Week is an annual international event organized by the American Geological Institute that encourages the public's appreciation for the Earth Sciences and advocates global stewardship for the Earth. In preparation for the event this year, animators Megan Willy (UMBC/IRC) and Ivy Flores (UMBC/IRC) assisted in the production of a six-episode video series, "Tides of Change". The series explores the importance of Earth's ocean in global climate change, from its critical role in regulating the Earth's carbon balance to the potential threat of rising sea levels on coastal populations. Collaborating with producer Michelle Williams, physical scientist Bruce Cook, and oceanographer Gene Feldman (all of NASA/GSFC), Flores led the team in the creation of a 53-second animation depicting the Carbon Cycle. This versatile piece has been used to explain the complex cycle to people from a grade school to a graduate school level. In addition, Willy and Flores worked with Williams and world-renowned hydrologist Matt Rodell (NASA/GSFC) in the completion of a detailed 1.5-minute Water Cycle animation describing its intricacies and the effects of human interference. Both animations work as self-explanatory stand-alone products and have been integrated into numerous NASA TV vodcasts for educational purposes. Previously, no animations describing these cycles with such high-quality scientific approval were readily available for public use.

Science for a Hungry World

Agricultural production and landscape changes developing today are affecting the sustainability of the world's food supply. "Science for a Hungry World: the View from Space" was a campaign designed to raise awareness about NASA's role in global agriculture and food supply. Conceptual animators Ivy Flores and Megan Willy completed animations to be used in a six-episode vodcast series, premiering one each Wednesday from September 23 through October 28, 2009. This huge collaborative effort allowed Flores and Willy to work alongside producer Michelle Williams, science writer Gretchen Cook, SVS animator Horace Mitchell, and research scientist Molly Brown (all of NASA/GSFC), as well as research scientist Cynthia Rosenzweig (NASA/GISS), and representatives from USAID and the United States Agency for International Development. The 10-second title opener that Flores animated involved Willy's stylistic modeling of three of NASA's remote-sensing satellites: Landsat, Terra, and Aqua. The satellite models were also used in a minute-long animation by Willy, and demonstrated different environments of what the satellites monitor. Flores completed another minute-long animation that follows the intricate path food follows from the farm to the consumer's table. Other animations touch on topics such as deforestation, remote sensing techniques, and time-lapse footage of plants dying. In total, the 14 animations amounted to an impressive six minutes of animation. As concern with global warming increases, these publicly available animations and vodcasts are sure to be utilized widely in the classroom, by the media, and in other important venues.

Numerous Conceptual Animations

Aside from the two large vodcast campaigns this year, Ivy Flores and Megan Willy also completed five other conceptual animations. All five animations are included in numerous educational outreach efforts and are continuously being excerpted in NASA vodcasts. They are also available to the public on NASA Goddard's Scientific Visualization Studio's webpage: http://svs.gsfc.nasa.gov/.

Flores collaborated with producer Jennifer Shoemaker (NASA/GSFC) on two animations (25- and 47-seconds) that illustrated how plants' earlier blooming seasons affect honeybees' hive weight and their role in plant pollination. The animations were incorporated into a 5-minute video showcasing NASA research scientist Wayne Esaias' work with climate and pollination. Flores is in the process of working with Shoemaker on an animation to be used nationwide on movie theater kiosks that will draw attention to NASA's role in the Earth Sciences.

In collaboration with producer Maria Frostic (previously with NASA/GSFC) and oceanographer Gene Feldman (NASA/GSFC), Willy created 27-seconds of animation describing a marine food web that illustrates some of the ecological pathways between species within the marine ecosystem. Willy also worked closely with hydrologist Matt Rodell and producer Michelle Williams on a still to be used in the popular magazine *Science* alongside a published article by Rodell about India's decreasing water supply and the GRACE satellites' importance in its monitoring. In preparation for the American Geophysical Union's annual conference, Willy collaborated with Frostic, atmospheric scientist Bill Lau (NASA/GSFC), and Goddard Scientific Visualization Studio's Horace Mitchell (NASA/GSFC) on two detailed 20-second conceptual animations that described Lau's "Elevated Heat Pump", a unique hypothesis that aerosol presence in the Himalayas precipitates global climate change. Willy continues to work on two animations that will be used in support of the Operation Ice Bridge campaign in April 2010. With the help of an intern, the animations will feature NASA's DC-8 aircraft.

Objectives for the Coming Year

In the upcoming year, the Imaging Research Center (IRC) plans to continue to work closely with NASA Goddard's Earth Science team to create more conceptual science animation and illustration. Goddard's Earth Science Storytelling Team is comprised of data visualization specialists, science writers, and producers. The IRC, a critical part of this team, supplies conceptual animation and science illustration core content to a wide variety of products distributed through NASA-TV, nasa.gov, and Goddard's informal education distribution channels.

The IRC's NASA Goddard's conceptual science animation team continues to grow, as a search is being conducted for up to two new animators in the coming year. In addition, Flores and Willy are overseeing the work of three interns in the Spring 2010 semester. Future projects on the horizon include a long-anticipated Sea Level Rise campaign this spring and a 15-screen display to be permanently kept in Goddard's visitor center. Upcoming missions that the IRC will provide visual support for include ICESat-II, NPP, GPM, and Landsat/LDCM. The animators will be working on stories linked to papers appearing in leading science journals such as *Science* and *Nature*. Other projects are sure to surface with the expansion of Goddard's Earth Science Storytelling Team. The IRC's aim is to create more timeless animations and other visuals that will be used indefinitely in the educational realm and be available to the public on Goddard's SVS webpage.

Global Modeling and Assimilation Office (Code 610.1)

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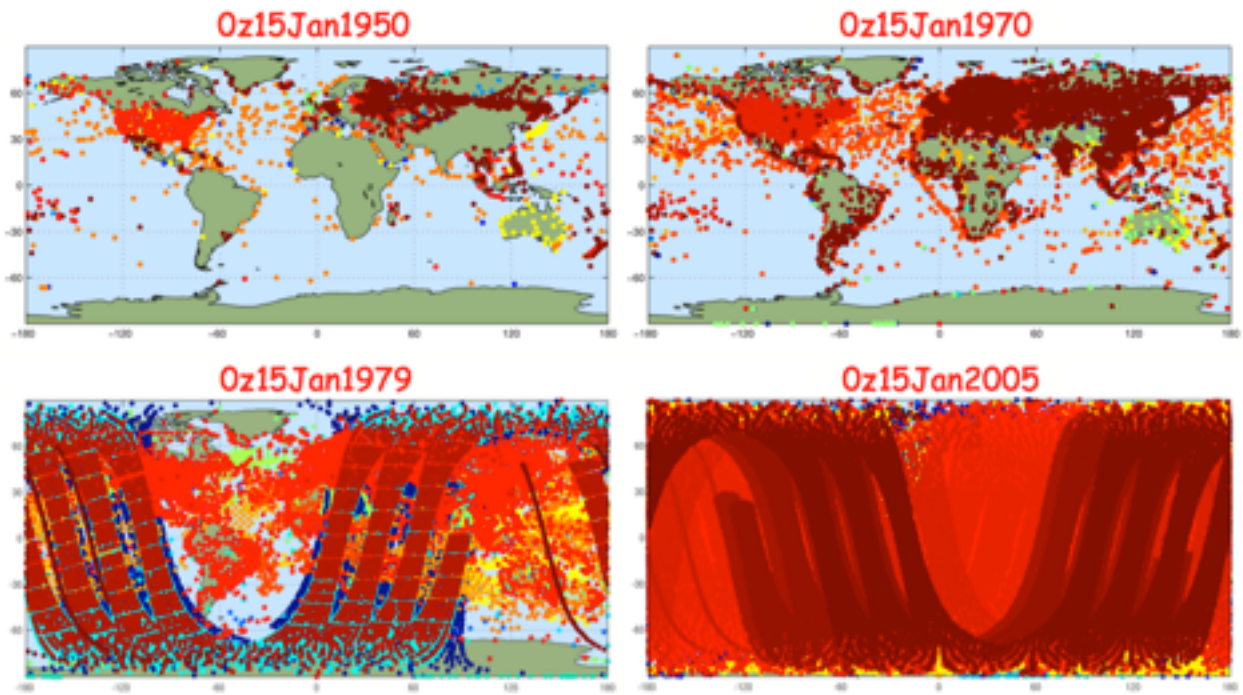
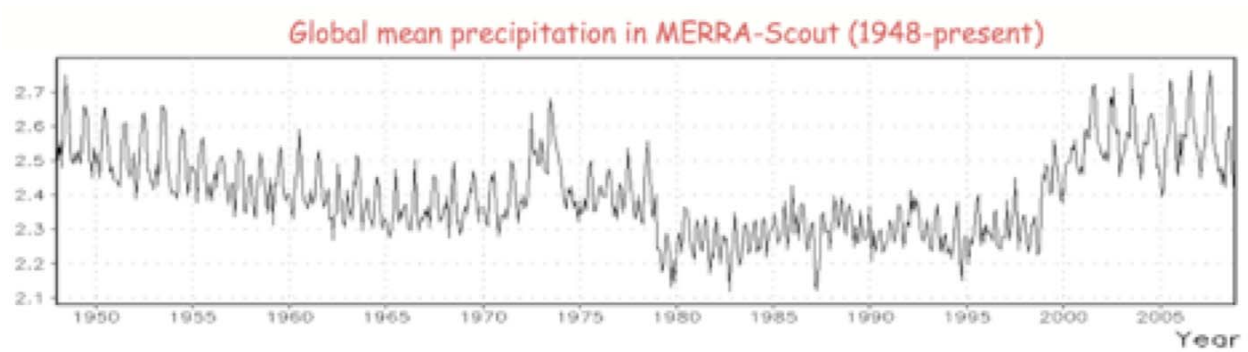
GEST Highlight: MERRA-Scout Reanalysis

Hailan Wang





Figures: The MERRA-Scout reanalysis (1948-present) shows significant sensitivity of the NASA/GMAO data assimilation system to the changing observing system (upper figure). Such sensitivity is well reflected in the time series of global mean precipitation (lower figure), which is characterized by a gradual decrease from 1948 to early 1960s when global conventional observational data coverage gradually increases, a significant jump in 1972-1973, a sudden drop in late 1978 due to the introduction of global satellite data, and a considerable increase around 1998 due to the inclusion of the NOAA 15 satellite radiance data.

Dr. Hailan Wang has performed and completed the MERRA-Scout experiment, a coarse resolution of NASA's MERRA, with the NASA GEOS-5 data assimilation system for the period 1948-1978. The MERRA-Scout run Dr. Wang carries out (1948-1978) serves as an extension of the MERRA-Scout run for the period 1979-present that the GMAO operations group performs. The combination of these two MERRA-Scout runs provides a reanalysis data set of 1948-present that is not only useful for the decadal climate research at the GMAO but also valuable to many other projects, including the ongoing initialized decadal climate prediction effort by NASA's GMAO for the IPCC's 5th Assessment Report (AR5).

Task 610-67-232: **Simulations of Stratospheric Chemistry and Polar Stratospheric Clouds**

GEST Investigator: Craig Benson

Collaborators: Steven Pawson (PI, GSFC 610), Anne Douglass (GSFC 613.3), Anne Douglass (GSFC 613.3), Bryan Duncan (GSFC 613.3), Andrea Molod (GEST), J. Eric Nielsen (SSAI), Luke Oman (GSFC 613.3), Lesley Ott (GEST), Henry Selkirk (GEST), Rich Stolarski (GSFC 613.3)

Description of Research

The goals of this project are to evaluate the characteristics of the GEOS-5 model, with a focus on the chemistry of the stratosphere. Polar stratospheric clouds (PSCs) form at extremely low temperatures in the Arctic and Antarctic stratosphere, providing catalytic surfaces for heterogeneous chemical reactions leading to ozone loss, and are therefore a major component of this study. In addition, a major sudden stratospheric warming (SSW) was observed in early 2009 and characterized by the GEOS-5 model and Microwave Limb Sounder (MLS) observations. An extensive series of model diagnostics was conducted in support of these studies.

Additionally, GEOS-5 model development is a component of this study, such as the implementation of a multiple instantiation scheme, in which several different chemistry parameters can be applied to the same grid box to represent differing surface conditions. Finally, work toward a climatology of ice water content in the upper troposphere and lower stratosphere (UTLS) has been initiated with the ultimate goal of improving model treatment of aircraft-induced cirrus clouds.

Accomplishments during the Reporting Period

High-resolution GEOS-5 simulations of 2008-2009 winter were performed under “replay” conditions, which allowed analyzed wind, temperature, and water vapor measurements to drive the model dynamics. This winter featured a sudden stratospheric warming (SSW), in which vortex winds are disrupted by upper tropospheric wave activity propagating upwards that was the strongest and most prolonged on record. The model results were analyzed and compared to measurements from the Microwave Limb Sounder (MLS) instrument. The GEOS-5 model resolves the onset time and length of the SSW consistently with the MLS measurements. High-resolution zonal wind and potential vorticity data show a high level of detail in the evolution of the vortex split associated with the SSW, and the subsequent recovery of the polar vortex.

As a corollary to the GEOS-5 SSW simulations, a series of diagnostic model runs were performed to assess the characteristics of the GEOS-5 replay mode. Model runs were performed at high, medium, and low resolutions, under a range of replay implementation techniques, and on several different high-end computing systems. It was found that some implementations of high-resolution replay runs caused dynamic instabilities at or near the model top, which propagated downwards, eventually leading to significant errors in temperature and dynamical meteorological fields. However, low-resolution replay simulations appear to provide results free of these instabilities, and some replay implementations show no evidence of instabilities even at high resolution.

In addition to the SSW simulations, a series of lower resolution replay runs were performed to tune the GEOS-5 PSC parameterization. PSC formation in the model relies on a set of six different variables; by carefully tuning these variables, it should be possible to minimize the error in calculated dehydration and denitrification due to PSC formation. The PI and his team found that several of the variables do significantly affect the vertical distribution of HNO_3 and H_2O due to formation, sedimentation, and sublimation of PSC particles of different

sizes and characteristics. However, significant uncertainties remain in the GEOS-5 PSC parameterization, and tuning of the model parameters does not fully alleviate discrepancies between the model output and remotely sensed datasets.

One limitation to the GEOS-5 system is the lack of ability to resolve subgrid-scale variations in initial conditions. For example, a single 2°x2.5^{o} grid box can contain several types of terrain, such as urban, forested, or mountainous, each of which is associated with a unique emissions profile. One solution is to allow the GEOS-5 chemistry module to run several instances in the same grid cell, with each instance representing one of the terrains contained in that grid box, ultimately combining the various outputs in a weighted average. Benson has been working toward an enhanced GEOS-5 chemistry subroutine, which would allow multiple instances of chemistry to be performed in a single GEOS-5 model run; testing on this subroutine should begin shortly.

Finally, a multi-year project has been launched to assess the climatic impacts of aircraft-induced cirrus clouds in the GEOS-5 model. As a first step, an overall climatology of ice particles in the UTLS is being generated, using data from the MLS instrument and MOZAIC campaign, which places scientific instrumentation on commercial aircraft. Initial results show some differences with relative humidity as measured by the two techniques, with more supersaturation evident in MLS measurements, and an expected bimodal structure in the MOZAIC, but not MLS, data. Some latitudinal and seasonal differences are also apparent.

Objectives for the Coming Year

The GEOS-5 replay studies will be concluded, with an analysis of a 10-year simulation focusing on stratospheric transport and PSCs to be submitted for publication. Multiple instantiations of the GEOS-5 chemistry module will be implemented and studied. Studies of aviation-induced cirrus clouds will continue. Finally, Benson will begin supporting the validation of the meteorological state of GEOS-5 MERRA data, using lidar, SABER, and other remotely sensed datasets.

Task 910-14-123: **Evolution of MJO Hindcast Skill of the GEOS 5 Coupled Model**

GEST Investigator: Yehui Chang

Collaborators: Siegfried Schubert (PI, GSFC 610.1)

Description of Research

The Madden-Julian Oscillation (MJO) is the leading mode of intraseasonal variability in the tropics. Efforts to improve predictions of such a significant tropical mode as the MJO are crucial to the success of predictions on sub-seasonal time scales. It also requires a better understanding and ability to simulate the relevant dynamical interactions between MJO and ENSO variability.

The first part of the work uses the GEOS-5 coupled models, which takes advantage of the new MERRA reanalysis, as well as related replay methodology that were developed in the GMAO, to validate and constrain the model. The technique called “replay” allows Chang to assess, for example, the impact of the surface wind stresses and/or precipitation on the ocean in a controlled environment. By running the coupled model in replay mode, the researcher can in fact constrain the model using any existing reanalysis data set. For this study, Chang replayed the model constraining (nudging) it to the Scout reanalysis for the period 1979-2009; in particular, he examined the model’s ability (when forced in replay mode by the Scout run) to reproduce the ocean variability associated with the major anomalous events of 1983, 1997 and 1988. The events in 1983 and 1997 are closely associated with a major warm anomaly, while the 1988 event is a cold event in the tropical Pacific.

The second part involves a large set of hindcast experiments designed to assess the baseline skill of the GEOS-5 coupled model on subseasonal to seasonal time scales. In the case of coupled model predictions, initial states are typically created using uncoupled assimilations. For example, starting from the separately generated ocean initial states and atmosphere initial states, the forecast systems undergo initialization shocks that can be detrimental to forecast skill, especially for sub-seasonal forecasts. In this study, the use of coupled replay provides a natural set of physically consistent initial conditions. The system can better preserve the coherent air-sea fluxes leading to improved forecast skill. The model's initial states generated from GEOS-5 replay simulation provide perfectly balanced initial states used in the Madden Julian Oscillation (MJO) hindcast study.

Accomplishments during the Reporting Period

The first phase of the study was to replay MERRA Scout reanalysis data from 1979-2009 with the GEOS-5 coupled model. After this was accomplished, a series of daily 6-month subseasonal hindcast experiments were made with the GEOS-5 coupled models from 1980-2009. These coupled hindcasts are initialized daily from states generated by the GEOS-5 coupled replay system during these periods. The model hindcast kills were evaluated for the tropical Outgoing Longwave Radiation (OLR) and 200mb velocity potential fields, using the NOAA OLR and MERRA Scout reanalyses as the verification. From the study, there is evidence showing the Week 2 and Week 3 anomaly correlation forecast skill that the model forecasts. The forecast skills are examined further by looking into the signal-to-noise ratio, which is a measure to quantify how much a signal has been corrupted by noise. The study indicates that temporal changes exist in the MJO forecasting skills and signal-to-noise ratios. The forecasting skills and the signal-to-noise ratios increase in accordance with the increase in the magnitude of the MJO in the initial conditions. The model tends to have a different signal-to-noise ratio on different initial phases of the MJO. Additionally, it has higher signal-to-noise ratios when reduced convections develop over the Indian Ocean and migrate to maritime continent.

The MJO has considerable interaction with the circulation and variability of Asian summer monsoons. Due to the recurrent nature of the MJO and its influence on the boreal Asian summer monsoon, predicting the MJO has a major implication of extreme events, such as severe floods and droughts over Southern and Eastern Asia.

The study of GEOS-5 forecast skill has already yielded some useful insights and ideas for exploring the sources of the errors as well as skill of the GEOS-5 forecasts over the tropic. The GEOS-5 coupled model has difficulties simulating MJO initiation, as well as maintaining the amplitude of strong MJO events that are already in the initial conditions. Recent research demonstrates that, given a good initialization of the MJO, a model with a relatively weak MJO simulation can produce skillful forecasts of MJO-related precipitation and dynamical variables. Based on these factors, it is likely that useful forecasts of the sub-seasonal tropical variability can be made using GCMs. The study also suggests that the following additional factors may be required for improving MJO forecasts and simulation: obtain an insight into the processes that regulate initiation of MJO convection over the Indian Ocean; create accurate initial conditions (*e.g.* wet and dry phases of an MJO over the Indian Ocean); improve the model physical package to simulate the realistic intra-seasonal variability associated with the MJO.

Objectives for the Coming Year

Chang's first objective focuses on the development of subseasonal ensemble forecast techniques. Seasonal forecast systems are faced with the detrimental impact of initialization shock and coupled model biases on forecast skill. While these impediments play a major role in subseasonal (3-to-6 weeks) forecasts, to date little effort has been made to initialize climate forecasts at the shorter time scale. Chang proposes to develop and test improved methods for initializing subseasonal forecast systems. This effort is a potential contribution to a multi-model ensemble forecast system through the

Climate Test Bed. The GEOS-5 system will build upon the coupled breeding developed for the CGCMv1 used by the GMAO for seasonal forecasts. A replay of a coarse resolution GEOS-5 reanalysis in coupled mode over the ocean and land surface will provide a consistent initialization of the coupled system. The sensitivity of subseasonal forecasts to perturbations in the coupled system will be used in case studies alongside the subseasonal NCEP Global Ensemble Forecast System (GEFS) to define an optimal initialization strategy. The project builds upon the resources developed for the current GEFS and leverages much of this work with current projects at EMC and the GMAO. It also addresses the issue of subseasonal predictions from a seamless weather to climate perspective.

The ocean data assimilation/initialization with GEOS-5 system will be conducted within a coupled framework. The impact from frequently updated atmosphere analyses (every 6 hours) will be taken into account during the ocean assimilation. The benefits include improving the forcing fields for the ocean and letting atmosphere and oceanic states evolve close to the coupled trajectory for the initialization of the coupled forecasts. With this strategy, the prediction skill at 3-6 weeks is expected to improve because of more realistic atmospheric conditions. In addition, the structures of coupled BV will be incorporated within the ocean assimilation in order to allow the corrections to be projected on the coupled uncertainties. The coupled breeding cycle will be performed within the analysis mode. Such procedures may also be beneficial to the prediction skill of intra-seasonal variability by optimizing the coupled BV structure with a rescaling parameter relevant to that timescale.

Chang's second objective is regarding the nature and predictability of interannual to decadal changes in the global hydrological cycle and its regional impacts. The sea surface temperature (SST) changes have had profound impacts on long-term hydroclimate variability in a number of regions throughout the world. Evidence is also emerging that in some regions land feedbacks may play an important role; however, a number of uncertainties about the physical processes link regional climate to remote SST changes, the strength and nature of the land impacts, and the predictability of regional hydroclimate variations on these long time scales. The PI's goals are to further quantify the physical mechanisms linking North American hydroclimate variability to the leading patterns of decadal SST variability in the Indo-Pacific and Atlantic basins, including an assessment of the impact of global warming. The study will also assess the nature and predictability of Pacific Decadal Oscillation (PDO)-like SST variations with a focus on the role of Pacific subtropical cells and the 1970s climate shift, as well as the more recent shift in the late 1990s. Chang also plans to assess the nature and predictability of Atlantic Multidecadal Oscillation (AMO)-like SST changes during the 1960s and 1990s, with a focus on the role of the thermohaline circulation (the Meridional Overturning Circulation or MOC).

Task 910-31-155: **Goddard Earth Observing System Data Assimilation System**

GEST Investigator: Ronald Errico

Collaborators: Ronald Gelaro (PI, GSFC 610.1), Ricardo Todling (SAIC), Runhua Yang (SSAI), Meta Sienkiewicz (SAIC), Will McCarty

Description of Research

Work was performed for the portion of this broad task concerning the development of the infrastructure for conducting Observing System Simulation Experiments (OSSEs) at the GMAO. Essentially, these mimic the entire data assimilation process, requiring "observations" to be drawn from a long-period, high-resolution simulation of nature, produced by a well-validated forecast/climate model. This capability will permit OSSEs for estimating potential improvements of data assimilation, climate analysis, and weather forecasting products due to proposed augmentations of the global observing system. It will also facilitate the development and evaluation of proposed future data assimilation techniques. Since the utility of data assimilation products is primarily a function of observational and background errors as well as of how the observational signals are utilized, simulation of these errors is proportionally more important than the signals themselves. As with any simulations, the results obtained are only reliable to the degree that the performance is properly validated, which thus comprises most of the development effort.

Accomplishments during the Reporting Period

Experiments have been performed to determine tuning parameters for the OSSE simulations of observation errors. These concern sums of instrument plus representativeness errors. The latter concern errors in the observation models employed by data assimilation systems to relate its representation of the atmosphere (*e.g.*, as gridded fields for particular variables) to what is actually observed. Unfortunately, little is known about these errors in reality; therefore, rather indirect methods for tuning models of these errors are required.

More than a dozen tuning trials have been performed and analyzed during the reporting period. Progress was slowed by the necessity to wait for corrections and updates to the NCEP/GMAO grid-point, statistical interpolation, data assimilation system software. For example, halfway through the reporting period, it was discovered that the version of the data assimilation system then employed had an outdated version of the JCSDA community radiative transfer model that created unexpected, unrealistic, observation error biases for some critical instruments. This required transitioning to a newer system that was still under development and subsequently restarting the tuning procedure afresh. Also, as work progressed, the need for new diagnostic capabilities became apparent. The additional software required for these new purposes has been created.

One major re-design of the OSSE system whose need became apparent toward the end of the reporting period was an ability to create random observation errors that are horizontally correlated. The validation data set produced from assimilating real observations indicated that, even after bias corrections, radiance observation errors are strongly correlated in space. Such errors tend to reinforce, rather than cancel, each other as observational values are averaged in the data assimilation algorithm. Consequently, they tend to create larger analysis increments. In order to match statistics of analysis increments as well as those of innovations, the insertion of horizontally correlated errors is necessary.

As a result of the OSSE tuning, a baseline set of simulated observations and corresponding errors is now available. This includes observations simulated for rawinsondes, wind profilers, land stations, ships, aircraft, buoys, and satellite-observed cloud-track winds, and radiances provided by AMSU-A/B, MSU, HIRS-2/3, and AIRS. Along with the software used to produce them, these are being made available to the

community. Documentation describing the simulation algorithms and software is being prepared along with a manuscript describing the validation of this baseline. These products represent the best-validated OSSE data set produced anytime, anywhere.

Objectives for the Coming Year

Further validation of the baseline GMAO OSSE will continue, and documentation and manuscripts will be prepared. Reports will be presented at interested research centers. Errico will identify the remaining deficiencies in the baseline data set and explore their causes. The baseline will be used to characterize analysis error in the real assimilation context. Additionally, the PI will reexamine the suitability of the ECMWF nature run. Other possible related projects include the use of a new, higher resolution, nature run produced with the cubed-sphere version of the GEOS model and an examination of ensembles of OSSEs produced with different realizations of random simulated errors.

Task 610-89-310: **Research and Advisory Activities for NDACC, SPARC, IO3C, GCOS, WMO, UNEP, and the NASA/JPL Panel for Data Evaluation**

GEST Investigator: Michael J. Kurylo

Description of Research

This task provides support for several international activities important to NASA's Atmospheric Composition Focus Area in Earth Science. It covers programmatic leadership of the Network for the Detection of Atmospheric Composition Change and consultancies to the SPARC Project of World Climate Research Programme, to the International Ozone Commission, to the Global Climate Observing System, and to UNEP and WMO on activities associated with the Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer. It also covers participation in the evaluation of photochemical and kinetic data by the NASA/JPL Panel for Data Evaluation.

Accomplishments during the Reporting Period

Kurylo continued to serve as elected Co-Chair of the international Steering Committee (SC) for the Network for the Detection of Atmospheric Composition Change (NDACC). In this position, he shares responsibility for overall network management, including operational continuity and growth, collaboration with international organizations and networks associated with ozone and climate observations, and representation of NDACC to various scientific organizations and at various scientific assemblies. During the past year, he developed an NDACC Cooperating Network Protocol for networks of instruments operating independent of NDACC but where strong measurement and scientific collaboration would be mutually beneficial. To date, he has solicited and finalized agreements between NDACC and AERONET, MPLNET, SHADOZ, AGAGE, and NOAA/HATS.

In his capacity as Co-Chair of the NDACC SC, Kurylo was asked by the GCOS Working Group on Atmospheric Reference Observations to provide advice on the developing operational structure for GRUAN (the GCOS Reference Upper Air Network). He attended the first GRUAN Implementation and Coordination Meeting where he discussed the role of measurement-versus-parameter-focused working groups in NDACC and their potential applicability to GRUAN. He also identified possible collaborative activities between the two networks.

As an elected member of the International Ozone Commission (IO_3C), Kurylo worked with the other NDACC SC Co-Chair to involve the NDACC Ozone Working Group in a series of Ozone Theme Meetings jointly organized by WMO/GAW, NDACC, and IO_3C. These meetings have focused on critical issues associated with the global measurements of both the ozone column and its profile, most recently

focusing on evaluating the various spectral parameters that are used in ozone retrievals.

As an Ex-Officio member of the Scientific Steering Group (SSG) for the Stratospheric Processes And their Role in Climate (SPARC) Project of the World Climate Research Programme (WCRP), Kurylo provided an update on NDACC measurement and analysis activities relevant to SPARC objectives, and presented an annual report on NASA's space-based and related research activities. At the most recent SSG meeting in Kyoto, Japan, he also summarized the results stemming from a SPARC initiative on documenting the Role of Halogen Chemistry in Polar Stratospheric Ozone Depletion, which he co-chaired with Bjoern-Martin Sinnhuber (U. Bremen). The results from an initiative workshop in Cambridge, UK (June 2008) have been summarized in a SPARC report (Kurylo *et al*., 2009). Together with results from a spectrum of studies (laboratory, modeling, and observations analyses) fostered by the initiative, the SPARC report is being used as input to chapters in the 2010 WMO/UNEP Scientific Assessment of Ozone Depletion.

The Space Studies Board of the National Research Council of the National Academies requested that Kurylo serve on a committee evaluating NASA's Suborbital Research Capabilities. He attended three committee meetings and participated in several teleconferences and was the lead author of the reports section on NASA's Airborne Science Program. This report is in its pre-publication phase, and Congressional staff and NASA upper management have been briefed on its findings and recommendations.

At the request of the NASA Headquarters Program Managers in Atmospheric Composition, Kurylo is serving as a peer reviewer and panelist for evaluating the technical, management, logistics, and costs aspects of proposals for sustained suborbital investigations proposed under NASA's first set of Venture-Class Investigations (Earth Venture-1).

As a long-time member of NASA's Panel for Data Evaluation and participant in the international ozone assessments, Kurylo is serving as an interface between the NASA Panel and the leadership of the 2010 UNEP/WMO Scientific Assessment of Ozone Depletion. Along with other panelists, he finalized an updated set of recommendations for photochemical and kinetic parameters having the highest priority for modeling calculations being performed for the 2010 Assessment (Sander *et al*., 2009). With Vladimir Orkin (NIST), he conducted a complete review and update of rate constant recommendations for the reactions of OH radicals with halocarbons. This review is being finalized for release as a NASA/JPL report in 2010 (Sander *et al*., 2010) and is being used for updating the atmospheric lifetimes of numerous trace gases (naturally occurring and anthropogenic) for the 2010 Ozone Assessment.

Based on his expertise in stratospheric ozone science and in the determination of trace gas atmospheric lifetimes from laboratory photochemical kinetic data, Kurylo was asked by the leadership of the 2010 Scientific Assessment of Ozone Depletion to participate as co-author for Chapter 1 (Ozone-Depleting Substances and Related Chemicals), as a contributor and primary reviewer for Chapter 2 (Stratospheric Ozone and Surface Ultraviolet Radiation), and as a reviewer for the Prologue to the Assessment. In these capacities, he has provided extensive chapter inputs and participated in the preliminary review of the entire assessment document conducted in November 2009.

Objectives for the Coming Year

Kurylo will continue to fulfill his responsibilities as a Co-Chair of the NDACC SC, as a member of the SPARC SSG, and as a member of the IO_3C. He will continue to participate as an author and reviewer for chapters in the 2010 WMO/UNEP Scientific Assessment of Ozone Depletion, including attendance at the final assessment review meeting in June 2010. He will also continue as an advisor for the implementation of the GRUAN and will participate in ongoing activities of the NASA/JPL Panel for Data Evaluation.

Task 910-14-124: **Global Precipitation Measurement Mission**

GEST Investigator: Xin Lin

Collaborators: Arthur Hou (PI, GSFC 610.1)

Description of Research

The Global Precipitation Measurement Mission (GPM) is an internationally sponsored partnership of multiple space agencies using a multi-member, rain-measuring satellite constellation to improve precipitation measurements over the Earth. The baseline GPM constellation was originally envisioned to comprise a fleet of dedicated and operational conically scanning microwave radiometers. The Dual-frequency Precipitation Radar onboard the GPM Core Spacecraft will be able to improve the calibration and retrievals of these passive microwave (PMW) measurements. In addition, rain estimations made by operational high frequency microwave sounders, such as the NOAA AMSU-B heritage, are also considered a likely option to enhance sampling and coverage on the global scale.

In order to achieve better sampling and coverage on the global scale, one of the most important issues is to obtain an improved understanding of satellite retrieval error statistics of current PMW radiometer and sounder data over land and oceans. The researchers have comprehensively examined rain detection capabilities and retrieval error characteristics of current satellite microwave rainfall estimates, including both radiometer and sounder data through coincident comparisons against TRMM Precipitation Radar data between 35ºS and 35ºN. In addition, the sampling and coverage of the future GPM satellite constellations also have been thoroughly evaluated. Such a feasibility study provides valuable information for the GPM mission planning.

Accomplishments during the Reporting Period

Using retrievals from the TRMM Precipitation Radar and merged surface radar/gauge measurements over the US continent as references, Lin compared instantaneous rainfall estimates provided by the current generation of retrieval algorithms for PMW sensors. In particular, statistics of departures of these coincident retrievals from reference measurements were computed as a function of rain intensity over land and oceans. Results of this study provide some important guidance for the GPM planning.

Tremendous amounts of satellite rainfall observations from TRMM PR and TMI, DMSP/SSMI, and AQUA AMSR-E have been analyzed to investigate the frequency distribution of precipitation between Y2001 and Y2009. Based on the rainfall error statistics obtained from a coincident evaluation of satellite rainfall retrievals, Lin and Hou are able to determine at what rain intensity ranges can provide the researchers with more confidence in rainfall frequency distributions from individual PMW rain retrievals. They also have noticed a significant change in frequencies of light, moderate, and heavy rain events between Y2002 and Y2009. Such a study is vital for a better understanding of the occurrence of extreme rain events in a changing climate, and will serve as an important test bed for evaluating the NASA GMAO MERRA analysis and the NASA GSFC Global Cloud Model.

In addition, they have also investigated the impact of GPM satellite sampling at monthly and diurnal time scales, and estimated the sampling capability of GPM constellation and individual satellites on Hurricane Katrina. Statistics of preliminary GMAO MERRA analyses were evaluated and the operational analysis data was prepared for use in Observation System Simulation Experiments (OSSE).

Objectives for the Coming Year

As more and more MERRA analysis data become available, by simulating the GPM constellation in the rainfall space, several OSSE experiments are being carried out. The researchers greatly anticipate answering the following questions for the GPM mission planning. First, regarding idealized experiments, supposing that there are no retrieval errors (perfect observations), how well can GPM constellations at different years capture rainfall statistics at various temporal and spatial scales, particularly, variances and rain PDFs as a function of rain intensity? What is the impact of diurnal under-sampling errors and orbit drifting over different rain/cloud regimes? Second, regarding realistic experiments, when assigning estimated RMS errors and biases (as functions of rain intensity) to simulated satellite sensors in GPM constellations, can researchers coarsely estimate the impact of different error sources, and design approaches to minimize these non-meteorological factors? If some light rain events are misidentified by passive microwave sensors, what errors can be expected at different temporal and spatial scales? Lin and Hou plan to write and publish a number of papers on this subject. Dr. Wei-Kuo Tao's global cloud model results at GSFC could also be used in this study.

Additionally, they will continue to explore the relationship among cloudiness, precipitation, and radiative fluxes between Y2002 and Y2009, focusing on changes in their frequencies, and try to develop new theories based on high-resolution satellite data.

Task 610-67-231: **The Simulation of Doppler Wind Lidar Observations in Support of Future Instruments**

GEST Investigator: Will McCarty

Collaborators: Ron Gelaro (GSFC Sponsor, 610.1), Ron Errico (GEST, GSFC 610.1)

Description of Research

To maximize the use of a future spaceborne instrument in the context of data assimilation, it is best to utilize the heritage of such instruments to prepare the data assimilation as much as possible prior to launch. For instruments that have no predecessor, this approach becomes invalid, as is the case for global Doppler wind lidar measurements. To compensate, observations can be simulated to characterize the anticipated nature of the future instrument. Though the true nature of the future observations will likely differ from the simulation, it allows the development of the framework within the data assimilation necessary for the future instrument, limiting the amount of effort necessary post-launch for maximum utilization, particularly if an instrument has a limited and predictable lifespan. These concepts are being undertaken at the Global Modeling and Assimilation Office (GMAO), as a member of the Joint Center for Satellite Data Assimilation (JCSDA), to prepare for the launch of the European Space Agency (ESA)'s Atmospheric Dynamics Mission (ADM) in late 2011.

Accomplishments during the Reporting Period

To simulate measurements for the ADM mission, the framework of an Observing System Simulation Experiment (OSSE) is being utilized. Typically, OSSEs are performed to promote the utility of a proposed instrument. In this case, though, the ADM mission is already funded and undergoing pre-launch testing. Through the use of the Joint OSSE nature run created by the European Centre for Medium-Range Weather Forecasting (ECMWF), ADM simulations are in the process of being performed, utilizing the Lidar Performance Analysis Simulator (LIPAS) obtained from colleagues at the Royal

Netherlands Meteorological Institute (KNMI). Using the instrument simulator, observations and their associated errors anticipated from the ADM mission post-launch are being realistically generated from the meteorological fields of the nature run.

The simulated observations are a function of many meteorological variables. As an active lidar operating at 355 nm, the measurements are very sensitive to clouds and aerosols. To obtain realistic simulated observations, the researcher must input realistic cloud and aerosol fields. Extensive verification of the cloud fields is being concluded of the nature run, which is a year-long free-running climate simulation of the global atmosphere. As compared to CALIPSO and CloudSat-derived climatologies, the nature run is being shown as deficient in clouds to the order of 12% globally and, in many cases, far larger deficiencies regionally. The cloud fields are not independent of the all-encompassing meteorological scenarios encapsulated in the nature run. To create a properly simulated ADM dataset, these deficiencies need to be properly accounted for. A manuscript is being prepared for submission on the cloud verification and is expected to be readily useful to anyone utilizing the Joint OSSE framework. Upon the simulation of the ADM measurements, they will leverage off the efforts of Dr. Ron Errico and associated researchers to simulate the entire existing observation system. Utilizing his efforts, researchers will find it possible to perform scientifically valid data assimilation experiments, as both *in situ* and remotely sensed observations will exist to compete and complement the spaceborne Doppler wind lidar measurements. Without the entire observation system, any behavior observed in an OSSE-based data assimilation system would have limited utility to the ADM measurements post-launch. This future effort has been essential to the current development, as the framework of Dr. Errico's efforts has been an essential building block to this manuscript.

Also, a dataset of highly idealized Doppler wind lidar measurements was created for the initial development of the data assimilation system. These data contained no error and were used explicitly for the development of the operators necessary to transform the background state in the data assimilation problem to the observation space. This necessary first step was successfully performed and will serve as the most basic portion of the more advanced data assimilation framework necessary in development for ADM measurement utilization.

In early 2009, during McCarty's first few months as a GEST employee, work was performed to finish up the research associated with his dissertation, and concluded with a publication (McCarty *et al.*, 2009). Though the basis of the effort preceded his position at GEST, final simulations and analysis as part of the peer-review process were performed locally.

Objectives for the Coming Year

The GEST investigator will be leaving the GEST center for a transition to civil service on March 12, though these efforts and collaborations will still continue to mature.

Task 971-00-002: **Land Surface Modeling in Support of the Development of Global Modeling and Assimilation Office (GMAO) Coupled Climate Model**

GEST Investigator: Sarith P.P. Mahanama

Collaborators: Michele Rienecker (PI, GSFC), Randal Koster (GSFC), Max Suarez (GSFC), Rolf Reichle (GSFC)

Description of Research

Research in the land modeling group of the GMAO emphasizes understanding land surface process to improve the climate and weather prediction. Interaction between the land and atmosphere plays an important role in the evolution of weather and the generation of precipitation. Understanding the aspects that control the land-atmosphere interaction in AGCMs can improve the skill of AGCM's precipitation and temperature forecast. At the land surface, soil moisture controls the partitioning of moisture and energy fluxes to the atmosphere and is a key variable in weather and climate prediction. Moreover, the memory associated with soil moisture is likely the chief source of mid-latitude forecast skill.

Accomplishments during the Reporting Period

Mahanama continued researching land surface processes in view of improving seasonal forecast of AGCMs and macro scale hydrological applications. Investigations on the land atmosphere coupling strength in the GEOS-5 AGCM are parallel to the development of the GEOS-5 modeling system.

Mahanama led a project to quantify the contribution of soil moisture information to stream flow prediction in the snowmelt season in the contiguous United States (CONUS). In areas dominated by winter snow cover, the prediction of stream flow during the snowmelt season may benefit from three pieces of information: the accurate prediction of weather variability leading up to and during the snowmelt season; estimates of the amount of snow present during the winter season; and estimates of the amount of soil moisture underlying the snow pack during the winter season. The surface meteorological information and knowledge of the snow amount are important for obvious reasons. The soil moisture contribution is more subtle yet potentially very important. If the soil is dry below the snow pack, the snowmelt may be more likely to infiltrate the soil and evaporate later, and is thus lost to stream flow and potential reservoir storage. On the other hand, a wet soil below the snow pack may encourage greater stream flow and thus may contribute more to water resources.

In this study, Mahanama evaluated this forecast potential much more directly and comprehensively, using multi-decadal naturalized stream flow measurements covering much of the western United States, a suite of state-of-the-art land surface modeling systems, and true forecast experiments (as opposed to linear regression analyses) quantifying forecast skill at seasonal leads. In essence, January 1 initial conditions were used to forecast stream flow for March to June (MAMJ) with four modeling systems using an experimental design that isolated the separate contributions of soil moisture and snow initialization to forecast skill. The results show that January 1 soil moisture and snow information both provide useful skill to the prediction of MAMJ stream flows in many areas. In effect, the study demonstrates that today's land surface models are of sufficient accuracy to transform meteorological data into soil moisture and snow data of direct value to stream flow forecasts at seasonal leads. While snow is generally assumed to be the key predictor of springtime stream flow, the study showed that in some basins, soil moisture information by itself contributes most significantly to seasonal-lead forecast skill.

The GEST investigator was also involved in the second phase of the Global Land-Atmosphere Coupling Experiment (GLACE-2). The project aims to quantify, with a suite of long-range

forecast systems, the degree to which realistic land surface initialization contributes to the skill of subseasonal precipitation and air temperature forecasts. Results on North America show significant contributions to temperature prediction skill out to two months across large portions of the continent. For precipitation forecasts, contributions to skill are much weaker but are still significant out to 45 days in some locations. Skill levels increase markedly when calculations are conditioned on the magnitude of the initial soil moisture anomaly.

The GEOS-5 climate modeling system uses the catchment Land Surface Model (LSM) to resolve the water and energy budget on the Earth's land surface during climate integrations. The catchment LSM implementation on the GEOS5 requires pre-processing high-resolution topography, soil, and vegetation (satellite-based observations and otherwise) to resolve the Earth land surface into hydrologic catchments and derive a set of parameters on each computational catchment. On the model development front, Mahanama developed software tools for this process.

Objectives for the Coming Year

A short manuscript based on the snow study in the western U.S. has been prepared and intend to be submitted to *Science*. The study will be extrapolated to see if any signal from October, November and December soil moisture can be seen in MAMJ stream flows, and a comprehensive paper will be submitted to a leading journal in the field. Separately, the catchment Land Surface Model will be forced offline using high quality, bias-corrected, surface meteorological forcings for a period of 58 years. Then, the offline simulations derived from soil moisture initial states at the beginning of the month will be prescribed to the GEOS-5 AGCM during a model integration for the same period. The motivation of this study to investigate the impact of realistic land surface states on the skill of summertime air temperature and precipitation forecast of the AGCM.

Task 610-92-322: **Support GEOS-5 atmospheric modeling and diagnostics**

NASA Grant: **Constraining Uncertainty in Simulations of Tropospheric Composition: Implications for Prediction of future air quality**

GEST Investigator: Andrea M. Molod

Collaborators: Yuri Vikhaelev (GEST); Max J. Suarez and Siegfried Schubert (GSFC 610.1); F. Robertson and T. Miller (NASA/MSFC); Lawrence Takacs and A. Eichmann (SAIC); Juilin Li (NASA/JPL); B. Duncan (GSFC 613); A. Fiore (NOAA/GFDL); C. Benson (GEST)

Description of Research

An overarching goal of the GMAO atmospheric modeling effort is to develop a single atmospheric model suitable for data assimilation, weather forecasting and climate simulation. Climate simulation includes atmosphere only, coupled ocean atmosphere, and coupled chemistry-climate modes. The model's collection of physical parameterizations is of central importance to the success of the GMAO's modeling effort. This year's development effort focused on improvements in the physical parameterizations that resulted in a single model with improved atmosphere only and atmosphere-ocean coupled climate simulations.

The goal of the larger, parent project is the assessment of simulations of tropospheric ozone and the identification of the model characteristics responsible for the known biases, particularly over the eastern United States in summertime. The specific aspect of this work being pursued by Molod is the development of a new approach to modeling the sub-grid scale heterogeneity of emissions and ozone precursor

reactions, which are tied to sub-grid scale heterogeneity in underlying land surface type and characteristics of the near-surface turbulence.

Accomplishments during the Reporting Period

The Fortuna-2_0 version of the GEOS-5 GCM was developed, tested and released. Results of the atmosphere-only climate simulations with the new version exhibit major improvements over the previous version, particularly in the simulation of stationary waves and of tropical precipitation patterns. Toward this end, adjustments were made to the moist processes in collaboration with J. Bacmeister (GEST) and to the turbulence parameterization. The major adjustments to the moist processes included increasing the re-evaporation of grid scale precipitation, reformulating the critical relative humidity criterion for phase changes of in-cloud and precipitating liquid and ice, and implementing a resolution-dependent stochastic trigger for cumulus convection. The adjustments to the turbulence parameterization included reducing the impact of the non-local turbulence scheme and increasing the impact of the local scheme in the presence of large wind shear. The development of Fortuna-2_0 was done in collaboration with J. Bacmeister (GEST), M. Suarez (GSFC) and L. Takacs (SAIC).

The optimization of moist physics and turbulence parameterizations to improve coupled atmosphere-ocean climate simulations was completed as part of the development of the new model version. In addition to the model changes outlined above, the Fortuna-2_0 model included changes to the moist processes and to the cloud-radiation interaction that were specifically targeted at improving the coupled simulations: the removal of warm fog layers and the decrease of the response of the radiation to the presence of anvil clouds. Results of coupled simulations show substantially reduced errors in ocean temperatures near the surface, and show realistic patterns of seasonal and interannual variability. This work was done in collaboration with J. Bacmeister (GEST), Y. Vikhaelev (GEST) and M. Suarez (GSFC).

The capability to run Fortuna-2_0 in its single column model configuration was vastly expanded to include a wide collection of simulations commonly performed in the modeling community. Along with a set of utilities to extract single column model driving data from MERRA output and generate the necessary auxiliary data, this capability has enabled GEOS-5 users to perform various single column model simulations. The GEOS-5 single column simulations that have been analyzed behave reasonably over the tropical Pacific, in the South China Sea, and in the U.S. Central Plains. This work was done in collaboration with A. Eichmann (SAIC). The set of idealized simulations outlined in the CGILS (CFMIP GCSS Inter-comparison of Large-Eddy and Single column models) project, performed at several points along a transect from the California coast to the central Pacific, were included in the suite of available cases, and the results of the simulations were presented at the CGILS workshop. The GEOS-5 simulations were generally within the scope of behavior seen in other GCMs, except for the difficulty simulating near-shore stratus decks over cold oceans.

An analysis of a positive land-atmosphere feedback loop present in certain hydrologic regimes continued in collaboration with R. Koster (GSFC). A proposal detailing the preliminary results and the future plans was prepared and submitted to the National Science Foundation’s Climate and Large Scale Dynamics Program, but was not funded.

The first year of the project related to tropospheric ozone was devoted to detailed planning of the steps of the code implementation and developing a simplified version for idealized testing.

The code implementation design resulted in the following planned steps. First, Molod implemented a calculation of two entirely separate sets of chemical evolution equations in each grid box using the same emissions and surface turbulence characteristics. These are the "chemistry tiles" of the "mosaic". The calculations will result in identical results,

demonstrating the robustness of the code. Second, she changed the emissions and surface turbulence separately and together in a set of idealized experiments. The emissions in the idealized experiments are set by allocating 100%, 50% and 25% of the grid-box total emissions in one of the "tiles", and the turbulent transfer coefficients will be set to 0.5, 1.0 and 2.0 times their "grid box average" values. The differences among these different experiments will gauge the potential impact of the "chemistry-mosaic" scheme. Third, she computed realistic emissions and turbulent transfer coefficients for each "chemistry tile", and fourth, Molod implemented the "chemistry tile" approach for a subset of the chemical equations.

This design was primarily motivated by the complexity of the code and coding environment, and by the desire to perform idealized experiments to examine the potential impact of the technique as early as possible in the process. The first step has been nearly completed. The code has been written, and the process of testing and assuring the robustness is well under way.

Objectives for the Coming Year

The development effort for the GEOS GCMs physical parameterizations during the coming year will focus primarily on the identification and removal of model behavior, which is discontinuous in nature. The analysis of GCM and single column simulations has pointed to errors specifically connected to the discontinuities in the behavior of the turbulence and moist parameterizations. The aspects of the parameterizations that will be specifically addressed include the assumption of a ‘top-hat’-shaped sub-grid scale distribution of water vapor and sudden onset of phase changes in the prognostic cloud scheme, and an abrupt end to buoyant ascent in both the convective and turbulence parameterizations. The model parameterizations will also be examined to remove behavior that is inherently dependent on vertical resolution. Removal of these discontinuities is anticipated to reduce model error and enable a more continuous response to parameter changes during model tuning endeavors. In addition to correcting these known errors, the PI also plans to replace the current version of the cumulus parameterization with the more modern RAS-2, which includes the simulation of a cumulus downdraft and a modified mass flux entrainment profile for shallow convection.

In addition to the model development effort, Molod plans to analyze in detail the assessment of the improvements in GCM simulations brought by the Fortuna-2_0 changes. The changes in the parameterizations that resulted in the improvements in tropical precipitation and global stationary wave pattern will be understood in the context of the existing theory about tropical organization and teleconnections. The results of this study will be submitted for publication.

The initial period of the next year’s effort on the tropospheric ozone project will be devoted to completing the testing and carrying out the idealized experiments. The work will continue with the computation of surface emissions in several configurations of “chemistry tiles”, and the mapping of the turbulent transfer coefficients from the “catchment tile space” to the “chemistry tile space”. Experiments will be conducted to assess the optimal tile configuration.

Task 910-01-010: **Cloud Data Assimilation**

GEST Investigator: Peter M. Norris

Collaborators: Arlindo da Silva (GSFC Sponsor, 610.1), Lazaros Oreopoulos (GSFC 613.2)

Description of Research

It is widely recognized that clouds play an essential role in moderating the climate, which has prompted continuing efforts to improve the representation of clouds in global climate models. What is currently needed is the ability to test these cloud representations against different sources of observed cloud data with global or large-scale coverage. In particular, NASA has made a large investment in high-resolution satellite cloud observing systems (*e.g.*, MODIS, AMSR-E, OMI and CloudSat) that can be used for this purpose. This is the background for the current task within the NASA Global Modeling and Assimilation Office (GMAO) to use retrieved cloud data to validate cloud properties within the Goddard Earth Observing System (GEOS) model, to measure the capability of trial cloud representations, and to assimilate cloud measurements directly into the GEOS data assimilation system. This task is also particularly concerned with developing climate model cloud representations that benefit from realistic statistical descriptions of the cloud scale variability provided by high-resolution NASA cloud data.

Accomplishments during the Reporting Period

Currently, climate models have grid sizes too large (due to computational restrictions) to model many important cloud processes, so several solutions are currently being explored by the GCM community. One approach is to model not just the mean properties of a model gridbox, but other statistical properties as well. The so-called statistical or assumed-PDF cloud schemes fall into this category. These schemes assume a certain parametric form for the PDF of sub-grid-scale moisture variability, from which the cloud fraction and condensed water content are diagnosed. To close the system, the PDF parameters must be diagnosed or prognosticated by the GCM.

Norris continued to build upon his work on these statistical cloud parameterizations, based on the key paper of the previous year (Norris *et al.* (2008)). Further study of GCE cloud-resolving model simulation data has highlighted the significant influence of resolved scale trends in the moisture fields. These trends occur on the larger scales that are modeled by GCMs but continue down to scales of the order of a single GCM grid box and smaller. There may be no clear scale separation between these trend scales and the smaller turbulence and convection driven scales typically considered in statistical cloud parameterizations. Nevertheless, to make progress in parameterization, the approximate PDFs associated with the trend scales must be convolved with the assumed PDFs of the small-scale variability. Significant detailed work on formulating these combined PDFs has been conducted this past year and forms part of a major new publication in preparation.

Second, Norris has been working as the PI of the ARM grant *"Evaluation of GCM Column Radiation Models under cloudy conditions with the ARM BBHRP Value Added Product,"* in collaboration with Dr. Oreopoulos, on applying the PDF/copula statistical approach to some high-resolution cloud radar data taken at the ARM Southern Great Plains site. This data has proved to be a very useful complement to the simulated GCE data in quantifying the forms of the layer moisture PDFs and the copula relationships between layers. Drs. Norris and Oreopoulos presented some preliminary results from this investigation at the ARM Science Team Meeting in Louisville, Kentucky, March 30-April 2, 2009. Specifically, Norris formulated a new maximum likelihood method

for estimating the form (parameters) of various candidate total water moisture PDFs from the layer condensate data alone, which often represents only the upper tail of the total water PDF. This new method is key for continuing investigations of cloud data assimilation into GCM statistical cloud parameterizations via parameter estimation. In addition, a related method was developed to constrain the inter-layer rank correlations of total moisture using the condensate data from pairs of separated layers. These inter-layer correlations are needed to parameterize GCM cloud overlap and cloudy radiative transfer.

The above two works --- on a general and flexible parameteric form for subgrid-scale moisture variability and on the estimation of the parameters of that variability using ARM condensate data --- tie in very well to the larger goal of cloud data assimilation into GCMs, which is the major focus of the currently funded four-year NASA grant "*Assimilation of A-Train satellite data for constraining a new PDF-based cloud parameterization in GEOS-5,"* for which Norris is a co-I. In collaboration with the PI, Dr. Arlindo da Silva, Norris has been making progress in devising realistic strategies for this complex task. Specifically, they have been working on appropriate methods to handle cloud observations from MODIS and other instruments in the context of multiple cloud layers within a GCM grid box sized domain.

Finally, the GEST investigator has continued to collaborate with Dr. da Silva on the effect of subgrid-scale moisture variability on aerosol optical depth. Within the GMAO this work is an important ongoing application of the statistical parameterization work described above. Norris

conducted a detailed theoretical study of the humidification of hydrophyllic aerosols and its effect on cloud optical depth. This theoretical work and studies of the effect of subgrid-scale moisture variability in GCE data on the analysis of GCM aerosol optical depth will be published this coming year.

Objectives for the Coming Year

Further analysis of the forms of the layer moisture PDFs (including both small scale variability and grid-scale trends) and inter-layer (copula) correlations will be conducted using additional GCE case studies and ARM and CloudSat cloud radar data. The results will be published with Drs. Arlindo da Silva and Lazaros Oreopoulos. Norris will continue to work on formulating a new GEOS-5 statistical cloud parameterization and its constraint via parameter estimation using satellite cloud observations, from MODIS and other instruments, such as AMSR-E and OMI. This cloud data assimilation work will permit more accurate simulations of clouds and precipitation within GEOS-5 and 6, and is the focus of the NASA grant, "*Assimilation of A-Train satellite data for constraining a new PDF-based cloud parameterization in GEOS-5"* (mentioned above), for which the GEST investigator is a co-I. Finally, Norris plans to continue theoretical and analysis work on aerosol humidification and its parameterization in GCMs, leading to a paper with Dr. Arlindo da Silva. This work is an important component of the aerosol optical depth parameterization in GEOS-5.

Task 610-97-341: **Trace Gas Transport**

GEST Investigator: Lesley Ott

Collaborators: Steven Pawson (PI, GSFC 610.1), Kenneth Pickering (GSFC 613.3), Bryan Duncan (GSFC 613.3), Andrew Tangborn (JCET, GSFC 610.1), Zhengxin Zhu (SSAI, GSFC 610.1), Sarah Strode (SAIC, GSFC 610.1)

Description of Research

The GEOS-5 AGCM is a powerful research tool designed for a wide range of weather, climate, and atmospheric chemistry applications. Comparisons with *in situ* and satellite observations of trace gas concentrations are necessary to understand the properties of trace gas transport in the model. In addition to

understanding the trace gas distributions produced by the model, it is important to understand the roles of the underlying physical processes, which determine these distributions. Several processes, including convective transport and stratosphere-troposphere exchanges, are currently being studied in detail using ensemble simulations and tagged tracer methods. Efforts have also focused on understanding the role played by diabatic heating from biomass burning aerosols in locally altering atmospheric circulation and trace gas transport.

Accomplishments during the Reporting Period

The role of convective transport in determining trace gas distributions has continued. An ensemble of simulations was constructed using perturbations to parameters in the GEOS-5 moist physics schemes to represent the uncertainty introduced into trace gas distributions by uncertainty in the underlying convective parameterization. Simulations replicating the concentrations of radon, CO, and CO_2 have been completed. In addition to CO and radon emitted from all sources, simulations include radon and CO tracers tagged by emission regions. The addition of tagged tracers to simulations employing differing convective strengths allows the researchers to better understand the influence of convective transport in different regions. A preliminary analysis of simulated CO_2 suggests that alterations to parameters in the model's moist physics schemes can significantly alter CO_2 mixing ratios both near the ground and aloft. Surface locations in the northern hemisphere's mid- and high latitudes tended to show the greatest differences between simulations employing differing representations of convection. Because modifications to convection also influence the large-scale circulation, the transport of CO_2 from the northern to southern hemisphere is also affected.

The impact of aerosol heating on atmospheric dynamics has also been examined by analyzing two sets of GEOS-5 AGCM simulations, one set that includes aerosols produced by 2006 Indonesian wildfires and another set that does not. Each set consists of a ten-member ensemble of simulations, produced by initializing the model meteorology with fields representing different days in April. Diabatic heating from BB aerosols increased temperatures over Indonesia between 150 and 400 hPa. The higher temperatures resulted in strong increases in upward grid-scale vertical motion, which increased water vapor and CO over Indonesia. In October, the largest increases in water vapor were found in the mid-troposphere (~25%) while the largest increases in CO occurred just below the tropopause (80 ppbv or ~50%). Diabatic heating from the Indonesian BB aerosols caused CO to increase by 9% throughout the tropical tropopause layer in November and 5% in the lower stratosphere in December. The results demonstrate that aerosol heating plays an important role in the transport of BB pollution and troposphere-to-stratosphere transport. Changes in vertical motion and cloudiness induced by aerosol heating can also alter the transport and phase of water vapor in the upper troposphere/lower stratosphere.

The influence of STE on surface CO_2 mixing ratios has also been examined using the GEOS-5 AGCM. Several recent studies have shown evidence of STE processes influencing upper tropospheric CO_2 mixing ratios. Because surface data are often used to estimate CO_2 fluxes, it is important to understand the processes through which CO_2 is transported from the stratosphere to the surface. In order to study this problem, several new CO_2 tracers have been implemented in GEOS-5. In addition to being 'tagged' by stratospheric origin, these tracers were also tagged by the calendar month in which they were transported across the tropopause and then followed for three subsequent months in order to study transport timescales. The greatest latitudinal variability of the stratospheric air mass tracer is found ~30-60 days following the time of the cross-tropopause transport. As the time from the STE is extended past 60 days, spatial variations in the percentage of this stratospheric air at the surface diminish. Individual locations studied show a pronounced seasonal cycle in surface stratospheric tracer amount dictated by the seasonal cycle in stratosphere-to-troposphere transport which tends to peak in the midlatitudes

of each hemisphere during winter. Errors in model representation of stratosphere-to-troposphere transport are most likely to affect surface CO_2 mixing ratios in source regions where the largest differences between surface and tropopause mixing ratios occur. At remote locations, transport errors tend to have a relatively small influence.

Objectives for the Coming Year

In the next year, newly available observations of CO_2 from the AIRS and TES satellite instruments will be used to validate GEOS-5 simulated CO_2 distributions in the mid- and upper troposphere and to improve understanding of model transport. Research designed to improve understanding of the role of convective transport in determining trace gas distributions will continue. Previous efforts to understand uncertainty in trace gas fields caused by convection were focused on simulations unconstrained by atmospheric observations; future work will seek to understand how differing representations of convective transport affect assimilation of CO and CO_2 observations. In addition, high-resolution models capable of resolving cloud systems will be used to simulate a storm observed during the African Mansoon Measurements Analysis field campaign conducted in 2006. The results will be compared to aircraft chemical measurements as well as radar and satellite observations of storm evolution. Simulations using a single column version of GEOS-5 will be used to assess the performance of the parameterized convective transport and wet scavenging processes. Planned research will also focus on the hydrologic cycle in GEOS-5. An analysis of *in situ* and remote sensing observations will be used to improve the representation of simulated water vapor and ice in the upper troposphere. The improved model will be used to study the impact of aircraft emissions in current and future climate regimes. In addition, work is currently ongoing to incorporate water vapor isotopes in GEOS-5. Simulated water isotopes will be compared to TES observations in order to further understand the processes that govern the distribution of moisture in the atmosphere.

Task 100-02-904: **Director, Joint Center for Satellite Data Assimilation**

GEST Investigator: Lars Peter Riishojgaard

Collaborators: Franco Einaudi, Goddard Sponsor (until Jan 31, 2010)

Description of Research

Riishojgaard's main responsibility is to serve as Director of the Joint Center for Satellite Data Assimilation (JCSDA), which was created in 2002 as an interagency organization sponsored by NASA, NOAA and the Department of Defense, and is tasked with accelerating and improving the use of satellite data in a broad suite of environmental modeling and prediction applications. The JCSDA Director is part of the Joint Center Executive along with a Deputy Director and Associate Directors representing each of the six JCSDA partnering institutes or groups. The Director reports to a Management Oversight Board, consisting of senior managers from the JCSDA parent agencies. In addition to his JCSDA duties, Riishojgaard is active in a number of space mission initiatives, both nationally and internationally, *e.g.* the Canadian PCW and ESA's Atmospheric Dynamics Mission. He is also the Chair of the WMO Open Program Area Group on the Integrated Observing System and is co-chairing of the US Working Group on Space-Based Wind Lidars.

Accomplishments during the Reporting Period

Following the recommendation from the JCSDA Director, the Management Oversight Board for the Joint Center formally adopted an overarching focus on Numerical Weather Prediction (NWP) skill in March 2008. This step was taken in recognition of the fact that the operational skill of US systems has fallen behind with respect to the international competition. Over the next several months a new Strategic Plan for the Joint Center was developed. The

new document emphasizes the crucial role of NWP to the economy of the nation and to the safety of lives and property of its citizens and outlines the steps the Joint Center intends to take to help improve the quality of US model predictions.

The Joint Center hosted its 7th Annual Science Workshop on June 10-11, 2009. The Workshop was well attended; around 90 participants gathered to present, review and discuss progress and plans for Joint Center research and development. A new format was used for this workshop. In past years, most of the Workshop would consist of up to five parallel sessions, which typically allowed for a large number of presentations overall, at the expense of providing JCSDA management (and everyone else) with a comprehensive overview of ongoing work. This year, selected projects and programmatic activities were presented in plenary, with the rest of the projects displayed in a dedicated poster session, which was followed by a discussion session in breakout groups aligned with the JCSDA Working Groups. The new format was very well-received by the participants, and several of them expressed their appreciation of the chance to get an overview of the entire scope of JCSDA activities. Another consistent element of the feedback following the Workshop was the request to create additional JCSDA Working Groups; several topical areas were suggested as suitable candidates for this.

In spite of the fact that data assimilation is a crucial component of environmental prediction capabilities in a growing number of areas, university activities in data assimilation remain scarce. As a result, many young scientists embarking on a career in data assimilation are lacking in dedicated training in the field. In order to help address this situation, the Joint Center for Satellite Data Assimilation hosted a two-week Summer Colloquium in Stevenson, WA from July 7-17, 2009. Over the course of the colloquium, the 37 participants (Ph.D. students and early career scientist who had been selected on a competitive basis) were provided with a comprehensive overview of the field through a series of lectures given by a roster of world-class scientific experts. Based on the feedback from both lecturers and participants, the event was a resounding success, and it is expected that the Joint Center will follow up with a similar effort in 2011.

Further progress was made on the JCSDA Community Radiative Transfer Model in terms of new sensors supported – *e.g.* the current DMSP F-18 suite and ATMS scheduled to fly on NPP and NPOESS - and in terms of improved algorithms. The CRTM was implemented also in the NAVDAS system used by the Naval Research Laboratory and the Fleet Numerical Meteorology and Oceanography Center; it is now used by all JCSDA partner institutions.

Outside the main task of leading the Joint Center, the investigator continues to be active in space system development. He is a member of the Mission Advisory Group of ESA's ADM/Aeolus Wind Lidar Mission, a member of the International Users and Science Team of the Canadian PCW mission, and a Co-Chair of the US Working Group of Space-Based Wind Lidars.

Objectives for the Coming Year

Riishojgaard plans to further strengthen the partnerships of the Joint Center, both nationally and internationally. On the internal side, he and his collaborators plan to constitute additional JCSDA Working Groups covering the areas Land Data Assimilation and GPS Radio Occultation. Partnerships with the Hurricane Forecast Improvement Project (HFIP) and NOAA's Precipitation Measurement Mission Steering Group will be further developed. On the international side, a closer collaboration with the European Center for Medium Range Weather Forecasts is likely to develop. In June 2010, JCSDA and ECMWF will co-host their first Workshop on Assimilating Satellite Observations of Clouds and Precipitation into NWP Models. Discussions about closer collaboration on a range of satellite issues and on ensemble prediction are also ongoing. Finally, in response to repeated criticism from both staff and the JCSDA Advisory Panel, they plan to use NASA funding to significantly expand the computational resources available to JCSDA-sponsored researchers.

Task 610-92-318: **Remote Sensing and Public Health**

GEST Investigator: Radina Soebiyanto

Collaborators: Richard King (PI, GSFC 610.2), Farida Adimi (GSFC 610.2, Wyle)

Description of Research

Climatic and environmental factors play significant roles in both the temporal and spatial spread of infectious diseases such as malaria, dengue, cholera and influenza. For example, rainfall can provide a breeding habitat for malaria vector, *Anopheles* mosquitoes, but does not necessarily increase malaria transmission risk. A heavy but short rainfall or a following storm can flush the larval habitat and in effect reduce transmission. Instead, it is the intensity and timing of rainfall that determine transmission variability. The climatic and environmental factors influence the disease spread in a non-linear fashion that is not intuitively understood. Therefore, this study is aimed at developing mathematical models to forecast and facilitate the understanding of disease transmission – specifically for malaria and influenza – using environmental and climatic factors obtained from satellites. The model essentially provides a tool for public health support to prevent or manage disease outbreaks. In addition, the model would be able to address the effect of climate change on communicable disease transmission.

Accomplishments during the Reporting Period

Seasonal influenza continues to be a significant global burden, causing up to 300,000 deaths annually worldwide. Observations show that the pattern of influenza spread varies with latitudes, suggesting the role of varying climate and environmental conditions in the transmission. In fact, recent biological experiments show that low temperature and humidity increase the effectiveness of aerosol-borne transmission. This finding is consistent with influenza that peaks during winter months in the temperate regions. With evidences pointing at climate as one of the drivers in influenza transmission, Soebiyanto developed mathematical models based on the climatic factors that can predict influenza cases in the range of a few weeks to one season in advance, in which the results can be used in devising a vaccination distribution strategy and in health preparedness and response. Specifically, the GEST investigator first developed a classical time series regression model called Auto-Regressive Integrated Moving Average (ARIMA) to predict influenza in Hong Kong and Maricopa County, Arizona. The model shows the correlation between Land Surface Temperature (LST) retrieved from the MODerate resolution Imaging Spectroradiometer (MODIS) data set, rainfall as measured from the Tropical Rainfall Measuring Mission (TRMM) and humidity, with influenza cases in Hong Kong. As for Maricopa County, temperature and maximum pressure were found to improve influenza forecast capability. This work was accepted in January for publication in the journal *PLoS ONE*.

In addition to the regression model that can predict influenza a few weeks ahead, Soebiyanto has developed a Neural Network (NN) model to forecast influenza one season ahead. Predictions were made for influenza cases in Hong Kong, New York City and Maricopa County. TRMM and MODIS data were used in developing the models, in conjunction with ground stations data that measure humidity, sunlight and temperature, among others. Part of this research has been submitted as a book chapter that will be published in the coming year.

In this past year, the GEST investigator has also developed a stochastic, spatial model for avian influenza transmission between poultry farms. The model illustrates how fast an infection in one farm can affect the other farms within the vicinity. Bio-security measures were included in the model; hence, further analysis can recommend bio-security improvements to prevent infection. While the model was

developed in a hypothetical setting where farms are randomly seeded, once data is available, it could be applied into a real setting.

Objectives for the Coming Year

For the coming year, Soebiyanto will continue working on the seasonal influenza model, with more emphasis on the sensitivity of the climatic factor on the different strains of influenza. The one-season-ahead influenza prediction using Neural Network will be submitted for publication. Once data is available, she will apply her avian influenza farm-to-farm spread model to a real setting. Soebiyanto will also resume her work on other climate-sensitive diseases that will now be focused on the role of climate in the variability of the disease spatial spread.

Task 610-80-274: **Improving Gravity Wave Parameterization in NASA GEOS-5 GCM**

GEST Investigator: In-Sun Song

Collaborators: Max Suarez (GSFC), Michele Rienecker (GSFC), Julio Bacmeister (NCAR)

Description of Research

The dynamic importance of atmospheric gravity waves (GWs) lies in their capability of transporting momentum and heat fluxes across wide areas and several atmospheric layers. In fact, GWs interact with the global circulations by depositing atmospheric momentum and heat fluxes extracted from the GW source regions into the large-scale flow located far from the source regions. Yet the fact that GWs manifest themselves at a broad range of spatial and temporal scales has hampered the explicit representation of the GW-mean flow interaction in global models. Hence, effects of unresolved GWs have been parameterized in low-resolution models, and the GEOS-5 model also includes a gravity wave parameterization (GWP) as one of its principle model components. However, the current GWPs present fundamental questions as the researchers enter an era of mesoscale-resolving (or higher-resolution) global modeling: will current GWPs disappear or be transformed into different forms in high-resolution global models? Until now, these questions have not been answered. Therefore, this task has two purposes: first, to improve the GWP for the low-resolution GEOS-5 general circulation model (GCM) by finding out more appropriate parameters for unresolved GWs; second, to suggest an outlook or new framework of GWPs for use in a high-resolution global model by examining resolved GWs in high-resolution GEOS-5 model data.

Accomplishments during the Reporting Period

Momentum and energy conserving GWP, developed during the last fiscal year, has been tuned for implementation into the GEOS-5 GCM. The new GWP is expected to be included in the GEOS-5 GCM as the official GWP since GEOS-5 version Fortuna 2.1. Tuning has been done to deal with two issues: one issue is the westerly biases in the QBO, and the other is an unrealistically tall southern subtropical jet in the austral summer that leads to strong westerly biases in the lower stratosphere. The westerly bias in the QBO is partially reduced by increasing the horizontal wavelength of the background GWs from 100 km to 700 km in the tropics alone. This increase in wavelength allows the equatorial background GWs to be broken down more gravitationally in the lower stratosphere and consistent with constraints of the generation of the QBO suggested by Campbell and Shepherd (2005). The subtropical jet issue is more or less alleviated by increasing the efficiency factor for the southern hemispheric orographic GWs generated mainly by isolated mountains (Alexander *et al.*, 2009) and by assuming the background GWs are stronger in the southern subtropics than in the northern subtropics, due to the convective activities in the elongated south-pacific convergence zone (SPCZ). In addition to this tuning, impacts of momentum and energy conserving GWP in the GEOS-5 GCM are examined. Among several factors required for conservation, the top boundary condition of the

new GWP is found to give the largest impact in the model climate. One prominent effect of the top boundary condition is the temperature change by as much as 10 K in the southern polar lower stratosphere, which is consistent with Shaw *et al.* (2009).

Objectives for the Coming Year

In this fiscal year, efforts will be made to analyze resolved GWs revealed from high-resolution GEOS-5 model output, in addition to supplementary tuning works for the new GWP. As a first step, the GW analysis will be made for stationary GWs induced by orography. For a systematic analysis, a continuous spherical directional wavelet technique (Antoine *et al.*, 2004) will be employed. The technique allows researchers to examine the spectral characteristics of GWs according to horizontal scales and wave propagation directions at each position on the spherical globe. Also, the amplitude and spatial structure of GW packets with various horizontal scales will be reconstructed using the spherical wavelet frame (Bogdanova *et al.*, 2005). From the reconstruction, GW momentum flux and drag forcing can be represented as a function of the horizontal scales and propagation direction. This scale-dependent reconstruction of GW flux and forcing is expected to be able to give local estimations of the spectral and directional distributions of GW flux and forcing. Furthermore, the scale-dependent reconstruction of GW flux and forcing will be attempted at model resolutions of $1/4^o$, $1/8^o$, and $1/16^o$. This will allow for the investigation of the behavior of the GW flux and forcing at the mesoscales or at the smaller horizontal scales. Hence, the scale-dependent GW flux and forcing computed based on wavelet technique may be able to provide some hints about the dependency of GW forcing on the horizontal scales, and the necessity of the GWP at mesoscales or smaller horizontal scales. Also, the scale-dependent analysis may produce interesting arguments about the existence of a power law in the GW flux and forcing (or fractal structure in the local GW fields), as expected from the observations that the mountain elevations can be fractal and exhibit a power-law variation (*e.g.*, Bannon and Yuhas, 1990).

Task 610-67-230: **Coupled Climate Modeling**

GEST Investigator: Yury Vikhliaev

Collaborators: Michele Rienecker (PI, GSFC 610.1), Max J. Suarez (GSFC 610.1), Julio Bacmeister (GEST, GSFC 610.1), Andrea Molod (GEST, GSFC 610.1).

Description of Research

The goal of this work is the development of a GEOS-5 coupled general circulation climate model (CGCM). The main components of the GEOS-5 CGCM are atmosphere general circulation model (AGCM) and land surface model (LSM) developed by the Global Modeling and Assimilation Office (GMAO), and the MOM4 ocean model, an externally developed ocean general circulation model (OGCM). The GEOS-5 architecture, which relies on the Earth System Modeling Framework (ESMF), simplifies the combination of different components of the climate model using a universal coupling interface. This project involves performing and analyzing multi-year to improve the model climate significantly. The high-resolution climate simulations. During test simulations, model deficiencies are detected and solved. The model is currently used for data assimilation, and is to be used for climate forecasting and climate sensitivity studies.

Accomplishments during the Reporting Period

During the reporting period, all components of the GEOS-5 coupled general circulation model went through a major update. Extensive testing of the model was performed in the course of over fifty coupled multi-decadal numerical experiments and two multi-century ocean model runs forced by climatological boundary conditions. This testing allowed tuning of the atmosphere and ocean components of GEOS-5 most notable improvements are in the tropical

Pacific region, where model biases were the largest.

The tropical Pacific is a region of special interest to the climate community since ocean-atmosphere interaction in the tropics strongly affects the global climate. Prior testing of GEOS-5 revealed that the errors in the tropical climate produced by the model resulted from complex feedbacks between atmosphere and ocean components. Due to deficiencies in the parameterization of sub-grid scale processes, the ocean component tends to produce too cold sea surface temperature (SST) in the eastern tropical Pacific ocean, causing too strong meridional SST gradient. In turn, the atmosphere component advects the air from the warm SST to cold SST regions, causing excessive formation of low clouds that reduces the incoming shortwave radiation and amplifies the cold bias in the eastern Pacific. It was found that the cold tropical bias in the OGCM component is very sensitive to the parameterization of vertical mixing. Increasing of vertical mixing in the ocean mixed layer reduces water upwelling in the equatorial region and affects the formation of cold surface water. The sensitivity of the amplitude of Tropical Instability Waves (TIW) to the parameterization of horizontal ocean viscosity was tested, since the intensity of TIW affects the meridional diffusion of SST. It was found that, although reducing the viscosity in tropics increases the amplitude of TIW, the meridional SST gradient is not reduced significantly enough to suppress low cloud formation. On the AGCM side, tuning of the vertical diffusivity profile in the turbulent boundary layer resulted in a reduction of an excessive cloud radiative forcing in tropical regions and increased an insufficient cloud radiative forcing in the extra-tropics. Multi-century OGCM simulations forced with climatological boundary conditions were used to analyze the model steady state and to choose a proper parameterization of background vertical diffusivity. As a result of these efforts, the GEOS-5 simulates a reasonable mean climate. A set of parameters found during test simulations described above is used as the default in a new version of GEOS-5.

During the reporting period the ocean component of GEOS-5, MOM4, was updated to the latest public release. Additional testing and tuning of MOM4 under the GOES-5 framework was necessary after the update. The new MOM4 version includes a generic tracer module, which was used to couple the MOM4 with the locally developed ocean biogeochemistry component under the GOES-5 framework. The coupled model with ocean biogeochemistry component is currently in testing phase.

The GEOS-5 is intended for use for high-resolution climate simulations. In the scope of these plans, a high-resolution 0.5 degree-grid with 60 vertical levels and a set of initial conditions were generated. This grid is currently being tested in a coupled simulation.

Objectives for the Coming Year

Currently, coupled GEOS-5 simulates the reasonable mean climate comparable to many other state-of-the-art CGCMs. Further tuning of the model will be focused on long time scales. For this purpose, Vikhliaev will undertake multi-decadal runs, including high-resolution runs, which will be used to document a performance of the model on interannual and decadal time scales. To analyze the dominant modes of variability at decadal time scales, the GEST PI will perform a multi-century coupled run to be used as the basis for studies of climate predictability at decadal time scales. Vikhliaev also will analyze the performance of some test cases of long time scale forecasts of the coupled model initialized for seasonal climate forecasts to compare the predictability with that estimated from the uninitialized coupled runs.

Task 610-73-252: **On the Nature and Predictability of Interannual to Decadal Changes in the Global Hydrological Cycle and its Regional Impacts**

NOAA Grant: **Roles of ENSO and Slowly Varying SST Modes in Influencing the Development of Drought over the United States: A Modeling Study (NA08OAR4310580)**

GEST Investigator: Hailan Wang

Collaborators: Siegfried Schubert (GSFC 610.1), Max Suarez (GSFC 610.1), Randal Koster (GSFC 610.1), Junye Chen (UMD ESSIC)

Description of Research

The most important recurring patterns of SST variability that exert profound impacts on the North American climate are those associated with ENSO, and at longer time scales, a decadal pan-Pacific pattern related to the Pacific Decadal Oscillation (PDO) and the Atlantic Multi-decadal Oscillation (AMO). In addition, SST variations in the Indian Ocean and a global linear trend pattern appear to be important. The goals of the first project are to improve the researchers' understanding of the mechanisms that link North America's hydroclimate variability to the leading patterns of decadal SST variability in the Indo-Pacific and Atlantic basins, as well as the impact of global warming, and to provide better assessments of the nature and predictability of the PDO-like and AMO-like SST variations. The goals of the NOAA project are to investigate the roles of ENSO and leading slowly varying SST modes, *i.e.*, Global Warming (GW), PDO and AMO, in initiating, sustaining and terminating major historical U.S. droughts, and address the relative roles of these slowly varying SST modes in modulating ENSO teleconnection over the U.S.

Accomplishments during the Reporting Period

As a prerequisite to the coupled modeling investigation of the nature and predictability of the PDO-like and AMO-like SST variations, Wang performs and completes the MERRA-Scout experiment, a coarse resolution of the MERRA run, with the NASA GEOS-5 data assimilation system for the period 1948-1978. This MERRA-Scout run (1948-1978) serves as an extension of the MERRA-Scout run for the period 1979-present that the GMAO operations group performs. The combination of these two MERRA-Scout runs provides a data set of 1948-present that is sufficiently long for studying the mechanisms of the climate shift in the Pacific in the mid-1970s as well as the AMO phase changes around 1970 and 1990. Such complex long period data sets will be not only useful for the decadal climate study but also valuable to many other studies. After completing the MERRA-Scout run for the period 1948-1978, Wang analyzes the Scout reanalysis and finds significant sensitivity of the NASA/GMAO data assimilation system to the changing observing system. Such sensitivity is well reflected in the time series of global mean precipitation, which is characterized by a gradual decrease from 1948 to the early 1960s, when global conventional observational data coverage gradually increases, a significant jump in 1972-1973, and a sudden drop in late 1978, due to the introduction of global satellite data. To investigate the causes for the global mean precipitation jump during 1972-1973, Wang further performs a number of MERRA-Scout experiments forced with various subsets of the observational data for the period 1972-1973. Results show that it is the upper air data, particularly the Office Note upper air data provided by the NCEP EMC, that largely constrains the MERRA-Scout output and causes the precipitation jump during the period 1972-1973.

Wang also plays an important role in the U.S. CLIVAR Drought Working Group in which the modeling groups at the NASA/GMAO, NOAA/NCEP, LDEO climate group of the

Columbia University, NOAA/GFDL and NCAR performed identical idealized AGCM experiments to address the effect of leading SST patterns on U.S. drought. She collaborates with members of the Drought Working Group in investigating the physical mechanisms of the SST changes affecting the drought phenomenon, as well as addressing model dependence on the response of drought to SSTs and the role of soil moisture. As a result, four papers (lead-author in one and a co-author in three) have been published in the special issue of the *Journal of Climate* for the U.S. CLIVAR Drought Working Group. In particular, Wang and the GMAO colleagues use the NASA NSIPP-1 AGCM to investigate the physical mechanisms by which the leading patterns of the annual mean SST variability impact U.S. precipitation. The focus is on a cold Pacific pattern and a warm Atlantic pattern that exert significant drought conditions over the North American continent. The investigation shows that while the cold Pacific and warm Atlantic are two spatially distinct SST patterns, they nevertheless produce similar diabatic heating anomalies over the Gulf of Mexico during the warm season. In both cases, the diabatic heating anomalies force an anomalous low-level cyclonic flow over the Gulf of Mexico that leads to reduced moisture transport into the central U.S. and increased moisture transport into the eastern U.S. The precipitation deficits over the Great Plains in both cases are greatly amplified by the strong soil moisture feedback in the NSIPP-1 AGCM. In contrast, the response over the southeastern U.S. to the cold Pacific during spring is primarily associated with an upper tropospheric high anomaly over the southern U.S., which is remotely forced by tropical Pacific diabatic heating anomalies, leading to greatly reduced stationary moisture flux convergences and anomalous subsidence in that region.

For the NOAA project, Wang investigates the impact of slowly varying SST modes, particularly the PDO, in modulating ENSO teleconnection over the U.S. during winter and summer. The investigation consists of three parts. First, using available observations, she performs stationary wave modeling experiments to address the relative roles of leading slowly varying SST modes in modulating the atmospheric circulation anomalies excited by El Niño-associated diabatic heating anomalies. The effects of the leading slowly-varying SST modes are represented by adding their associated atmospheric circulation anomalies onto the 3-D climatological background states. Preliminary analysis shows that PDO in its positive phase tends to weaken El Niño-forced atmospheric circulation anomalies over the U.S., especially during winter. Second, using the outputs of idealized AGCM experiments forced with ENSO and PDO SST patterns available from the U.S. CLIVAR Drought Working Group (DWG) modeling effort, Wang finds that, for both winter and summer, ENSO-teleconnection over the U.S. weakens (strengthens) when the PDO is in its positive (negative) phase. Such impact of PDO on ENSO teleconnection is supported by a limited comparison with observations. Third, a series of idealized NSIPP-1 AGCM experiments forced with various combinations of a temporally evolving El Niño SST anomaly (from January of year 0 to December of year 1) and fixed slowly varying SST modes are performed. Model results show the importance of land initial conditions at the beginning of year 0 in affecting the precipitation response over the U.S. in the following summer. If consistent with observations, this result implies that part of the warm season predictability of U.S. precipitation could originate from the land condition in the preceding winter.

In addition to the above major efforts, Wang and her GMAO colleagues are currently investigating the mechanisms for summertime precipitation variation over the eastern U.S., using the newly available MERRA data.

Objectives for the Coming Year

Wang will further quantify the physical mechanisms that link North America's hydroclimate variability to the leading patterns of decadal SST variability in the Indo-Pacific and Atlantic basins. With the GEOS-5 AGCM, version Fortuna 2.1 soon available, she will perform a comprehensive set of AMIP-type experiments, including the standard AMIP runs and AMIP runs with aerosols such as dust. Wang will also help to perform the idealized

AGCM experiments forced with leading SST patterns. The outputs of these experiments will be used to address roles of leading SST variability, soil moisture and aerosols for the North American hydroclimate variability. In addition, Wang will help assess the nature and predictability of PDO-like and AMO-like SST variations. The work will use NASA's GEOS-5 model (coupled and uncoupled) and atmosphere and ocean data assimilation systems, including a "replay" methodology that allows running the coupled model under various atmospheric constraints.

With the newly available MERRA data, Wang and GMAO colleagues will conduct two studies investigating the mechanisms for the eastern U.S. precipitation variation during summer, and the mechanisms for the distinct maximum precipitation response in fall associated with ENSO. The results of these studies are to be included in the *Journal of Climate*'s MERRA Special Issue.

For the NOAA project, Wang will continue to examine the mechanisms for the impact of leading slowly varying SST modes in modulating the ENSO-teleconnection over the U.S. In addition, she will perform additional AGCM experiments to investigate the relative roles of ENSO and slowly varying SST modes in the development of historical U.S. droughts.

Mesoscale Atmospheric Processes (Code 613.1)

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Task 912-52-202: **The Micro-Pulse Lidar Worldwide Observational Network (MPLNET)**

GEST Investigator: Timothy Berkoff

Collaborators: Judd Welton (PI, GSFC 613.1), James Campbell (UCAR), Sebastian Stewart (SSAI, GSFC 613.1), Larry Belcher (GEST), Si-Chee Tsay (GSFC 613.2), Brent Holben (GSFC 614.4)

Description of Research

MPLNET is a network of lidar systems (MPLs) that provide long-term observations of aerosol and cloud properties at multiple sites around the globe. Sites in the network use an elastic-scattering lidar co-located with a sun-photometer to provide data products of aerosol optical and physical properties. Expansion of the network is based on partnering with research groups interested in joining MPLNET. Reliable and accurate instrumentation performance in the field is essential to ensure the generation of high-quality data from remote sites. To promote the success of MPLNET, technology and calibration issues are investigated in relation to network operational activities. Instrumentation oversight is provided for implementation of systems in the field, laboratory calibration/validation facilities and equipment, as well as data characterization efforts.

Accomplishments during the Reporting Period

General management of MPLNET instrumentation matters were carried out during the reporting period to enable MPLNET participation in field campaigns and the continued operation of multiple sites around the globe. Sites included in this effort were the Korean Global Atmosphere Watch Observatory in Anmyeon-do, Korea, NASA Langley's CERES Ocean Validation Experiment (COVE) platform in the Atlantic Ocean, National Central University's site in Taiwan, Goddard Space Flight Center's Greenbelt site in Maryland, Seoul National University's station in Korea, Naval Research Laboratory's Monterey site in California, National Institute of Polar Research (Japan) operating a lidar at Syowa station in Antarctica and Ny-Alesund station in Norway, NOAA's South Pole Atmospheric Research Observatory in the Antarctic, Trinidad Head Observatory in California, Ben-Gurion University site in Israel, and University of New Hampshire's Thompson Farm site in New Hampshire. Ongoing operational issues were investigated to address and improve network performance: characterizing and identifying the causes of laser transient data corruption; detector transient and dark count studies; and, investigating window dielectric-coating degradation effects. Technical feedback was provided to correct a wide range of operational issues.

Development activities included analyzing and investigating key technology and calibration improvements, such as empirical evaluation of the Micro-Pulse Lidar (MPL) overlap function and related measurements using a wide field-of-view (WFOV) receiver. The MPL overlap function is the non-linear signal-loss response for measurements that occur closer than 6 km to the lidar and represents the most problematic calibration for this type of instrument. This receiver is able to generate data with minimal influence from the overlap effect and was used to generate overlap calibrations multiple times for the MPL operating at NASA GSFC. Support, operational training, and improvements in the use of the approach were provided for this ongoing effort. Results from this receiver were used to generate the operational overlap correction for the NASA GSFC, the primary calibration lidar for the entire network.

Additional development efforts included the investigation of thermal effects on instrument performance, and the implementation of IDL-compatible code and correction table for temperature corrupted data products. Thermal

expansion of the MPL telescope introduces a bias error in the data. Prior work demonstrated the feasibility of this approach using a paraxial optics model to correct data. During this reporting period, the prior model output was adapted for use with network wide data sets, and for the first time was implemented within the MPLNET operational framework. As a result, thermal corrections can now be applied to a wide variety of data sets and sites.

Objectives for the Coming Year

The main goals for the upcoming year are to further improve MPLNET by continuing to investigate instrumentation matters for the network, as well as key technology and calibration improvements. This would include qualifying instrument improvements for MPLNET operations, studying ground-based to satellite comparisons, and investigating new aerosol calibration techniques.

Task 912-54-204: **Development and Applications of the Goddard Multi-Scale Modeling Framework**

GEST Investigator: Jiun-Dar Chern

Collaborators: Wei-Kuo Tao (PI, GSFC 613.1), C. Peters-Lidard (GSFC 614.3), Bo-Wen Shen (ESSIC), Toshihisa Matsui (GEST)

Description of Research

The representation of convective clouds and cloud systems in a global climate model is one of the most challenging problems in climate modeling. Climate models rely on cumulus parameterization to represent the sub-grid convective cloud processes; however, the progress of cumulus parameterization was very slow in the past decades. To break the cloud parameterization deadlock, a new modeling approach was developed: the Multi-scale Modeling Framework (MMF). The idea is to use cloud-resolving model (CRM) in each column of a general circulation model (GCM) to explicitly represent small-scale and mesoscale cloud processes and interactions among them. The use of a GCM will enable global coverage, and the use of a CRM will allow for better and more sophisticated representation of model physics. The MMF has been shown to substantially reduce common systematic errors in climate models. Coupled with forward satellite simulators, the high-resolution CRM outputs from the MMF can provide global detailed cloud statistics that can be compared directly against observations from NASA satellite platforms, such as the Tropical Rainfall Measuring Mission (TRMM), the Moderate Resolution Imaging Spectroradiometer (MODIS), Microwave Limb Sounder (MLS), and the CloudSat. The main objective of this research is to use NASA satellite products for improving the cloud microphysics schemes in CRM and the representation of moist processes in climate models.

Accomplishments during the Reporting Period

The Goddard MMF has been developed based on the finite-volume General Circulation Model (fvGCM) and 2D Goddard Cumulus Ensemble Model (GCE). It has been successfully applied to long-term climate studies (such as AMIP-type climate simulations and climate change simulations), inter-annual variability (such as El Nino and La Nina simulations), inter-seasonal and seasonal variability (such as Madden-Julian Oscillation, Africa Easterly waves, drought and flood, tropical cyclones), and short-term weather events and diurnal cycle studies. Overall, the MMF is superior to fvGCM in simulating the geographical distribution of precipitation, high cloud amount, the Madden-Julian oscillation (MJO) signal, and diurnal cycle of precipitation over land and ocean (Tao *et al.* 2009).

The 2005 Atlantic hurricane season featured a record 15 hurricanes with a record four landfalling U.S. major Hurricanes (*i.e.* categories 3-5 on Saffir-Simpson scale). The hurricane activities in the Atlantic basin were near normal with only 5 hurricanes in 2006, even with the prevailing favorable preseason conditions. The cooling of the Atlantic basin by Saharan dust and the anomalous upper-level convergence and sinking motion across the Caribbean Sea due to

the El Nino activity have been suggested as two possible causes that foiled the 2006 hurricane forecasts. The Goddard MMF and fvGCM two-year (2005-2006) control simulations forced by the observed weekly sea surface temperature show both models agree well with the TRMM combined product in simulating more precipitation during the 2005 season. The results show the MMF has better precipitation bias with less rainfall amount over the North Atlantic. In addition, the dry areas associated with the subtropical Bermuda high are more realistic than that of the fvGCM. Both models tend to produce excessive precipitation in the Eastern Pacific tropics. In the future, a tropical cyclone (TC) detection and tracking scheme is needed to quantify the activity of TC. The MMF simulations with a higher resolution are also needed to study the effects of resolution and terrain on TC forecast.

To examine the MMF's capabilities in simulating the regional droughts/floods variations during 2006 and 2007, the PI and his team conducted three-year (2005-2007) MMF simulations. The model climatology is constructed based on the averages of these three-year simulations. Monthly anomalies show that it still remains challenging to simulate intra-annual variations of moist fields in regional areas with a coarse resolution MMF. Longer simulations may be needed to better represent a model climate along with improved resolution to represent the realistic terrain in MMF. To access the MMF's suitability for extended-range weather forecasts, MMF simulations were conducted to study the life cycle of two individual MJO events. The results showed the MMF is capable of reproducing the initiation and intensification of large-scale organized convection in the Indian Ocean, the slow propagation prior to reaching the Maritime continent, and the fast propagation and weakening after passing the Maritime continent. However, Chern also noted that the simulated MJOs produced stronger vertical motion than the NCEP/GSF reanalysis.

The long-term 11-year MMF control simulation has been carried out to establish the baseline climate of the current MMF system. Many MMF sensitivity studies also have been successfully carried out to study the impact of temperature dependent particle size distribution of ice species in a new bulk microphysical scheme. The new scheme has significant effects on the global energy and water balances. Further tuning of the scheme is needed to achieve the energy balance at the surface and at the top of the atmosphere. Many recent and future NASA satellite programs can provide measurements of clouds, radiation, precipitation, aerosols, land characteristics and other data at very fine spatial and temporal scales. However, direct comparisons between climate model results and high-resolution satellite data is very challenging due to the differences in spatial and temporal scales. Since the MMF system can explicitly simulate cloud processes at the natural space and time scales of cloud-dynamical processes, model pixel-scale statistics of cloud fields can be directly compared against satellite measurements. The capability of a suite of forward satellite simulators has been continuously improved. The TRMM triple-sensor three-step evaluation framework (T3EF) was applied to evaluate the Goddard MMF. T3EF utilizes multi-sensor satellite simulators and novel statistics of multi-sensor radiance and backscattering signals observed from the TRMM satellite. Specifically, T3EF compares CRM and satellite observations in the form of combined probability distributions of precipitation radar (PR) reflectivity, polarization-corrected microwave brightness temperature (*Tb*), and infrared *Tb* to evaluate the candidate CRM. The evaluation revealed that Goddard MMF captured the global distributions of shallow raining system well, yet it over-predicted the occurrence of cirrus-overlapped cumulus congestus systems. T3EF also revealed that Goddard MMF over-predicted the PR reflectivity and microwave *Tb* depression in the tropical warm pool. Unveiling the detailed errors in the Goddard MMF performance provides better direction for model improvements.

Objectives for the Coming Year

The PI will work with members of Goddard's Mesoscale Dynamics and Modeling Group to continue improving cloud microphysics in the Cloud-Resolving Model (CRM) and applying the improvements into the MMF system to study their impacts on large-scale circulation and global climate. He also will work with the Goddard Land

Information System Group to couple the Land Information System (LIS) with the MMF to assess the effects of land surface processes on cloud formation and precipitation intensity. Additionally, Chern plans to work with the Global Modeling Assimilation Office (GMAO) to develop a new MMF system based on the state-of-the-art GEOS-5 global model. He also will conduct more MMF control and sensitivity experiments to assess the performance of the model and compare the results with NASA high-resolution satellite observations by using forward satellite simulators.

Task 912-21-140: **Precipitation Estimation from Satellite Active and Passive Microwave Observations**

GEST Investigator: Mircea Grecu

Collaborators: Scott Braun (PI, GSFC 613.1)

Description of Research

Precipitation retrievals from satellite passive microwave observations are an ill-posed problem, *i.e.*, multiple solutions are possible. This indeterminacy stems from the fact that it is always possible to find multiple precipitation profile solutions that are consistent with the single instrument observations, due to noise in the observations or variations in geophysical parameters that cannot be uniquely determined from observations. To reduce the range of possible precipitation estimates that can be associated with single instrument observations, coincident radar and microwave brightness temperature observations are utilized: first, a set, or "ensemble", of precipitation profile solutions consistent with the radar-only observations is produced by randomly generating noise or geophysical parameter variations within realistic bounds; second, a simulated distribution of upwelling microwave brightness temperatures is calculated from the ensemble of radar-only profile solutions. Based upon a statistical analysis of differences between the calculated and observed brightness temperatures, an updated ensemble of precipitation profiles consistent with the brightness temperature data is then derived; the mean of this ensemble is the "best estimate" precipitation profile.

Accomplishments during the Reporting Period

The investigator continued working on the development and the application of an extended EnKF framework for precipitation estimation. The developed algorithm differs from existing methods by the fact that it does not systematically look for a single solution – *e.g.*, through a gradient-based search method like the algorithm of Grecu *et al.* (2004) or through an exhaustive search in a database of predetermined solutions, like the algorithm of Masunaga and Kummerow (2005); rather, this algorithm determines a solution based upon a statistical analysis of possible radar-only retrievals. The algorithm can provide estimates of geophysical parameters other than precipitation (*e.g.* cloud water, water vapor, surface wind speed, etc.) and can be easily applied to any radar-only precipitation estimation algorithms developed within the NASA Precipitation Measuring Mission (PMM) Science Team.

As previously mentioned, there are multiple variables (*a priori* assumptions) that have a significant impact on precipitation estimates derived from a radar retrieval algorithm. These include the vertical distribution of water vapor, cloud water, cloud ice, and precipitation under the TRMM/GPM detectability threshold, the relationship between the density of ice (snow) particles and their equivalent-mass sizes, and the electromagnetic modeling of ice (snow) and melting particles. In the developed framework, possible vertical distributions of water vapor, cloud water, and cloud ice for various environmental conditions are derived using high-resolution cloud resolving model (CRM) simulations. Specifically, the Weather Research and Forecasting Model (WRF) is run for various

conditions and seasons at various locations the aforementioned variables are statistically analyzed using Empirical Orthogonal Functions (EOFs). Random combinations of EOFs with randomly specified scaling coefficients (within prescribed bounds) are used to produce realistic profiles of water vapor, cloud water and cloud ice fully consistent with the WRF output. Models describing ice particle geometries, their density-size relationships, and their electromagnetic properties are also randomly selected from existing parameterizations. Additional sources of uncertainties, such as errors in the PIA estimates from a surface reference technique (SRT) are readily generated at random, based on the SRT accuracy.
Based on the consistency of possible radar-only precipitation retrievals with radiometer observations, the most likely combined radar radiometer retrieval is derived using an efficient ensemble filtering methodology. That is, radiometer brightness temperatures are simulated from radar only retrievals (which are considered the "*a priori*" distribution of precipitation retrievals) and a *posteriori* distribution (*i.e.* the distribution that is most consistent with the radiometer observations) of precipitation retrievals is derived using a Kalman filter formulation (Grecu and Olson, 2008). Since every radiometer footprint includes multiple radar profiles while every radar profile falls with multiple radiometer footprints, difficulties arise and they are approached using an effective sequential processing formulation.

Objectives for the Coming Year

In the coming year, the combined algorithm will be extended to be applicable to GPM around the globe, and the vertical distribution of observations. Although true GPM-like observations will not be available before the deployment of GPM, the proposed algorithm can be tested using simulated GPM observations. In this respect, TRMM-combined retrievals are of paramount importance. Starting from TRMM-combined retrievals, GMI observations will be simulated, *i.e.*, Dual frequency Precipitation Radar (DPR) and GPM Microwave Images (GMI) observations. As previously mentioned, single frequency radar observations can support only parameterized retrievals of PSD intercepts. Also, because the TMI observations are characterized by large footprints, many retrieved variables (*e.g.* relative humidity, cloud water, etc.) may exhibit unrealistic smoothness. Observations synthesized from variables that exhibit less variability than in nature may not lead to challenging test beds for evaluating DPR-based combined algorithms. Therefore, Grecu intends to use simple but physically acceptable techniques to derive, from TRMM combined retrievals, precipitation and associated variables that exhibit variability similar to that derived from either high-resolution ground observations or theoretical considerations. These enhanced variables will be used as a reference, and the GPM-like observations calculated from them will be used to test the proposed combined algorithm. GPM synthetic observations derived from TRMM-combined retrievals using the procedure outlined above are likely to provide a more effective testing framework than synthetic observations derived exclusively from cloud resolving models.

Task 912-54-203: **Algorithm Development for Space-Borne Dual Frequency Radar**

GEST Investigator: Mei Han

Collaborators: Scott Braun (PI, GSFC 613.1), William Olson (JCET), P. Ola. G. Persson (CIRES, NOAA/ESRL), Jian-Wen Bao (NOAA/ESRL), Christopher Williams (CIRES, NOAA/ESRL)

Description of Research

This research emphasizes the use of satellite-based observations from NASA satellites (TRMM and Aqua) and numerical models (MM5 and WRF) to study winter precipitation over ocean and land. Although designed to monitor and study precipitation throughout the tropics, the Tropical Rainfall Measuring Mission (TRMM) has coverage in the higher latitudes (up to ~38° N and ~38° S). The valuable observations from TRMM Precipitation Radar (PR) and Microwave Imager (TMI) provide opportunities to study winter precipitation systems and to evaluate the performances of cloud and precipitation models and retrieval algorithms in the middle latitudes. In the Global Precipitation Measurement (GPM) mission formulation phase, research efforts have been extended to study winter cyclones, fronts, and precipitation with more focus on their landfall processes and interactions with terrain.

Accomplishments during the Reporting Period

Han completed a study (see in press publications) of applying TRMM PR and TMI measurements to assess cloud microphysical schemes in the fifth-generation Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) Mesoscale Model (MM5) model. This paper uses both active and passive microwave observations from the TRMM satellite to evaluate the cloud microphysical schemes in the MM5 model (version 3.7.4) for a wintertime frontal precipitation system over the eastern Pacific. By incorporating a forward radiative transfer model, the radar reflectivity and brightness temperatures are simulated and compared to the observations at PR and TMI frequencies. The main purpose of this study is to identify key differences among the five schemes (Simple ice, Reisner1, Reisner2, Schultz, and GSFC) in the MM5 model that may lead to significant departures of simulated precipitation properties from both active (PR) and passive (TMI) microwave observations.

Radiative properties, including radar reflectivity, attenuation, and scattering in precipitation liquid and ice layers are investigated. In the rain layer, most schemes are capable of reproducing the observed radiative properties to a reasonable degree; the Reisner2 simulation, however, produces weaker reflectivity and stronger attenuation than the observations, possibly attributable to the larger intercept parameter (N_{0r}) applied in this run. In the precipitation ice layer, strong evidence is found regarding the differences in the microphysical and radiative properties between a narrow cold-frontal rainband (NCFR) and a wide cold-frontal rainband (WCFR) within this frontal precipitation system. The performances of these schemes vary significantly on simulating the microphysical and radiative properties of the frontal rainband. The GSFC scheme shows the least bias, while the Reisner1 scheme has the largest bias in the reflectivity comparison. It appears more challenging for the model to replicate the scattering signatures obtained by the passive sensor (TMI). Despite a common problem of excessive scattering in the WCFR (stratiform precipitation) region in every simulation, the magnitude of the scattering maximum seems better represented in the Reisner2 scheme. The different types of precipitation (ice, snow and graupel) are found to behave differently in the relationship of scattering vs. reflectivity. The determinative role of the precipitation ice particle size distribution (intercept parameters) is extensively discussed through sensitivity tests and a single layer radiative transfer model.

This study is the first of its kind to systematically evaluate all the available microphysical schemes in a mesoscale model using a multi-sensor satellite instrument. Its findings provide guidelines on improving the cloud microphysical schemes through remote-sensing technique and important contributions on advancing the satellite retrieval algorithms for precipitations.

Han also studied a land-falling cyclone and flood event occurring in the California-Nevada mountain and valley regions in the winter of 2005-2006 with the Weather Research and Forecasting (WRF) model, the TRMM and Aqua satellites, as well as multiple ground-based radars. Several microphysics schemes have been evaluated, and primary results show that the

simulations were able to replicate the general characteristics of the precipitation system. However, large variations occur in the vertical profiles of hydrometeor distributions, terminal velocities and reflectivities, as well as precipitation accumulations in different terrain regimes. Further research will be carried out to validate the model simulation and to understand the microphysical cloud and precipitation processes.

Objectives for the Coming Year

The investigation of the WRF simulation for the landfalling extratropical cyclone will continue. Data from multiple satellites (TRMM and Aqua) and ground-based observations from the NOAA Hydrometeorological Testbed (HMT) program will be used to verify numerical simulations and to study the variation of precipitation characteristics over complex terrain. Han will investigate five cloud microphysics schemes in the WRF model; note, due to limitations in the TRMM satellite coverage, observations from a NOAA S-band vertical profiling radar (S-prof) will be particularly used to validate the microphysical processes represented in the different cloud schemes.

Task 613-103-354: **Algorithm Development for Space-Borne Dual Frequency Radar**

GEST Investigator: Hyokyung Kim

Collaborators: Robert Meneghini (GSFC 613.1), Jeffrey Jones (SAIC), Liang Liao (GEST)

Description of Research

Following the success of the Tropical Rainfall Measuring Mission (TRMM) launched in 1997, the next-generation precipitation radar (PR) should be launched aboard the Global Precipitation Measurement (GPM) core satellite in 2013. With the goals of obtaining more accurate data from space-borne weather radar and increasing the types of information that can be retrieved, the GPM satellite will accomplish these objectives by use of dual frequency radar working at Ku- (13.6 GHz) and Ka- (35.6 GHz) bands.

Many dual-frequency algorithms have been proposed to retrieve drop size distribution (DSD) and rain-rate estimation at each range bin along the vertical profile using combined Ku- and Ka-measured reflectivity. The performance of the algorithm is evaluated by comparing it to the simulated profile of measured radar reflectivity with a certain DSD assumption.

The goal of this research is to generate more realistic and various synthetic profiles of measured reflectivity using the high-resolution profiles of hydrometeors of cloud-resolving models at GPM frequency, and to compare and to evaluate the performance of the proposed algorithms. In addition, the microphysical retrievals by dual-frequency algorithms can be compared with those of TRMM-like single-frequency algorithms at each frequency.

Accomplishments during the Reporting Period

Kim's research focused on the following two objectives: optimizing a radar simulation model to be working at GPM dual frequency radar, and the computer coding of a variety of single- and dual-frequency algorithms proposed by researchers.

Generating various realistic profiles of radar reflectivity is necessary to test and evaluate the performance of algorithms. Over several years, her collaborators had developed and updated a radar simulation model for the space-borne radars using the hydrometeors profile of a cloud-resolving model. The basic description of this radar simulation model can be found in the publication of Jones *et al.* (1997), and some minor updates were done to handle GPM simulation because this model was programmed for TRMM PR.

This radar simulation model includes not only the atmospheric model but also the surface model that calculates the surface return power at

the given radar beam angle. More realistic surface return information plays a very important role in testing the retrieval algorithms. Surface return power is modeled by computing a surface reflectivity, σ0, as a function of incidence angle. Surface reflectivity at both frequencies is randomly generated by assumption with the correlated normal distribution. The required statistical information, including the correlation coefficient, came from the data analysis of Airborne Precipitation Radar-2 (APR-2), which is operating at the same frequency as a prototype for dual-frequency space-borne radar for future space-borne precipitation measurement missions such as GPM and from the TRMM PR in the case of Ku-band.

Before the performance of the retrieval algorithms is evaluated, the algorithm coding should be completed. Kim designed or modified the existing algorithm codes, which are supported by her collaborators to be suited with the dataset generated by the radar simulation model. Generally, there are three main types of dual-frequency algorithm that can be used within a down-looking space radar: the forward method, where the DSDs are calculated at each bin starting from the top bin and moving down to the bottom; the backward method, where the algorithm begins at the bottom bin and moves upward to the top; and, the hybrid approach, which combines the advantages of both the forward method and the recursive backward method. Backward algorithms can be further divided into three groups: standard dual-wavelength; surface reference technique (SRT); and, iterative non-SRT (Le *et al.*, 2009). The algorithm coding for dual-frequency iterative non-SRT and single-frequency will be performed for the following year.

For quality control of the radar simulation model and retrieval algorithm codes, Kim implemented the generation of measured radar reflectivity profiles using Goddard Cumulus Ensemble model data sets and algorithm tests by comparing retrieved the drop size distribution parameter and rain-rate to that of model assumption.

Objectives for the Coming Year

Kim will continue to work on generating more test data sets using cloud model information and evaluating the performance of dual- and single-frequency retrieval algorithms. The simulated radar reflectivity data sets should also be demonstrated with observed ones. For Ku-band, the profile will be compared with that of TRMM PR.

In addition, she will create the test data sets by generating the measured reflectivity at Ka-band not from cloud model information but from that at Ku-band of TRMM PR. Those data sets will also be used to test retrieval algorithms in the same method as before.

For the linkage of radar and radiometer, Kim and her collaborators will add the computation module of brightness temperatures in radar simulation model by a radiative transfer scheme, based on the Eddington approximation (Kummerow, 1993) with a given set of the extinction coefficient, single scattering albedo, and asymmetry factor, derived in a consistent manner, with the backscattering and extinction coefficients applied to radar reflectivity simulations.

Task 912-29-152: **Aerosol-Cloud-Precipitation Interactions Through Modeling Studies**

GEST Investigator: Xiaowen Li

Collaborators: Wei-Kuo Tao (PI, GSFC 613.1)

Description of Research

A cloud-resolving model, the Goddard Cumulus Ensemble (GCE) model with an explicit bin microphysical scheme is applied in two fields: first, to study the impact of increasing aerosol concentrations on cloud structures, their radiative properties and surface precipitation (aerosol indirect effects); second, to compare the

simulated results with satellite observations for model validations, improvements of microphysical schemes used in the GCE, and for supporting satellite precipitation retrieval algorithm in GPM mission. Aerosols pose the biggest uncertainty to the future of climate according to ICCP reports, due to the complexity of their chemical compositions, physical characteristics, and their short lifetime in the atmosphere. Quantification of the direct effect of anthropogenic aerosols, *i.e.*, the radiative forcing of the aerosol itself, has achieved much progress using global circulation models. However, the indirect effect of aerosols, *i.e.*, changes of cloud life span and precipitation strength by increasing anthropogenic aerosols, is much harder to quantify, both by observations and by simulations. The investigator has been using the GCE model with bin spectral microphysical scheme to understand the physics of the indirect effect, with the emphasis on rain-producing deep convection. Last year's research also included snow-producing winter cyclone systems. The detailed particle size distribution information simulated in the GCE model is valuable for space-based remote sensing because all cloud, ice and surface precipitation retrieval algorithms require some level of assumption on the particle size distributions based mainly on sporadic *in situ* observations. The well-calibrated GCE model can provide consistent size distribution information over large spatial and temporal spans. Li is working on providing such information to the Global Precipitation Mission algorithm development teams.

Accomplishments during the Reporting Period

Li has continued to validate and improve the GCE bin spectral microphysical model during the past year. In all the microphysical schemes, the largest uncertainty is in the ice phase. Accurate simulation of ice nucleation and the interactions among different ice species is crucial in understanding earth's radiation budget, as well as precipitation retrievals at high latitudes. In addition to the 10-year TRMM PR and TMI observations of the mid-latitude squall line that the PI has composed for model validation, she and her team have acquired *in situ* airplane observations of ice particle size distributions for CRYSTAL-FACE case. These data have been used to validate the detailed bin microphysical scheme used in the GCE model, especially the ice-phase microphysics, where most of the uncertainties occur. The initial results have been accepted for publication in the *Quarterly Journal of Royal Meteorological Society*. New case studies include two snowfall events: the WMO-01 winter snow over Japan Sea, and the GPM field validation campaign C3VP in Canada. Li has developed a method that uses 3D WRF regional simulation to force the 2D GCE cloud model. The results agree reasonably well with radar observations. This paves the way for more efficient model validation and improvement using *in situ* measurements. The preliminary results were presented at conferences during past year.

Li has incorporated into the GCE model a major improvement of the bin microphysical scheme, which explicitly simulates of snow aggregates and graupel. This creates new opportunities for model validation using *in situ* measurements, and will also improve comparisons between model and satellite observations.

Surface disdrometer data and *in situ* airborne drop size distribution data were acquired to validate model simulated raindrop size distribution, and, ultimately, to facilitate algorithm development for satellite surface rainfall retrieval. Li and her collaborators found that raindrop size distribution for different precipitation systems all converge to the same normalized distribution in the model. Comparisons between the model and the observations are very good. These results were presented at the AMS Radar Conference.

Through previous research on aerosol-cloud-precipitation interactions, the investigator has presented a hypothesis that links aerosol concentration to tropical cumulus congestus formation. Low aerosol concentration in the tropical ocean promotes congestus formation, resulting in bottom-heavy diabatic heating in the tropical ocean, which has important implications in simulating and forecasting MJO.

Li also provided guidance to graduate students from Pennsylvania Sate University and the

University of Maryland, College Park, in using the spectral bin GCE model in their graduate studies. As a result of collaborating with a previous graduate student from the University of Virginia, a paper was submitted with the investigator as a co-author. Also, Li has received the best senior author award from NASA GSFC's Laboratory of Atmospheres for a paper published last year in *Journal of Atmospheric Sciences*.

Objectives for the Coming Year

Model development will be the main goal for the coming year. The validated and improved bin pectral microphysical scheme will be incorporated into the 3D MPI version of the GCE model to allow for faster and more realistic studies of cloud systems and to provide data needed by satellite algorithm development. Aerosol physics and chemistry will be included in the bin scheme to expand cloud model capability, and to further study the aerosol-precipitation interactions. Long-term equilibrium simulations of aerosol lifecycles in tropical oceans will be conducted using the MPI version of the GCE model.

Task 613-65-222: **Modeling of Interactive Cloud Processes and Precipitation Systems**

GEST Investigator: Toshihisa Matsui

Collaborators: Wei-Kuo Tao (PI, GSFC 613.1), Stephen Lang (SSAI, GSFC 613.1); Roger Shi, Xiaowen Li, Jiun-Dar Chern, and Xiping Zeng (all from GEST, GSFC 613.1); Derek Posselt (University of Michigan)

Description of Research

This research focuses on improving the precipitation process by applying multi-scale cumulus ensemble models, radiative transfer models, and satellite observations. The goals of this research are to establish multi-scale numerical cumulus ensemble simulations and their evaluation framework by using multi-sensor satellite simulators and direct radiance measurements from satellite remote sensing, and to support NASA's satellite missions by providing model-simulated geophysical parameters and satellite radiance in order to facilitate the remote sensing algorithm.

Accomplishments during the Reporting Period

Matsui continued to develop a comprehensive satellite simulator: the Goddard Satellite Data Simulator Unit (SDSU). This past year, several major developments were completed in the Goddard SDSU. First, a regional atmospheric modeling system (RAMS) microphysics option was created in addition to the present microphysics options: Goddard one-moment bulk microphysics and spectral bin microphysics. RAMS microphysics is one (or two)-moment 8-class bulk microphysics. The SDSU precisely accounts for specifications in RAMS microphysics, including flexible generalized gamma particle size distributions D) with their own unique mass-diameter relationships as a function of temperature and relative humidity. Second, a new message passing interface (MPI) domain decomposition option was included. Previously, the Goddard SDSU had input-file decomposition, which is advantageous when a large number of model files need to be processed. A new MPI domain decomposition assigns different sections (memory) of cloud resolving model (CRM) domains on different processors, which has advantages when processing large-domain CRM simulations. Thus, a user can significantly reduce computational time by choosing either domain or input-file decompositions in a multi-core computer. Third, the broadband simulator has been completely updated. A new broadband single-scattering module links tightly to a visible-infrared single scattering module. Thus, spectrum and broadband single-scattering properties can be computed from the identical single-scattering routine. Fourth, a prototype of a surface module was created, which contains various land- and water-surface single-scattering properties ranging from visible to microwave wavelengths. Fifth, a web site dedicated to the Goddard SDSU was created to introduce its

specifications and background: http://atmospheres.gsfc.nasa.gov/cloud_modeling/sdsu.html.

Using a new RAMS microphysics option in the Goddard SDSU, Matsui evaluated long-term simulations of the Goddard Cumulus Ensemble (GCE) model with the RAMS microphysics as a function of ambient cloud-condensation nuclei (CCN). An evaluation method followed the Tropical Rainfall Measuring Mission (TRMM) Triple-Sensor Three-step Evaluation Framework (T3EF). T3EF compares CRM and satellite observations in the form of combined probability distributions of precipitation radar reflectivity, polarization-corrected microwave brightness temperature (*Tb*), and infrared *Tb* to evaluate the candidate. Initial results showed that aerosol concentrations affected cloud structure and microphysics in simulated cumulus ensembles and consequently simulated TRMM-sensor radiance.

Matsui examined diurnal cycles of summertime rainfall rates over the contiguous U.S., using radar-gauge assimilated hourly rainfall data. Rainfall diurnal composites showed a strong rainfall-propagating delta zone over the Great Plains and an afternoon maxima area over the southern and eastern portions of the United States. Zonal phase speeds of rainfall streaks in three different small domains were estimated, and rainfall propagation speeds were examined with background zonal wind speeds. Unique rainfall propagation speeds in three different regions were well explained by latent-heat theory linked to convective available potential energy rather than density current theory linked to boundary-layer dew-point depression temperature. These results substantiated previous pioneering works, and the data should be a useful benchmark for evaluating high-resolution numerical simulations over the conterminous U.S.

Matsui also developed a Fortran-based software, Rainfall Hot-Spot Finder (RHSF). RHSF essentially utilizes the TRMM triple sensor database to find an ideal location to simulate the GCE using the Modern Era Retrospective-Analysis for Research and Analysis (MERRA) forcing. RHSF finds a location by selecting criteria (rainfall types and counts, over land or ocean, and etc.) from the TRMM satellite database.

Objectives for the Coming Year

Matsui will implement continuous developments to the Goddard SDSU and Goddard Multi-Scale Modeling Systems with unified physics. In particular, Matsui will establish the first case of the Synthetic GPM Simulator, which covers the Canadian CloudSat CALIPSO Validation Project (C3VP). All ground-based and aircraft-based measurements will be integrated and analyzed to improve the understanding of snow microphysics in high latitude regions. With these, *in situ* data will be used for constraining the physics assumptions in spectral-bin microphysics in the Weather Research Forecasting (WRF) model. These analyzed microphysics information and simulated fields will facilitate the algorithm developments for future Global Precipitation Measurement (GPM) missions.

Matsui will further investigate the performance of Goddard Multi-Scale Modeling Framework (MMF) simulations. Following up on the analysis of the cloud macro- and microstructure in the Goddard MMF, Matsui also will investigate the sensitivity of zonal and meridional atmospheric circulations to the microphysics changes.

Finally, Matsui plans to develop in-line coupling between the Goddard SDSU and NASA-Unified WRF through the Earth System Modeling Framework (ESMF).

Task 613-89-309: **Evaluating and improving the representation of cloud microphysical processes and cloud-aerosol-radiation interactions for regional and mesoscale models**

GEST Investigator: Jainn J. Shi

Collaborators: Wei-Kuo Tao (GSFC 613.1), Christa Peters-Lidard (GSFC 614.3), W. Lau (GSFC 613.0), Arthur Hou (GSFC 610.1), Toshihisa Matsui (GEST)

Description of Research

Mesoscale or regional-scale numerical models (having domains between several hundred and several thousand km) are indispensable research tools. They are extremely flexible and allow for a wide range of horizontal and vertical resolutions, a wide variety of physical processes, realistic representations of topography, full radiative transfer schemes (shortwave and longwave, including cloudiness and variable water vapor/cloud profiles), precipitation processes and complete land surface-atmosphere hydrology and energy coupling (including realistic vegetation/soil interaction and atmospheric PBL processes). The Weather Research and Forecast (WRF) model is a next-generation mesoscale model that has been developed to include such processes. It will replace MM5 (a research community model) and the NOAA NCEP numerical prediction model in the coming decade. The WRF dynamical core includes Eulerian finite-differencing to integrate the fully compressible non-hydrostatic equations in terrain following mass (pressure) coordinates with a time-split small time step for acoustic modes. The WRF model with cloud-aerosol-radiation interaction physics can be applied in two fields: first, to study the impact of increasing aerosol concentrations on cloud structures, their radiative properties and surface precipitation (aerosol indirect effects); second, to compare the simulated results with satellite observations for model validations, improvements of microphysical schemes used in the WRF, and for supporting satellite precipitation retrieval algorithm in GPM missions.

Accomplishments during the Reporting Period

With the rapid development of computational power, a regional model like the WRF can run high-resolution, cloud-resolving studies with sophisticated physics packages. However, traditional cloud-resolving models remain powerful and efficient tools in studying detailed cloud and precipitation processes. Current computer limitations and investigators' levels of knowledge require both types in scientific research. Here, Shi and his team experiment with methods to take advantage of both types of models. A snow band, which formed over the Japan Sea during the "Winter MCSs Observation over the Japan Sea -2001" on Jan 14, 2001, was simulated using the triple-nested WRF model. The grid sizes are 9, 3, and 1 km, respectively, with 61 vertical levels. NCEP GFS 1^0 global analyses were used in this case study. Comparisons between the WRF simulation and the surface C-band radar observation show good agreements on the snow band structure, and cloud streaks formed at its downwind shear side. The simulation captured the formation and propagation of the intense snow band over a 24-hour period. During the relatively steady, mature stage of the event, the researchers used WRF-simulated dynamics to force a 2D cloud-resolving model in order to study the mixed-phase microphysics and the impact of aerosol loading on precipitating snow band. The simulated cloud structures are similar among a WRF cross section, a 2-D GCE simulation using a bulk microphysical scheme, and a detailed bin scheme, respectively. The successful incorporation of two modeling frames greatly expanded cases available for detailed cloud-resolving simulations. The bulk simulation produces stronger vertical velocity and heavier

surface snowfall compared with the bin scheme using the same forcing and dynamical core. The partitioning of snow, graupel, and crystal ice were also quite different among the three different simulations; also, the liquid cloud water amount and its vertical distribution were different. These differences pose challenges to scientists' understanding of mixed-phase cloud microphysics, as well as in snowfall retrieval with remote sensing. This research shows the potential of combining simulations of both realistic storm dynamics and detailed microphysics to study snowfall events. Accurate hydrometeor profiles in a 3-D cloud system are vital in remote sensing retrievals, especially for space-borne instruments. While the WRF model can provide more realistic, 3-D spatial and temporal variations of the snow band, simplified bulk microphysical scheme in the WRF are not very informative in detailing size distributions of various hydrometeor species, especially in ice-phase. On the other hand, GCE model with detailed microphysics scheme has severe computational limitations. With this study, Shi aims to bridge these two approaches, as well as obtain meaningful statistics of hydrometeors' vertical profiles and mechanisms of aerosol impact on a snow band formation.

The WRF with the Goddard microphysics scheme was coupled with the SDSU to facilitate snowfall retrieval algorithms over land by providing a virtual cloud library including corresponding synthetic *Tbs* consistent with the GMI. This study tested two different options (2ICE and 3ICE-graupel) of the Goddard cloud microphysics scheme within the WRF for two snow events that occurred over the C3VP site in Ontario, Canada, Jan 20-22, 2007. When this study began, there were no prior published results using the WRF at cloud-resolving resolution (1 km or finer) for high-latitude snow events. For this project, Shi is studying the performance of a high-resolution mesoscale model like WRF for high-latitude snow storms and how the satellite, radar, aircraft and surface measurements can be jointly used to validate model results and vice versa. This study has shown the feasibility of using the WRF in this mode: corresponding radar reflectivities simulated by WRF were compared against radar and satellite observations; in turn, these comparisons indicated that the WRF could capture the basic cloud patterns observed by ground-based radar and satellite (*i.e.*, CloudSat and AMSU-B), including the snow band associated with the lake event. The model under-predicted the echo top heights for the lake event; however, the WRF captured the basic horizontal and vertical structure of each event, including the 2-layer cloud structure observed during the late stage of the synoptic event. Statistical comparisons between observed and simulated radar echoes using CFAD analyses showed that the model tended to have a high bias of several dBZ. Collectively, the results suggest that WRF could capture the cloud macro-structure reasonably well but not the cloud microphysical structure. The Goddard 3ICE-graupel and 2ICE options produced identical vertical profiles of cloud hydrometeors to each other for the lake event: neither produced any rain or graupel due to the cold temperatures and weak vertical velocities that were simulated. The same was true for the synoptic event. This also suggests that no graupel was either in the lake or the synoptic event due to the weak vertical velocities in these events. Comparisons between vertical profiles measured by aircraft and model-simulated ice and liquid water contents suggest that the model appeared to have simulated a reasonable amount of cloud liquid water for the synoptic event. The simulated snow bands were relatively shallow in the lake event, suggesting a mostly PBL phenomenon, consistent with past studies.

Objectives for the Coming Year

An improved version of the one-moment bulk microphysics scheme, in which snow and graupel intercepts are made a function of temperature, will be implemented into WRF. In addition, finer spatial resolutions than the current 1-km horizontal grid spacing may be required to realistically represent the evolution of vigorous cold cloud systems. For future research, WRF simulations will be conducted for the Indian aerosol-monsoon interaction study, wherein the WRF will be used to further explore the aerosol direct effect on the cloud microphysics, and WRF simulations will be conducted for the AMMA case of August 2006.

NASA Grant: **Reviving the Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) Data Set (NNG06GC99G)**

Task 612-79-272: **Studies on Hurricane Systems**

GEST Investigator: Chung-Lin Shie

Collaborators: Scott Braun (GSFC 613.1), Liguang Wu (GEST), Robert Adler (UMCP/ESSIC), Long S. Chiu (GMU), William Olson (JCET), Mircea Grecu (GEST)

Description of Research

Shie's research tasks consisted of three different studies/projects. The first study, a second-year funded project by the MEASURES program, intended to resume processing the widely used GSSTF product. The second study, involving a second-year funded EOS project, focused on investigating the impacts of the Saharan Air Layer (SAL) on Atlantic hurricane formation and intensification using numerical simulations, and satellite retrievals and sounding observations. The third study was in its final year of a funded NEWS project and concluded in late 2009; an algorithm was revised and improved to estimate the precipitation-related vertical latent heating profiles from TMI trained with TRMM PR estimates. In this improved algorithm, look-up tables derived from an enlarged sample population of cloud-resolving model simulations were used to relate precipitation profile features to vertical latent heating structures in the profile assignment procedure.

Accomplishments during the Reporting Period

Among the three subjects, research Subject 1, which involved an ongoing project for reviving the production of the GSSTF data sets, has occupied Shie for most of his overall research time. The GSSTF product has been widely used by scientific communities for global energy and water cycle research since its official release in 2000/2001. In this project, a new version of the GSSTF product (GSSTF2b) dataset has recently been produced and updated using the improved input datasets, such as the NCEP SST Reanalysis-V2 and the SSM/I surface wind speed and microwave brightness temperature V6 dataset (upgraded from V4) produced by RSS. The V4 surface wind speeds used for producing GSSTF2 was found in a previous study carrying a linear trend of 6% increase in a 13.5-year period. Such a spurious trend was, however, removed in the V6 product by RSS. Shie *et al.* (2009a) showed an improvement in the surface wind speed from V4 to V6 by comparing their respective daily surface wind speeds of a 46-day period (28 July - 11 September 1999) with the corresponding KWAJEX (the Kwajalein Experiment) *in situ* observation. Statistics indicated a rising correlation coefficient from 0.84 (V4) to 0.89 (V6), a significant reduction of root-mean-square/stand-deviation-error from 0.90/0.90 (V4) to 0.69/0.79 m s^{-1} (V6), and an improved bias reduced from 0.15 (V4) to 0.10 m s^{-1} (V6). The production of GSSTF2b that consists of 21.5-year (July 1987-Dec 2008) global daily turbulent surface fluxes has recently been completed. This 21.5-year product actually consisted of a total 645 months (containing daily variables) of data sets associated with the available individual satellites, such as F8, F10, F11, F13, F14, and F15. By combining the available daily data sets obtained from various satellites for each calendar month, a 21.5-year (258 calendar months) satellite-combined daily GSSTF2b product was then produced. These newly produced GSSTF2b turbulent fluxes, along with their counterparts from GSSTF2, were validated using available ship measurements obtained from several field experiments. The GSSTF2b product was found to generally agree better with observations than GSSTF2 did in all three of the flux components – latent heat flux (LHF), sensible heat flux (SHF), and wind stress (WST). An intercomparison of major meteorological input parameters such as wind speed, total & bottom-

layer precipitable water (W and WB), and and Qs) was also conducted between GSSTF2b and GSSTF2 for global and regional scales. One of the researchers' major findings was that WB, which was based on the SSM/I brightness temperature *Tb* (*i.e.*, Tb19v and Tb22v) and then used to retrieve Qa, indirectly contributed to the global tendency/trend found in the GSSTF LHF products. The monthly-mean datasets (July 1987-Dec 2008) were further produced for each individual satellite: F8, F10, F11, F13, F14, and F15 -- again, a total of 645 monthly datasets. Also produced were the associated satellite-combined monthly datasets of 258 months (July 1987-Dec 2008), along with the annual and seasonal (12 calendar months) climatology datasets of GSSTF2b for two time periods (1998-2000 and 1998-2008). These two climatology datasets of GSSTF2b with different time periods were compared with that of GSSTF2 (1998-2000) globally. The maximum latent heat flux that occurred in the subtropical region was found with a smaller magnitude for both periods of GSSTF2b climatology than the one period of GSSTF2 climatology. Such a finding was consistent to the aforementioned validation results that GSSTF2b closer to observations had a smaller bias than GSSTF2. However, some wiggling distributions of LHF found earlier in GSSTF2 disappeared in GSSTF2b. This promising improvement in LHF was mainly due to the application of an upgraded surface skin temperature (SKT) from NCEP R1 to NCEP/DOE R2. The results addressed above, which were presented in a series of conferences/meetings (Shie *et al.*, 2009a-j, 2010c), are currently being incorporated into a paper soon to be submitted for journal publication (Shie *et al.*, 2010a). Some scientists have shown genuine interest in using the GSSTF2b product and becoming pilot users of GSSTF2b in recent months prior to the surface air and saturation specific humidity (Qa upcoming official release of GSSTF2b in Spring 2010 (Shie *et al.*, 2010b). A detailed study on the temporal trend found in LHF has been conducted further (Chiu *et al.*, 2009, 2010; Gao *et al.*, 2009, 2010).

The second research subject involved studying the influence of the SAL on Atlantic hurricane formation and intensification. By using the relative humidity between 600-700 hPa retrieved from the AIRS suite on NASA's Aqua satellite to approximately identify intrusions of dry SAL air with respect to the tropical cyclone center, Shu and Wu (2009) suggested that the SAL could impact tropical cyclone intensity in both favorable and unfavorable manners during the intrusion of the dry air toward the tropical cyclone center. For the third research topic, an improved algorithm was developed to estimate the precipitation-related vertical latent heating profiles from TMI trained with TRMM PR estimates. Accordingly, estimates of Q_1-Q_R from TMI agreed favorably with the PR training estimates and showed only modest sensitivity to the cloud-resolving model simulations of heating used to build the training data (Olson *et al.* 2009; Grecu *et al.*, 2010b). In this research subject, the utility of radiometer observations in overland space-borne radar retrievals of precipitation and associated latent heating was also investigated (Grecu *et al.*, 2010a).

Objectives for the Coming Year

The first two of the three projects will be carried on for the next year, while the third project concluded in late 2009. For research Subject 1, producing an upgraded GSSTF3 dataset with a higher resolution will be the primary objective for next year. For Subject 2, Shie will continue to study the SAL's impact on Atlantic hurricanes.

Task 613-103-353: **Study of Cloud and Precipitation Properties Using NASA High Altitude Airborne Doppler Radars, Lidar and Radiometers Observations and In-situ Measurements**

GEST Investigator: Lin Tian

Collaborators: Gerry Heymsfield (GSFC), Bill Olson (JCET), Mircea Grecu (GEST)

Description of Research

Global observations of cloud and precipitation from space are important for understanding weather and climate changes and to improve numerical weather predictions. Rain has been very difficult to measure accurately over a wide range of intensities because there is generally insufficient information about the rain properties. A dual wavelength radar, such as the one proposed for the Global Precipitation Measurement (GPM), can improve the accuracy of rainfall estimation. However, the 14- and 35-GHZ frequencies proposed for the GPM radar may not resolve the raindrop size distribution in light rain, due to the small difference of the reflectivity at the two frequencies. By using a combination of 94-GHz and 10-GHz reflectivity, and Doppler information that is not available on the GPM, Tian and her team have found that light rain can be estimated more accurately.

Accomplishments during the Reporting Period

Tian's research activities were focused on three areas. First, although the main purpose of CloudSat Cloud Profiling Radar (CPR) is for cloud observations, light rain also has been observed. In principle, single-wavelength surface reference technique used by TRMM PR can be applied to retrieve light rain. However, the accuracy is limited by uncertainty in the raindrop size distribution (RSD), surface return, and water vapor distribution that vary both inside and outside of the rain region. The GEST PI and her collaborators continued to study the performance of SRT on cloud radar data use EDOP/CRS data. The results showed that W-band radar can measure the rain up to 5 mm/hr using path-integrated attenuation as a constraint. Second, the TC4 field campaign provided valuable data sets for studying the cirrus and deep convection systems. Tian collaborated with scientists in GEST, NASA Goddard and NCAR to study the microphysics of convective – generated cloud using TC4 radars and *in situ* measurements. The paper on TC4 *in situ* data analysis has been published in *JAS*. Finally, a dual wavelength conical scanning radar has been developed for the study of hurricanes and convective storms at Goddard, which will provide an opportunity for mapping the three-dimensional wind field inside hurricanes and convective storms. Tian is evaluating the different methods for retrieving 3D wind field.

Objectives for the Coming Year

Tian will continue to explore the different science applications of using airborne Doppler radar, lidar, radiometers measurements, and *in situ* data to study the cloud and precipitations process, and work on publishing more papers. She also will collaborate with other scientists on using airborne field experiment data for developing GPM algorithms, and she will test the methods of estimating 3D wind field from airborne conical scanning radars. Tian also plans to participate and provide support for field experiments.

Task 912-42-178: **Tropical Rainfall Climatology Based on a Composite of TRMM Products**

GEST Investigator: Jian-Jian Wang

Collaborators: Scott Braun (GSFC 613.1), Robert F. Adler (ESSIC, University of Maryland, College Park); Guojun Gu (GEST)

Description of Research

One of the key goals of TRMM has been to define the spatial and seasonal climatological rainfall in the tropics as accurately as possible in order to quantify this key component of the hydrological cycle. Wang's main effort is to utilize the multiple estimates based on TRMM data and the various TRMM standard products to estimate a composite TRMM-based climatology.

The goal of this study is to describe a new climatology of tropical surface rain based on a composite of ten years (1998-2007) of precipitation retrievals and analyses from the Tropical Rainfall Measuring Mission (TRMM). This TRMM Composite Climatology (TCC) consists of a combination of selected TRMM rainfall products over both land and ocean. This new climatology will be useful as a summary of surface rain estimates from TRMM (not replacing the individual products) and should be useful as a ready comparison with other non-TRMM estimates and for comparison with calculated precipitation from general circulation models.

Over ocean areas, the three TRMM products used are based on the passive microwave (2A12), radar (2A25) and combined retrievals (2B31). Over land, the multi-satellite product (3B43) is substituted for the passive microwave product. The mean annual precipitation over the TRMM domain of 35°N to 35°S in the new climatology is 2.68mm/d (ocean and land combined) with a standard deviation (σ) of .05mm/d, or 2.0%. The ocean (land) value is 2.74mm/d (2.54) with a σ/mean of 2.1% (5.4%). The larger dispersion (and assumed error) over land is due to the greater difficulty of satellite rain retrieval over land, especially with passive microwave techniques and especially in mountains and along coasts.

Accomplishments during the Reporting Period

Wang's main accomplishment over the past year is to provide a new ten-year tropical surface rain climatology based on a selection of TRMM products, taking into account the impact of the satellite boost. The usual tropical rain features, such as the massive Western Pacific Ocean maximum extending over the Maritime Continent and into the Indian Ocean, the narrow Inter-Tropical Convergence Zone (ITCZ) across the Pacific Ocean, the weaker and broader Atlantic ITCZ, and land maxima over Africa and South America, are well represented. The South Pacific Convergence Zone (SPCZ) extends southeastward from the Maritime Continent toward mid-latitudes, and at 5°S across the eastern Pacific Ocean a weak but clear second ITCZ can be distinguished.

Examining the ten-year composite means and variations among the estimates over large areas is very useful. Zonal average precipitation over oceans has always been a key variable, partly because of researchers' lack of knowledge from conventional observations and partly from numerous estimates made over the last 15 years from passive microwave retrievals using the low emissivity of the ocean surface as a background. Wang's team's result shows that the latitudinal profile exhibits a peak mean value of 5.8mm/d at 7°N, a relative minimum at the Equator, and a secondary maximum at 5°S, mainly due to the SPCZ.

In addition, the researchers have examined the zonal-averaged seasonal variation in precipitation according to the TCC. Over the ocean, the slight (~ 3°) latitudinal variation in the zonal-averaged, primary ITCZ is coupled with a factor of two in intensity variation, with the peak (minimum) rainfall occurring at the northernmost (southernmost) location. The weaker, second ITCZ, at about 6°S, is very evident from February through April, roughly when the Northern Hemisphere version is weakest. Over land, the latitudinal variation is larger and more complicated, with peak intensity during the Southern Hemisphere summer.

A comparison of different TCC components indicates that the annual mean of these TRMM products have a close agreement over the ocean, but greater variations over land, especially in mountainous regions. Some of the large anomalies, *e.g.*, over the Himalayas, may be due to residual false precipitation signatures in the passive microwave. The radar product (2A25) is lower than the mean over the Amazon and parts of the Maritime Continent. These types of differences do not indicate a bias, but rather just

how each product relates to the mean. The GEST PI also noted that the differences among the TCC components become more complicated seasonally. In the middle-latitude ocean, the passive microwave and radar products reverse their relative magnitudes with respect to each other from winter to summer. Over land, the multi-satellite product with monthly gauge information (3B43) often substantially differs from the other two products, probably as a result of the product having a gauge-based adjustment, whereas the other two products are satellite-only and both contain radar information. Over areas where gauge information is of high quality, one would expect the 3B43 estimate to be more correct; however, in other areas, the gauge-influenced estimate may be subject to bias errors.

Objectives for the Coming Year

From the recently developed 10-year TRMM composite climatology and its error estimation, Wang found that the annual mean rainfall amounts derived from TMI and PR have reasonable agreements over the ocean but significant differences over land. Among the TRMM retrieval algorithms, the TMI algorithm is known to have more problems over land compared to the more physically based PR algorithm. Therefore, the researchers' plan is to use PR rainfall estimates as a reference when evaluating and validating the TMI rainfall estimates. They will focus mainly over land, but will also pay attention to regions over the ocean with large TMI and PR discrepancies. Their primary goal is to investigate the source of error in each of the following three major procedures in TMI-land retrieval algorithms: rain/no-rain classification, convective/stratiform rain classification, and the relationship between rain rate and 85 GHz brightness temperature. To accomplish this, Wang and team will utilize the TRMM version 6 (V6) and upcoming version 7 (V7, to be released in 2010) data for both statistical analysis and case studies. They will have two central efforts: first, an analysis of the regional and seasonal variations of the differences between the TMI and PR rainfall estimates to evaluate the TMI algorithms; second, a study of the precipitation structure and rainfall characteristics in the regions with large biases to identify the physical features that may be incorrectly or incompletely represented by the existing retrieval algorithms.

Task 912-29-152: **Evaluating Long-Term Cloud-Resolving Model Simulations with Observations**

GEST Investigator: Xiping Zeng

Collaborators: Wei-Kuo Tao (PI, GSFC)

Description of Research

Clouds play a central role in weather and climate change. They are associated with cloud microphysics, radiation and circulations, and thus connect the processes together. Due to the difference in scale between cloud microphysics, cloud and large-scale circulation, numerical simulation plays an important role in studying the nonlinear relations of clouds to other processes. Hence, it is interesting to represent clouds in numerical models properly. Numerical weather prediction models use large spatial grid size, representing clouds implicitly with cumulus parameterization. However, the cumulus parameterization is far from satisfactory, especially in the Tropics.

Cloud-resolving models use fine spatial resolution, simulating clouds explicitly and properly representing the microphysical physics of clouds using parameterization. Therefore, the cloud-resolving models provide a framework to study the interaction between clouds and other processes (*e.g.*, aerosol, radiation and large-scale circulations). To evaluate long-term cloud-resolving model simulations, a cloud-resolving model or Goddard Cumulus Ensemble (GCE) model is run and the results are compared with field observations.

Accomplishments during the Reporting Period

Ice nuclei (IN), a kind of aerosol particle, can affect clouds and radiation via cloud microphysics, which the PI explored in the past year using a cloud-resolving model. In all the numerical experiments conducted, Zeng found that clouds and radiation are sensitive to IN. The cloud ice content in the upper troposphere, for example, increases with IN number concentration via supercooled droplets. As a result, the upward solar flux at the top of the atmosphere (TOA) increases while the infrared one decreases. Due to the opposite response of the two fluxes to IN concentration, the sensitivity of the net radiative flux at the TOA to IN concentration varies from one case to another.

Ten field campaigns provided data to model the effect of IN on radiation in different latitudes. As revealed in the simulations, the increase in the net downward radiative flux at the TOA from doubling the current IN concentrations becomes larger at higher latitude, which is attributed to the meridional tendency in the stratiform precipitation fraction.

Surface warming from doubling the IN concentrations, based on the radiative balance of the globe, is compared with that from anthropogenic CO_2. The GEST PI found that the former effect is stronger than the latter in middle and high latitudes but not in the Tropics.

With regard to the impact of IN on global warming, there are two factors to consider: the radiative effect from increasing the IN concentration and the increase in IN concentration itself. The former relies on cloud ensembles and thus varies mainly with latitude. In contrast, the latter relies on IN sources (*e.g.*, the land surface distribution) and thus varies not only with latitude but also longitude. Global desertification and industrialization provide clues on the geographic variation of the increase in IN concentration since pre-industrial times. Thus, their effect on global warming can be inferred and then compared with observations. A general match in geographical and seasonal variations between the inferred and observed warming suggests that IN may have contributed positively to global warming over the past decades, especially in middle and high latitudes.

Objectives for the Coming Year

In the coming year, Zeng will compare CRM simulations with the observational data from the field campaigns such as AMMA (African Monsoon Multidisciplinary Analysis) and MERRA (Modern Era Retrospective-analysis for Research and Applications). In particular, the modeled mesoscale convective systems (MCSs) will be compared with the observed. Numerical schemes on IN concentration will be further improved for a better simulation of upper-tropospheric water cycle.

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Climate and Radiation
(Code 613.2)

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GEST Highlight: Long Range Transport of Black Carbon and Dust

Teppei Yasunari

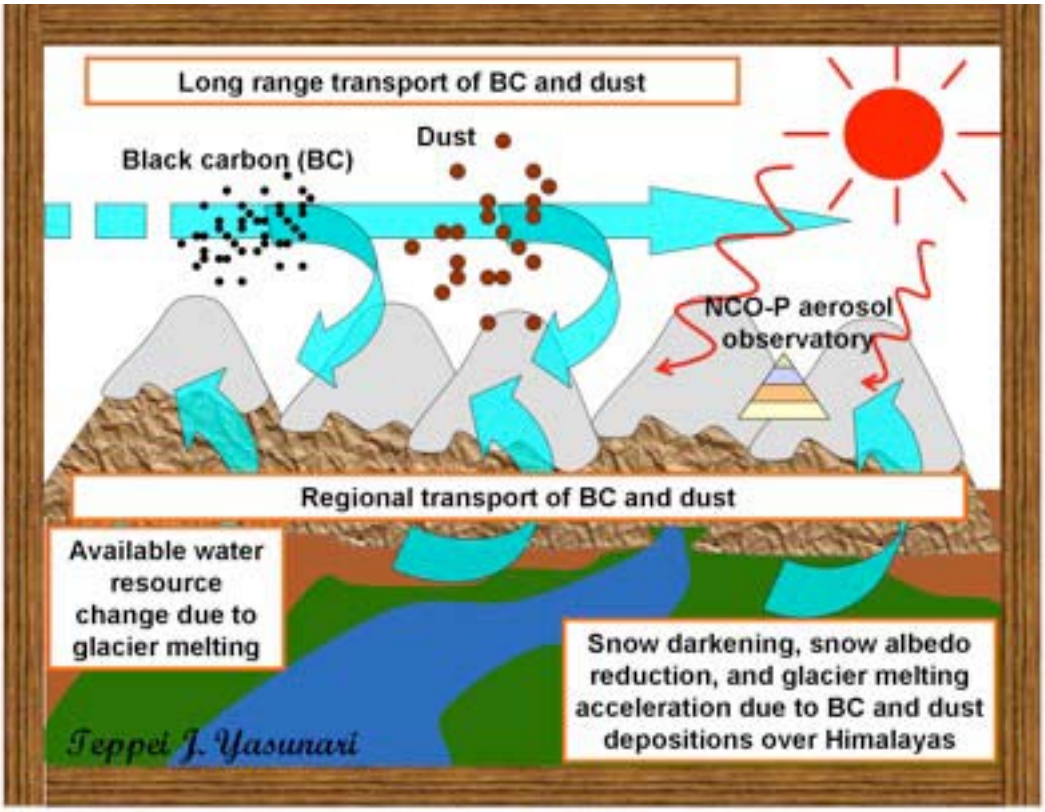

Figure: Atmospheric dust and black carbon (BC) emitted from desert regions and incomplete combustions of motor vehicles, industrial factories, and biomass burning: those aerosols are regionally and globally transported and absorb solar radiation. The BC absorbs more energy than dust. After the aerosols deposit on the foothills of the Himalayas, the snow darkening effect is seen, which reduces snow albedo and increases the snow surface's absorption of solar energy, leading to the acceleration of snow melting. Yasunari *et al*. estimated "lower bound" of its snow albedo reduction due to BC deposition over the Himalayas from aerosol and meteorological data in the atmosphere observed at the Nepal Climate Observatory-Pyramid (NCO-P) site during March-May 2006 (27.958°N; 86.815°E; 5079 m above sea level). During pre-monsoon periods, atmospheric pollution is very severe in the Indo-Gangetic Plain. If the amount of BC, which was estimated by using a fixed minimal deposition velocity, deposits onto 2-cm snow surface over the Himalayas, it will possibly reduce snow surface albedo about 2.0–5.2%. If the range of snow albedo reductions is adapted to a typical Tibetan glacier, additional snow meltings of 70–204 mm of water drainage equivalent of 11.6–33.9% of the annual discharge of the glacier will be probable, which was estimated by numerical experiments with a glacier mass balance model. The dust and BC are relevant to the radiation budget in the atmosphere and the snow surface leading to climate changes. In addition, the aerosols also can change available water resources for people who rely on melting water from the Himalayan glaciers.

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NASA Grant: **Forecast and Analysis of the Transport of Aerosol and Carbon Monoxide using GEOS-5/GOCART and MODIS/AIRS Satellite Measurements During ARCTAS (NNX08AD24G)**

NASA Grant: **Study of the Effects of Dust Radiative and Microphysical Properties on Energy Budget and Precipitation Using A-Train Satellite Measurements and a Cloud-Resolving Model (NNX07AJ13G)**

Task 78: **Improve EPA's AIRNow Air Quality Index Maps with NASA Satellite Data**

GEST Investigator: D. Allen Chu

PI: Lorraine Remer (GSFC 613.2)

Description of Research

Emissions from biomass burning in mid-latitudes of the northern hemisphere play an important role in global climate change. Vegetation stores carbon, which is released when it is burned in the forms of carbon monoxide, carbon dioxide, and aerosols such as organic carbon and black carbon. These emissions must be accurately parameterized in climate models in order to predict and understand the future climate, which is difficult, due to large inter-annual variability of biomass burning in addition to the variation of vertical structure and injection height of the resulting smoke plumes. A better understanding of the causes and characteristics of biomass burning variability and its connection to climate cycles (such as El Niño Southern Oscillation – ENSO, Pacific Decadal Oscillation – PDO, Arctic Oscillation – AO, and North Atlantic Oscillation - NAO) is necessary to reduce uncertainty in global climate models. A preliminary analysis using MODIS aerosol optical depth data led to a time-series of monthly high smoke activity HSA in North America and Eurasia. The summer mean HSA (June-August) in N. America is positively correlated with ENSO and PDO of previous winter months (November - February) whereas in Eurasia the summer mean HSA (May-July) is negatively correlated. The critical threshold sets the maximum correlation between HSA and MEI in both North America and Eurasia. NASA GEOS-5 aerosol and CO products are analyzed to compare with MODIS AOD and AIRS CO retrievals in the summer of 2008. The spatial resolution and vertical level resolved by GEOS-5 present a significant challenge in collocating with MODIS and AIRS retrievals. In addition, averaging the kernel function of CO retrieval is critical to the comparison with AIRS CO at 500mb as attributed to its broad wing convolving CO below and above 500mb. Significant progresses have been made in recent years to better estimate surface particulate matter concentration using remotely sensed aerosol optical depth when incorporating with boundary layer height.

Accomplishments during the Reporting Period

Aerosol Optical Depth (AOD) retrievals from the MODIS sensors on NASA's Terra and Aqua Satellites were used to derive HSA (defined by a number of events with mean AOD of 5° x 5° grids > 0.4 in a month) and correlate with ENSO and PDO in the boreal forests of Eurasia and North America (north of 50°N). The first-year study indicates a positive correlation with ENSO Multivariate ENSO Index (MEI) in N. America when discounting 2004 events, and negative correlation in Eurasia when discounting 2003 events. The causes of intensive biomass burning in Alaska and Western Canada in June-August 2004 and extensive burning in Siberia in May-July 2003 are not clear. Several studies indicate weather enhancements attributed to abnormal weather patterns. It is Chu's intension to study possible enduring drought, especially in

springtime, in these two regions. However, due to the availability of drought index data, the analysis is not complete. Full analysis will be postponed to the third year. New results of using monthly carbon emission (GFED emission inventory) data from 2000-2007 (previously 2000-2004) shows one-month shift peak monthly burning in Eurasia (May-June-July) as opposed to North America (June-July-August). The correlation coefficient derived from HSA and GFED carbon emission is shown as a function of aerosol optical depth. The threshold of AOD >0.4 producing the maximum correlation is defined as the "critical threshold". The refined correlation with one-month shift in peak carbon emission (i.e., May-June-July versus June-July-August) in Eurasia produces even stronger anti-correlation (R ~-0.92) with ENSO MEI when discounting 2003 data than previously found (R~-0.70). The correlation of HSA with PDO is also changed slightly but is not as pronounced as the correlation with MEI. In contrast, the correlation of HSA with respect to MEI is positive in North America, as is the correlation with PDO. An attempt is made to compare satellite and GEOS-5 derived CO/AOD ration over the regions with active fires in summer (June-July-August) 2008. The locations of active fires are selected based upon maximal MODIS AOD > 0.3 to make sure that there are significant amounts of smoke emitted into the atmosphere. Linear repressions of AIRS CO and MODIS AOD result in correlations >0.7. The intercepts, however, are in the range of 100-150 ppbv despite different slopes. The range of CO ~100-150 ppbv can be considered as the background level CO at 500mb where AIRS has the largest sensitivity in detecting CO, and different slopes could be related to the variation of smoke plume heights. Generally, the correlation derived from GEOS-5 is lower than that which was used for AIRS CO and MODIS AOD measurements. Also noticeable is the lower range of intercepts (60-90 ppbv) - CO background level at 500mb obtained from GEOS-5. The resolution of 0.5° x 0.67° of GEOS-5 may be responsible for less sensitivity to the emission of CO and AOD from local fires since MODIS AOD is retrieved at a resolution of 10 km and AIRS CO is retrieved at a resolution of 30 km. Convection parameterization could be another factor. Background aerosol loadings are compared in two areas off the coast of western Africa between 15° and 30°N, bounded by longitudes of 15-30°W/30°-60°W. The large change in AOD in these two regions reflects annual variability of dust outbreaks, confirmed by the sunpotometer measurements at Dakar and Cape Verde. Also noticeable are the differences between MODIS Terra and Aqua. Nevertheless, the mean aerosol loading of area (15-30°W and 15°-30°N) is shown to be two times higher than the one adjacent; the dryness of dust-rich airmass is considered the cause of the void of tropical storm. The DC-8 and MODIS-derived effective radiuses reveal their respective ranges of 0.7-1.3 mm and 0.5-0.9 mm. Despite the fact that DC-8 effective radiuses are consistently underestimated, the comparisons are generally within error ranges of DC-8 (35%) and MODIS (25%).

Several of Chu's manuscripts were accepted and published in professional journals. He also presented his findings at the ARCTAS Science Team Meeting and AGU Fall Meeting for studies related to ARCTAS and NAMMA projects. Collaborations with NASA Langley Research Center and a number of Universities led to several papers currently in preparation. A NASA-funded project enables further studies of applying MODIS-derived AHI to better estimate surface PM concentration.

Objectives for the Coming Year

The main objectives include continual post-mission analysis of ARCTAS satellite and *in situ* measurements, model/satellite intercomparisons, and the retrievals of AOD over snow/ice-covered surfaces. Multi-resolution AOD data in San Joaquin Valley and ARCTAS domains will be evaluated to optimize AOD retrievals in association with surface PM measurements. Specific planned flights of HSRL will be targeted for detailed examination of the effect of vertical distribution.

Task 610-89-311: **Improving OMI aerosols retrievals by using additional information from MODIS aerosol products**

GEST Investigator: Santiago Gassó

PI: Lorraine Remer (NASA), Omar Torres (Hampton University)

Description of Research

Aerosol absorption is important because it can disrupt the thermal structure of the atmosphere. For example, the extension and reduction of a cloud's lifetime as well as an increase of long-wave irradiance over clouds has been identified by models and some limited observations as an impact of absorbing aerosols.

Currently, only the Ozone Monitoring Instrument onboard Aura has sensitivity to aerosol absorption. For example, smoke and pollution aerosols can be differentiated in the near UV range because they have different absorption properties at these wavelengths. This is the approach used by the OMI detectors to detect aerosol absorption. However, OMI lacks good spatial resolution and the aerosol retrievals are prone to cloud contamination. On the other hand, MODIS has excellent spatial resolution for aerosol studies. Current identification of an aerosol type by MODIS is based on the spectral information of the upwelling radiance in the visible and near-IR. However, because it lacks UV bands, MODIS cannot distinguish between absorbing (such as smoke) and non-absorbing (sulfate) aerosols. Because the Aura satellite flies in formation with Aqua, absorption detection by OMI can be collocated with MODIS-Aqua. Thus, both OMI and MODIS retrieval schemes can benefit each other by exchanging cloud masking and aerosol absorption information.

Accomplishments during the Reporting Period

A methodology to overlap OMI Level 2 aerosol retrievals with Level 2 MODIS ocean aerosol products has been developed. The work is based on the method developed by Satheesh *et al.* (2009). The algorithm takes MODIS aerosol (MYD04) and OMI Aerosol (OMAERUV) Level 2 products and performs the following tasks: it collocates MODIS and OMI pixels, determines whether aerosol retrievals are available in those pixels, and tests the quality of the retrieval. For the suitable pixels with the adequate retrievals from both satellites, it derives a new aerosol absorption optical depth (AAOD) at 388 nm and the aerosol optical height (mean layer height). The outputs are then aggregated into 1x1 degrees (Level 3) or reported at the OMI Level-2 native resolution (13x24km nadir). Examples were generated for the months of January and July 2007.

Comparisons with independent measurements of absorption are difficult due to the limited data sets. Aeronet sites do provide single scattering albedo measurements, but the measurements occur at a different time than the satellite flyover, and there are not many suitable comparison sites. Also, it is possible to compare aerosol heights as determined by CALIPSO since it flies in formation with Aqua and does not have the time difference limitation of Aeronet. This approach is used for testing the MODIS-OMI algorithm. Comparisons for a handful of case studies resulted in reasonable agreement and significant departures in equal number.

Objectives for the Coming Year

Gassó will continue to analyze the OMI and MODIS combined retrievals. He will concentrate on studying the use of OMI measurements along with MODIS, and CALIPSO data will be carried out with the purpose of improving the performance of OMI retrievals over land. In addition, global maps of aerosol absorption will be produced and compared with global output from a model provided by Professor Chen Wang (MIT). Regarding studies of dust activity in Patagonia, Gassó and his colleagues plan to expand the case-by-case study of dust events with the following goals: determine the possible pathways of dust transport from Patagonia to the

Antarctic continent with the use of multiple satellite platforms (MODIS, OMI, CALIPSO), for selected case studies to examine ocean color maps downwind of Patagonia and determine if there is any ocean color response.

NASA Grant: **Characterization of Aerosols and Bidirectional Reflectance Distribution Function from Airborne Radiation Measurements Over Snow, Sea Ice, Tundra, and Clouds (NNX08AF89G)**

GEST Investigator: Charles K. Gatebe

Description of Research

The Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) provides a wonderful opportunity to study the Arctic from ground-, airborne-, and satellite-based measurements in an integrated manner. It also presents an opportunity to validate satellite retrievals, which are complicated by the highly reflecting nature of snow-covered sea ice, low sun angles, extensive cloud cover, and dramatic seasonal changes. The bidirectional reflectance distribution function (BRDF) or accurate surface albedo measurements are key to detecting changes in the arctic environment from remote sensing measurements. In this research, Gatebe uses NASA's Cloud Absorption Radiometer (CAR) measurements from ARCTAS over different types of surfaces such as snow, sea ice, tundra, cloud, smoke, and ocean to characterize the surface and aerosol optical properties. He seeks to build a well-calibrated and feature-rich data set to perform simultaneous retrievals of aerosol optical properties and spectral BRDF by combining related observations from the CAR and sunphotometer measurements. The airborne sensor has a wide scan range (190°) and an instantaneous field-of-view of 1°, and can capture full BRDF including the hotspot under low sun angle conditions commonly found in the Arctic. The instrument has the unique ability to measure, almost simultaneously, both down-welling and up-welling radiance at 14 narrow spectral bands located in the atmospheric window regions of the ultraviolet, visible and near-infrared. Developed for low- to medium-altitude aircraft, the instrument can be used to obtain data at different altitudes with varying spatial resolutions, which is important for addressing up-scaling needs for satellite validation.

Accomplishments during the Reporting Period

This progress report covers work conducted under NASA grant NNX08A89G for the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) for the calendar year 2009. From the outset the objectives of this research were varied: to participate in the ARCTAS during spring and summer 2008 field campaigns; to analyze CAR data from ARCTAS to remove the effects of atmospheric scattering and absorption so as to isolate the bidirectional reflectance properties of the underlying surface (snow-covered and snow-free sea ice, snow-covered and snow-free tundra and the arctic stratus clouds); to build a well-calibrated and feature-rich data set to validate sensors on Terra and A-Train satellites to make use of the increased spectral and spatial information available from CAR; and to perform simultaneous retrievals of aerosol optical properties and spectral BRDF by combining related observations from the CAR, Ames Airborne Tracking Sun-photometer (AATS) and Aerosol Robotic Network (AERONET).

Task 1 was completed successfully during the first year of funding in 2008. In the second year, Gatebe built upon the accomplishments made in the first year and embarked on Tasks 2-4, which resulted in two publications that were submitted to POLARCAT (Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport) special issue in *Atmospheric Chemistry and Physics*.

Gatebe was able to finalize the CAR calibration. Data was reprocessed and submitted to POLARCAT/ARCTAS data archive at NASA Langley (http://www-air.larc.nasa.gov/data.htm) and CAR website: http://car.gsfc.nasa.gov/data/ under "ARCTAS." Documentation for each CAR flight, including flight track maps (1D and 3D using CAR Autonomous Navigation System (CANS) data and GoogleEarth flight track maps), MODIS and GOES imagery, CAR quicklook imagery, pictures taken during the flight, and field notes are also available on the CAR website.

Objectives for the Coming Year

Gatebe anticipates being able to analyze CAR observations of value to satellite validation, as well as support process studies and multi-platform case studies of interest to other ARCTAS science team members. His goal is to retrieve and archive BRDF and aerosol products for all flights coinciding with satellites' overpasses. These will be in an easy-to-use HDF file format, accessible to all members of the ARCTAS science team as well as the outside scientific community.

Task 613-103-349: **Aerosol-Climate effects over South Asia**

GEST Investigator: Ritesh Gautam

Collaborators: Christine Hsu (PI, GSFC 613), William K-M. Lau (GSFC 613), Si-Chee Tsay (GSFC 613.2), Qiang Ji (UMCP), Richard A. Hansell (UMCP), Shaun Bell (SSAI), Brent Holben (GSFC 614), Alexander Smirnov (SSAI)

Description of Research

Tropospheric aerosols significantly influence the Earth's radiation budget by scattering as well as absorbing solar radiation and are considered to be one of the least understood components of the global climate system. Over Asian monsoon regions, increasing aerosol loading, accompanied by growing urbanization and industrialization in recent past decades, pose a serious environmental problem by affecting the regional hydrological cycle through modifications to the monsoon rainfall and circulation patterns as suggested by a number of climate model simulations. However, more observations and detailed characterization of the complex nature of the regional aerosol loading is required to better understand the associated climate effects. The GEST investigator's research is in the observational assessment of short- and long-term effects of aerosols on the regional climate through the integrated usage of satellite and surface measurements. Specifically, Gautam's work is to quantify the aerosol solar absorption and the associated tropospheric warming.

Accomplishments during the Reporting Period

One of the first tasks of the GEST investigator was to quantify the role of aerosol solar absorption in the radiative heating of the atmosphere and the tropospheric temperatures over South Asia in order to address the associated potential impacts on the monsoon rainfall and circulation. Together with the increasing pollution over South Asia, dust storms are a major seasonal phenomenon during pre-monsoon period (April-May-June) prior to the onset of the monsoon rainfall. Dust aerosols constitute the bulk of the regional aerosol loading over the Indo-Gangetic Plains (Gautam *et al*., 2009), which is one of the world's most densely populated regions, inhabiting about 900 million people. This region is situated downstream of the southern slopes of the Himalayas and is a highly agriculturally productive river basin. Gautam found that the Gangetic-Himalayan region is associated with an enhanced warming trend in the longest record of tropospheric temperatures derived from the Microwave Sounding Unit (MSU) data for the period 1979-2007. The tropospheric warming was most pronounced during the pre-monsoon period when dust transport over the IGP occurs

and causes maximum aerosol loading seasonally. Together with other datasets, it was shown that the tropospheric warming, concentrated over the western Himalayan-Gangetic region, was amplified due to aerosol solar absorption associated with the increasing regional aerosol loading (Gautam *et al*., 2009b). As a consequence of this anomalous warming, it was shown that the land-sea thermal gradient – fundamental to the onset of the Indian summer monsoon – had significantly strengthened in the past three decades, with enhanced Himalayan warming and a relatively stable temperature trend over the Indian Ocean, as indicated by the MSU measurements. The land-sea tropospheric thermal gradient drives the monsoon circulation with an influx of moist air from the oceanic regions toward the subcontinent and marks the onset of the rainy period from June through September. Further, the GEST investigator showed that the early summer June monsoon rainfall has been on the rise in recent past decades, using rain-gauge data distributed across India, associated with the strengthened land-sea pre-monsoon thermal gradient (Gautam *et al*., 2009c).

Gautam also conducted a 3-month-long field experiment in northwestern India with instrument deployments encompassing the source arid region to the foothills and slopes of the Himalayas to study the aerosol attenuation of solar flux during April-June 2009. This field deployment was in support of the Joint Aerosol Monsoon Experiment (JAMEX) (Lau *et al*., 2008) and was carried out in collaboration with scientists based at GSFC and in India. During the measurements in India, the GEST investigator was involved in planning and coordinating the measurements as well as deploying sunphotometers and flux radiometers. He also worked with the already operational setup of AERONET measurements in northern India. After the successful completion of the campaign, he was actively involved in processing and analyzing the surface measurements. He also integrated the surface database with vital information of spatial and vertical aerosol loading obtained from satellite sensors (MODIS, CALIPSO) as well as aerosol solar absorption estimation from radiative transfer simulations.

The GEST investigator has a publication conditionally accepted on the pre-monsoon aerosol vertical characterization and solar absorption effects over the northern Indian subcontinent. In addition, Gautam presented findings of the aerosol-monsoon research at the IAMAS meeting in July 2009 in Montreal. He was also invited to deliver a talk on the changing climate in the Himalayas at a UNEP-sponsored meeting in Delhi in December 2009 where he presented results on long-term tropospheric temperature trends and seasonal variations. The UNEP recently produced a detailed report on the recent trends in melting glaciers, tropospheric temperatures over the Himalayas and summer monsoon rainfall over India (UNEP, 2009) in which Gautam extended his contribution of tropospheric temperatures, rainfall over India and other published research work.

Objectives for the Coming Year

Gautam's first objective is to prepare for publication a comprehensive report of the ongoing analysis and findings of the surface and satellite observations of aerosol and solar flux in the Gangetic-Himalayan region from the 2009 JAMEX field campaign in India and Nepal. Second, the GEST investigator will characterize the dust aerosol transport over the Himalayas and investigate the impact of dust deposition on snow albedo through the usage of information derived from MODIS reflectance data and other related data products. Dust transport over northern India occurs at elevated altitudes in the troposphere (>3km) over the foothills and slopes of the Himalayas. A third area of research will be in the investigation of the response of aerosols over bright surfaces at the Top-of-Atmosphere flux and reflectance using space-borne CERES and MODIS data. A significant understanding of aerosol loading over bright surfaces and its interaction with solar radiation has already been published by the NASA/GSFC PI (Christina Hsu). Gautam will work on identifying new methods to characterize the interactions of aerosols with solar radiation over bright surfaces.

Task 613-104-357: **Effect of Tropospheric Aerosols on Climate**

GEST Investigator: Jingfeng Huang

Collaborators: Christine Hsu (PI, GSFC 613), Si-Chee Tsay (GSFC 613), Myeong-Jae Jeong (GEST, GSFC 613)

Description of Research

This study aims to investigate the direct and indirect effects of tropospheric aerosols on climate by employing long-term multi-platform satellite and *in situ* measurements of aerosols, clouds, radiative fluxes, and precipitation. Specific objectives also involve evaluations and improvements of the performance of satellite aerosol retrieval algorithms for constructing long-term aerosol climate data records, and radiative transfer modeling.

Accomplishments during the Reporting Period

For any aerosol-related climate studies, uncertainty in aerosol data is still a challenging issue. One particular example is that satellite aerosol retrievals or *in situ* aerosol measurements from sunphotometers still have cirrus contamination, even though they have extensive cloud screening algorithm built in. Huang and collaborators conducted a systematic investigation on the susceptibility of satellite and ground aerosol retrieval to cirrus contamination. They took the advantageous observing capabilities of space-borne lidar CALIOP and ground micro-pulse lidar, and matched up the aerosol retrievals with cirrus-existing scenes. Results from *in situ* measurements at the BASEASIA campaign show that cirrus contamination is one of the largest data uncertainty issues in the AOT measurements during the campaign. When cirrus contaminated the aerosol measurements, AOT was generally overestimated and larger particle size was observed. At satellite level, high thin cirrus, as observed by CALIOP, also contaminate MODIS AOT retrievals, particularly those in cirrus prevailing regions. In order to further improve current cloud screening algorithm to filter out such cirrus contamination or possibly correct effects from high thin cirrus in AOT measurements, the performance of a series of cirrus screening parameters were evaluated quantitatively. Important findings from the study will further improve the data accuracy of current aerosol retrievals, and therefore lead to more confident projections of aerosol effects on climate.

Besides cirrus contamination issues, in order to improve the Terra MODIS Deep Blue aerosol retrievals which uses MODIS band 3 (470 nm), Huang also investigated the possibility of calibrating this performance-degrading band through a vicarious approach by utilizing the stable SeaWiFS spectral signals at neighboring bands (443 nm and 490 nm). Based on both MODIS actual retrievals and radiative transfer model simulations, relationships among these three bands were established so that the apparent reflectance at 470 nm can be approximated and the difference to the actual Terra MODIS measurement calculated. Further evaluations of the impact of this vicarious calibration on the Deep Blue aerosol retrieval are underway.

With its launch date approaching, VIIRS data becomes more and more crucial for future aerosol observations and long-term aerosol climate data records. As part of the VIIRS aerosol environmental data record (EDR) calibration/validation team, Huang is also involved in the VIIRS pre-launch calibration activities. The available VIIRS-like aerosol products, which were calculated by applying VIIRS aerosol algorithms to MODIS proxy data, were evaluated against other satellite observations and *in situ* measurements, and more intensive testing tasks are underway.

Objectives for the Coming Year

Huang's first objective is to explore the high

potential of the long-term (13 years) newly developed SeaWiFS aerosol products on evaluating aerosol effects on climate. Second, the researchers plan to test more improvements in the current aerosol retrieval algorithms. Third, Huang and collaborators will evaluate the VIIRS aerosol algorithm by examining the VIIRS-like pre-launch aerosol product with current operational satellite and *in situ* aerosol measurements. This will serve as an ultimate goal of establishing a long-term aerosol climate data record.

Task 613-84-297: **Aerosol Retrievals from Satellite Remote Sensing**

GEST Investigator: Myeong-Jae Jeong

Collaborators: N. Christina Hsu (PI, GSFC 613.2), Si-Chee Tsay (GSFC 613.2), J. Huang (UMBC), Qiang Ji (UMCP), R. A. Hansell (UMCP), B. Franz (GSFC 614.2), G. Meister (Futuretech)

Description of Research

Aerosols impact the earth's climate in diverse ways by being involved in the disposition of the incoming solar radiation and by modifying the properties and lifetime of clouds, thereby further influencing the hydrological cycle of the system. It is critical to quantify the amount of aerosols in space and time together with their optical properties in order to study their effects on the climate system. NASA's state-of-the-art satellites enable scientists to obtain a quantitative view on the global distributions of aerosols. However, remote sensing of aerosols from space is still a very difficult task, especially over land surfaces, as the signals from complex underlying surfaces are convoluted with those from aerosols in the atmosphere. Thus, huge efforts on refining and evaluating aerosol remote sensing algorithms are necessary to derive high quality information suited for demanding science subjects (*e.g.*, climate change and air quality). The goal of this research is to more accurately derive the aerosol loading, especially over land surfaces, by refining existing aerosol remote sensing algorithms. In general, the results of this research can be crucial inputs to the studies of aerosols' effects on the climate and air quality.

Accomplishments during the Reporting Period

The *Deep Blue* aerosol products have been crucial parts of the operational MODIS/Aqua (crossing the equator around 1:30pm local time) aerosol products as the *Deep Blue* aerosol retrieval algorithm effectively detects aerosols, especially over bright surfaces like the desert, where aerosol loading is significant but not much other data are available. Dr. Christina Hsu and the GEST investigator delivered an updated version (Collection 5.1) of the *Deep Blue* aerosol retrieval algorithm through refinements made for the surface characterization and cloud-screening, together with improved data quality assurance (QA) flag. The quality assured *Deep Blue* AOT for MODIS/Aqua showed very good agreements with the AERONET AOT over North Africa and the Arabian Peninsula. The reprocessing and forward processing of this version of the *Deep Blue* aerosols products have been completed, and the new data are now publicly available as a part of the operational MODIS aerosol products (http://ladsweb.nascom.nasa.gov/).

The MODIS onboard Terra has been successfully monitoring the earth for nearly a decade, and has provided valuable information about aerosols, clouds, and greenhouse gases at unprecedented accuracy for a far beyond its mission life expectancy of 6 years. While the MODIS Characterization Support Team (MCST) put forth great effort in calibrating the MODIS measurements, Terra/MODIS reflective bands have suffered from aging, unexpected incidences, and changes in detectors' characteristics over time. For example, the contamination of mirror before launch and the permanent opening of a solar diffuser door may have affected Terra/MODIS in showing substantial instrumental changes. Also, it has been demonstrated that ocean color products from Terra/MODIS exhibit a significant

temporal drift of about 15% that can be attributed to increased instrument degradation and that resulting changes in MODIS response-versus-scan angle (RVS) and polarization sensitivity cannot be readily tracked by onboard calibrators, which suggests that Terra/MODIS is currently unsuitable for quantitative ocean color applications. In addition, the shape of MODIS RVS is fixed at pre-launch laboratory measurements and is linearly scaled based on two reference points corresponding to two independent on-orbit calibration procedures using solar diffuser and lunar observations. These issues have influenced the increasing calibration uncertainty over time, especially for Terra/MODIS band 8 (nominal wavelength of 412nm), one of key bands used for the *Deep Blue* aerosol retrievals. Jeong worked with collaborators to correct for the band 8 for Terra/MODIS. A cross-calibration method developed by the NASA OBPG to take care of the issues was implemented to correct for the band 8 reflectance and to produce the Terra/MODIS *Deep Blue* aerosol products for the first time. Preliminary results showed significant improvement in the retrieved AOT when compared with AERONET AOT, which has been used as ground truth in the aerosol remote sensing community. The operational codes were delivered and the operational Collection 5.1 Terra/MODIS *Deep Blue* products processing will be set to begin in March 2010. Jeong is also working on drafting a paper to report this improvement and the release of new Terra/MODIS Collection 5.1 *Deep Blue* aerosol dataset in a peer-reviewed journal.

As a part of continuing efforts of a five-year project to build a long-term record of AOT over the globe, the GEST investigator has been involved in the refinement of the *Deep Blue* aerosol retrieval algorithm for the SeaWiFS measurements. He worked on improving surface reflectance, which is a crucial input to aerosol retrieval. Jeong suggested a new method of determining surface reflectance over vegetation to be used for aerosol retrievals. The method is now undergoing thorough tests. An improved version of SeaWiFS Deep Blue aerosol products will be delivered in 2010.

Jeong and collaborators made a continuing effort to derive value-added information about aerosols and their radiative effects by synthesizing the data sets from multiple instruments. For instance, aerosol optical thickness of dust in an infrared wavelength (~10 micrometer) was derived using the Atmospheric Emitted Radiance Interferomenter (AERI). Then, the derived dust properties were utilized to assess the direct long-wave radiative effects of dust at the surface, together with data from Micro-Pulse Lidar, Multifilter Rotating Shadowband Radiometer, and CALIPSO satellite sensors. The results suggest that the direct long-wave radiative is around 42% of the diurnally averaged direct shortwave radiative effect at the surface but of opposite sign, partly compensating the shortwave losses. They concluded that the direct long-wave radiative effect can significantly impact the atmospheric energetics, showing the great potential of dust as an important component in influencing the regional climate variation. The results of this study were accepted for publication (Hansell *et al.*, 2009).

Objectives for the Coming Year

It is planned that the *Deep Blue* aerosol products will cover vegetated surfaces as well as bright desert surfaces to provide consistent aerosol data products across different types of underlying surfaces. Jeong will continue to work on expanding the spatial coverage of the *Deep Blue* aerosol products and refine the retrieval algorithm for MODIS onboard Terra and Aqua satellites. Jeong and collaborators will continue to build a long-term aerosol record by applying the *Deep Blue* algorithm to the SeaWiFS measurements.

Task 613-38-236: **Application of Satellite Surface Wind Data to Ocean Surface Analysis and Numerical Weather Prediction**

NASA Grant: **A Cross-Calibrated Multi-Satellite Ocean Surface Wind Vector Product**

GEST Investigator: Juan Carlos Jusem

Collaborator: Joseph Ardizzone (GSFC, 613.0)

Description of Research

Knowledge of oceanic surface winds is crucial to the understanding of the earth system and constitutes an indispensable element in oceanographic and meteorological applications. Prominent among these applications are the determination of the fluxes of mass, momentum and energy through the sea-atmosphere interface. Mass fluxes include the exchange of greenhouse gases like water vapor, which also moisten the atmosphere and increase salt concentration in the ocean, and carbon dioxide, which is of critical importance in marine biological processes. Momentum fluxes drive ocean currents and are responsible for wave generation and upwelling, while energy fluxes warm and cool the boundary layer, modifying in this way the static stability. No less important applications of sea-surface wind data are weather monitoring and climate diagnosis, as well as initialization of oceanic and atmospheric models.

Conventional observations of surface winds from ships and buoys are far from sufficient to cover the world's oceans. Therefore, the satellite wind observations constitute an irreplaceable tool to know the global distribution of air motion at the sea surface. But all the available satellite wind information constitutes a highly heterogeneous dataset, originated in measurements taken by different instruments, whose data products are valid for different periods of time. The purpose of this research is the optimum processing of that heterogeneous information and the physical interpretation of the output.

What the satellite sensors really measure is not the wind vector but the stress on the air-water interface. The wind is obtained from stress through a calibration that is platform-dependent. The conversion of stress into wind is a function of the atmospheric stability. The different observations become comparable with each other once they are reduced to both a common stability and a common height above sea level. The common stability is agreed to be zero (*i.e.* neutral) and the height, 10 meters. Therefore, the output from each calibration is equivalent to a neutral 10-meter wind set of observations. The incorporation of wind observations from ships and buoys poses a new difficulty derived from the different heights above the sea level, at which the observations are performed. In this case, the reduction to a common height involves the additional computation of the roughness parameter.

The optimum processing mentioned above is carried out by a variational analysis method (VAM) that generates a gridded surface wind field, which minimizes a function that measures the misfit of the analysis to a neutrally reduced background provided by a numerical model, the data, and certain *a priori* constraints. The numerical model is the European Center Reanalysis, which provides the "background" or first estimation of the 10 m-level wind, at a horizontal resolution of 1-degree latitude by 1-degree longitude, at 6-hour intervals. The analysis period begins in November 1987 (first set of satellite wind data) and ends in December 2008 (last month of reanalysis available to date). The final result of the optimization is a cross-calibrated, multiple satellite dataset, at a horizontal resolution of 25 km. Additionally, surface wind data from satellites also constitute a valuable input for analysis and forecasts with numerical weather prediction models, given their high resolution and accuracy.

Accomplishments during the Reporting Period
The validation of the oceanic wind climatology was extended from December 2002 to December 2008. Jusem has established a good piece of evidence that oceanic wind data can be used as a proxy for sea surface temperatures for ENSO monitoring. In fact, it has been found that an almost perfect correlation (r = 0.93) exists between SST anomalies on the eastern equatorial Pacific and zonal wind anomalies around the dateline: cold episodes are concomitant with strong easterlies, while warm episodes correspond to weak easterlies around the dateline. The SSTs were obtained from the Oceanic Niño Index (ONI) published by NOAA and the period of study was 1987-2008.

The implementation of sea level pressure inferred from QSCAT wind data in GEOS-5 forecasts has shown no significant impact.

A study of the impact of QuikSCAT and ASCAT wind data on a series of forecasts with the WRF model has been carried out. QuikSCAT data were beneficial for the prediction of hurricane Ike's 2008 landfall, and the ASCAT wind data improved the forecast for tracking hurricane Hanna in 2008.

Objectives for the Coming Year
The first objective is to extend the usefulness of satellite surface wind data to ENSO monitoring, and from being a proxy for SST to being utilized as a seasonal predictor.

The studies of the impact on hurricane forecast will continue with the incorporation of ASCAT surface wind data. Jusem also plans to participate in a project that extends the application of the "skewness" statistics to jet streams. In the simulated observation systems, an early hurricane detection technique will be implemented.

Task 613-71-249: **Aerosol-Water Cycle Interaction**

GEST Investigator: Kyu-Myong Kim

Collaborator: William K-M Lau (PI, GSFC 613)

Description of Research
The goal of this research is to understand the climate impacts of aerosol radiative forcing on the global monsoon water cycle at various time scales, from diurnal cycle to interannual variation of monsoon rainfall. Various satellite observations, including MODIS, TOMS, OMI, and TRMM, as well as *in situ* observations are being used to diagnose the relationship between aerosol distribution and the evolution of the monsoon water cycle. In addition, GCM experiments are also conducted to understand the mechanisms involved. Kim's main objective is to better understand the role of absorbing aerosols, such as black carbon and dust, as triggering elements of "Elevated heat-pump" on monsoon circulation, especially over the Indian sub-continent and the West African monsoon region.

Accomplishments during the Reporting Period
Long-term dry tendency in Indian monsoon from June-September has been linked to the weakening of the summer monsoon, which in turn is associated with the increasing aerosol loading over India sub-continent. The researchers used the regional monsoon rainfall and visibility data over India to investigate the possible role of absorbing aerosols. Results show that the all-India monsoon rainfall (AIMR) has a pronounced positive long-term trend in May-June, with contributions mostly from the northern part of the subcontinent. A significant negative trend in AIMR is found in July-August, with the largest contribution from the central and southern part of the subcontinent. The positive rainfall trend in northwestern and northern central India in May-June is consistent with the increasing trend in absorbing aerosols in the Indo-Gangetic Plain, and the EPH large-scale

fingerprints of a warmer upper troposphere, an anomalous anticyclonic circulation over northwestern Indian and the Tibetan Plateau, and a strong easterly vertical shear across the Indian subcontinent, all signaling a strengthened Indian monsoon in May-June.

The snow melting process over the Tibetan Plateau (TP) simulated by the NASA fvGCM with the Microphysics with Relaxed Arakawa Schubert (McRAS) and its relation with aerosol radiative forcing over Indo Gangetic Plain have been studied. The model includes state-of-the-art prognostic cloud water schemes and liquid- and ice-phase cloud microphysics and is coupled with simple slab ocean model. Global aerosol forcing is prescribed from monthly climatologies of three-dimensional distribution datasets of each of the five aerosol species (dust, black carbon, organic carbon, sulfate and sea salt) derived from the Goddard Chemistry Aerosol Radiation Transport (GOCART) model. The heating produced by aerosol radiative forcing initiates an atmospheric dynamical feedback (the so-called elevated-heat-pump (EHP) effect), which increases moisture, cloudiness, and deep convection over northern India, as well as enhances the rate of snowmelt in the Himalayas and TP. The accelerated melting of snow is mostly confined to the western TP, beginning slowly in early April and then rapidly from early-to-mid May. The snow cover remains reduced from mid-May through early June. The accelerated snowmelt is accompanied by similar phases of enhanced warming of the atmosphere-land system of the TP, with the atmospheric warming leading the surface warming by several days. A surface energy balance analysis shows that the shortwave and long-wave surface radiative fluxes strongly offset each other, and are largely regulated by the changes in cloudiness and moisture over the TP. The slow melting phase in April is initiated by an effective transfer of sensible heat from a warmer atmosphere to land, while the rapid melting phase in May is due to an evaporation-snow-land feedback coupled to an increase in atmospheric moisture over the TP induced by the EHP effect.

Based on model simulation and an analysis of TRMM and MODIS data, Kim and his colleagues found that aerosols enhance precipitation over the northern part of the rain belt and displace the ITCZ northward, especially for the June through September periods, in the tropical Atlantic Ocean. To explore the possible mechanisms for the northward shift of rain belts over the ocean and land, the easterly jet and associated wave activities are investigated. The easterly jet over West Africa is largely a response to the thermal gradients caused by the warm desert to the north of Sahel and the cool land and ocean to the south. In the presence of abundant aerosols, the surface temperature over the Saharan desert is much cooler than in an aerosol-free situation. Accordingly, the positive center of the meridional temperature gradient is moved further north from its mean location, as is the easterly jet. As a result, aerosols strengthen (weaken) the easterly jet northward (southward) of the axis of the jet. Thus, the displacement of the easterly jet alters the easterly wave activities and rainfall distribution.

Objectives for the Coming Year

In the coming year, Kim will continue to explore the effects of the elevated heat source induced by aerosols on the monsoon hydrological cycle. First, based on the long-term simulation of the GEOS-5 model with interactive aerosol and MERRA reanalysis data, Kim will examine the large-scale circulation and rainfall characteristics, as well as the evolution of easterly wave activities over the West Africa and Eastern Atlantic Ocean. Second, the diagnostics will be conducted to understand the possible impacts of aerosols from biomass burning on the weather and climate over Asian monsoon regions, based on the analysis of the long-term change in frequency and intensity of rainfall and cloud and/or rainfall susceptibility to aerosol. Finally, Kim will continue to work on the EHP effect on the Indian monsoon circulation and its impact on the snow melting process over TP, based on satellite observations and WRF model simulations.

Task 610-83-290: **Sounder Research Team (SRT) Activity Support**

GEST Investigator: Gyula I. Molnar

Collaborators: Dr. Joel Susskind (Code 610.5), Dr. John Blaisdell (SAIC), Lena Iredell (SAIC)

Description of Research

The AIRS/AMSU instrument is a state-of-the-art infrared/microwave sounding system, which has been providing operational quality measurements since September 2002. In addition to temperature and atmospheric constituent profiles, outgoing longwave radiation (OLR) and basic cloud parameters are also derived from the AIRS/AMSU observations. However, to date several key AIRS products have not been rigorously validated and/or evaluated on larger spatial and longer-term temporal scales. Thus, Molnar has extended to 7+ years the validation and assessment of the monthly mean, 1° x 1° gridded AIRS-retrieved products (referred to as Level 3 or L3 data, available to the public through the GES DISC at NASA/GSFC). In particular, extremely good agreement was found between the CERES-Terra and AIRS OLR anomaly trends, down to GCM grid-scale spatial resolution. He also continued to evaluate their utility for climate change assessments in general and climate model development in particular. The results indicate a high level of consistency/accuracy of the AIRS products considered, thus enabling them for model validations and (shorter-term) climate trend assessments. The inter-relationships of crucial climate parameters displayed in Molnar's AIRS analyses may also prove useful to test/improve model parameterizations of atmospheric processes. While the current AIRS climatology covers only about 7.5 years, researchers hope it will extend many years into the future.

Accomplishments during the Reporting Period

The GEST investigator has completed the replacement of the current (Version 5) AIRS OLR scheme which uses rather dated spectroscopy (the radiative transfer model or RTM used so far is based on rather outdated spectroscopic data). Molnar has fully implemented the AER OLR algorithm (http://www.rtweb.aer.com/rrtm_frame.html), which allows for the relatively rapid and accurate computation of OLR and CLOLR in column atmospheric models and in GCMs, into the AIRS retrieval algorithm. Based on the latest spectroscopy, the AER OLR RTM is highly regarded in the remote sensing/modeling community. Molnar has shown that the full implementation of the AER RTM into the AIRS retrieval code reduces the Version 5 AIRS-OLR vs. CERES-OLR biases very close to zero, so the AER RTM has been accepted to be used for the next generation, the "Version 6" AIRS retrieval algorithm to be released later this year.

Molnar continued to explore interrelationships and correlations among climatically important AIRS-retrieved parameters, including temperature, humidity (both at various levels in the atmosphere), cloud parameters and OLR/CLOLR based on the first 7+ years (09/02-12/09) of the new "Version 5" results. After the AIRS Version 5 six-year 1° x 1° monthly mean "climatologies" were generated, the investigator computed the monthly mean anomalies for each gridpoints. Next, "trend-lines" were fitted to the anomaly timeseries of each grid-point also, the end result being a "trend-map". Considering the relatively short length of the AIRS dataset, regional anomalies/trends, which tend to be larger than global anomalies/trends, are expected to be less affected by possible instrumental drifts or spurious global trends. Indeed, comparisons of similarly created trend-maps of cloud cover (MODIS on Aqua), OLR/CLOLR (CERES on Aqua and Terra), temperatures at various atmospheric levels (AMSU on Aqua) show greater than 0.9 correlations with the

corresponding AIRS-based ones. In particular, the AIRS OLR trend-map of the longest time period considered so far (09/02 – 12/09) shows a 0.98 correlation with the CERES-Terra Edition1 trend-map of the same period. These high correlations also argue for the robustness of the regional "trends" seen in these trend-maps, which could be very useful to validate regional climate change predictions made by the most sophisticated coupled GCMs. In addition, longitude-time Hovmoller diagrams of AIRS-retrieved deep tropical climate variables show remarkable inter-correlations. These are most likely signs indicating real physical connections, which in turn should also be exhibited by GCM climate simulations. Thus, coupled GCMs validated with such AIRS-based trend-maps and Hovmoller relationships could be considered highly valuable/reliable regarding their longer-term climate predictions as well, such as their man-induced greenhouse warming response.

In summary, these initial AIRS-based climate analyses show informative and physically plausible interrelationships among temperature, humidity, clouds, OLR, CLOLR both on the spatial and temporal scales considered (Susskind and Molnar, 2009 and Molnar and Susskind, 2009). These results imply that GCMs, to be trusted for climate predictions, should be able to closely reproduce these AIRS-derived "trends" and interrelationships. In summary, satellite sounder datasets could/should also be used for GCM validations and model parameterization improvements, as well as for longer-term climate analyses in general.

Objectives for the Coming Year

Molnar will continue to work on optimal merging of AIRS and TOVS climatologies. This will include reprocessing the existing TOVS climatologies to create an updated OLR, CLOLR TOVS database using the new OLR code implemented into the AIRS algorithm. In addition, he will continue to develop ways to interpret other AIRS Level 3 data for climate change assessments, and to further explore plausible ways how GCMs could/should use the high quality AIRS retrieval results in making their models more reliable for climate change predictions. The GEST investigator's participation in any newly arising AIRS retrieval-development/validation problems is also anticipated.

NASA Grant: **Multiple Factors Affecting the African Easterly Jet (AEJ) and Cyclone development over the tropical Atlantic (NNX07AN20G)**

Task 610-107-366: **Relationships among precipitation characteristics, atmospheric water cycles, climate variability and change**

Task 613-110-386: **Simulating and Predicting Sub-seasonal and Longer-term changes in Tropical Storm Characteristics using High Resolution Climate Models**

GEST Investigator: Oreste Reale

Collaborators: William K. Lau (GSFC 613), Yaping Zhou (GEST), A. da Silva (GSFC 610.3), K.-M. Kim (GEST), E. Wilcox (GSFC 613.2, Siegfried Schubert (GSFC 610.3), M.-I. Lee (GEST), Man-Li Wu (GSFC 610.3), Max Suarez (GSFC 610.3)

Description of Research

The GEST investigator was involved in three different research activities. The research performed under the NASA grant refers to a proposal funded within the NAMMA framework, in which Dr. W. K. Lau was PI and Dr. Reale, Dr. A. daSilva (NASA), Dr. K.-M. Kim (GEST) and Dr. E. Wilcox (NASA) were co-Is. The research conducted under this proposal concluded on September 30, 2009, and was focused on tropical cyclogenetic processes in the Atlantic, the impact of Saharan air and Saharan dust, and more generally the dynamics of the African Monsoon. The investigation was

centered on the capability of higher resolution global models in representing the structure of Saharan air and its role in the tropical cyclogenetic process. The goal of the project was to shed further light on the role of Saharan dust as a tropical cyclone suppressant, and to further enhance the understanding of tropical development, by benefiting from a new capability of the GEOS-5 system, namely an interactive dust aerosol component inclusive of its direct radiative effects. This effort produced an article on a special collection dedicated to NAMMA, which appeared in the *Journal of Atmospheric Sciences*.

The new task, which began at the conclusion of the NAMMA grant, focuses on improving the GEOS-5 depiction of precipitation fields by using AIRS products in partial cloudy conditions. It is part of a funded proposal of which Dr. W. K. Lau is the PI ("Relationships among precipitation characteristics, atmospheric water cycle, climate variability and change"). This part of the work benefits from the collaboration with Dr. Susskind (NASA) that provides AIRS data. An article based on this research and co-authored by Reale has been published in *Geophysical Research Letters*.

The task "Simulating and predicting Sub-seasonal and Longer-Term Changes in Tropical Storm Characteristics using High Resolution Climate Models" refers to a funded proposal with the same title, of which Reale is co-I and Dr. Schubert is the PI. Reale's contribution focuses on the development of diagnostics to assess the quality of tropical cyclones in global models. Some of his findings were presented remotely at an international workshop held in Trieste, Italy in August 2009. Research within this activity led to a co-authored article in the *Journal of Climate*.

Accomplishments during the Reporting Period

This was a very successful year for Reale in terms of publications, since he co-authored four published articles, two as a first author, one as a second author, and one as a third author.

The effort funded under the NAMMA Proposal was based on a number of experiments at different resolutions and with different data sets, which were performed with the most recent version of the GEOS-5, and provided strong evidence that Saharan air appears to exert some suppressing role on tropical cyclogenesis. Another clear result is that global models at a horizontal resolution of at least a quarter of a degree are needed to realistically represent such a process. A paper was published in the *Journal of Atmospheric Sciences*, in the special collection on NAMMA.

The work performed by Arlindo DaSilva on implementing an interactive aerosol component on the GEOS-5, was tested by producing a set of experiments with and without aerosol components, parallel to the ones done for the NAMMA period. Reale analyzed these results and is preparing an article on the impact of aerosol modeling on the African Easterly Jet.

The effort funded under the precipitation proposal in which Dr. Lau is PI focuses on investigating the impact of AIRS products on precipitation analyses and forecast within the NASA GEOS-5 data assimilation and forecast system. This has lead to another published article, in which Dr. Zhou (GEST) was the leading author. A follow-up study investigating the dynamics of the impact, with focus on changes in tropical cyclone structure as induced by AIRS data, is currently being prepared and will be submitted during 2010.

The effort under the new proposal on long term modeling of tropical cyclone activity has been focused on assessing the quality of the tropical cyclone representation in a series of long runs produced by Dr. M.-I. Lee (GEST). Work under this task was presented remotely by Reale at an international workshop hold in Trieste, Italy in August 2009. The results of an activity initiated previously, but concluded under this task, were in an article in the *Journal of Climate*, which focused on the African Easterly Jet and was led by Dr. Wu (NASA) and co-authored by Reale and others.

Finally, one other article, which resulted from funding concluded in 2009, focused on tropical cyclone Nargis, a catastrophic cyclone that hit

Myanmar during the previous year, was published in April and was the subject of a NASA press release.

The PI continued to mentor a graduate student (Ms. Fuentes) from Howard University, until she concluded her dissertation (on tropical cyclogenesis in global models), which she successfully defended in August 2009.

Objectives for the Coming Year

One paper whose research was supported by the NAMMA effort, currently in preparation, will be finished and submitted. The subject is the impact of aerosol simulation in the GEOS-5 on the African Easterly Jet. Other research currently supported by the task 000050727 (on the impact of AIRS on changes in dynamics and precipitation structure produced by tropical cyclones) is being finalized and compiled into an article to be submitted in the coming year. Reale also plans to perform more analyses on already performed runs to assess the impact of AIRS-derived information on the Inter Tropical Convergence Zone (ITCZ), and particularly on waves, westerly bursts and ITCZ relaxation.

Reale is a co-I on a pending proposal on CALIPSO submitted last year (PI: Dr. Lau). If funded, Reale plans to perform research on tropical cyclogenesis and aerosol impacts, giving special emphasis to the effect on tropical cyclone dynamics consequential to interactive aerosol and use of CALIPSO data for validation.

As a part of the task originated by the funded proposals on long-term simulation of tropical cyclone activity (PI: Dr. Schubert), Reale plans to continue performing diagnostics of existing and future simulations, and to collaborate with Dr. Wu on another article on the African Easterly Jet. The GEST investigator expects, among other goals, to keep developing and testing metrics to objectively assess the quality of hurricane simulations in different global models and to produce one article on this subject during the year.

Finally, Reale plans to submit at least one more proposal during the year.

Task 913-48-190: **Atmospheric Solar Radiative Transfer**

GEST Investigator: Guoyong Wen

Collaborators: Robert F. Cahalan (GSFC), Alexander Marshak (GSFC), Lazaros Oreopoulos (GSFC), Sirpa Hakkinen (NASA/GSFC), Tamás Várnai (JCET/UMBC), Peter Pilewskie (LASP, Univ. of Colorado), Jerald Harder (LASP, Univ. of Colorado), Thomas Woods (LASP, Univ. of Colorado), Hiroko Miyahara (Nagoya University), Atsumu Ohmura (E.T.H. Zürich)

Description of Research

The aerosol amount in the vicinity of clouds is an important parameter in studying aerosol-cloud interaction, cloud processes, and their associated impact on Earth's climate. To study how aerosol can modify cloud microphysics and the cloud reflectance on a global scale, satellite observation is obviously a good choice, since one can have both cloud properties and aerosol amount in the clear region nearby. However, satellites do not directly observe aerosols. An operational algorithm uses 1-D radiative transfer to retrieve aerosol properties; in the operational aerosol retrieval process, clouds near clear regions are ignored, which may lead to an incorrect interpretation of satellite observation. A simple example is that shadowed pixels in a satellite image will be misinterpreted as low aerosol loading if a researcher does not account for 3-D effects. Similarly, clouds can scatter sunlight into nearby non-shadowed pixels, making those pixels appear to be brighter. Hence, aerosol in those clear pixels would be mistakenly interpreted as having more aerosols in 1-D model. This research focuses on quantifying 3D cloud effects on reflectance in clear regions nearby, to improve researchers' understanding of the underlying physical process, further to make corrections in aerosol retrieval from satellite observations.

Solar radiation is the ultimate energy source for atmospheric and oceanic circulations, and a unique external forcing for Earth's climate. Understanding this input energy and its spectral distribution is crucial for understanding the physical, chemical, and biological processes of the Earth-atmosphere system. There is increasingly strong evidence to link the solar variations to Earth's climate. The objective of this research is to study the climate responses to solar irradiance variations on decadal and centennial times scales. The spectral and temporal variations of solar output energy observed from the SORCE (Solar Radiation and Climate Experiment) satellite are used as input for a modeling study of the Earth's atmosphere-ocean system's response to solar variations.

Accomplishments during the Reporting Period

Based on their earlier findings (Wen *et al.*, 2001), the investigator developed an algorithm for correcting cloud-induced reflectance enhancement in the vicinity of clouds. The investigator applied this algorithm to MODIS images acquired over the SGP site of the ARM Program and other regions of interest. Substantially large corrections were made to MODIS operational retrieved aerosol optical thickness. Results have been presented at international conferences (Wen *et al*., 2009a,b).

Observations of solar spectral irradiance from Spectral Irradiance Monitor on SORCE satellite show that the SSI in UV, visible and infrared spectrum, varies out of phase, while the proxy-reconstructed SSI shows in-phase variations. The investigator applies the 1D RCM to study climate response to spectral solar variations in decadal time scale. He also uses SIM-based and proxy-based solar variations as input to GISS GCM. He and his colleagues find that stratosphere, troposphere, and ocean mixed layer have remarkably different responses to the two scenarios of solar forcing. The results have important implications for stratospheric research, comprehending the current climate change, and future climate prediction. A paper to describe their results is in press in *Geophysical Research Letters* (Cahalan *et al.*, 2010).

Objectives for the Coming Year

Wen will continue studying 3D aerosol-cloud radiative interactions and sun-climate research. He will extend the 1D RCM to include deep-ocean in investigating the climate response to solar variations on centennial time scales. The investigator will further collaborate with scientists at GISS to investigate the response of GCM to spectral solar irradiance variations on centennial time scales.

NASA Grant: **Cloud Detection and Avoidance for the Landsat Data Continuity Mission**

GEST Investigator: Michael Wilson

Collaborators: Lazaros Oreopoulos (PI, GSFC 613.2), Tamás Várnai (JCET)

Description of Research

The Landsat Data Continuity Mission (LDCM) will follow the legacy of Landsat-5 and Landsat-7 in providing moderate-resolution satellite imagery to the public. This dataset is expected to allow people to analyze changes over the Earth's surface over several decades. Through Landsat, people will be able to see changes in urban sprawl, vegetation, land use, and many other facets of the earth.

Clouds and cloud shadows often contaminate these images. Manually-screened imagery can be effective, but the sheer volume of Landsat imagery makes this a daunting task. In addition, clouds over bright surfaces and cloud shadows over dark surfaces are difficult for even a trained eye to interpret.

The mission of this grant is to investigate and create algorithms to automatically screen clouds and cloud shadows for the current Landsat missions and the LDCM. These algorithms are currently being tested against a variety of manually screened Landsat images over the entire globe. The best algorithms will be

recommended for incorporation into the future LDCM mission.

Accomplishments during the Reporting Period

The investigator joined this project in late August 2009. Prior to this time, his research focused on investigating the properties of clouds in the Arctic and Antarctic. Clouds are generally cold and bright, which provides little contrast to the underlying ice and snow. However, oblique measurements from the Multi-angle Imaging SpectroRadiometer (MISR), on-board EOS-Terra, show that the forward scattering properties of clouds and snow differ. Through this property, the investigator was able to create thresholds for an algorithm to detect clouds over ice and snow. In addition, his work included modeling clouds over bright surfaces using popular radiative transfer models such as MODTRAN, Streamer, and DISORT.

At GEST, Wilson became responsible for investigating and developing cloud and cloud shadow screening algorithms. Cloud shadow analysis was initially conducted by using a subset of 43 manually screened cloud shadow scenes. For each scene, an optimal threshold was applied to each Landsat band to detect cloud shadows. Then, the ability of that threshold to discern between cloud shadows and other features was tested. Results showed that the single-band technique performed poorly, and more advanced techniques were required to adequately detect cloud shadows.

Wen *et al.* (2001) approached cloud shadows by applying a spectral separation index (SSI) to two Landsat bands. For most band combinations, approximately 10-20% of the clear pixels in a scene had similar properties to 20-30% of cloud shadow pixels. The ability of any of the SSI combinations to further discern these scenes varied dramatically between scenes, suggesting that this approach was not consistently effective.

Luo *et al.* (2008) designed a cloud and cloud shadow mask for the MODerate Resolution Imaging Spectroradiometer (MODIS) instrument, which could be applied to Landsat. The cloud shadow capabilities in Luo *et al.* are directly dependent on the cloud masking algorithm. Therefore, if the cloud masking algorithm from Luo *et al.* (2008) fails to properly detect clouds, the cloud shadow algorithm will also suffer. As a result, an investigation was first conducted on the performance and improvement of the Luo *et al.* cloud mask.

Since the Luo *et al.* algorithm does not incorporate a thermal band, Wilson reclassified clear and cloudy pixels through histograms of brightness temperature. Confidence levels were also applied to pixels, depending on how well they passed the classification criteria in the Luo *et al.* scheme. Brightness temperature classifications improved some scenes, at the expense of deserts, ice, and mixed land and water scenes. Investigation into the feasibility of incorporating the brightness temperature into the Luo *et al.* cloud masking algorithm will continue into the next year.

The investigator also programmed a cloud shadow projection mask, based on solar geometry and anticipated cloud height. The Luo *et al.* algorithm uses a combination of cloud projection and radiance thresholds to determine the presence of cloud shadows. Refinements to the projection algorithm will continue into the next year.

Objectives for the Coming Year

In the next year, Wilson will continue to refine cloud-masking techniques using brightness temperature and will develop a more realistic cloud shadow projection algorithm. In addition, he will research alternative methods to cloud and cloud shadow masking for the LDCM mission. Some candidates for future study include using time signatures, cloud mask intercomparisons, and the 1.38 um band (anticipated for the LDCM mission). Finally, he will become part of the Continual Intercomparison of Radiation Codes (CIRC) project, which seeks to evaluate radiative transfer codes using data that is largely observation-based.

Task 613-97-340: **Use of CALIPSO in understanding the effect of clouds on aerosol properties and interpreting MODIS aerosol observations near clouds**

GEST Investigator: Weidong Yang

Collaborators: Alexander Marshak (PI, GSFC, Code 613.2), Tamás Várnai (UMBC, JCET), Guoyong Wen (UMBC GEST)

Description of Research

Aerosol plays an important role in radiative forcing and in cloud formation, persistence and dissipation. Aerosol properties in the vicinity of clouds are different from those in cloud-free regions, and a strong correlation exists between aerosol optical depth and cloud cover. Understanding and quantifying the variability of aerosol properties in these regions from satellite data, such as MODIS, is particularly challenging because of issues such as cloud contamination and cloud adjacency effects. CALIPSO, on the other hand, provides a large range-resolved dataset of global cloud and aerosol properties that is not affected by cloud adjacency effects, thus helping quantify the aerosol direct and indirect radiative forcings and their uncertainties. The major objectives of this project include understanding the effect of clouds on aerosol properties and aerosol direct radiative forcing with the help of CALIPSO and MODIS observations, and improving the interpretation of MODIS aerosol observations near clouds by using CALIOP data for improving and testing models that account for cloud adjacency effect.

Accomplishments during the Reporting Period

During the reporting period, Yang's research focused on analyzing the backscattering properties of aerosols and clean air near clouds over marine regions by using linear and non-linear data processing methods. Particularly, he investigated the correlations of aerosol backscattering enhancement with other factors such as latitude, distance to neighboring clouds and the strength of clean air backscattering. The results show that near-cloud enhancements are stronger and extend to a wider area in regions of high cloud cover. The results also display a behavior that may be a sign of aerosol-cloud interactions, that backscatter right near clouds (within about a km) is higher in cases when operational CALIPSO algorithms do not detect any aerosol layers than when they do detect an aerosol layer. In addition, Yang found that backscatter enhancements near clouds are weaker if researchers exclude areas with higher uncertainties in cloud-aerosol discrimination.

Objectives for the Coming Year

In the coming year, more investigations of the above correlations will be conducted. Further research will include examining the geographical distribution of near-cloud aerosol enhancements by considering latitude, longitude, altitude, season, and surface type. Yang, along with the collaborators, will also examine the way aerosol enhancements depend on the properties of nearby clouds by combining data of cloud fraction, cloud phase, cloud optical thickness, and cloud texture.

Task 613-82-282: **Modeling A532nm Micro-Pulse Photon Counting Lidar System in Clear and Cloudy Atmospheres in support of the Icesat-II Mission**

GEST Investigator: Yuekui Yang

Collaborators: Alexander Marshak (PI, GSFC 613.2), Stephen Palm (SSAI), Tamás Várnai (JCET), Warren J. Wiscombe (GSFC 613.2), and Ping Yang (Texas A&M)

Description of Research

The Ice, Cloud, and land Elevation Satellite-II (ICESat-II) mission is recommended by the National Research Council's Decadal Survey as one of the top priority NASA missions. The current design of ICESat-II adopts a 532 nm micro-pulse photon counting lidar system with single photon detectability. The system will measure the time of flight of the arriving photons that are reflected by the surface to deduce the elevation of the underlying terrain. This study established a framework that simulates the behavior of the photon counting system in cloudy and clear atmospheres. Within this framework the following questions are addressed: How does the system behave under clear and cloudy conditions? How well can clouds be detected using the system? What is the bias in surface altimetry caused by the potentially undetected clouds?

Accomplishments during the Reporting Period

In support of the ICESat-II mission, this study establishes a framework that simulates the behavior of such a space borne lidar in cloudy and clear atmospheres. To investigate how clouds affect surface elevation retrieval, Yang and collaborators first adopted the Poisson distribution for simulating the distribution of the number of arriving photons under clear sky conditions; second, a 3-D radiative transfer model is utilized in simulating the probability distribution of photon path length and the number of photon returns under cloudy sky conditions; third, the photon arrival time for each laser shot is determined with the Monte Carlo method and surface elevation is derived through statistics of multiple laser shots. Results show that the ICESat-II system's requirement of a photon probability 0.8 for clear air over ice surface can be closely approximated by the Poisson distribution with a mean of 1.5.

For each pulse, the photon counting system only records the time of the first arriving photon that is reflected by the surface. Since part of the laser shots will have multiple photon returns, the retrieved surface elevation will be biased toward the first photon and make the surface appear to be higher, hence creating the first photon bias. For simulations conducted in this study, the first photon bias for clear sky is ~6.5 cm. Clouds affect the surface elevation retrieved from the photon counting system through two ways. First, clouds lower the average number of arriving photons. Due to the first photon bias, less arriving photons makes the surface appear lower compared to clear sky. Second, cloud forward scattering increases the photon path's length and makes the surface appear to be lower as well. Simulations in this study show that for COD = 1.0, the total bias (compared to clear sky) caused by cloud is 4.7 cm, among which the first mechanism contributes 66% and the second mechanism contributes 34%. If surface elevations are retrieved based on the statistics of 100 laser shots, the uncertainty is around 14.4 cm for clear sky; for COD=1.0, it is about 18.0 cm. If averaged over a distance of 7 km (1 second in time), the uncertainty would be lowered to 1.4 cm for the clear sky case and 1.8 cm for COD = 1.0. These values are lower than the ICESat uncertainty (~2.4 cm) when averaged over the same distance. For the cases simulated in this study, surface roughness only slightly increases retrieval uncertainty.

This study also found that a feasible way of cloud masking for the photon counting system is to use surface apparent reflectance. Due to the variability of surface reflectance, some of the clouds will be undetected. These undetected clouds will cause bias in the surface altimetry. To lower the bias, accurate knowledge of surface variability is required.

Yang also conducted research on detecting blowing snow using MODIS's observations with its 0.84 μm and 2.1 μm observations. Results show that even though blowing snow may not be observed from the visible channel, it can be detected by using the shortwave infrared channel at 2.1 μm. At this wavelength, blowing snow particles are much smaller than snow grains on the ground and therefore absorb less solar radiation. As a result, areas affected by blowing snow will be brighter than the surrounding surface.

In addition, the GEST investigator conducted research on the properties of stratospheric clouds using GLAS and MODIS data. Results showed that, with the exception of the tropics, the

amount of clouds around 15 km observed by both GLAS and MODIS during the L2A campaign (from Sept 25 to Nov 19, 2003) is small (< 0.05% over East and West Antarctica; though < 6% over the globe) and they are generally optically thin (COD < 0.1-0.2; opaque clouds < 0.6% over the globe). It is very unlikely that these clouds could result in a ghost ground return under the 10 kHz laser repetition rate. These results are helpful in determining the pulse repetition rate for ICESat-II.

Objectives for the Coming Year

Yang's first objective is to continue to study the impact of clouds on lidar altimetry from the photon counting system. The ICESat-II Science Definition Team has defined a variety of scenarios with different atmospheric conditions for the team to study. These scenarios are also among the foci of the GEST investigator's research. Second, Yang will examine different ways of cloud masking with lidar observations. He has demonstrated with GLAS data that cloud detection results are different for the 532 nm and 1064 nm lasers (Yang *et al.* 2010b). An additional study on cloud detection through utilizing surface apparent reflectance will be conducted.

Task 613-106-361: **Data analysis and modeling studies of the impacts of absorbing aerosols on snow impurity changes and glacier mass balance in the Himalayas and possible effects on the South Asian monsoon**

GEST Investigator: Teppei J. Yasunari

Collaborators: William K.-M. Lau (PI, GSFC Code 613), Randal Koster (GSFC Code 610), Yogesh Sud (GSFC, Code 613), Mian Chin (GSFC Code 613), Qian Tan (GEST, GSFC Code 613), Kyu-Myong Kim (GEST, GSFC Code 613)

Description of Research

A central goal of the JAMEX project is to provide better understanding of the physical mechanisms and multiscale interactions associated with the aerosol–monsoon water cycle in the IGP during the pre-summer monsoon and monsoon period over India. Especially, solar-absorptive dust and soot are the key parameters in the JAMEX project to assess the atmospheric heating over the foothills of the Himalayas, associated with the Elevated Heap Pump (EHP) effect, and the Himalayan glacier melting due to aerosol depositions. The absorptive aerosols in the atmosphere and over snow surface are likely to have an important impact on Himalayan glacier retreats.

Accomplishments during the Reporting Period

The snow surface albedo changes due to dust and BC deposition are important for estimating the amount of snow melting. The albedo changes largely depend on dust and BC concentrations in surface snow. The BC is a more absorptive material than dust; however, there still have not been many studies on direct observations of BC concentration over Himalayan glaciers. Hence, Yasunari and collaborators first estimated a lower bound deposition amount of BC and related albedo reductions over the southern slope of the Himalayas during the pre-monsoon period (most polluted season) using aerosol particulate data, equivalent BC concentration data, and meteorological components in the atmosphere observed at NCO-P site at the southern slope of the Himalayas. The site is maintained by Italian and French groups, and the study was carried out collaborating with those groups. The GEST PI and team estimated a total BC deposition rate of 2.89 $\mu g\ m^{-2}\ day^{-1}$ providing a total deposition of 266 $\mu g\ m^{-2}$ for March-May 2006 at the site, based on a calculation using a minimal deposition velocity of $1.0\times10^{-4}\ m\ s^{-1}$ with equivalent BC concentration data in the atmosphere. If all the BC is deposited uniformly in the top 2-cm pure snow, the corresponding BC concentration is

26.0–68.2 μg kg^{-1} assuming snow density variations of 195–512 kg m^{-3} of one typical Himalayan glacier close to NCO-P site. Such a concentration of BC in snow could result in 2.0–5.2% albedo reductions and would lead to a runoff increase of 70–204 mm of water drainage equivalent of 11.6–33.9% of the annual discharge of a typical Tibetan glacier by some numerical tests with a glacier mass balance model. Better estimates of albedo reductions with more detailed snow physical parameters in the regions from satellite and by model studies are essential for assessing snow albedo feedbacks and accompanied snow melt runoff from glaciers in future studies.

The estimations of horizontal distributions of dust and BC concentration in snow over Himalayas associated with albedo reductions and snow melting are the next step in extending the discussion at one location mentioned above to larger Himalayan and Tibetan areas. Regional and global model simulations are essential for this purpose. Currently, the LSM used in GEOS-5/NASA does not include any impurity effects on snow albedos and cannot estimate dust and BC impacts on snow albedos. Hence, the researchers have been incorporating aerosol-impurity effects on snow albedo for visible and near infrared waves in LSM/NASA. A validation test was carried out using observed mass concentration data in surface snow and meteorological components in Sapporo, Japan, during the winter of 2003-2004. The daily migrations of snow albedos for visible and near-infrared regions during the winter periods were relatively well reproduced and further improved than the albedos calculated in the previous LSM/NASA. However, improvements are still necessary, especially for albedo estimations for the beginning of snow accumulation and snow melting seasons. In addition, snow impurity movement in snow layer is important to determine impurity concentrations in snowpacks and this process is currently under investigation.

Objectives for the Coming Year

The coming year will focus on two tasks. First, after incorporating the code of impurity flushing effect due to snow melting in the LSM/NASA, off-line simulation of the LSM/NASA over the Himalayan region will be carried out with the output data of dust and BC depositions from GOCART/NASA (chemical transport model) and of meteorological components from the GEOS-5/NASA (atmospheric general circulation model). Second, after off-line simulations and related analyses, on-line simulations LSM/GOCART/GEOS5 will be carried out. The simulation results would provide them with how much dust and BC impact the snow albedo changes, as well as the EHP effect on Himalayan and Tibetan glacier melting and impacts of water resource changes in the surrounding areas. Two papers are expected from each of the above tasks.

NASA Grant: **Development of Theoretical Algorithms and Software for Retrieving Aerosol and Cloud Optical and Microphysical Properties from Observations to be Performed with Airborne and Spaceborne Polarimeters**

Task 913-57-211: **Development of Theoretical Algorithms and Software for Retrieving**

GEST Investigator: Hongbin Yu

Collaborators: Mian Chin (GSFC 613.3), Lorraine Remer (GSFC 613.2), J. Vanderlei Martins (JCET, UMBC), Huisheng Bian (GEST), Qian Tan (GEST), Yan Zhang (GEST)

Description of Research

Aerosols affect the Earth's energy budget directly by scattering and absorbing radiation and indirectly by acting as cloud condensation nuclei, thereby affecting cloud properties. The overall forcing by anthropogenic aerosols is likely to be negative (*i.e.*, cooling effect) and may be comparable in magnitude to the positive

forcing (*i.e.*, warming effect) by anthropogenic greenhouse gases. Aerosols can be transported thousands of miles downwind, thus having important implications for climate change and air quality on a wide range of scales, from local to regional to hemispheric and global. Past assessments of aerosol direct forcing and intercontinental transport were conducted mostly through modeling efforts, and large uncertainties exist in model simulations. Newly enhanced satellite passive sensors introduced in the last decade, the emerging measurements of aerosol vertical distributions from space-borne lidars, and several intensive field experiments conducted around the world all provided the opportunity to attempt measurement-based assessment of aerosol radiative forcing and long-range transport. Such satellite-based methods can play a role in extending temporal and spatial scales of field campaigns, and evaluating and constraining model simulations. On the other hand, model simulations and measurements from field campaigns can provide essential parameters that satellites do not observe. The overall goal of this research is to assess aerosol direct radiative forcing, aerosol-cloud interactions, and aerosol intercontinental transport through an integration of multiple satellite observations and measurements from intensive field campaigns supplemented by model simulations.

Accomplishments during the Reporting Period

Yu has continued the integrated analysis of aerosol distributions from satellite observations and model simulations during this period. He and his colleagues have performed a comprehensive analysis of global aerosol vertical distributions from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) lidar and the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model simulations. The first global distributions of seasonal average scale height of aerosol extinction have been derived from CALIPSO lidar measurements over an 18-month period from June 2006 to November 2007. The aerosol scale height provides a useful index for characterizing the aerosol vertical distribution on regional and global scales that involves large volumes of data, in particular for satellite-model and model-model intercomparisons. Successes and issues with both CALIPSO and GOCART were identified. A paper documenting the analysis approaches and findings has been accepted for publication in the *Journal of Geophysical Research*. They have also analyzed aerosol optical depth (AOD) above warm clouds (*e.g.*, cloud top below 4 km) from CALIPSO measurements. Several hot spots of above-cloud AOD occur in major smoke and dust regions. This would have important implications for quantifying the aerosol radiative effects.

Yu has contributed to the definition of aerosol science questions for NASA's future Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission as recommended by the Decadal Survey. He examined spatial and temporal variations of AOD over southern California by examining high-resolution Community Multiscale Air Quality (CMAQ) model simulations, Aerosol Robotic Network (AERONET) measurements, and the Geostationary Operational Environmental Satellite (GOES) retrievals. Both model simulations and observations show that aerosol has large spatial and temporal variations. Autocorrelation analyses of AOD suggest that these variations can be adequately (with correlation coefficient $r > 0.9$) captured by satellite observations with time resolution on an order of 1-2 hours and spatial resolution of 4-7 km. Both model simulations and observations show substantial day-to-day variations of aerosols over the region, which is mainly determined by the evolution of land-sea breeze circulations interacting with mountain flows. The increase of AOD occurs mainly above the atmospheric boundary layer (ABL); thus, it is challenging to relate AOD to surface particulate matter (PM) air quality in coastal areas. Yu and his colleagues have also been analyzing AERONET data of spectral AOD, spectral absorption, and aerosol direct radiative forcing over the Americas to document and understand the daytime variations of aerosol. Yu has also contributed to the definition of the aerosol science objectives and its integration into GEO-CAPE's Atmospheric Science Traceability Matrix (STM). Yu and his colleagues have achieved other accomplishments in the past year

as well. They published a paper that integrates the MODIS aerosol retrievals with GOCART and the Global Modeling Initiative (GMI) simulations to characterize marine aerosol fine-mode fraction and improve the derivation of anthropogenic component of AOD from MODIS. They examined fine-mode AOD and CO relationships on different temporal and spatial scales from both satellite measurements and model simulations to understand emissions, chemistry, and transport in determining the distributions of aerosols and CO. Additionally, they contributed to a section on the radiative forcing impacts by the aerosol intercontinental transport in the United Nations' Task Force on Hemispheric Transport of Air Pollution (HTAP) 2010 Assessment report (first draft submitted in January 2010).

Objectives for the Coming Year

In the coming year, Yu and his colleagues will extend the CALIPSO analysis to daytime measurements, examine possible day-night differences, and improve dust and non-dust discrimination by using the upcoming release of CALIPSO version 3 data. They will complete the analysis of aerosol daytime and/or spatial variations based on AERONET observations over the Americas and CMAQ simulations. The 7-year GOCART simulations will be analyzed to study interannual variations and short-term trends of aerosol and its direct radiative forcing. They will also assess the role of aerosol intercontinental transport in regional climate forcing by analyzing nine HTAP model simulations, each with a base run, and four perturbation runs will be conducted for a respective 20% reduction of anthropogenic emissions in North America, Europe, East Asia, and South Asia.

Task 613-107-370: **Aerosol Impacts on Energy and Hydrology Cycles**

GEST Investigator: Yan Zhang

Collaborators: Hongbin Yu (GEST, GSFC 613.2), Rong Fu (UT Austin), Robert Dickinson (UT Austin)

Description of Research

As the biggest rainforest and second warm pool, the Amazon plays a very important role in influencing global and regional climate and ecosystems. Smoke aerosols from biomass burning dominates the atmospheric aerosol composition of Amazonia from June to October, the transition from dry to wet season, which is important to the local economy, such as the power plant, fishing, and farming. The influence of aerosols on clouds and convection over Amazonia has been investigated extensively through field experiments, satellite observations and numeric models. Those studies focused on how aerosols influence cloud microphysics and local thermodynamics at scales of a cloud or a convective complex. Zhang's research focuses on the influence of biomass burning aerosol on the transition from the dry season to the monsoon onset. For this purpose, the combination of the MODIS aerosol optical depth and the Goddard Chemistry Aerosol Radiation and Transport (COCART) model is used in the Regional Climate model (RegCM3) to study the impact of aerosol on the surface energy and water fluxes, the evolution of atmospheric boundary layer (ABL), clouds and precipitation during the transition from the dry to wet season.

Accomplishments during the Reporting Period

Zhang and her collaborators conducted ensemble simulations of RegCM3 forced by the aerosol direct radiative forcing (Zhang, *et al.*, 2009). They found that biomass burning aerosol can work against the seasonal monsoon circulation transition, and thus reinforce the dry season rainfall pattern for southern Amazonia. The modeled radiative forcing by smoke aerosols reduces surface solar flux and stabilizes the lapse rate from the surface to the top of the

smoke layer in southern Amazonia where the smoke center is located. In addition, the smoke aerosol radiative forcing also warms the atmosphere well above the smoke layer, presumably through an enhanced mid-troposphere subsidence. These changes increase the surface pressure in the smoke center, weaken the southward surface pressure gradient between northern and southern Amazonia, and consequently induce an anomalous moisture divergence in the smoke center and anomalous convergence in north western Amazonia. This increase in atmospheric thermodynamic stability, surface pressure and divergent flow in Southern Amazonia may inhibit synoptic cyclonic activities propagated from extra tropical Southern America, and reinforced winter-like synoptic cyclonic activities and rainfall in southeastern Brazil, Paraguay and northeastern Argentina.

Objectives for the Coming Year

In the coming year, Zhang and her colleagues at GEST and NASA will continue to study the impact of aerosol on water cycle by using both MODIS AOD data and the regional climate model. They will focus on how the aerosol influence on the ABL processes depends on land surface type. In addition, Aerosol Robotic Network (AERONET) data will be used to investigate the diurnal cycle of aerosol optical properties and radiative forcing over the Americas. This activity will support the definition of aerosol science objectives for the Decadal Survey recommended Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission.

Task 613-95-338: **Toward infrared remote sensing methods for cloud optical and microphysical properties monitoring: Application to MODIS**

GEST Investigator: Zhibo Zhang

Collaborators: William Lau (GSFC 613), Oreste Reale (GEST/UMBC), Yogesh Sud (GSFC 613.2), Robert Rosenberg (SAIC), Huey-Tzu Wu (SSAI)

Description of Research

Cloud has a crucial but still poorly understood role in the climate system. Cloud-climate feedbacks have long been identified as the largest source of uncertainty in climate change predictions. The need for a better understanding of cloud's role in the climate is evident. To meet this need, continuous global observations of cloud properties from satellite-based instruments are indispensable. The MODIS instrument has proven to be an excellent platform for cloud observations. The current MODIS retrieval algorithm has used the solar reflectance channels to estimate important cloud microphysical properties such as cloud particle size and cloud optical depth. MODIS has also made measurements at several infrared (IR) wavelengths that provide information for estimating the same cloud microphysical parameters. To date, no infrared approach has been developed and applied to the MODIS observations to fill the nighttime gap in the presence of cloud microphysical properties from MODIS. The major objectives of this project include assessing the capabilities and limitations of MODIS infrared channels for cloud property retrieval, investigating the consistency between cloud property retrievals based on the solar reflective method and infrared method, and investigating the possibility of synergetic use of MODIS solar and infrared bands for cloud property retrieval.

Accomplishments during the Reporting Period

Zhang and his collaborators investigated the effects of ice particle size vertical inhomogeneity on two popular passive ice cloud property retrieval methods, the solar reflectance bi-spectral (SRBS) method and the infrared split-window (IRSpW) method, both based on passive satellite observations. Understanding the

retrieval difference between these two methods is critical for establishing long-term global satellite-based ice cloud property records and therefore improving our understanding of ice cloud's role in the changing climate. The main findings of this study suggest that the homogenous cloud assumption can affect the solar reflective and infrared split window method to different extents and, consequently, can lead to significantly different retrievals; therefore, caution should be taken when comparing and combining the ice cloud property retrievals from these two methods. A related manuscript has been submitted to the *Journal of Geophysical Research* (Zhang *et al.*, 2010).

Among other reasons, cloud vertical inhomogeneity is one important reason that may cause inconsistency between different cloud retrieval methods. Global algorithms based on SRBS and IRSpW methods usually assume that the observed cloud is homogenous, although most ice clouds are vertically inhomogeneous to some extent. Zhang and his collaborators investigated whether this assumption could lead to significant discrepancies between the two methods. The main findings can be summarized as follows:

First, when an ice cloud is optically thin and yet has a significant vertical variation in effective radius (r_e), the retrieved effective radius retrieval under the homogenous assumption (r^*_e) amounts to an interpolation problem. The radiative properties of ice clouds vary nonlinearly with ice particle effective radius. As a result, in both methods the retrieval under the homogenous cloud assumption tends to give retrievals smaller than the optical depth weighted average. Because the nonlinearity in the IRSpW method is generally larger than that of SRBS method, the r^*_e based on the IRSpW method tends to be smaller than that based on the SRBS method.

Second, consistent with previous studies, it is found that when the ice cloud has a moderate optical thickness, the r^*_e retrieval based on the SRBS method is weighted toward the r_e value close to cloud top. Utilizing the new concept of an apparent emissivity weighting function, the researchers discovered a compensating mechanism that limits the contribution of cloud emission to the r^*_e signal. Because only small ice particles exhibit significant absorption efficiency (Q_a) difference between any two of the IR wavelengths considered, while the Q_a of large ice particles are rather spectrally flat, the signal for r^*_e in the IRSpW method is contributed mostly by surface emission transmitted through the ice cloud and is more sensitive to the small ice particles than the larger ones. When the inherent sensitivities of the two methods are taken together, it was found that when r_e increases from cloud top toward cloud base, r^*_e based on the two methods are in qualitative agreement. On the other hand, when r_e decreases from cloud top toward cloud base, r^*_e based on the SRBS method is substantially larger than that based on the IRSpW method.

Finally, in both simple prescribed causes and the more realistic and complex cases, Zhang and his team found only a very limited impact of the size vertical inhomogeneity on t^*_c retrievals using either method. Therefore, in both methods, the error in IWP retrievals caused by the homogenous cloud assumption follows closely with the difference between r^*_e and optically averaged r_e. Depending on the optical thickness of the ice cloud and the vertical structure of r_e, the IWP retrievals based on the two methods can be significantly different.

The above findings have several implications for the remote sensing of ice clouds properties and the use of these retrieved properties in model validation and parameterization. First, they suggest the existence of potential significant bias in current IWP retrievals, caused by the homogenous cloud assumption. They also suggest that caution should be taken when comparing the ice cloud property retrievals between the SRBS and IRSpW methods. The

vertical inhomogeneity of ice cloud may lead to significant discrepancies between the two methods, even if they are applied to the same cloud and other uncertainties are well constrained. In this sense, even a close agreement between the two methods needs to be examined and interpreted carefully.

Objectives for the Coming Year

In the next year, Zhang and his colleagues will continue their efforts on the development of IR cloud property retrieval algorithm for MODIS. In particular, the investigator will attempt to obtain a comprehensive understanding of the capabilities and limitation of MODIS IR channels for cloud optical thickness and effective radius retrieval, as well as investigate the reasons for inconsistent solar and IR cloud retrievals.

Task 913-12-117: **Relationships Among Precipitation Characteristics, Atmospheric Water Cycle, Climate Variability and Change**

GEST Investigator: Yaping Zhou

Collaborators: William Lau (GSFC 613), Oreste Reale (GEST/UMBC), Yogesh Sud (GSFC 613.2), Robert Rosenberg (SAIC), Huey-Tzu Wu (SSAI)

Description of Research

One of the most profound impacts of climate change is the change in the Earth's hydrological cycle. The objective of this research is to identify and understand trends and long-term variations in the tropical rainfall distributions and characteristics in relation to large-scale circulation, climate variability and change. Research will focus on the specific science issues regarding the trends and characteristics of rainfall in association with tropical overturning circulation, tropical cyclones, and extreme rainfall events. Relationships between the trends in rainfall and the microphysical properties of suspended particles in the atmosphere (aerosol, clouds and precipitation) will be explored. Long-term and short-term satellite measurements will also be used to evaluate global and cloud-resolving model physics and different data assimilation schemes.

Accomplishments during the Reporting Period

In the previous study (Lau *et al.* 2008), satellite-derived global rainfall data from the Tropical Rainfall Measuring Mission (TRMM, 1998-2007), the Global Precipitation Climatology Project (GPCP, 1979-2007), and sea surface temperature data were used to study the relationships among extreme rainfall events, tropical cyclones and long-term sea surface temperature trends in the North Atlantic and Northwest Pacific Ocean. Results showed that heavy rain in the tropics occurs more frequently, while moderate-to-light rains occur less frequently in an increasingly warm climate. Tropical cyclones are feeding more extreme rain events in the last 27 years, with the strongest positive trend found over the North Atlantic, but the trend signal is muted in the Northwest Pacific because of the strong decadal variations. The above trend signals appear to be related to the rate of increase of the size of the warm pool. By expanding the above research on all major ocean basins and computing the accumulated precipitation for each tropical cyclone over its lifecycle, it is found that the accumulated total rainfall along storm tracks for all tropical cyclones shows a slightly positive trend over the whole tropics. However, when stratified into storm intensity, total rainfall associated with Category 4-5 storms shows a significant positive trend, and with Category-2-3 storms, a significant negative trend since 1980. Storm intensity defined as total rain produced per unit storm shows an increasing trend for both Category 2-3 and 4-5 storms. All major basins, *i.e.*, North Atlantic, Northwest Pacific, Southern Oceans, Northern Indian Ocean, except for the Northeast Pacific, show a significant increase in total number and rainfall amount in Category 4-

5 storms from the first half (1980-1993) to the second half (1994-2007) of the period. Stratification of the storm category by rain amount, *i.e.*, total latent energy, shows consistent results with a significant increase in the number and total energy of heavy rain-bearing storms in the latter period.

The change of tropical hydrological cycle in association with tropical overturning circulation is being investigated using GPCP and ISCCP data. The GPCP precipitation data showed significant trends of changes in the rising (sinking) branch of the Hadley and Walker circulation over the past 29 years. The intensification of the hydrological cycle is manifested via increasing precipitation in the tropical rain band and decreasing precipitation (further drying) of the subtropical dry band regions; a discernible polarward shift of the dry zone implies the broadening of the Hadley cell. Further evidence of change is investigated with ISCCP cloud and radiative forcing data. In particular, the artifacts in the ISCCP cloudiness data are examined to rule out any possible influence on the derived climate trend. A short paper was initially submitted to *Geophysical Research Letters*, which is being revised and will be submitted as a full paper.

Another important application of high-resolution satellite rainfall measurements is to evaluate and improve global climate and weather model performance and evaluate different data assimilation and moisture physics parameterizations. A study was conducted to examine the impact of incorporating Atmospheric Infrared Sounder (AIRS) quality-controlled temperature retrieval on precipitation assimilation in GOES-5 Data Assimilation system (DAS) and the corresponding forecast from GOES-5 global model for three tropical cyclones: Nargis (April 27 - May 03, 2008) in the Indian Ocean, Wilma (October 15-26, 2005) and Helene (September 12-16, 2006), both in the Atlantic. Three one-month-long assimilation experiments were conducted with the GEOS-5 DAS to cover the corresponding periods of TC Nargis, Wilma and the initial development stages of TC Helene. For each experiment, three assimilation runs were performed: a control run (CONTRL) assimilating all the operational (conventional and satellite) data used by NCEP, with the exception of AIRS data; a radiance run, which adds AIRS clear-sky radiances (RAD) in a fashion similar to operational analyses; and a retrieval run, in which AIRS temperature retrievals under partially cloudy conditions (AIRS) are assimilated in place of AIRS radiances. Three sets of 5-day forecasts with corresponding assimilation were also run with GEOS-5 global model. Zhou found that the precipitation analysis obtained when assimilating AIRS cloudy retrievals (AIRS) can capture regions of heavy precipitation associated with tropical cyclones much better than without AIRS data (CONTRL) or when using AIRS clear-sky radiances (RAD). The precipitation along the storm track shows that the AIRS assimilation produces larger mean values and more intense rain rates than the CONTRL and RAD assimilations. The corresponding precipitation forecasts initialized from AIRS analysis show reasonable prediction skill and better performance than forecasts initialized from CONTRL and RAD analyses up to day-2. This study was published in *Geophysical Research Letters* (Zhou *et al.*, 2010).

Objectives for the Coming Year

Zhou will focus on research in the following three areas: first, precipitation from tropical cyclones from all major ocean basins will be analyzed using GPCP pentad data from 1979. Total latent heat energy from tropical cyclones will be computed and analyzed for relationship with storm intensity, distribution and trend in the last three decades. Second, she will analyze detailed characteristics of extreme rainfall events from various synoptic systems with multi-instruments TRMM measurements through the use of a precipitation feature database developed by the University of Utah. Third, large-scale changes in hydrological cycle in association with Hadley and Walker circulations will be investigated with GPCP and ISCCP precipitation, cloud and radiation data sets.

Task 613-107-369: **Development of Theoretical Algorithms and Software for Retrieving Aerosol and Cloud Optical and Microphysical Properties from Observations to be Performed with Airborne and Spaceborne Polarimeters**

GEST Investigator: Viktor Zubko

Collaborators: Lorraine Remer (PI, GSFC 613.2), J. Vanderlei Martins (UMBC, GSFC 613.2)

Description of Research

Understanding and quantifying the effects of aerosols/clouds on the climate system remains a significant challenge for the scientific community. The only efficient way to proceed with this difficult task is by performing global measurements of aerosol/clouds properties by means of satellite remote sensing. NASA plans new space missions that will target aerosols, clouds, and climate and carry state-of-the-art sensors capable of capturing multi-wavelength, multi-angle, and polarization measurements of solar light reflected by the "atmosphere-aerosols-clouds-surface" system. The important task is how to get the most from the upcoming massive array of the measurements. Thus, the main goal of this research is to develop theoretical models, algorithms, and software for solving inverse problems of retrieving aerosol/cloud particle properties from the orbital observations.

Accomplishments during the Reporting Period

The general plan of the research includes experimenting with various aerosol retrieval algorithms, conducting respective sensitivity studies, and estimating information content of the satellite data. One main tool needed to accomplish the work is the radiative transfer (RT) code. Key requirements to the code are handling the full polarized radiation (Stokes vector) and polarized surfaces including rough ocean, a capability of working with scattering matrices, both internally calculated with the Mie theory (for spherical particles) and externally input from file (for particles of arbitrary, non-spherical form), and an availability of good documentation and code comments for making code modifications if needed. Several publicly available RT codes are on the web, which are potentially useful for the work: MODRAD by Ahmad and Fraser (1982), RT3 by Evans and Stephens (1991), 6SV by Kotchenova *et al.* (2008), VLIDORT by Spurr (2006), and PRT by Zubko and Laor (2000). Thus, at the initial stage, a critical evaluation of the RT codes was performed; however, none met the requirements completely. Therefore, the researchers selected the PRT code, which was developed by Zubko, because it meets the most requirements, and to add the missing features, including the reflection by polarized rough ocean and land and the Rayleigh reflection by the atmospheric gases.

Zubko performed significant upgrades to his PRT code, which now fully meets the requirements, and can be used to proceed with the research. The upgrades include the rough ocean reflection part with optional contributions of wind speed directionality, whitecaps reflection, surface wave shadowing, underwater radiances and input options for wind speed, wind azimuth, sea water salinity, and pigment concentration. They also include optional Rayleigh scattering by atmosphere with an input option for the depolarization factor. Upgrades relating to aerosols are a possibility to choose any number and height of aerosol layers, and to assign for each layer any number of aerosol species characterized by the type of size distribution: log-normal or gamma distribution, optical constants, and column number density. The following aerosol properties can be optionally used as a primary property instead of the aerosol column number density: extinction optical thickness, absorption optical thickness, or scattering optical thickness. Plus, any amount

of extra view angles (in addition to the basic view angles used by the code) can be optionally defined with the code output quantities calculated exactly at the extra angles. Finally, the code was upgraded by adding the graphical output in the form of both usual 2-dimensional plots and polar images with the use of the Gnuplot plotting program: the code generates necessary Gnuplot, Latex, and shell scripts, and then runs the scripts from within the code.

The PRT code was carefully validated by intercomparing with results of other codes. First, it demonstrates an excellent consistency, mostly within 0.03% with the standard "Coulson tables" by Coulson *et al.* (1960), which provide the Stokes vector of radiation emerged from a Rayleigh-scattering atmosphere over the Lambertian surface. There is also a very good agreement with the RT3 code (Evans and Stevens, 1991): usually better than 0.01%. In another experiment, PRT's functions that calculated the rough ocean reflection matrix were replaced with the respective subroutines from the RT code by Mishchenko and Travis (1997), and results derived with both codes are well within 0.05%. Finally, a generally quite good agreement was found within 1% with MODRAD (Ahmad and Fraser, 1982) and the Successive Orders of Scattering (SOS) code by Lenoble *et al.* (2007). The consistency is a bit worse than in previous cases, because both MODRAD and SOS codes are iterative, and thus their accuracy drops down for optical thicknesses larger than 0.3-0.5.

Objectives for the Coming Year

Zubko's first objective is to develop an aerosol retrieval algorithm that uses combined observations of same area with Glory/APS and MODIS sensors. Second, he plans to develop a special code, retrieval framework to experiment with aerosol retrieval algorithms, perform sensitivity studies, and estimate information content for multi-wavelength multi-angle polarimetric sensors. Third, he plans to prepare a paper that will describe the PRT code features and present the results of the intercomparison study.

Atmospheric Chemistry and Dynamics (Code 613.3)

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Task 613-94-325 **Development of Small Spectrometer Systems**

GEST Investigator: Nader Abuhassan

Collaborators: Jay Herman (JCET), Alexander Cede (UM), Matthew Kowalewski (GEST)

Description of Research

During the past decade, ground-based measurements have played a major role in improving researchers' knowledge of the impacts of trace gases and aerosols on local pollution and its effects on air quality and human health. Atmospheric trace gases have a controlling effect on the chemistry affecting ozone and smog formation in the troposphere, and NO_2 partly determines the ozone distribution in the Earth's atmosphere.

Tropospheric NO_2 high diurnal variability is influenced by both natural and anthropogenic emissions. Fossil fuel combustion is a major source of NO_2, and high NO_2 concentrations are usually confined to areas with high industrial activities, such as power generators, and have relatively several hours of lifetime in the polluted boundary layer. NO_2 concentrations and transport range from its sources depends on local wind speed and lower OH and aerosol concentrations in the middle and upper troposphere can lead to a longer NO_2 lifetime from several days to a week.

PANDORA is a ground-based Goddard-built spectrometer instrument system for measuring trace gas amounts and ozone profiles. This is an innovative concept and a highly cost effective approach initiated by the GEST team to address a currently missing component of trace gas amounts and ozone profiles. Completely autonomous and operating with high temporal and spectral resolution in both the UV and Visible spectral ranges, it possesses the unique capability for additional measurements of O_3, NO_2, SO_2, H_2O, and aerosols. Processing algorithms have been developed and successfully tested during several field campaigns during the past year.

The PANDORA instrument has been proven to be a valuable source of new measurements that has improved the theory and model simulations of tropospheric chemistry. Pandora is an effective scientific tool for control and economical monitoring of the pollutants leading to photochemical smog, haze, and climate change.

Accomplishments during the Reporting Period

The GEST team successfully completed the design and development of the first Pandora SUN &SKY head sensor. During the CINDI inter-comparison campaign in CABAUW/Netherlands, the team was able to deploy three instruments and successfully monitored the capabilities and the excellent stability of the Pandora instrument. Pandora SUN&SKY data demonstrated a very good agreement with the reference instrument during the CINDI campaign.

Objectives for the Coming Year

The PI plans to initiate a local network of 12 instruments, and participate in national and international field campaigns. He will also work on validating the CLEO instrument for global radiation measurements.

Task 916-39-176: **Improvement and Application of multiple Chemical Transport Models (CTMs) in Atmospheric Chemistry study and mission support**

GEST Investigator: Huisheng Bian

Collaborators: Mian Chin (GSFC 613.3), Randy Kawa (GSFC 613.3), Jose Rodriguez (GSFC 613.3), Allen Chu (GEST/UMBC), Paul Newman (GSFC 613.3)

Description of Research

Three Chemistry and Transport Models (CTMs) are being developed and/or improved in Goddard's Atmospheric Chemistry and Dynamics Branch (code 613.3) for a range of scientific objectives. The CTM coupled with GSFC's Goddard Global Modeling and Assimilation Office (GMAO) GEOS-5 system forecasts aerosol and CO/CO_2 fields for mission planning support, such as the upcoming NASA unmanned aircraft systems for the Aura validation experiment (GloPac). The new development in GEOS5 CCM provides the model a capacity to simulate gas and aerosol tracers together with including their dynamic feedbacks. The Global Modeling Initiative (GMI) serves as a comprehensive test bed, which can be used for the assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry. The improved GMI aerosol simulations have been supplied to the assessment activities of Hemispheric Transport of Air Pollution (HTAP) projects. The efforts of coupling gas and aerosol simulation have been devoted to GMI as well. PCTM is a 3D global CTM specifically designed for CO_2 study. It has been extended to CH_4 simulation and the results will be supplied to Transcom-CH_4 assessment activity.

All three models share common features that provide global chemical and aerosol perspectives to aid in interpreting surface, aircraft, and satellite observations and comparisons. However, each model is specifically designed to pursue its particular purpose. Bian contributes to all these models in both model development and application.

Accomplishments during the Reporting Period

Bian has supported field campaigns by taking charge of GEOS-5 CO simulations. GEOS-5 has an online parameterized CO simulation. This feature enables it to provide real time interaction between meteorological fields and the tracer's dynamic and chemical processes. Therefore, GEOS-5 becomes a powerful tool to support field campaigns. In the reporting period, Bian was awarded the NASA group achievement award due to her contribution to the ARCTAS mission in 2008. She analyzed aircraft measurements, as well as model and satellite data, for both CO and aerosols and conducted case studies to investigate the impact of tracers' atmospheric evolution (chemistry and deposition) on their distribution after long distance transport, and to identify origins of plumes (local vs. long-range transport, biomass burning vs. anthropogenic emissions). The results have been presented at both the ARCTAS science team meeting and Fall AGU meeting in 2009. To support an upcoming GloPac field campaign in 2010, she worked closely with other team members to carefully design a plan that not only meets the mission's objectives but also can deliver the products on time.

Bian played a major role in the development of coupling gas and aerosol simulations in two models: GEOS5 CCM and GMI. She proposed the strategy for coupling implementation and was involved in the model development. She also conducted sanity checks by running models and analyzing the output against results from other models. These models with gas-aerosol coupling capacity provide a good model framework with which she and other team members can proceed with a study for nitrate and ammonium funded in 2009 by NASA MAP (PI: Bian). Scientific communities desire the investigation of atmospheric nitrate and ammonium aerosols and their impact on radiation, chemistry and the ecosystem, since nitrate and ammonium are among the least studied aerosol constituents and their impacts could be important.

Bian extended PCTM, a 3D global CTM model that was designed specifically for atmospheric CO_2 simulation, to simulate global atmospheric CH_4 distribution. With this new capability, the model can participate in a recent international protocol for TransCom CH_4 inter-comparison, which aims to quantify the role of transport, flux distribution and chemical loss in simulating the seasonal cycle, synoptic variations and the diurnal cycle in CH_4 mixing ratio.

In addition to model development, improvement, and application, Bian was an organizer of an international effort, photocomp-2008, to perform a comparison of photolysis rates among chemistry-transport models and coupled chemistry-climate models. During 2009, she analyzed the submitted results, pointed out apparent errors to the participants, and wrote the assessment report together with Dr. Michael Prather (UCI). The assessment is expected to

allow researchers to understand and reduce model-model differences caused by varying treatment of J-values. The work will be reported as part of Chapter 6 in the SPARC CCMVal report in 2010.

Objectives for the Coming Year

In the coming year, Bian will lead the model development by implementing a thermodynamic equilibrium model supported by NASA ROSES 2008 MAP. She will continuously assist the coupling model development in GEOS5 CCM and GMI. She will deliver PCTM CH4 results to TransCom-CH4 campaign. She will analyze and summarize the aerosol and gas phase tracer results obtained from the ARCTAS campaign and from the team's model simulations. In addition to the scientific studies using GOES5 CCM, GMI, and PCTM models, Bian will support the NASA field campaign GloPac by leading the GEOS-5 CO simulation.

Task 613-85-300: **Nitrogen Dioxide Measurements from the Ozone Monitoring Instrument (OMI)**

GEST Investigator: Edward A. Celarier

Collaborators: James Gleason (NASA/GSFC 613.3), Dr. Eric Bucsela (SRI International)

Description of Research

Celarier develops the algorithms that convert the OMI measurements of the solar irradiance and earthshine radiance into estimates of the amount of nitrogen dioxide (NO_2) in the Earth's atmosphere. NO_2 is an important component of polluted air, and is produced by combustion and lightning; large concentrations are found around urban and industrial centers, fossil fuel burning power plants, and areas of agricultural burning and wildfires. As a contributor to photochemical smog, it serves as a source of ozone in the troposphere, and thus has significant health implications. NO_2 is also found in the stratosphere, where it participates in ozone chemistry.

OMI, aboard the EOS-Aura satellite, travels in a polar, sun-synchronous orbit, which enables it to "see" every part of the sunlit portion of the Earth once every day. Celarier's algorithms compile all the measurements in order to produce a daily map of NO_2. His team produces a number of data products, from user-friendly color maps to more detailed science-grade products, which are archived on the Goddard DISC and are readily available on the Internet.

In addition to maintaining and improving the algorithms, the GEST PI works with scientists in other groups on validating the OMI NO_e data products, and provides technical support to the ever-growing community of users of these data. He also works with other groups around the world using the NO_2 data to study air quality.

Accomplishments during the Reporting Period

Celarier has maintained and improved the software that produces the Level 2 Standard NO_2 Product, realizing further speedups. Significant work has been done toward the completion and release of a Version 2 algorithm and product, including improvements in the lookup tables used in the algorithm, using monthly climatological profiles, based on the combination GMI model. Uncertainty estimates are being improved. Geolocation data are being extended to include the locations of the FOV corners. The hierarchical structure of the data product is being reconfigured to enhance the ease of use by the scientific community, and the product metadata is being extended.

In FY 09-10, Celarier made several corrections and expansions to the documentation that is available online, describing the OMI NO_2 product. He is writing a more complete set of documentation for the algorithm, code, and product, which will be available to the users.

During this period, an anomaly was identified in the data from OMI, which appears to be due to an obstruction (most likely some insulation material) in the optical path of the instrument. Celarier produced quantitative diagnostic characterizations of this anomaly, and ensured that the flagging and processing criteria within the algorithm takes account of this anomaly.

Celarier has worked closely with colleagues at NASA and GEST to improve the Level 3 NO_2 Product, developing and implementing tests for the product. The Level 3 product is now being archived at the Goddard DISC and on the Aura Validation Data Center (AVDC). Archiving at the DISC also makes the data available through the NASA Giovanni tool, thus easily available to a wider user community. Additionally, Celarier worked with colleagues at the Harvard-Smithsonian Center for Atstrophysics to help develop and verify a data product that contains the FOV corners for each OMI measurement. He has been instrumental in communicating with the community of users of the NO_2 data product, in order to help ensure that those users are well-informed about the features and limitations of the data, and to gather feedback about the quality of the data as a guide to the continuous improvement of the product.

Celarier was a co-chair of the session "Characterization of Air Pollution and Its Interactions With Weather and Climate in East Asia Before, During, and After the 2008 Beijing Olympic Games" at the 2009 Joint Assembly Meeting in Toronto, Canada. He also served as a volunteer site organizer and teacher for Adventure in Science, a Saturday morning program sponsored by 4-H, and supported by the National Institute of Standards and Technology (NIST), NIH, and Lockheed-Martin. He has developed several innovative hands-on science and mathematics projects for high school, middle school, and elementary school students, and has served as a volunteer on-site scientist for programs for high school graduates from the Instituto Technólogico de Monterrey Campus Guadalajara, Mexico, that traveled to Alaska and the US Virgin Islands, to observe natural phenomena connected with global warming, climate change, and the impact of development on natural systems. He was also an instructor for the symposium "Interpreting NASA Satellite Data: Climate Change and its Impact on Life," at the same institute in March 2009, and an instructor for the teacher-training workshop "NASA Aerosol Data Network for Student Research Aerosol and Climate Workshop," in Mayagüez, Puerto Rico in July 2009.

Objectives for the Coming Year

Celarier anticipates completion of the validation and release of Version 2 of the OMI NO_2 Standard Product, and derived products (Level-2g, Level 3, Station Overpass data sets in the early part of the coming year. He will complete the release of the new technical documentation. He also anticipates that, following the release of the reprocessed (Version 2) NO_2 Standard Product, additional opportunities for algorithm improvement will be identified and pursued.

Celarier will initiate validation studies of the reprocessed NO_2 Standard Product using the validation data (including any updates thereof) that were used in the previous study (Celarier *et al.*, 2008).

Additionally, he will pursue opportunities for collaborative work to apply the OMI NO_2 Standard Product to air quality studies.

NASA IPA: **Climate Change Science Program Through a NASA-Supported Intergovernmental Personnel Act (IPA) Appointment**

GEST Investigator: Robert J. Curran

Collaborators: Jack Kaye (NASA HQ)

Description of Work

The U.S. Global Change Research Program (USGCRP) is a collaborative interagency program designed to improve the federal coordination of climate science, mitigation and adaptation activities, and to be responsive to those in need of this information. The USGCRP was established by Congress in 1990 to enhance understanding of natural and human-induced changes in the Earth's global environmental system; to monitor, understand, and predict global change; and to provide a scientific basis for decision-making. The congressional act that established the USGCRP authorized the publication of an annual report to Congress that summarizes recent achievements by the 13 federal agencies involved in climate research, their near-term plans, and their progress in implementing long-term goals. In addition, the act calls for an overview of recent and near-term expenditures in global change research and of requested funding. The annual report, entitled *Our Changing Planet*, is also widely used by the scientific community and others who are interested in global environmental change research as a means of tracking the program's progress and plans. Development and distribution of this report is a key responsibility of this appointment.

Accomplishments during the Reporting Period

The primary purpose of the annual report, *Our Changing Planet*, is to provide support for Climate Change Research in the submission of the President's budget to Congress for the upcoming fiscal year. For that reason, it is important that this document be available as soon after the submission of the President's budget as is practically feasible. In support of the President's FY 2010 budget submission, this document was published in October 2009. The publication is currently available on the web at: http://www.globalchange.gov/publications/our-changing-planet-ocp.

Objectives for the Coming Year

The FY 2011 budget submitted early in calendar year 2010 is the first of President Obama's to reflect the revised priorities of this administration. Likewise, the annual report, *Our Changing Planet FY 2011*, supporting the FY 2011 budget is expected to have a new scope, aggressive schedule, limited size and budget description. Developing and publishing the new reporting approach will be the major objective of the coming year.

Task 916-62-216: **Three-Dimensional Modeling of Atmospheric Chemistry and Aerosol Processes**

GEST Investigator: Thomas L. Diehl

Collaborators: Mian Chin (PI, GSFC 613.3), Qian Tan (GEST), Hongbin Yu (GEST), Tom Kucsera (GEST), Martin Wild (ETH), Mariya Petrenko (Purdue University)

Description of Research

The goal of this task is to develop and extend the Goddard Chemistry Aerosol Radiation and Transport model (GOCART), use it to investigate the influence of aerosols on air quality and climate radiative forcing, quantify the intercontinental transport of natural and anthropogenic aerosols, understand the chemical, optical and microphysical properties of aerosols and the processes that control these

properties, and improve the sources and processes in the model based on datasets from satellites, networks of ground stations like Aeronet and *in situ* measurements. GOCART can simulate the major atmospheric aerosols, including sulfate, dust, black carbon, organic carbon and sea-salt, from both natural and anthropogenic sources. It is a global scale model and is driven by assimilated meteorological data from the GEOS DAS.

Accomplishments during the Reporting Period

A previous analysis by Diehl indicated that the elevated aerosol optical depth values after the Pinatubo eruption of 1991, as computed by the GOCART model, took about 2 years too long to return to observational background levels. Since the main portion of the sulfate aerosol produced by this eruption was located in the stratosphere, the only effective mechanism for the removal of the aerosol is gravitational settling. Diehl therefore implemented a gravitational settling algorithm for sulfate in the GOCART model. The effective radii of the sulfate particles required for the algorithm were generated from the SAGE II instrument database for the period June 1991 to December 1998 as global stratospheric monthly averages, with a typical value of about 0.5 µm. Only valid measurements above the tropopause height were used, and the observed radii were assumed to be the dry particle radii, *i.e.* the water content of aerosol particles in the stratosphere was neglected. For the troposphere, the growth of the particles due to the ambient relative humidity is determined via a look-up table.

Diehl rewrote the generic gravitational settling algorithm, which is also applied to dust and sea salt aerosol. First, the formula for the terminal velocity was re-derived, avoiding some inconsistencies in GOCART's original algorithm, and the values of the coefficients in the Knudsen and Weber term for the slip-flow correction were updated with more recent values from the literature. In a second step, the numerical method used to solve the resulting equation was replaced by an upstream advection method with a 4th order polynomial fitting to reduce the diffusivity of the solution. Also, flux limiters were applied to ensure positive definiteness of the fluxes.

In a study for the Aerocom community, the GEST investigator performed a detailed comparison of the IPPC AR5 emission inventory and the Aerocom hindcast emission inventory, which had previously been compiled by Diehl. The major results of this analysis were that while the global anthropogenic emissions are generally similar (with better agreement for SO_2 than for carbonaceous aerosol), there are significant differences for biomass burning emissions. While the IPCC AR5 inventory provides more species, the Aerocom inventory has a higher temporal resolution and also provides volcanic emissions.

Diehl performed a number of future emission (FE) experiments for the TF HTAP. The main purpose of the FE simulations is to test the linearization of the earlier HTAP runs over the range of emissions drawn from the RCPs that have been developed for the IPCC AR5. From these RCPs, two years from two different integrated assessment models were selected: one with relatively high and one with relatively low emissions. With these high- and low-emission scenarios as baselines, sensitivity simulations were conducted, in which emissions in various source regions are decreased by 20%. The emissions sensitivities from FE can be compared to those calculated previously in the present-day experiments to estimate how future changes in the spatial distribution of emissions will likely impact the sensitivity of the receptor regions to intercontinental transport.

The researcher created a software package based on the Goddard solar radiation transfer model to compute shortwave radiation fluxes from the results of GOCART experiments. When applied to the results of the hindcast run, it turned out that the albedo variables provided by the GEOS DAS version 4 contained unrealistic patterns. Using the albedo provided by the GEOS DAS version 5 solved this problem.

To facilitate the migration toward the usage of meteorological fields from the GEOS DAS v5 in GOCART, Diehl implemented and tested a tool

for the online regridding of variables. He also determined the specific variables required from GEOS-5 for the large scale rainout and washout processes in GOCART and the algorithmic code changes to be implemented in order to be consistent with GEOS-5.

As in previous years, the researcher contributed to a project with a summer student to determine long-term dust sources through the Normalized Difference Vegetation Index (NDVI) based on AVHRR measurements, taking into account both long-term land-cover changes and seasonal variations. Diehl also collaborated with a graduate student on a project to determine biomass burning emission heights.

Diehl supervises the research analyst Tom Kucsera. Kucsera's projects include generating back trajectory analyses for the globally distributed AERONET network. Analyses are generated twice per day (00Z and 12Z). The long-time research work provided on this project has resulted in a progressively increasing archive of more than ten years of analyses at more than 250 AERONET sites that are distributed throughout the world. Other tasks of Kucsera are computer system administration, mission campaign support, and data processing and analysis.

Objectives for the Coming Year

Diehl will continue to migrate the GOCART model toward the usage of meteorological fields from the GEOS DAS version 5. Another research focus will be to evaluate the new gravitational settling algorithm for dust, sea salt, and sulfate particles, and to conduct a new hindcast run with settling for sulfate enabled and to compare the results with AVHRR data. Diehl plans to compute radiation fluxes for the model results and to evaluate the fluxes with observations from GEBA and BSRN stations. The volcanic emission database will be extended to 2008, and possibly to 2009.

Task 613-104-356: **Regional Modeling and Variability analyses in support of GEO-CAPE**

GEST Investigator: Melanie Follette-Cook

Collaborators: Kenneth Pickering (PI, GSFC 613.3), Scott Janz (PI, GSFC 613.3), Bryan Duncan (GSFC 613.3), Yasuko Yoshida (GEST UMBC), Dale Allen (University of Maryland, College Park)

Description of Research

Satellites in geostationary orbit have the capability of both high temporal and spatial resolution. These features will be especially advantageous for measuring the trace gases associated with the emission, transport, and chemistry of air pollution. However, challenges lie in determining the horizontal, vertical, and temporal resolutions needed to adequately represent these previously unresolved processes. This work focuses on quantifying tropospheric trace gas and aerosol variability in order to inform the recommendations for spatial and temporal resolution of the currently proposed NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) satellite.

Accomplishments during the Reporting Period

In order to quantify trace gas and aerosol variability, WRF/Chem was used to generate 4-km horizontal resolution fields of the trace gases O_3, NO_2, CO, SO_2, and HCHO, as well as $PM_{2.5}$, over the Eastern U.S. for a high ozone episode that occurred on July 9, 2007. Using a spatial autocorrelation analysis, horizontal variability of the tropospheric column was calculated as a function of distance in an attempt to quantify the resolution needed to ensure a sufficient amount of explained variance (EV). Results were presented in terms of the amount of variance explained for each horizontal resolution tested. Based on the analysis over the Eastern U.S., a 4-km resolution yielded 90% EV for O_3, CO,

HCHO, and $PM_{2.5}$ but only 50% EV for NO_2 and SO_2. In addition, both NO_2 and SO_2 displayed the most rapid decay of autocorrelation with distance. These two species are dominated by point and line sources and therefore have higher spatial variability than the other more regional pollutants.

A temporal correlation analysis was performed to determine the optimal temporal resolution needed from a geostationary instrument. The tropospheric column fields for each species were correlated with the fields one, two, three, etc., hours prior to and after a central time. It was determined that a temporal resolution of 1-hr yielded 90% EV for O_3, NO_2, CO, and HCHO, and 75% EV for SO_2 and $PM_{2.5}$. At a 3-hr temporal resolution, all species showed only 50%, indicating a rapid decay with coarser resolution.

Due to the limited vertical information expected from a geostationary view, correlations were also calculated to determine the vertical variability of these important species in the troposphere and boundary layer. When ozone in the boundary layer (BL) was correlated with ozone in the free troposphere (defined as from the top of the BL to 500 hPa), no significant correlation was observed; however, there was a very strong correlation between the BL and the tropospheric column for this event. The same results were seen when only a small subdomain, centered over the Maryland and Washington, DC corridor, was analyzed.

Data from this simulation have been supplied to other teams preparing for GEO-CAPE. Trace gas profiles were supplied to the sensitivity team for calculating radiances and testing retrieval schemes. Model-generated trace gas fields have also been supplied to other variability groups for their analyses. Similar correlation analyses have begun on a 1.5-km horizontal resolution Community Multi-scale Air Quality (CMAQ) model simulation for the July 2007 East Coast pollution episode as well as a 4-km resolution CMAQ simulation of the Los Angeles Basin during July 2007.

In addition to the model analysis, work has begun on the retrieval of NO_2 and O_3 from the Airborne Compact Atmospheric Mapper (ACAM) instrument. ACAM was flown on the WB-57 aircraft in September 2008 during the Newly-Operating and Validated Instruments Comparison Experiment (NOVICE).

Objectives for the Coming Year

To achieve the most useful results for planning GEO-CAPE, the GEST PI and her team need to examine how the variability statistics change from one polluted region to another at the same horizontal resolution. A separate WRF-Chem simulation will be performed at 4-km horizontal resolution over the Houston area for the September 2008 time period of ACAM flights on the WB-57 aircraft. This coincides with the ongoing objective of deriving slant column NO_2 and O_3 retrievals from the same ACAM data at multiple spatial resolutions. The variability in the ACAM data over Houston will be compared with the variability seen in the regional model output. In addition, Follette-Cook will be on the ACAM team during the Global Hawk Pacific (Glopac) Mission in March-April 2010, performing near-real time retrievals of NO_2 and O_3.

Task 923-39-175: **Interpretation of VIIRS Sensor Development, Calibration and Characterization for NPP Environmental Data Products**

GEST Investigator: Bruce Guenther

Collaborators: Dr. William Blackwell (ATMS, MIT-Lincoln Laboratory); Dr. Gail Bingham (Utah State Univ.- Space Dynamics Lab, Logan, UT), Dr. Scott Janz (NASA/GSFC), Dr. Frank DeLuccia (Aerospace Corp., El Segundo, CA), Dr. Karen St. Germain (NOAA, Chief, NPOESS Data Products Division), Ms. Pam Sullivan (NASA GSFC)

Description of Research

The objective of this research is to develop the calibrated and earth-located Sensor Data Records (SDR, Level 1-b) products for the space sensors on the NPOESS Preparatory Project. The activity involves a team of NOAA sensor scientists and their organizations to assess sensor calibration testing and develop constants and look-up tables necessary for the operation of the operational and research SDR software code. The activity also involves development of innovative and perceptive testing of the flight sensors. The NOAA team involves numerous subject matter experts across the earth-sciences community including academic, government and industrial partners.

Accomplishments during the Reporting Period

The NPP VIIRS sensor was delivered from the sensor builder factory to the NPP spacecraft factory in early 2010. Support and guidance provided through this task were essential for the Government getting this delivery completed. These activities were accomplished with the Task Leader providing nearly full-time on-site support in Raytheon, El Segundo, CA to the VIIRS Government Program Manager. The activity included guidance and interaction with the Northrop Grumman, Raytheon, NASA and NOAA teams on the relative importance of individual tasks and measurements, and oversight of the work performed by the VIIRS Sensor Scientist and his team in processing the complete VIIRS test data stream.

Several special tests have been completed or designed for VIIRS during this period. The VIIRS polarization test was executed with excellent results for sensor performance in polarization sensitivity determined from the testing. The MODIS polarization testing was not ever performed to the complete satisfaction of the Government MODIS science team, and the first two VIIRS polarization characterizations were not successful either. A third attempt was performed under guidance provided from this task. Results from this third measurement sequence showed that apparently anomalous results from earlier observations were due to (known) cross-talk effects but those effects were appearing with unexpected signatures in the polarization data. Two tests not previously performed on this class sensors are in development for the upcoming reporting period. These tests are an End-to-End test (testing VIIRS as a reflectometer in the reflected solar portion of the spectrum) and a flood illumination spectral test. For both tests, the equipment was devised and built for use in VIIRS calibration by the National Institute of Standards (NIST), and dedicated for these measurements. These activities were accomplished and facilitated by the work of the Task Leader.

Work accomplished under this task includes defining extended testing of the CrIS bench calibration infrared blackbody source by the NIST and laying out the framework for improved testing of the NPOESS ATMS sensor.

SDR algorithms for all four of these NPP sensors were enhanced and adjusted to correspond to actual sensor performance. Outreach materials for the NPOESS Program and NPP Mission provided to the research and operational community this year includes

offering dedicated NPP Sessions at the IGARSS 2009 and Calcon (Space Dynamics Laboratory, Logan, UT), and receiving approval for following sessions at the 2010 holdings of these two organizations. Guenther made presentations on VIIRS at IGARSS 2009, the AGU Fall Meeting, San Francisco, CA in December 2009, and the American Meteorological Society Meeting, Atlanta, GA in January 2010.

Objectives for the Coming Year

The conversion of sensor test data to sensor constants and look-up tables to run the operational SDR products will be completed for all NPP sensors this year. Thermal Vacuum sequence #4 test data for CrIS will be analyzed. Testing upgrades for the ATMS sensor for flight unit #2 will be defined, defended and agreed to through the Joint Polar Satellite System (JPSS) management structure, and IPO-conducted tests for VIIRS on the NPP spacecraft will be conducted, and test data analyzed.

Task 613-190-379: **Radiometric Calibration and Development Laboratory and Ground-Based Instrument Development**

GEST Investigator: Matthew Kowalewski

Collaborators: Scott Janz (GSFC), Nader Abuhassan (GEST), Alexander Cede (UM), Jay Herman (JCET)

Description of Research

Observations of atmospheric trace gas constituents provide data that help scientists understand some of the most important pollutants that directly affect the health of the population. Remote sensing observations of tropospheric and boundary layer pollutants, such as ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), formaldehyde (HCHO), and aerosols also help to serve as a basis for future air quality and ocean science decadal survey geostationary mission planning support. Stratospheric O_3 helps to protect the planet from large levels of harmful UV radiation while ground level O_3 is a known hazard for its effects on the human respiratory system. NO_2 plays an important role in the creation and destruction of ground level ozone as well as being a respiratory hazard at high concentrations. The primary sources of NO_2 are combustible processes, such as automobiles, industry and power plants, and forest fires. Volcanic activity and power plants are the primary sources of atmospheric SO_2 and is of importance due to its role in acid rain formation and air traffic safety. HCHO can be used as a proxy for isoprene variability, an important component in tropospheric O_3 production. Biomass burning events, such as those routinely seen in South America, Africa, and Indonesia, and certain forested areas (Ozarks in the U.S.), can produce isoprenes.

Through participation in air and ground field campaigns and pre-launch satellite calibration programs, the Radiometric Calibration and Development Laboratory (RCDL) and PANDORA projects provide valuable information to climate modellers and mission planners studying atmospheric chemistry. In direct support of these activities, the laboratory designed and developed the Airborne Compact Atmospheric Mapper (ACAM) in order to provide airborne measurements of the troposphere and boundary layer. Additionally, the ground-based PANDORA instrument system generates data for ozone column, ozone profile, and NO_2 retrievals. The Ozone Mapping Profiler Suite (OMPS) on the National Polar-orbiting Operational Environmental Satellite System Preparatory Project (NPP) is currently undergoing pre-launch test and integration activities. OMPS will provide daily global ozone total column and profile data and continue the long-term data record first begun with the Total Ozone Mapping Spectrometer (TOMS) and Solar Backscatter Ultraviolet (SBUV) instruments.

Accomplishments during the Reporting Period
The first achievement was the successful implementation of design enhancements of ACAM and its preparations for participation in the Global Hawk Pacific (GloPac) campaign in Spring 2010. The instrument has been prepared for the maiden science flights of the Global Hawk by adding an upward viewing capability to the hyper-spectral spectrometers, thus improving the tropospheric trace gas retrieval accuracy of the instrument. In addition, the nadir viewing visible camera has been replaced with a high-definition Ethernet-based visible video camera with increased resolution and frame rates.

In addition to the ACAM design work, the OMPS on the NPOESS has progressed with inputs regarding the enhancements of the instrument calibration and test program and design. Specifically, recommendations pertaining to the implementation of a quasi-volume diffuser for use during on-orbit solar calibration observations were made. These recommendations resulted in the implementation of a test and evaluation program to determine the effectiveness of such a diffuser design.

Objectives for the Coming Year
Objectives for the 2010 calendar year include evaluation of ACAM performance during the GloPac mission and quantification of its effects on science data products. Improvements to the RCDL calibration capabilities will be made through equipment modernization, while optimization of air- and ground-based hyper-spectral imaging instruments will enhance atmospheric retrieval studies. Continued support and oversight of the Ozone Mapping Profiler Suite (OMPS) Flight Model 2 (FM2) development and OMPS Proto-Flight Model (PFM) post-launch characterization will ensure a successful test and characterization phase of the instrument. Finally, the optical design and detector enhancements to ground-based UV/VIS/NIR trace PANDORA system will be evaluated with respect to the tropospheric retrieval science requirements.

Task 916-04-074: **UV Remote Sensing**

NASA Grant: **Mapping SO_2 Emissions with NASA AURA Ozone Monitoring Instrument (OMI) and GOCART Model for Air Quality and Climate Science**

NASA Grant: **Spectral absorption properties of aerosols in UV wavelengths**

GEST Investigator: Nickolay Krotkov

Collaborators: P.K. Bhartia (GSFC 613.3), Jay Herman (GSFC 613.3), Arlin Krueger (JCET, UMBC), Simon Carn (MTU), Kai Yang (GEST, UMBC); R. Dickerson (UMCP), Z. Li (UMCP)

Description of Research
Satellite Remote sensing in near ultraviolet (UV) spectral region (300nm to 400nm) provides unique information on the atmospheric composition: from global ozone depletion to air quality to volcanic emissions to the effects of UV radiation on biosphere and photochemistry and air quality. The Dutch-Finnish Ozone Monitoring Instrument (OMI), launched in July 2004 on the polar-orbiting EOS Aura satellite, offers unprecedented spatial and spectral resolution, coupled with global contiguous coverage, for space-based UV measurements of trace gases, aerosols and surface UV radiation. This research focuses on the development of advanced SO_2 and UV algorithms for OMI as well as validation with concurrent satellite and ground-based measurements. These algorithms also require as input information on UV aerosol absorption, which was measured using ground-based remote sensing techniques.

Accomplishments during the Reporting Period

GEST researchers (http://so2.umbc.edu/omi/) maintained OMI operational data products for SO_2 plumes in the PBL, lower and middle troposphere, and in lower stratosphere corresponding to different pollution sources: fossil fuel combustion, smelters, volcanic degassing, and volcanic eruptions. The OMI SO_2 data set is continuing the long-term (since 1978) record from heritage Total Ozone Mapping Spectrometer (TOMS) (*e.g.* http://toms.umbc.edu), but the improved sensitivity and smaller footprint of OMI have extended the range of detection to smaller eruptions, degassing volcanoes, and older clouds, and to anthropogenic pollution (http://so2.umbc.edu/omi/). The orbital level-2 and daily gridded level-2G data are available from September 2004-present from the Goddard public archive: http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omso2g_v003.shtml. The overpass SO_2 time series were also created (http://avdc.gsfc.nasa.gov/index.php?site=48128718&id=21) for a large number (>120) of ground locations. http://avdc.gsfc.nasa.gov/index.php?site=48128718&id=21Near Real-Time OMI SO_2 and ash data are produced in collaboration with NOAA/NESDIS for pre-operational use in volcanic aviation hazard avoidance. Global images and subsets are made available within 3 hours of data collection and distributed to decision support systems via dedicated website: http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2. UMBC SO_2 website (http://so2.umbc.edu/omi/) features archived daily SO_2 images and tonnages for main volcanic geographical regions as well as large eruption case studies. In June 2009, OMI tracked a dense cloud from Sarychev Peak volcano (http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=38975), which was the largest SO2 tonnage observed in 2009. In addition to explosive eruptions, OMI is sensitive to volcanic degassing and heavy anthropogenic emissions in the lower troposphere. Additional empirical background corrections, as well as air mass factor corrections due to SO_2 profile shape, cloud, and aerosol corrections, need to be applied to the operational OMI SO_2 data to improve correlation with the models (de Foy *et al.* 2009; Lee *et al.* 2009). Monthly area averaged OMI SO_2 data were used to detect regional changes before, during, and after the Olympic Games over Beijing and provinces affected by the emission control measures (ECM) (Witte *et al.* 2009). The data were analyzed for trends in 2005 through 2008 over the domain (110°-119^oE, 34°-40^oN) in Central – East China. Within this domain, regional PBL SO_2 reductions in 2008, relative to 2005-2007, were found to be 11% in August and 14% in September. The data suggests that the ECMs applied to the targeted provinces within the researchers' domain have resulted in effectively lowering the SO_2 emissions for the long term.

Atmospheric aerosols with enhanced UV absorption (*i.e.* dust, organic carbon) interfere with OMI SO_2 retrievals. Aerosol data from NASA AERONET network (http://aeronet.gsfc.nasa.gov) were combined with co-located measurements from the modified UV-MFRSR instrument (http://uvb.nrel.colostate.edu) to measure UV aerosol column absorption. To enable direct comparisons between the two techniques, a commercial UV-MFRSR instrument was modified by replacing the standard 300nm filter with the 440nm filter used in the AERONET network. The modified UV/VIS–MFRSR has been mostly deployed at the AERONET calibration site at NASA GSFC in Greenbelt, MD, but also at a number of field campaigns (at Mauna Loa Observatory in 2005, at Thessaloniki, Greece in July 2006, in Bolivia in September 2007, and in NE China in March 2008). While the UV-MSFRSR instrument is highly susceptible to calibration drifts, these drifts can be accurately assessed using co-located AERONET direct-sun AOT data. In 2006, a quartz dome was installed atop the MFRSR diffuser, which stabilized calibration drifts in 2007-2009. After correcting for remaining calibration changes, the AOT and single scattering albedo (SSA) at the UV wavelengths can be accurately inferred by fitting the measurements of global and diffuse atmospheric transmittances with the forward RT model at each UV-MFRSR spectral channel. Derived AOT and SSA at the common

wavelength 440nm by two different techniques are generally in good agreement. It was found that SSA becomes smaller in the UV wavelengths and has strong wavelength dependence across blue and near-UV spectral ranges. The measured enhanced UV absorption might suggest the presence of selectively UV absorbing aerosols.

Objectives for the Coming Year

The science quality OMI SO2 data set (level 3) will be created and archived at Goddard. Krotkov will analyze regional SO_2 plumes from China to study their long-range transport over the Pacific using trajectory modeling and MODIS aerosol and cloud data. The GEST researcher will continue algorithm development for ground-based passive remote sensing of column aerosol and gaseous (SO_2, NO_2, O_3) absorption across UV-visible spectral range at the NASA/GSFC site and field campaigns using a combination of instruments and techniques.

Task 613-71-244: **Stratospheric Dynamics and Chemistry**

GEST Investigator: Leslie R. Lait

Collaborators: Paul Newman (GSFC), Mark Schoeberl (STC), Tom Clune (GSFC), David Fahey (NOAA), Karl Froyd (NOAA)

Description of Research

Research activities under this task centered around investigating the dynamical context of atmospheric measurements to aid in their interpretation. Data from a wide variety of sources, such as satellite, balloon-borne, aircraft, and ground-based instruments, are analyzed with an emphasis on using techniques that assist in combining disparate data sources to yield a unified picture of the whole. In addition, support is provided to aircraft field experiments, including the use of forecasts and modeling results to aid in planning aircraft flights to maximize the scientific return and test the feasibility of various flight path scenarios. Activities also include oversight of local data systems to facilitate analysis.

Accomplishments during the Reporting Period

Lait's major activity during the reporting period was continued preparation for the upcoming Global Hawk Pacific Mission (GloPac) field experiment. Currently scheduled to take place in March-April 2010, this will be NASA's first use of the Global Hawk long-range unpiloted aircraft. The aircraft will carry a number of remote-sensing and *in situ* instruments to measure meteorological fields, chemical trace gas concentrations, and aerosol properties in the upper troposphere and lower stratosphere over the Pacific Ocean in the Northern Hemisphere. The GEST investigator participated in planning activities for the mission, including two planning meetings at NASA's Dryden Flight Research Center as well as numerous teleconferences. Procedures and documentation worksheets/checklists were developed for use during the mission.

A major element of support for the GloPac experiment was the further development of GEST-developed software for planning aircraft science flights. This software facilitates better communication and interaction between the scientists and the flight operations personnel. Along with numerous enhancements, additional types of data displays were added to the software, and the simulation of ascent maneuvers of the Global Hawk aircraft was made more accurate. Also, new software was written to read meteorological fields from an OPeNDAP data server run by NASA's Global Modeling and Assimilation Office (GMAO), which was incorporated into the flight planner.

A collaborative effort continued with the Software Integration and Visualization Office (SIVO) to develop a new modular trajectory code that will be able to run on a massively parallel computer to simulate the paths of billions of air parcels simultaneously as they are

transported by the winds. Lait worked closely with SIVO, providing research scenarios using the model, advising on the software design, and reviewing the code and documentation. A software routine was written to read meteorological fields from the Goddard Earth Sciences Data and Information Services Center, for incorporation into the model. SIVO staff presented a poster on the model at the 2009 Fall AGU meeting.

Collaborative work with Dr. Karl Froyd of NOAA's Earth System Research Laboratory in Boulder, CO was completed with the preparation and publication of results. The GEST investigator's contribution involved using trajectory models to determine the origin of air sampled by airborne instruments during the 2004 Pre-AVE (Aura Validation Experiment) and the 2006 CRAVE (Costa Rica Aura Validation Experiment) field experiments.

Additionally, Lait assisted in diagnosing and fixing problems with the computation and dissemination of files of tropospheric total ozone.

This research task contributes to the development and evolution of the computing infrastructure of the Branch as well. Several new analysis software packages were evaluated, and standardized installation procedures were created for them. Local web pages for the Atmospheric Chemistry and Dynamics Branch continued to be improved. Lait also served on the Code 600 Web Council, participating in the design of scientific web pages for Code 600.

Objectives for the Coming Year

Work will continue in preparation for the GloPac experiment, and GEST staff will participate in the experiment, doing science flight planning and providing stratospheric meteorological support.

Development of the gtraj trajectory model will continue. Performance testing and profiling will be done, and the ability to read more new data sets from the Goddard Global Modeling and Assimilation Office (GMAO) will be added. A few sample applications will be written.

Pending completion and testing of the gtraj model, work will resume on evaluating the foundations of the quasi-conservative coordinate analysis technique, using the new trajectory model to examine conservation of potential vorticity over a variety of seasons and meteorological data sources. A proposal will be written and submitted to improve and maintain the gtraj model, and assistance will be provided in writing and submitting other proposals.

Additionally, attempts will continue to align branch computing practices appropriately with imposed Agency-mandated changes in NASA IT practices.

Task 612-76-265: **Climate Change and the Stratospheric Ozone Layer**

GEST Investigator: Feng Li

Collaborators: Richard Stolarski (PI, GSFC 613), Steven Pawson (GSFC 610), Anne Douglass (GSFC 613), Paul Newman (GSFC 613), Darryn Waugh (JHU)

Description of Research

This task aims to investigate coupled climate-ozone change between 1950 and 2100. This spans times when there was little anthropogenic destruction of ozone, through the period of peak CFC loading (around 2000) and into the future as CFCs return to pre-1970 levels and chemical ozone loss is eliminated. Foci of the project are the impacts of this decay and recovery of the ozone layer on climate and on the impacts of climate change on ozone.

Accomplishments during the Reporting Period

Li studied the impact of climate change in the stratosphere on ozone layer recovery in the 21st century using simulations with the Goddard Earth Observing System – Chemistry Climate Model (GEOS-CCM) (Li *et al.*, 2009). Model results reveal that, in the 2060s when the

stratospheric halogen loading is projected to return to its 1980 values, the extratropical column ozone is significantly higher than its 1980 levels, but the tropical column ozone does not recover to 1980 values. Upper and lower stratospheric ozone changes in the post-CFC era have very different patterns. The uniform upper stratospheric ozone increase is a photochemical response to greenhouse gas induced strong cooling, and the lower stratospheric ozone changes are consistent with enhanced mean advection transport due to a stronger Brewer-Dobson circulation (BDC). These findings are highlighted as a feature story entitled "Climate Change and Atmospheric Circulation Will Make for Uneven recovery" at NASA.gov.

Li also investigated the interactions between tropospheric and stratospheric climate change in the latter half of the 20th century (Li *et al.*, 2010a). This study found, using GEOS CCM simulations and reanalysis data, that the strengthening of the BDC is strongly projected onto the high index of the Southern Annular Mode (SAM) during the austral summer. An increase in the downwelling in the Antarctic stratosphere is highly correlated with a decrease in the geopotential height and temperature in the Antarctic troposphere and a barotropic poleward shift of the tropospheric jet. The trends in the BDC and the SAM are driven by Antarctic ozone depletion, which increase stratosphere-troposphere interactions through a delayed Antarctic vortex breakup. The prolonged persistence of stratospheric westerlies enhances upward propagation of tropospheric wave activity into the stratosphere and strengthens the BDC. The increased stratospheric wave flux and westerlies in turn drive a SAM trend toward its high index. This BDC-SAM relationship is also robust on the interannual timescale.

The widening of the tropical belt under climate change is a very active research topic. Li investigated two aspects of tropical expansion that have not been previously examined: the narrowing of the BDC and the narrowing of the Hadley cell's rising branch (Li *et al.*, 2010b, submitted to *Geophys. Res. Lett.*). Using GEOSCCM simulations of the 21st century, he found that the narrowing of the BDC is caused by an equatorward shift of Rossby wave critical latitudes and EP flux convergence in the subtropical lower stratosphere. Model results suggest that the narrowing of the Hadley ascent is also eddy-driven. Suppressed equatorward propagation of eddy flux in the subtropical upper troposphere, possibly a result of an increase in the tropospheric static stability, drives a secondary indirect meridional circulation whose sinking branch pushes the boundary of the tropical upwelling toward the Equator.

Objectives for the Coming Year

Li will investigate changes in transport and circulation associated with ozone-climate change in the atmosphere. The main objective will be to characterize transport changes by using age spectrums to isolate whether or not transport pathways change substantially over time, and, if so, identify the underlying mechanisms. Li will also study the variability of stratospheric tracers and its links with circulation change using satellite measurements and model simulations.

Task 613-111-388: **Stratospheric-Troposphere Exchange and its Impact on Atmospheric Ozone**

GEST Investigator: Qing Liang

Collaborators: Richard S. Stolarski (PI, GSFC 613); Anne R. Douglass (GSFC 613), Jose M. Rodriguez (PI, GSFC 613)

Description of Research

The stratospheric ozone depletion exerts a significant impact on climate change through radiative forcing while the tropospheric ozone is of key interest for surface air quality regulation. The stratosphere and troposphere are tightly coupled, both dynamically and chemically. The troposphere-to-stratosphere transport of man-made ozone depleting substances, such as CFCs, and naturally-emitted ozone depleting substances, *e.g.* short-lived bromocarbons, contributes to catalytic destruction of ozone in

the stratosphere. The stratosphere-to-troposphere transport of ozone and NO_y rich air plays a vital role in tropospheric ozone variability and photochemistry. This research investigates the dynamics of stratosphere-troposphere exchange and how it affects ozone photochemistry in the stratosphere as well as the troposphere.

Accomplishments during the Reporting Period

Liang has contributed to two major projects during the reporting period. First, Liang has developed a new emission estimate of two most important short-lived bromocarbons, bromoform ($CHBr_3$) and dibromomethane (CH_2Br_2) from the ocean and has improved the simulation of bromine chemistry in the GEOS CCM to account for the currently missing component in the stratospheric bromine budget (Liang *et al.*, 2010). The top-down emission estimates of $CHBr_3$ and CH_2Br_2 are derived using airborne measurements in the Pacific and North American troposphere and lower stratosphere obtained during previous NASA aircraft campaigns. This emission estimate suggests that to reproduce the observed concentrations in the free troposphere, a global oceanic emission of 425 Gg Br yr-1 for $CHBr_3$ and 57 Gg Br yr-1 for CH_2Br_2 is needed, with 60% of emissions from the open ocean and 40% from coastal regions. Although this simple emission scheme assumes no seasonal variations, the model reproduces the observed seasonal variations of the short-lived bromocarbons with high concentrations in winter and low concentrations in summer. This indicates that the seasonality of short-lived bromocarbons is largely due to seasonality in their chemical loss and transport. The inclusion of $CHBr_3$ and CH_2Br_2 contributes ~5 pptv bromine throughout the stratosphere, agreeing well with *in situ* and satellite measurements. Both the source gases and inorganic bromine produced from source gas degradation (BryVSLS) in the troposphere are transported into the stratosphere and are equally important. Inorganic bromine accounts for half (2.5 pptv) of the bromine from the inclusion of $CHBr_3$ and CH_2Br_2 near the tropical tropopause and its contribution rapidly increases to ~100% as altitude increases. More than 85% of the wet scavenging of BryVSLS occurs in large-scale precipitation below 500 hPa. A sensitivity study with wet scavenging in convective updrafts switched off suggests that BryVSLS in the stratosphere is not sensitive to convection. Convective scavenging only accounts for ~0.2 pptv (4%) difference in inorganic bromine delivered to the stratosphere.

Secondly, Liang has contributed to the post-mission data analysis of the NASA ARCTAS mission. Liang has submitted the GEOS-5 simulation products, including meteorological variables, chemical tracers (CO and tagged tracers, CFC-12, SO_2), and aerosols (dust, sulfate, organic, black carbon and their optical properties) to the NASA ARCTAS data archive for the ARCTAS science team and for public use. In addition, Liang has led a scientific analysis looking at various air masses sampled during ARCTAS and their contribution to ozone in the Arctic troposphere. Various air masses, *i.e.* biomass burning, anthropogenic pollution from Asia, Europe, and N. America, and stratospheric air, were observed during both the spring and summer phases of ARCTAS (Duncan and Liang, 2009). Liang used a principal component analysis of observed various trace gases and GEOS-5-tagged CO tracers to identify different air masses sampled by DC-8 aircraft. Three leading empirical orthogonal functions (EOFs) were identified: stratospheric air, biomass burning plumes, and anthropogenic plumes. Biomass burning plumes identified by PCA during the summer phase display different characteristics as compared with spring, showing enhanced CO, HCN, CH_3CN, PAN, C_2H_2, C_2H_6. This implies a difference in air mass composition between the aged spring Siberian agricultural biomass burning and fresh summer boreal forest fires. Since the $\Delta O_3/\Delta CO$ ratio is a commonly used variable to measure the ozone production efficiency, the $\Delta O_3/\Delta CO$ ratio is calculated in the identified air masses to understand the contribution of biomass burning and anthropogenic pollution to ozone in the Arctic troposphere. Anthropogenic plumes observed during both spring and summer show weak positive ozone productivity. Biomass burning plumes (mostly Siberian agricultural burning) observed during spring has a $\Delta O_3/\Delta CO$ ratio of 0.28, while the summertime boreal forest

fires display a $\Delta O_3/\Delta CO$ ratio ~ 0, indicating very fresh plumes with little ozone production.

Objectives for the Coming Year

The investigation into the impact of very short-lived bromocarbons from this reporting period will be expanded to further review how this additional stratospheric bromine will impact stratospheric ozone depletion, particularly in the lower stratosphere, where catalytic destruction of ozone by bromine is important. The relative efficiency of bromine as compared to chlorine in destroying the stratospheric ozone and its variation from 1960 to 2100 will be calculated to understand the importance of bromine-related ozone depletion in a changing climate. The investigation of the ozone budget and photochemistry in the Arctic troposphere will also be expanded. Liang will use observations obtained during an ARCTAS mission together with the Global Modeling Initiative (GMI) model and the GEOS Chemistry Climate Model (CCM) to look at the ozone-NO_x photochemistry in the Arctic tropospheric during spring and summer, and to quantify the impact of stratosphere-troposphere exchange on ozone budget and net ozone production rates.

Task 916-37-173: **Stratosphere-Troposphere Exchange**

GEST Investigator: Mark Olsen

Collaborators: Anne Douglass (GSFC 613.3), Mark Schoeberl (STC), Paul Newman (GSFC 613.3), Steven Pawson (GSFC 610.1), Jose Rodriquez (GSFC 613.3), Yasuko Yoshida (GEST 613.3), William Gallus, Jr. (Iowa State University), Susan Strahan (GEST 613.3)

Description of Research

The exchange of air and chemical species across the tropopause has implications to many atmospheric chemistry and climate problems. In addition, the tropopause region significantly influences the radiative properties of the atmosphere. Thus, it is important to quantify and qualify stratosphere-troposphere exchange (STE) and to accurately represent STE in research models. An understanding of the transport in the upper-troposphere/lower-stratosphere (UTLS) and the impact on composition is likewise important. This research focuses on the analysis of STE and UTLS transport in global atmospheric data sets and model output. Science issues addressed include ozone trends and budget in the UTLS; seasonal and interannual trends in STE of total mass and ozone mass; stratospheric circulation; the importance of STE to climate change; and the transport of water vapor from the troposphere to the stratosphere.

Accomplishments during the Reporting Period

The previously developed algorithm to diagnose ozone laminae in High Resolution Dynamic Sounder (HIRDLS) profile data was further refined. The improved laminae statistics were used to continue an investigation of year-to-year differences in the lower stratospheric distributions of ozone. Ozone distributions from 2005 to 2007 were examined using the equivalent latitude coordinate to remove the impact of reversible meridional transport. The analysis shows large differences in the amount of irreversible transport during the late winter in the lower middle latitudes, with the least occurring in 2006. However, the number of laminae occurring at this time was greater than in other years. These results show that there is large variability in the year-to-year reversibility of meridional transport and that observed laminae frequency in profile data cannot be interpreted as an indicator of the net meridional transport. The variability in the amount of irreversible transport is likely due to interannual differences in the non-linearity of the eddy transport. The relations of the quasi-biennial oscillation (QBO) phase and the polar vortex state to the reversibility of meridional transport are currently being investigated using model output from the Goddard Chemistry-Climate Model (CCM). This study also uses the equivalent latitude formulation to determine the

impact of irreversible transport from the tropics on the middle latitude ozone distributions. Initial results indicate that the tropical influence on the lower middle latitudes is slightly less during the easterly phase of the QBO. Occurrences of stratospheric sudden warmings (SSWs) that break down the polar vortex are associated with a much greater reduction of the tropical influence on the middle latitudes. An interaction between the two forcing processes is also indicated.

Cases of laminae identified in HIRDLS profiles and the related climatology have been used to evaluate the output of several models and assimilation systems. The results indicate that the Goddard Modeling and Assimilation Office (GMAO) ozone assimilation fails to satisfactorily reproduce the observed laminae. Output from two simulations of the Global Modeling Initiative (GMI) model driven by GEOS-4 and GEOS-5 analysis fields has also been compared to the observed laminae. The GEOS-4-based simulation shows much better agreement with the observations than the GEOS-5 simulation. Both simulations tend to have fewer laminae than observed. However, the GEOS-5 simulation only reproduces about 15% of the observed laminae, while the GEOS-4 simulation frequently reproduces about 80%. In addition, the climatology of laminae in the GEOS-4 simulation agrees much better with the observed climatology of laminae thickness and magnitude. The reasons for the discrepancies between the simulated ozone fields and the observations are not well understood and are being investigated further.

The extratropical STE of mass and ozone in simulations by the GMI model and two versions of model “replay” mode have been examined. The representation of mass and ozone STE in the GMI and Scout replay simulations shows good agreement of the magnitude and spatial distribution with estimates of prior model and observational studies. The magnitude of the annual STE of mass in the regular replay mode of MERRA also agrees well. However, the spatial distribution of the mass flux across the 380 K potential temperature surface and the diabatic mass flux across the tropopause are significantly different from prior studies. In addition, the magnitude of ozone STE is consistently at least 50% too low and the spatial distributions are not consistent with previous results. This suggests that the stratospheric transport in the MERRA replay simulation is not consistent with observations. The stratospheric transport deficiencies and the cause of them are currently being investigated.

Trajectory analyses of tropical lower stratospheric air parcels show a strong seasonal dependence of how many originated from the tropospheric Asian monsoon and outflow region. The water vapor content of the parcels have been modeled using a simple saturation scheme. It is found that the seasonal cycle of tropical lower stratospheric water vapor is better reproduced when parcels originating from the subtropical and midlatitude monsoon region are included compared to results using only parcels of tropical origin. The mean magnitude of the tropical lower stratosphere water vapor content using this scheme is biased high relative to MLS observations. This is consistent with the finding that the water vapor in the GEOS-5 analyses of the tropical lower stratosphere is high-biased relative to MLS.

Objectives for the Coming Year

The climatology and variability of irreversible meridional transport will be examined using a wave breaking identification algorithm and a mass balance method of estimating the net transport. The mechanisms controlling the year-to-year variability of irreversible transport and its relationship to ozone distributions will be investigated. The relationship of ozone STE to tropospheric column ozone estimates will be examined using two diagnostics of ozone STE with satellite data. Evaluations of the ozone assimilation and models will continue with the goal of improving the capability to reproduce observations. Finally, the temperature trends in the Goddard CCM and other models will be compared to Microwave Sounding Unit observations and be related to the simulated trends of the Brewer-Dobson circulation.

Task 613-106-362: **The Influence of Mean Climate on the Equatorial Pacific Seasonal Cycle and ENSO: Simulation and Prediction Experiments using CCSM3**

GEST Investigator: Xiaohua Pan

Collaborators: Bryan N. Duncan (GSFC Code 613.3)

Description of Research

This research was done as the investigator's Ph.D dissertation in 2009 (prior to her joining GEST in November 2009). The influence of mean climate on El Niño-Southern Oscillation (ENSO) characteristics is crucial, according to the theoretical study based on observations. However, the asymmetric structures in mean climate are substantially weakened in current coupled ocean-atmosphere general circulation models (CGCMs). Therefore, the influence of mean climate on the seasonal cycle of equatorial Pacific and the ENSO is investigated in depth using the Climate Community System Model Version 3 (CCSM3) developed by National Center for Atmospheric Research (NCAR) in this study.

Accomplishments during the Reporting Period

Pan applied an empirical time-independent heat flux correction over the tropical ocean to the oceanic component of CCSM3. In comparison with the fully coupled control run, the heat flux-corrected run simulates a more realistic mean climate of not only the sea surface temperature (SST) but also wind stress and precipitation. Although the heat flux correction is time-independent, the annual cycles of SST, wind stress and precipitation over the equatorial eastern Pacific are more realistic in the flux-corrected simulation, suggesting that, superimposed on a better mean state, the ocean and atmosphere interact more realistically on seasonal time scales. Instead of a strong and regular biennial oscillation in the equatorial Pacific Ocean found in the control run, the equatorial Pacific variability is less regular and of a longer period in the heat flux-corrected simulation, which resembles more of the observed ENSO cycle. However, the amplitude of the model ENSO is more damped in the flux-corrected run.

Pan further examined the impact of the mean climate on ENSO prediction by performing a series of monthly hindcasts using CCSM3 with and without the heat flux correction from 1982 to 1998. The flux-corrected forecast shows slightly higher prediction skill in 7-9 month lead for the January forecast and 9-11 month lead for the July forecast. However, the differences are not significant at the 90% confidence level.

Objectives for the Coming Year

In the coming year, Pan will work with Bryan Duncan and others at NASA Goddard Space Flight Center to improve and evaluate the NASA Chemistry Climate Model (CCM). Pan will assist with the evaluation of the coupled chemistry and aerosols package and the interactive ocean through a number of sensitivity simulations. Her goal is to understand the impact of aerosols (direct and semi-direct effects) from biomass burning events on tropical dynamics, including the feedbacks from changes in SSTs.

Task 613-108-375: **The Impacts of absorbing aerosols on global and regional climates**

GEST Investigator: Cynthia Randles

Collaborators: Peter R. Colarco, Arlindo da Silva, and Bryan Duncan (GSFC 613.3); Huisheng Bian (GEST), Ravi Govindaraju (SSAI)

Description of Research

Tropospheric aerosols directly scatter and absorb incoming solar radiation; in doing so, they may also affect atmospheric stability (Hansen *et al.*, 1997; Johnson *et al.*, 2004) and the hydrologic cycle (Lau *et al.*, 2006; Chung *et al.*, 2002; Menon *et al.*, 2002). Depending on the aerosol composition, the vertical distribution of aerosol with respect to clouds (Haywood and Ramaswamy, 1998), and the underlying surface albedo (Chýlek and Coakley, 1974), aerosols may exert a radiative warming or cooling effect on the surface via the direct effect. Most general circulation models (GCMs) currently impose aerosol distributions calculated off-line. As a result, changes in model dynamics associated with the aerosol direct and semi-direct effects do not feedback on the aerosol forcing. In addition, modeled aerosol species typically exist as external mixtures, and aerosol microphysical interactions and their impacts on aerosol optics, forcing, and lifetime are not considered. Because regional circulation and precipitation patterns are particularly sensitive to aerosol absorption (Randles and Ramaswamy, 2008), GCMs need to account for interactions between aerosols and dynamics aerosol microphysics. Both of these capabilities are present in the GMAO's GEOS-5 atmospheric GCM.

Accomplishments during the Reporting Period

Fundamentally, the composition and size distribution of atmospheric aerosols determine their interaction with radiation. These aerosol properties are typically represented by a few key optical parameters. The aerosol extinction optical depth (AOD) is the sum of the aerosol scattering optical depth and absorption optical depth (AAOD), and the single scattering albedo (SSA) is the ratio of aerosol scattering to extinction. The growth factor *f(RH)* parameterizes the increase in extinction associated with growth due to water uptake by hygroscopic aerosols (Randles et al., 2004), and the asymmetry parameter (*g*) gives the directionality of scattered light. In addition to these optical parameters, the mass distribution of aerosols in the horizontal and vertical as a function of time must be known. Using the NASA GEOS-5 atmospheric GCM forced by prescribed, observed sea surface temperatures (SSTs), the sensitivity of the climate to forcing from on-line aerosols generated from the GOCART model is currently being investigated in GSFC's so-called Preliminary Integrated Earth System Analysis (PIESA) experiments. Randles and colleagues are first ascertaining the validity of on-line aerosol distributions through comparisons of present-day modeled and observed aerosol optical properties from NASA ground- and satellite-borne instruments. They are also assessing the impact of the model's dynamical feedback on the direct aerosol radiative forcing. The climate response to the associated changes in aerosol properties, particularly aerosol absorption, is being examined and compared to available measurements. They have presented preliminary results from the PIESA experiments at the 8th International AeroCom Meeting and the 2009 Fall AGU meeting.

Randles and her colleagues are also currently working on implementing a number of improvements to the representation of biomass burning processes in the GEOS-5 AGCM as part of their proposed Interdisciplinary Science (NASA IDS) proposal *"Biomass Burning and the Earth's Water and Energy Cycles: GEOS-5 Response to Satellite Derived Emissions"* (pending; Dr. Randles is Co-I). Examples of improvements to the biomass burning in GEOS-5 include implementation of a diurnal-cycle emissions scheme, use of a new emissions scheme based on MODIS Fire Radiative Energy (FRE), and introduction of a pyro-cumulus parameterization scheme to distribute emissions in the vertical. Once these improvements are made, Randles plans to evaluate the response of the GEOS-5 AGCM climate and hydrodynamics to biomass burning aerosol forcing as part of her NASA New Investigator Program (NIP) proposal *"Biomass Burning Aerosol Forcing and Feedbacks: Towards a better understanding of how aerosol absorption impacts the surface energy balance and the hydrologic cycle"* (pending; Dr. Randles is PI).

Efforts to improve aerosol source characterization and emission inventories (Chin *et al.*, 2002) have reduced differences between modeled and observed aerosol distributions;

however, assessment of the aerosol direct effect remains difficult due to assumptions of aerosol optical parameters and aerosol lifetimes (Kinne *et al.*, 2003). Implicit in the calculation of aerosol optical parameters, typically calculated off-line using Mie theory, are assumptions of aerosol size distribution and aerosol composition (viz. refractive indices). Such assumptions neglect aerosol microphysical interactions, such as condensation and coagulation, between multiple aerosol species and between aerosols and clouds. Interactions between aerosol species lead to internal mixing, which, for absorbing carbonaceous aerosols combined with scattering aerosols or water, can amplify aerosol absorption by a factor of two to three (Fuller *et al.*, 1999). Microphysical interactions may alter aerosol lifetime, due to wet and dry removal processes depending on the parameterization of these processes. Absorbing aerosols that interact with the hydrological cycle through the semi-direct effect may also impact aerosol lifetime by altering precipitation rates (Randles and Ramaswamy, 2008). Such changes in aerosol lifetime can have a significant impact on aerosol distributions and subsequent forcing. Randles and colleagues are planning to examine the impact of an aerosol microphysics scheme (CARMA), on the spatial and temporal evolution of aerosol optical properties and forcing in the NASA GEOS-5 GCM, with a special focus on the monsoon region in south Asia as part of their NASA MAP proposal *"Improvements in Aerosol Microphysics, Radiation, and Chemical Interaction in the GEOS Chemistry-Climate Model: Applications to Atmospheric Brown Clouds"* (funded; Dr. Randles is Co-I).

Objectives for the Coming Year

Randles and colleagues aim to improve estimates of the aerosol direct radiative forcing and to explore the sensitivity of the climate response to changes in carbonaceous aerosol absorption while explicitly accounting for interactions between aerosols and dynamics aerosol microphysics. Activities will focus on three areas, with specific attention paid to the direct effects of absorbing carbonaceous aerosols. They will first compare NASA observations of the spatial and temporal evolution of aerosol optical properties to model-derived aerosol optical properties obtained both with and without dynamical feedback in the NASA GEOS-5 atmospheric GCM. Special attention will focus on the evolution of aerosol forcing and response in the monsoon region of southern and eastern Asia, since Randles' previous research has shown that the monsoon circulation and precipitation is sensitive to the AAOD associated with carbonaceous aerosols (Randles and Ramaswamy, 2008). Next, they will examine changes in aerosol optical properties, forcing, and lifetime associated with the inclusion of an aerosol microphysics scheme (CARMA; (Toon *et al.*, 1988)) in GEOS-5. Comparing these results to observations will indicate if the microphysics scheme improves estimates of the aerosol direct effect. Finally, they will explore the impact of dynamical feedback and the aerosol microphysics scheme on the transport of anthropogenic carbonaceous aerosols and biomass burning aerosols. NASA field campaign observations will be used and remotely sensed observations will be made to assess the improvement in aerosol direct effect estimates.

Task 613-85-295: **EOS-Aura Instrumentation Validation and Support**

GEST Investigator: Christian Retscher

Collaborators: M. R. Schoeberl (GSFC 613.3), J. Gleason (GSFC 613.3), R. D. McPeters (GSFC 613.3), E. Celarier (GEST)

Description of Research

This task supports the validation efforts of the data products from atmospheric chemistry instruments onboard the EOS-Aura satellite. It includes the system's redesign, maintenance of the code base, as well as scientific data production. The Aura Validation Data Center (AVDC, http://avdc.gsfc.nasa.gov) provides a

central data archive, generating data subsets, collecting correlative data, and supporting the validation efforts of the Aura instrument teams, NRA investigators, and national and international ground-truth and satellite validation teams. A further part of the task is to support NASA aircraft and field campaigns by providing data.

Accomplishments during the Reporting Period

Most of the activities in this reporting period correspond to enhancing the functionality of AVDC and maintaining existing datasets and data reporting mechanisms. Retscher also continued to support the four Aura instrument teams by providing instrument data subsetting capabilities and field of view (FOV) prediction capabilities for campaigns and ground stations. In 2009, he also supported the Cabauw Intercomparison Campaign of Nitrogen Dioxide measuring Instruments (CINDI) and the Measurements of Humidity in the Atmosphere and Validation Experiments (MOHAVE) campaign.

New overpass data for the Aqua and Terra MODIS cloud product were incorporated into AVDC. Retscher has further investigated O_3 and NO_2 products from the GOME-2 sensor. Overpass data are made available through the AVDC website. The OMNO2 service was refined and GES-DISC has taken over the operational processing of datasets in 0.25x0.25 resolution while Retscher continued to investigate higher resolution data. Support for CO_2 data validation was continued.

Other activities comprise the maintenance and enhancement of the Generic Earth Observation Metadata Standard (GEOMS; former EVDC/AVDC meta-data standard). Templates for FTIR, MWR, balloon, and buoy data were refined. The DataCenter InterOperability (DCIO) initiative with main partners European Space Agency (ESA), Network for the Detection of Atmospheric Composition Change (NDACC) and involvement of European Aerosol Research LIDAR Network (EARLINET) and the World Meteorological Organization (WMO) has been further developed. Actual metadata and data exchange for Envisat and Aura validation is now in place with new centers to join in 2010. Rigorous intercomparison and validation of the A-Train data products are achieved through a joint effort in the collection and hosting of ground-truth data.

Objectives for the Coming Year

Retscher will maintain and expand the AVDC, and investigate support for NPP and Glory cal/val. He will continue with efforts for DCIO and GEOMS. With GEOMS, he plans to establish a long-term database for sonde, FTIR, MWR and LIDAR data in hierarchical data formats. Retscher will provide support for the further integration of UVVIS and Radio Occultation (RO) data and establish a collaboration with the Ground European Network for Earth Science Interoperations - Digital Repositories (GENESI-DR). He will work toward a major expansion of offered validation data sets from established data centers and new partners (*e.g.* aerosol research). Retscher will continue to enhance the OMNO2 service and review further parts of the production code, as well as provide further support to validation activities of CO_2 products.

Task 613-98-344: **Effects of Tropospheric and Stratospheric Composition on Climate**

Task 610-105-359: **Aura Validation**

US DOT Contract: **Modeling and observational studies of moisture in the upper troposphere and lower stratosphere and the climate effects of radiation (DTRT57-10-C-10017)**

GEST Investigator: Henry Selkirk

Co-Investigators: Lesley Ott (GEST), Craig Benson (GEST)

Collaborators: Richard Stolarski (PI, GSFC Code 613.3); Anne Douglass, Luke Oman, Steven Pawson (all GSFC Code 613)

Description of Research

This research is concerned with investigating the composition of the troposphere and stratosphere and its effects on chemistry and climate. It involves the development and testing of comprehensive models of the Earth system and their evaluation using measurement data, especially that taken by instruments on NASA satellite, aircraft and ground-based missions. In particular, this includes the carrying out of a continuing program of high-resolution balloonsonde measurements of water vapor and ozone in collaboration with Costa Rican scientists. Investigations are focused on the interplay of dynamical transport, chemical and radiative processes in the troposphere and stratosphere in the context of the NASA Goddard chemistry-climate model (GEOS CCM) that has now been coupled with the combined stratosphere-troposphere chemistry model (the GMI Combo). Of particular interest are the role of ozone and water vapor in the upper troposphere and lower stratosphere on climate and the effects of aviation in changing climate conditions in the coming decades.

Accomplishments during the Reporting Period

Under Task 344, Selkirk has been investigating the fine-scale vertical structure of ozone and water vapor in the upper troposphere and lower stratosphere in balloonsonde data and examining the vertical with kilometer-scale data from EOS satellite instruments as well as with output from the GEOS CCM and GMI models. The sonde data show copious supersaturation in the upper tropical tropopause layer in both the northern summer and winter as well as mixing of stratospheric levels of ozone.

Under Task 359, Selkirk has assumed management of the TICSONDE/SHADOZ project in Costa Rica under which monthly balloon soundings with the Cryogenic Frostpoint Hygrometer (CFH) instrument in a payload with an ECC ozonesonde are made. These soundings have been ongoing since 2005 and are a critical data source for validation of satellite water vapor in the tropics. The analysis of these data from NASA missions in 2005 and 2007 was the focus of a manuscript that Selkirk submitted in September to the special section of the *Journal of Geophysical Research* on the NASA TC4 mission. The paper, entitled “The detailed structure of the tropical upper troposphere and lower stratosphere as revealed by balloonsonde observations of water vapor, ozone, temperature and winds during the NASA TCSP and TC4 campaigns”, has been accepted pending minor revisions.

In October, Selkirk supported the CFH launch effort of Goddard colleague David Whiteman and his team in the Measurements of Humidity in the Atmosphere and Validation Experiments (MOHAVE) 2009 campaign at the JPL Table Mountain Facility in Wrightwood, CA. The goal of the campaign was a thorough evaluation of Raman lidar measurements of water vapor throughout the troposphere by comparing them to RS92 radiosonde and Cryogenic Frost-Point Hygrometers profiles.

Work under the DOT (ACCRI) task began January 1, 2010. The first task is to complete a 30-year time-slice integration of the most recent version of GEOS CCM; this will provide a baseline for studies of the climatic effects of aviation under ACCRI. An analysis of water vapor data from the MOZAIC program has begun with comparisons to MLS measurements and to CFH data.

Objectives for the Coming Year

The first objective is to complete the revisions on the manuscript accepted by *JGR*. The second objective is to continue analyzing the TTL structure of water vapor and ozone using the sonde data and to relate these results to the water vapor tape recorder and to the in-mixing of air into the tropics from the middle latitude. Third, Selkirk and colleagues aim to continue their sounding observations in Costa Rica on a regular basis. Fourth, under ACCRI, there are three primary objectives: to compute a moisture climatology for the baseline GEOS CCM, to examine the effect of 2006 aircraft emissions in the baseline model, and to make modifications to the GEOS CCM to improve the representation of water vapor and ice water in the upper troposphere and lower stratosphere where the air traffic is greatest.

Task 916-54-206: **The NASA Global Modeling Initiative (GMI) and Process-oriented Model Evaluation**

GEST Investigator: Susan Strahan

Collaborators: Jose Rodriguez (GSFC 613.3), Anne Douglass (GSFC 613.3)

Description of Research

The theme of this research is twofold: to use atmospheric observations to understand stratospheric transport and to apply that knowledge to critically evaluate transport characteristics of atmospheric models. Several new diagnostics of stratospheric transport were developed from observations of N_2O, CH_4, and 'mean age' (CO_2). The main focus of this research is to use both new and existing diagnostics to define a comprehensive set of transport diagnostics for both the tropics and extratropics, and then apply them quantitatively to 18 chemistry climate models (CCMS) participating in the World Meteorological Organization's (WMO) assessment of stratospheric ozone. The goal of the research is to identify which of the CCMs demonstrate the credibility necessary for predictions of future atmospheric composition. The results of the transport diagnostics are reported in the *SPARC CCMVal report*, to be published in 2010.

Accomplishments during the Reporting Period

Strahan is a Lead Author for the transport chapter of the 2010 SPARC report on chemistry climate model evaluation (Eyring *et al.*, in press). She is assisted by a co-Lead Author and a supporting team of 6 scientists from the U.S., Canada, the U.K., and New Zealand. The SPARC CCMVal report comprehensively evaluates stratospheric chemistry, dynamics, and radiation in 18 CCMs participating in the 2010 WMO ozone assessment. The conclusions published in this report will be used to reduce the uncertainty in model predictions of future ozone levels in the upcoming WMO ozone assessment.

This year's efforts were dominated by the development, refinement, and application of observationally derived transport diagnostics to participating CCMs. Wide ranging aspects of stratospheric transport (*e.g.*, tropical ascent, subtropical mixing, and polar vortex isolation) were objectively evaluated and quantitatively graded for 18 CCMs. The results of the model evaluations will be published as a chapter in the peer-reviewed CCMVal report; the report's final draft was recently submitted and will be published in 2010. Strahan is also a contributing author for the WMO 2010 assessment.

As GMI Project Manager, Strahan continues to oversee and evaluate new CTM simulations. GMI's main focus this year has been the use and evaluation of GEOS-5 assimilated meteorological fields into the GMI chemistry

transport model (CTM). Stratosphere-troposphere simulations using these GEOS-5.1 fields have been integrated for the recent past and are used by scientists at GSFC, Harvard University, NASA JPL, and other institutions to interpret satellite observations of trace species such as O_3, CO, and NO_2. An important aspect of this work is comparison with simulations that used different meteorological fields (*e.g.*, GEOS4-DAS) to determine which aspects of stratospheric transport are well or poorly represented by these fields. Areas of concern have been identified in GEOS-5 fields and investigations are continuing.

Other GMI work investigates a new modeling tool provided by the GMAO called 'Replay', which has the same scientific applications as the GMI CTM. Simulations using GEOS-5 met fields in the Replay model and the GMI CTM have been compared to determine each model's credibility in the troposphere and stratosphere. This work has verified Replay's ability to produce credible stratospheric transport; the tropospheric evaluation is not yet complete. This study has also revealed important differences in stratospheric residual circulation between different versions of GEOS-5; an investigation into the nature and causes of these differences continues.

Finally, a series of experiments using the GMI CTM is being integrated with the purpose of more accurately determining the ozone depletion potential (ODP) of various halocarbons and greenhouse gases. The results of these experiments are expected to provide necessary updates for international assessments predicting future atmospheric composition. Strahan also supervises Stephen Steenrod, a scientific programmer working on GMI model development and analysis. Strahan also manages new simulations through coordination with NASA SIVO computing manager, Dr. Gary Wojcik.

Objectives for the Coming Year

Climatologies of chlorofluorocarbons and long-lived trace gases from the ACE instrument on SCISAT-1 will be combined with results from the CCMVal transport chapter to determine empirical age spectra in the lower stratosphere. Transport pathways of young air appear to be crucial to chemistry climate model credibility.

The study of ozone depletion potentials will be completed and published.

Efforts will continue to identify the best modeling tool and best meteorological fields for simulations of the recent past. GMI will continue the evaluation of several new modeling tools, including a new advection core for the offline CTM and the online 'Replay'. New simulations will be evaluated relative to previous GMI simulations so performance differences can be understood. This work will also include evaluating transport characteristics of different versions of GEOS-5 meteorological fields.

Task 613-82-281: **Aerosol variability, an analysis with a global-regional atmospheric modeling system and ground-based observations**

GEST Investigator: Qian Tan

Collaborators: Mian Chin (PI, GSFC Code 613), Hongbin Yu (GEST), Huisheng Bian (GEST), Thomas Diehl (GEST), Georg Grell (NOAA), Tom Eck (GSFC 614), Alexander Smirnov (GEST), Ralph Kahn (GSFC 613)

Description of Research

Fine particulate matter (PM), or aerosols, is an important air pollutant, which can affect both air quality and climate on various scales. Aerosols and their precursors come from multiple sources, both natural and anthropogenic, and they undergo various chemical and physical processes within their life cycle. As a result, significant variability, both temporal and spatial, can be seen in aerosol distributions. Multiple tools have been developed to monitor and trace the cause of that variability. A 3D chemical transport model, together with ground-based and space-based measurement, greatly helps to

advance researchers' understanding of those complicated processes.

Accomplishments during the Reporting Period

Tan set up a ten-year aerosol simulation using a global aerosol model GOCART (Goddard Chemistry Aerosol Radiation and Transport model) with fine spatial resolution (1°x 1.25°). First, she diagnosed reasons for the simulated aerosol budget difference related to model spatial resolution and temporal resolution, and their sensitivities to the calling frequency of the physics and chemistry processes. She also applied the newly developed dust source map, which is based on satellite-observed NDVI (Zheng *et al.*, 2008, You *et al.*, 2009) in the simulation, with modifications to those of East Asia based on ground-based desert surveys. The results of this long-term simulation have been used in multiple analyses.

In order to support the planned future geostationary satellite mission, GEO-CAPE, the GEST investigator analyzed the diurnal variability of aerosols seen from existing observations. Because their emissions and the atmospheric physics and chemistry processes aerosols they undergo are highly variable, including both meteorological conditions and photo-chemical conditions, within a day aerosols often change significantly on scales less than one day. Since geostationary satellites will provide more frequent observations, it would be a great platform to monitor and trace the evolution of aerosols on finer temporal scales. Tan examined the aerosol diurnal variability from two ground-based aerosol monitoring networks, EPA's AIRNOW and NASA's AERONET, and found that over the North American continent the daily dispersion of the surface PM mixing ratio is about 120-150% of its daily mean, and daily dispersion of the column aerosol optical thickness (AOT) is ~60-90% of its daily mean. In terms of the standard deviation of daily observation, for surface PM mixing ration it is ~30-40% of the daily mean, and for AOT it is ~20% of the daily mean. There are significant differences among individual sites for both $PM_{2.5}$ surface mixing ratios and for column AOT. Aerosol optical thickness shows larger seasonal variations.

Tan also participated in a multi-group effort to develop a NASA-Unified WRF (Weather Research and Forecast) model. This interdisciplinary project aims to combine the expertise of scientists in the fields of hydrology, land surface characterizations, cloud microphysics, radiation, atmospheric chemistry, and meso-scale modeling to build a common platform using WRF, and apply this powerful tool to study the interactions of various atmospheric processes and hydrological cycles in very fine spatial resolutions. Tan tested the newer version of WRF-Chem-GOCART and changed its pre-process module to use a new biomass burning database to drive the model. GBBEP (GOES Biomass Burning Emissions Products) is an emissions inventory based on NOAA GOES satellite fire observations and real time fuel loading information from MODIS and AVHRR. GBBEP data have hourly temporal resolutions and provided important information to study the diurnal variation of aerosols.

Objectives for the Coming Year

Tan will continue to analyze the aerosol diurnal variability as seen in available observations and model simulations. She will further validate the WRF-Chem-GOCART model and help to set up links between aerosol module and land surface information systems. She will study the impact of more realistic land surface characterizations on the atmospheric aerosol simulations.

Task 613-98-343: **Integrated Modeling of Aerosol, Cloud, Precipitation and Land Processes at Satellite-Resolved Scales**

GEST Investigator: Zhining Tao

Collaborators: Christa Peters-Lidard (PI, GSFC 614), Wei-Kuo Tao (co-PI, GSFC 613), and Mian Chin, co-PI, GSFC 613)

Description of Research

Understanding transport and chemical/physical transformations of atmospheric trace species is essential to assess their effects on climate and air quality. Improving model representations of those processes will greatly enhance model forecast capability and provide better information to policy makers. Integrating satellite measurements into model development and evaluation provides promising means of improving model skills.

Accomplishments during the Reporting Period

Tao joined GEST in September 2009 after working for over five years at the Illinois State Water Survey of University of Illinois at Urbana-Champaign. Since then, WRF/Chem, an on-line regional weather forecast and chemical model, has been set up and tested on a NASA supercomputer for the North America domain, which covers the contiguous United States, northern Mexico, southern Canada, and parts of the Pacific, the Atlantic, and the Gulf of Mexico. The goal is to build up the modeling capability of chemical transport and transformation, and to provide a test base of an ongoing WRF/Chem modification project carried out at GSFC.

Objectives for the Coming Year

Tao's first objective for 2010-2011 is to improve the interfaces between WRF/Chem and other global and/or regional models, including but not limited to global chemical transport models and emissions process models. The applicability of the WRF/Chem model will then be extended to Asian areas to provide Tao with a better position when the opportunity arises. The second objective is to support the ongoing NASA-unified WRF project. The third objective is to seek ways to integrate the NASA satellite precipitation measurements into the National Atmospheric Deposition Program.

Task 910-00-008: **Assimilation Studies**

GEST Investigator: Clark Weaver

Collaborators: Arlindo da Silva (GSFC 610.1), Randy Kawa (GSFC 613.3), James Abshire (GSFC 554), Brent Holben (GSFC 614.4)

Description of Research

This task's goal is the development of an assimilation/retrieval system for atmospheric aerosols and CO_2. One effort is to reduce the uncertainty in measurements of the absorption of solar radiation by atmosphere aerosols. Satellite and ground-based instruments provide information on aerosol absorption, but under conditions of low aerosol loading absorption values are uncertain. A secondary effort on this task is the development of a separate algorithm that retrieves CO_2 column concentrations for a laser-sounder instrument. A third effort is to study how atmospheric aerosols contaminate retrievals of CO_2 from passive space-borne instruments, such as the GOSAT.

Accomplishments during the Reporting Period

Weaver has continued to refine his retrieval algorithm to accept almucantar and principal plane radiances from ground-based sky scanning instruments. This satellite/ground-based retrieval/assimilation system varies the particle index of refraction, mean radius, layer altitude and the particle shape. The algorithm solves for instrument biases and reduces the uncertainty in the retrieved aerosol single scattering albedo. Preliminary results from this new retrieval algorithm show slightly more absorption than the standard AERONET retrieved product.

Weaver has continued to refine a retrieval algorithm for aircraft and ground-based versions of a CO_2 laser sounder. Weaver provided almost on-time retrieval support for several Aircraft Campaigns during Summer 2009. The challenge for this algorithm is to separate the CO_2 signal from the instrument system response. Weaver was part of a successful proposal to obtain GOSAT satellite data from the Japan Space Agency.

Objectives for the Coming Year

In the coming year, the aerosol activities will focus on processing AERONET radiances at selected sites and comparing them with the standard AERONET retrieved products. A publication is planned.

For the 2009 CO_2 airborne campaign, Weaver will continue to refine the CO_2 laser retrieval algorithm and will complete a retrieval-related analysis of the measurements. For the upcoming 2010 CO_2 airborne campaigns, Weaver will participate in the measurements, and perform both quick look and detailed post-flight analyses.

Weaver plans to submit a proposal to analyze the GOSAT data. In addition, he is currently working with a group of scientists proposing a Martian orbiting satellite instrument to measure methane.

Task 614-69-240: **OMI Ozone Profile Algorithm Development**

NASA Grant: **NASA Volcanic Cloud Data for Aviation Hazards (NNS06AA05G)**

GEST Investigator: Kai Yang

Collaborators: Pawan K. Bhartia (PI, GSFC 613.3), Xiong Liu (GEST, now at Harvard Smithsonian), A. J. Krueger (PI, JCET), N.A. Krotkov (GEST), S. A. Carn (MTU)

Description of Research

Ozone (O_3) and sulfur dioxide (SO_2) are trace gases that have important effects on climate and air quality. The spatiotemporal distributions of these trace gases, which can be measured by space-borne ultraviolet (UV) instruments, provide essential information needed to monitor their changes over time and space, estimate their climate and pollution impacts, and understand the chemical and physical processes in the atmosphere. SO_2 is also a unique marker of explosively injected volcanic plumes, which pose a significant threat to aircraft. Tracking volcanic plumes in near-real-time provides critical information for aviation hazard mitigation. The GEST investigator has developed and implemented a number of techniques for accurate retrievals of O_3 and SO_2 from UV measurements simultaneously and for near-real-time mapping and tracking of volcanic eruption clouds. The main objective of this research is to improve O_3 and SO_2 retrievals by taking full advantage of hyper-spectral backscattered UV radiance measurements.

Accomplishments during the Reporting Period

In collaboration with Dr. Xiong Liu, Yang has implemented an advanced ozone profile algorithm and delivered it as an application (named PROFOZ) to OMI Data Processing System (OMIDAPS). PROFOZ algorithm performs spectral fitting of OMI radiance

measurements in the wavelength range 270 – 330 nm, and relies on an optimal estimation method to derive vertically resolved ozone columns over the globe. Successful PROFOZ retrievals not only yield accurate total ozone columns (equal to the sums of vertical profiles), but also the partitions of total columns between stratosphere and troposphere. Therefore, this product can be used for quantifying stratospheric ozone changes and tracking tropospheric ozone evolutions due to convection, biomass burning, pollution transport, and stratospheric intrusion.

Yang has conducted research on the physical mechanisms through which the vertical distribution of an SO_2 plume perturbs the solar backscattered UV radiance at the top of atmosphere. New insight gained from this research has resulted in a practical satellite retrieval technique, named Extended Iterative Spectral Fitting (EISF) algorithm, for the simultaneous retrieval of SO_2 plume height and amount. The EISF algorithm reduces systematic errors of previous satellite backscattered UV algorithms that rely on prescribed SO_2 vertical distribution and an assumption of linear backscattered UV response to SO_2 loading. Using OMI observations of recent eruptions as examples, Yang has demonstrated for the first time that a wide range of volcanic SO_2 plume altitudes (from lower troposphere to lower stratosphere) can be estimated directly from hyper-spectral backscattered UV measurements. These examples have also showed improvement of the retrieval accuracy of volcanic SO_2 columns, and that hyper-spectral measurements reduce the impact of measurement noise, leading to higher precision. Consequently, weaker SO_2 loadings, such as those from anthropogenic emissions and volcanic degassing, can now be more reliably detected and quantified.

Yang has demonstrated that the new UV Aerosol Index (AI) derived from the EISF algorithm provides a more reliable means for ash detection compared to the traditional ash detection using infrared satellite measurements. Weaker ash signals can be clearly detected with the new UV AI without many artifacts.

Objectives for the Coming Year

In the coming year, Yang will improve the PROFOZ algorithm by speeding up the processing, refining soft calibration, and introducing a new scheme for accounting for the Ring effect. Second, Yang will study the impacts of aerosol on EISF algorithm retrievals, and apply this algorithm to various volcanic events for estimated amounts of SO_2 emissions and their corresponding injection heights. Finally, Yang will work on improving retrievals of small SO_2 loading cases, such as SO_2 from volcanic degassing and anthropogenic emissions.

Task 916-21-144: **The Development of Tropospheric Ozone Data Products from Aura OMI/MLS and their Scientific Evaluation**

Task 916-43-181: **The Validation of Aura Ozone Measurements Using Cloud Slicing**

GEST Investigators: Jerry Ziemke and Sushil Chandra

Collaborators: P. K. Bhartia, Joanna Joiner, and Bryan N. Duncan (GSFC 613.3); Lucien Froidevaux (JPL, Pasadena, CA)

Description of Research

One of the goals of this research is to derive tropospheric ozone from OMI-only or combined OMI/MLS and provide the data to the public on the NASA GSFC Code 613.3 website. A second objective is the scientific evaluation of the data. Another objective is to update the NASA GSFC database of tropospheric ozone from 1979 to the present time by combining previous TOMS measurements with recent OMI data. The TOMS and OMI data are used to address many key questions ranging from the effects of regional pollution to trends and climate change issues, ENSO (*i.e.*, El Niño /La Niña) events, and shorter time-scale changes, including the Madden-Julian Oscillation.

Accomplishments during the Reporting Period

During this reporting period, ozone measurements from Aura OMI and MLS instruments were used to derive global measurements of tropospheric ozone on an almost continuous basis. This was accomplished using a residual method, which subtracted SCO (derived from MLS ozone profile data) from OMI total column ozone (Ziemke *et al.*, 2006). From the launch of the Aura spacecraft in July 2004 into 2010, there have been four ENSO events. One was a La Niña event (mid-2007 to May 2008) and three were El Niño events. One El Niño occurred in the latter half of 2004, a second in the latter half of 2006, and a third occurred in late 2009 into 2010. During this reporting period, Chandra and Ziemke have written several new refereed papers, including the first-ever satellite measurements of ozone inside deep convective clouds (Ziemke, *et al*., 2009), the 2006 El Niño event and effects on tropospheric ozone and carbon monoxide (Chandra *et al.* 2009), and recent biomass burning events in the tropics and their effects on tropospheric ozone and other pollutants (Ziemke *et al*., 2009). The OMI/MLS tropospheric ozone data products generated from their research have been made available to the public since March 2007. These represent both monthly means and daily along-track measurements for late October 2004-to-present with near global coverage for both datasets. These data are obtainable from the Code 613.3 tropospheric ozone webpage link from the TOMS homepage http://toms.gsfc.nasa.gov/.

Several past studies using balloon ozonesondes have shown exceedingly low to near-zero ozone in the tropical upper troposphere associated with the passing of deep convective clouds. (The first such study was Kley *et al.* 1996). Ziemke and Chandra, along with their research collaborators, have developed a way to measure ozone inside deep convective clouds in the tropics using OMI satellite ozone data. OMI is unique in doing this and yields a large database – the only other measurements of ozone inside thick convective clouds have come from a sparse number of aircraft flights, such as one DC8 flight during the TC4 campaign from Costa Rica in July-August 2007.

OMI measurements suggest that ozone concentration in deep convective clouds is largely caused by a vertical injection of boundary layer ozone. OMI measures near-zero ozone in thick clouds over the Pacific and Indian Oceans, whereas large ozone amounts are measured in thick clouds over the more polluted landmass regions, such as southern Africa and South America during the biomass burning season (centered around September-October each year). This is an ongoing and very important research project, which will spawn new studies involving cloud physics and photochemistry of ozone and other trace gases.

During this reporting period, the OMI/MLS data were also used to evaluate TCO from the GMI's CTM developed at GSFC (B. N. Duncan, NASA GSFC, personal communication). The model and measurements show similarities with respect to spatial distributions and seasonal cycle variations, yet there are notable differences, particularly in the northern hemisphere where the GMI model appears to over-prescribe the effects of STE of ozone from the stratosphere into the troposphere. However, both GMI model and OMI/MLS TCO often agree to within 1-2 DU on intra-seasonal to ENSO timescales. These similarities and differences between the GMI model and OMI/MLS are currently being further studied under joint collaboration.

Objectives for the Coming Year

Ziemke's and Chandra's objectives for the coming year are to provide continued validation and analysis of OMI/MLS tropospheric ozone data to characterize seasonal, intra-seasonal, and El Niño- related variability and to distribute the data to the community via the Goddard tropospheric ozone website. Along with their collaborators, they have established an important new method from OMI to measure ozone inside deep convective clouds. A part of the work in the coming year will involve the OMI in-cloud measurements. Another important part of their work will include the cross-evaluation of tropospheric ozone from the GMI CTM model and OMI/MLS data.

Hydrospheric and Biospheric Sciences (Code 614)

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Task 923-06-092: **Studies of Earth's Surface Interannual Variability Using data from Satellites and Distributed Ground Stations**

GEST Investigator: Assaf Anyamba

Collaborators: Compton J. Tucker (GIMMS - GSFC), Christopher O. Justice (University of Maryland College Park), Curt Reynolds (USDA/Office of Global Analysis – Foreign Agricultural Service), Kenneth Linthicum (USDA/Center for Medical, Agricultural & Veterinary Entomology) Clara Witt (Department of Defense - Global Emerging Infection Surveillance and Response System), Wendy Fanaselle, David Oryang (Food and Drug Administration), Rasmus Fensholt (University of Copenhagen, Denmark), Pierre Formenty (World Health Organization, Switzerland), Stephane De LaRocque (Food and Agricultural Organization of the United Nations (FAO)

Description of Research

The primary goal of the Global Inventory Modeling and Mapping Studies (GIMMS) group at NASA's Goddard Space Flight Center is to produce, provide and analyze scientific Earth systems research quality time series vegetation index measurement from a variety of satellite instruments including Advanced Very High Resolution Radiometer (1981- present), Systeme Probatoire pour l'Observation de la Terre - Vegetation (1998 - present) and the Moderate Resolution Imaging Spectroradiometer (2000 – present). Observations from these multiple instruments are utilized in a variety of scientific studies, including inter-annual climate variability associated with El Niño / Southern Oscillation (ENSO), long-term trends in global photosynthetic activity, desertification, deforestation and applied research and development in such fields as food security, vector-borne disease outbreaks, agricultural monitoring and agricultural pest outbreaks. In addition, GIMMS provides research development and applications support to governmental projects, government-sponsored agencies and non-profit organizations. The measurements from the above optical-based vegetation sensors instruments are coupled with other data sets, such as rainfall from Tropical Rainfall Monitoring Mission (TRMM), METEOSAT, global sea-surface temperature measurements (SST), outgoing long-wave radiation (OLR) and land surface temperature to validate and understand the observed land surface anomaly patterns and to determine the climate forcing on the vegetation dynamics. In addition, new remote sensing measurements from the Meteosat Second Generation (MSG) -- a geostationary satellite are being validated, to improve the quality of measurements for land surface studies. All of these measurements are employed to understand dry and wet cycles, examination of the relationships between ENSO and global vector-borne disease outbreak patterns and monitoring global agricultural regions.

Accomplishments during the Reporting Period

The transition from an El Niño event in 2006-2007 to a La Niña event in 2008-2009 of the ENSO cycle resulted in anomalous displacements of precipitation across the global tropics. These conditions resulted in different vegetation response patterns and, due to flooding, created ecological conditions for the reemergence of a Rift Valley fever (RVF) disease outbreak in Southern Africa in 2008 – 2009 following an epizootic/epidemic in East Africa in 2006 – 2007 (Anyamba, *et al.*, 2009). At the same time, drought prevailed in other regions of the world, including East Africa and Australia leading to shortfalls in agricultural production. Through satellite vegetation measurements over the last four years, consistent observations of the earth's biosphere have enabled Anyamba and researchers to understand better the impacts of ENSO – climate forcing on the variability and sensitivity of the photosynthetic capacity of different regions around the world. To complement measurements from polar-orbiting platforms, the GEST investigator carried out validations of MSG data from *in situ* measurements in Kenya and Senegal to show that the new generation of geostationary

remote sensing data can provide high temporal resolution cloud-free (< 5 days) measurements of the environment, which will enable rapid assessment of environmental conditions and natural resource applications. As a contribution toward global agricultural monitoring efforts, Anyamba and his colleagues set up a data processing system at GSFC to process MODIS data (Becker-Reshef, 2009), in addition to the process of developing a data system to produce a vegetation index time series from MetOp AVHRR sensor at 1km spatial resolution. All of these efforts will contribute toward NASA's mission in creating long-term climate data records for a variety of research and applications areas.

Objectives for the Coming Year

The first objective will be to finalize a review paper documenting the use of the AVHRR series of sensors in global drought mapping. Second, Anyamba will evaluate data sets from the new generation of the AVHRR instrument that he and his team plan to produce from MetOP. Third, he will evaluate the use of land surface temperature data from MODIS in drought mapping and vector borne disease studies. Lastly, other work will include the continuation of managing GIMMS contributions in support of operational MODIS for Agricultural production system for global agricultural monitoring and forecasting by the USDA Foreign Agricultural Service, and continued operational support to USAID/FEWSNET and DoD/GEIS program activities and Food and Drug Administrations pathogens risk assessment project.

Tasks 555-107-364: **Coordinating and Implementing NASA Global Water Cycle Research**

GEST Investigator: Deborah R. Belvedere

Collaborators: Robert Schiffer (GEST), Paul Houser (GMU), David Toll (GSFC, 614.3)

Description of Research

As a response to the emergence of cross-cutting water-cycle research initiatives brought forth by inter-agency and government-administrative science panels, this GEST task supports scientific collaboration and coordination for NASA's global water and energy cycle research.

In 2003, NASA established the NASA Energy and Water cycle Study (NEWS), whose long-term grand challenge is to document and enable improved, observationally based, predictions of water and energy cycle consequences of Earth system variability and change. However, recognizing that, the broad objectives of energy and water cycling related climate research extend well beyond the purview of any single agency or program, and call for the support of many activities that are matched to each agency's respective roles and missions. Therefore, to achieve the ultimate goal of credible global change predictions and applications across all significant scales, NASA continues to seek collaborations with other Federal and international agencies, the scientific community-at-large and private industry.

Accomplishments during the Reporting Period

Since the November 2008 NEWS annual team meeting, Belvedere and colleagues have been working on how to refine the NEWS' team approach to tackling integration. In response to comments voiced at the meeting, NEWS created a new structure that allows for consistency from existing NEWS activities, (a.k.a. conservation of scientific momentum), and at the same time welcomes the new NEWS PIs and their projects. To these ends, the project created four co-chair-led NEWS working groups that were developed off of all the projects and the previous NEWS question-based groups.

The primary responsibilities of the new working groups are to enhance the coordination and integration of the individual investigations across NEWS and to identify opportunities for exploiting relevant research outside NASA. The

December 2009 meeting (planned by Belvedere and collaborators) provided the first opportunity to test this strategy under which the working group co-chairs provided the necessary leadership.

The objective of the 2009 Science Team meeting was to become aware of project accomplishments, identify the integration needs and make the needed connections within four main working groups: Drought and Flood Extremes, Evaporation and Latent Heating, Water and Energy Cycle Climatology, and Modeling and Water Cycle Prediction. The principal goal of the working groups is to propose and implement the development of papers that integrate various NEWS research within the working group topic. To date, Belvedere and collaborators have participated in regularly scheduled teleconferences with all four working groups to ensure progress toward goals, provide collaboration/coordination support as needed, and respond regularly to Program Manager requests for highlights, presentations, or posters.

Objectives for the Coming Year

The primary goal for the upcoming year is for Belvedere to expand the scope, looking both inward and outward, to identify additional potential water and energy cycle connections. In addition the GEST investigator, collaborators and NASA Program Manager will meet to define the future strategy for NEWS, set goals and plan for implementation, provide NASA HQ with water and energy cycle focus area highlights, and organize and attend the next annual NEWS Science Team meeting.

Task 975-34-167: **Remote Sensing of Sea Surface Salinity from Space**

GEST Investigator: Paolo de Matthaeis

Collaborators: David M. Le Vine (PI, GSFC Code 614.6), Saji Abraham (RSIS), Emmanuel P. Dinnat (GEST), Daniel S. Jacob (GEST)

Description of Research

The work is done in support of the Aquarius mission, whose goal is to provide global sea surface salinity maps from space for the study of large-scale ocean processes and climate change. The Aquarius science instruments will include an L-band radiometer, whose received signal is sensitive to salinity, and a radar scatterometer that will help correct for the effect of the sea surface roughness. Models are being developed for both instruments to simulate their response to geophysical parameters of the ocean surface and atmosphere as aids in developing the science retrieval algorithm.

Accomplishments during the Reporting Period

Knowledge of water salinity and temperature is critical for understanding the ocean circulation and its effects on climate. While global measurements of sea surface temperature are routinely made from satellite sensors, no equivalent estimate of sea surface salinity from orbiting instruments is available yet. The Aquarius / Satélite de Aplicaciones Científicas - D (SAC-D) mission, developed by NASA in partnership with the Argentine Space Agency CONAE (Comisión Nacional de Actividades Espaciales) and scheduled for launch into orbit

in the coming months, has the objective of estimating the sea surface salinity based on the changes that it produces on the thermal emission from seawater.

Aquarius is a combination of two microwave instruments, a radiometer and a scatterometer. The primary science instrument is the radiometer, a set of three separate radiometers that operate in the radio astronomy window at 1.413 GHz (L-band). One major source of error in the retrieval of salinity from these measurements is ocean surface roughness due to the sea waves; to help with the correction of brightness temperature for roughness, a unique feature of the Aquarius instrument is the inclusion of the scatterometer. The scatterometer also operates at L-band, but at a slightly different frequency (1.26 GHz) than the radiometer, and shares the antenna feeds with it. The antenna is designed to produce scatterometer footprints that are nearly identical to those of the radiometer, and the timing is designed to produce measurements that are nearly simultaneous.

As part of the preparation for the Aquarius mission, a simulator is under development for the scatterometer instrument. This model reproduces the transformations encountered by the radar signal along its path from the transmitting antenna ports to the receiving antenna ports. The geophysical inputs to the model are sea surface salinity, sea surface temperature, surface wind speed, and the Faraday rotation of the electromagnetic field as it propagates through the ionosphere. Other auxiliary inputs needed for the simulation include the satellite orbit data. The wind speed is used to derive the surface roughness statistics, and from there the backscattering coefficient is determined by means of an electromagnetic model for scattering from ocean-like random rough surfaces. The backscattering of the radar signal is modeled using a two-scale approximation, according to which the scattering from the sea surface is found as the sum of two contributions, one coming from the large-scale waves, the other from the small-scale waves.

The scatterometer simulator considers effects such as the weighting of the received microwave radiation by the non-ideal antenna patterns, the Faraday rotation in the ionosphere, the attenuation due to the spreading of the electromagnetic wave and the coordinate rotation between polarization vectors in the antenna reference and in the local plane tangent to the Earth surface. A bias is introduced in the scatterometer-received power by the antenna patterns, the presence of the atmosphere, the receiver and transmitter bandwidth and the geometrical configuration and other factors. Such bias has been estimated under different wind speed conditions for each of the three antenna beams.

Work has also begun on developing an inverse model to estimate the ocean surface roughness and wind speed and use these results in the radiometer simulator. In this contest, it is essential to use a compatible approach in both radiometer and scatterometer inverse models. Starting with the radiometer model, a method for removing the effect of the antenna gain is under investigation. Once this has been achieved, a similar method will be used in the scatterometer model. The goal of this study is to find a suitable set of coefficients to use in the retrieval of the salinity from the Aquarius data. In particular, these coefficients are used to estimate (based on the measured antenna temperatures) the values of the surface brightness temperature at the beam center and its average over the resolution cell. These inversion coefficients depend on the Faraday rotation, the antenna gain, the sea surface temperature, the sea surface salinity and the wind speed. The effect of the satellite altitude over the Earth surface has been shown to be negligible. A few different methods are being considered to correct for the error introduced by Faraday rotation.

Objectives for the Coming Year

The development of the scatterometer simulator will be continued to include secondary effects, such as attenuation due to the atmosphere and the microwave emission from the surface. Further work will also be done to integrate the output from the scatterometer simulator with that from the radiometer simulator.

The estimation of the inversion coefficients for the radiometer model will be completed and a look-up table for the values of the inversion coefficients as a function of SST and SSS will be generated, and used as a first guess in an iterative algorithm. Subsequently, a sensitivity study will be carried out to investigate the instrument performance in the presence of various types of noise.

The development of an inverse model for the Aquarius scatterometer to estimate the ocean surface roughness and wind speed will follow. A set of inversion coefficients, analogous to those defined for the radiometer inverse model, will be defined and estimated in a range of different conditions of wind speed, sea surface salinity and sea surface temperature. The two models together will constitute the basis of an iterative inversion algorithm.

Task 612-76-263: **Remote Sensing of Sea Surface Salinity by Means of L-Band Radiometry**

GEST Investigator: Emmanuel P. Dinnat

Collaborators: David M. Le Vine (GSFC 614), Saji Abraham (Wyle Information Systems), Paolo de Matthaeis (GEST), Daniel Jacob (GEST)

Description of Research

Sea surface salinity (SSS) is a key factor influencing the oceanic circulation, but is not yet regularly monitored on a global scale. The Aquarius/SAC-D satellite (launch date: December 2010) will perform radiometric measurements at L-band (1.4 GHz) to provide global monthly fields of SSS. Retrieving SSS requires a challenging accuracy on the radiometric measurements and on their correction for unwanted influences from environmental parameters other than SSS. Dinnat's research focuses on the Aquarius simulator that models signals emitted from the Earth's surface and the celestial sky, and the processes affecting those signals up to the output of the antenna. Dinnat has previously investigated sources of errors on the accuracy of the retrieved salinity, due to unwanted signals from geophysical and celestial sources as well as instrumental effects. During the past year, Dinnat continued to develop the simulator by adding or improving components (*e.g.* geodetic transformation, computation of lookup tables). New simulator results regarding the third Stokes parameter and cold sky calibration have been analyzed and interpreted. The integration of the simulator in a retrieval assessment framework has begun.

Accomplishments during the Reporting Period

The Aquarius simulator involves complex computations of signals emitted all around the antenna and of the processes affecting them on the way to the antenna. Such complexities can result in significant computation time that reduces the practicality of the use of the simulator. Some of the complex computations are inevitable but others can benefit from simplifications. For example, the Sun glint is a second order source of error that is also mostly dependent on just a few variables, such as the local Sun elevation and wind speed in the main beam. Dinnat computed lookup tables of the Sun glint contamination as a function of wind speed and Sun directions that can be used to approximate the Sun glint contamination for the three Aquarius radiometers. The sampling of the lookup table has been set in order to satisfy an accuracy of the interpolations on the order of 0.01 K. The lookup table will be used by the Aquarius operational simulator and for data processing (implementation planned for mid-2010).

The simulator has been using the assumption of a spherical Earth in order to simplify most of the geometric computations, such as the projection of the antenna field of view on the Earth surface and the computation of the local incidence angles of the pixels in the FOV. This assumption is most likely not very problematic in many remote sensing applications. It should be noted

though that the SSS retrieval requires measurement accuracy of the order of 0.1 K and that many items of the error budget are in the sub-0.1 K range; therefore, a challenging new level of accuracy is required here. As an order of magnitude, a change in the local incidence angle of 0.1 deg induces a change of the order of 0.1 K. Dinnat and his collaborators also have shown that land surfaces induce a large contribution to the signal even hundreds of kilometers off the coast. Therefore, an accurate collocation of measurements and the coastline would be important for land signal detection and mitigation. An algorithm for computing the measurement geometry for an oblate spheroid Earth (*e.g.* according to the WGS-84 parameters) has been developed, and will be used to assess the impact of the Earth's changing curvature and derive appropriate correction if proven necessary.

During the computation of complete signal from the simulator, a new feature has been identified on the third Stokes parameters. It is already known that the land, ocean and ice have very different brightness temperatures in vertical (V) and horizontal (H) polarization. This results in steep transition of the measured signal at V or H polarization between two different levels when a transition between two surfaces is encountered. However, the behavior of the third Stokes parameter at these surface interfaces is different than the one of V and H polarizations. The signal exhibits spikes at the surface transitions that overshoot levels for both surfaces. Detailed analysis of the simulator results obtained under different test conditions (*e.g.* suppression of crosspol gain) showed that this behavior was due to both the existence of anti-symmetric crosspol gain and geometric polarization rotation. This analysis has been accepted for publication in *IEEE TGARS* and will be presented at the IGARSS 2010 conference and the Aquarius algorithm workshop in 2010.

The simulator has been used to identify appropriate times for a "cold sky" calibration of the Aquarius radiometers. During a cold sky calibration, the satellite is rotated so that the radiometers point toward the celestial sky instead of the Earth surface. The sky offers large regions of fairly uniform and known brightness temperature, which makes it a convenient target for instrument calibration. An analysis was performed to identify times during the Aquarius mission, satisfying a few requirements for a successful calibration. First, the cold sky area pointed at during the calibration mode has to be uniform. In addition, the portion of the signal coming from the Earth surface through the antenna back lobes has to be as small and stable as possible, and therefore has to have negligible land contaminations. Finally, the impact of the Sun and Moon would also have to be minimum. Regular periods of time satisfying these requirements have been documented for a full year. This study will be presented at the MicroRad 2010 conference.

Objectives for the Coming Year

The changing curvature of the Earth (oblate spheroid) will be assessed for its impact on the local incidence angle of the pixels inside the FOV, the localization of emission fronts (transition between land/sea/ice surfaces or geophysical fronts over a given surface) and its impact on the final signal and ability to retrieve SSS. If the impact is found to be noticeable, the use of approximations will be assessed. By the middle of 2010, the Aquarius simulator should be ready for operational real-time mode. Dinnat will deliver the necessary code and lookup tables to include the effects of Sun and Moon glint. Using the completed simulator, Dinnat will develop a SSS retrieval algorithm during Spring 2010. The radiometric measurements will be corrected for the effects of antenna patterns, contamination by land and ice surfaces, atmosphere, and such, using predicted impacts by the simulator. The scatterometer measurements will be used to derive a correction for roughness-induced signals (surface emissivity contrast, glint for galaxy, Sun and Moon).

Task 923-03-067: **AERONET Ground-Based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Thomas F. Eck

Collaborators: Brent N. Holben (GSFC 614.4)

Description of Research

The primary motivation to investigate the optical properties of atmospheric aerosols within AERONET is twofold: first, for application to study the effects of aerosols on the atmospheric radiation balance and climate second, for the validation of satellite retrievals of aerosol properties. This research is centered on the analysis of measurements made by automatic sun-sky scanning radiometers that are globally distributed as a part of the NASA-managed Aerosol Robotic Network (AERONET; project leader: Brent N. Holben, GSFC). The measurements of spectral direct sun intensity and sky radiance distributions are utilized to infer a complete description of the column integrated optical properties of the aerosols. These ground-based remote sensing retrievals of aerosol optical properties are analyzed to better understand the dynamics of aerosol properties as a function of source region, transport, aging processes, and interaction with clouds.

Accomplishments during the Reporting Period

The GEST investigator traveled to Linan City, China from August 15-22, 2009 to participate in the AERONET Network Sunphotometry Training workshop and Second International Conference of Aerosol Science and Global Change. Eck made presentations on operational AERONET calibrations and utilization of AERONET data for various analyses. He also conducted workshops on the Langley calibration of master reference instruments (on Mauna Loa data) and on the inter-calibration of field instruments against the master instruments.

Eck published a paper in the *Journal of Geophysical Research* in June 2009 titled "Optical properties of boreal region biomass burning aerosols in central Alaska and seasonal variation of aerosol optical depth at an Arctic coastal site", which focused on the analysis of data collected from the Bonanza Creek (BC) and Barrow AERONET sun/sky radiometer sites, both located in Alaska. Long-term monitoring of aerosol optical properties at a boreal forest site (BC) in interior Alaska was performed from 1994 -2008. Large inter-annual variability was observed, with some years showing near background AOD levels, while 2004 and 2005 had August monthly means that are similar in magnitude to peak months in major tropical biomass burning regions. Observed high single scattering albedos suggest a significant amount of smoldering phase combustion of woody fuels and peat/soil layers. AERONET monitoring at Barrow, Alaska (71^0 N) showed transport of biomass burning aerosols to the Arctic in summer resulting in individual events with AOD much higher than occur during spring Arctic haze.

Eck attended the Fall Meeting of AGU in San Francisco from December 13-17, 2009 and gave a presentation titled "Optical properties of fine/coarse mode aerosol mixtures". He showed examples of the retrieval of aerosol absorption (parameterized by the single scattering albedo (SSA) from AERONET retrievals and the change in SSA as fine mode fraction (FMF) changes.

Eck submitted a paper to the *Journal of Geophysical Research* on February 3, 2010 for review, titled "Climatological aspects of the optical properties of fine/coarse mode aerosol mixtures" by T. F. Eck and several co-authors. Aerosol mixtures composed of coarse mode desert dust combined with fine mode combustion generated aerosols (from fossil fuel and biomass burning sources) were investigated at three locations that are in and/or downwind of major global aerosol emission source regions. Multi-year monitoring data at AERONET sites in Beijing (central eastern China), Kanpur (Indo-

Gangetic Plain, northern India), and Ilorin (Nigeria, Sudanian zone of West Africa) were utilized to study the climatological characteristics of aerosol optical properties, especially absorption. Multi-year climatological averages of SSA versus FMF of aerosol optical depth at 675 nm at all three sites exhibited relatively linear trends up to ~50% FMF.

Eck collaborated with various researchers in the USA, India and Canada and co-authored four papers (published during the reporting period) on studies of boreal forest biomass burning aerosol optical properties, satellite retrievals of aerosol absorption, a database of AOD measurements taken from ships, and the global assessment of model computed aerosol optical properties.

Objectives for the Coming Year

A primary objective will be writing a paper for publication in the *Journal of Geophysical Research (JGR)* on the analysis of aerosol that has been processed by clouds or fog. Eck will analyze AOD spectra and AERONET almucantar retrievals from several years from the urban site of Kanpur, India (in the Ganges floodplain) where fog interacts with pollution aerosol primarily in the winter month of January. Additionally, data from Arica, Chile will also be analyzed to investigate the interaction between stratocumulus cloud and aerosol that is dominated by sulfates from regional copper smelting.

Another objective for the coming year is to participate in a workshop in Monterey, California from April 27-29, 2010 titled "Atmospheric Composition Forecasting Working Group: Aerosol Observability". Eck will represent the AERONET group and discuss data availability for verification and validation of the model forecasts.

Additionally, Eck will participate in executing a pilot study in the local region (Maryland and Virginia) in July-August 2010 to study spatial variance of aerosol and to collect data to enable improvements in satellite retrievals of AOD of land surfaces of variable spectral reflectance.

Task 971-20-137: **Aquarius Sea Surface Salinity**

GEST Investigator: S. Daniel Jacob

Collaborators: David LeVine (GSFC 614.6), Saji Abraham (RSIS), Emmanuel Dinnat (GEST), Paolo de Matthaeis (GEST), Richard Ray (GSFC 698.0), Brian Beckley (SGT), Richard Ullman (GSFC 586.0), and Yonsook Enloe (SGT)

Description of Research

The NASA Earth System Science Pathfinder (ESSP) Aquarius mission scheduled to launch in May 2010 will provide excellent spatial and temporal SSS coverage to better estimate the net transfer of water vapor from the ocean surface. At the Aquarius operating frequency of 1.4 GHz, sea surface emissivity depends on the SSS, temperature and roughness induced by the surface wind. Additionally, contribution from the sun, moon and galactic sources also affect Aquarius measurement. Therefore, a full forward model that quantifies these contributions is needed for the retrieval of SSS. As part of the Aquarius science team research, numerical simulations are conducted using a global ocean general circulation model. The second focus area with the NASA Standards Process Group (SPG) works toward standardizing data distribution and archival methods and protocols and to foster collaboration between the NASA and an inter-agency Integrated Ocean Observing Systems standards processes. A third focus area on the multi-mission ocean altimeter data for climate research seeks to provide research quality data with consistent corrections across various altimeter missions and to analyze the Argo profiling floats to quantify sea level change due to steric and mass components.

Accomplishments during the Reporting Period

The Aquarius salinity forward model has two components. The ocean component of the simulator is a primitive equation ocean general circulation model. A massively parallel version of the fully global hybrid coordinate ocean model coupled with an ice model (HYCOM) was implemented on the Goddard Discover super cluster at 0.72° horizontal resolution. The model set up during the last reporting period, relaxed to NCEP sea surface temperature provided surface salinity and temperatures starting in the early 90s to the present. In this reporting period, the model was relaxed to Argo near surface salinity from 2005 to part of 2008 to provide sea surface salinity data at 0.25° and 1° resolution to the Aquarius science team; additionally, upgrades were performed to the forward model. While the satellite attitude information was added to the simulator in the prior reporting period, the numerical error isolated was fixed in the simulator. Portions of the simulator code were completely rewritten to remove the numerical artifacts associated with the integration. Simulated brightness temperatures at the satellite along with the ancillary data were prepared for the algorithm development team to retrieve the input sea surface salinity for the years 2001 and 2007. In addition to the software update, the documents and flowcharts are also updated on a regular basis. All members of the Aquarius team at Goddard use this code and these documents.

The GEST investigator conducted an experiment using the NASA P3 aircraft in the Labrador Sea to assess the state of the ocean. Three different types of expendable probes were deployed which acquired data in the ocean extending up to a depth of 1500 m; these data then were reprocessed and analyzed to remove spurious data points. An inter-comparison with the Argo profiling float data confirmed that the expendable probes acquired good quality data. These results were compiled as part of a technical data report that will be released in the upcoming year.

In the second focus area, Jacob's work with the NASA SPG is continuing successfully. As part of this work, he is currently serving as the Technical Working Group (TWG) Chair and the Request for Comments document editor of two

standards candidates this year. He is also serving as a member of two other TWGs. The collaboration between the NASA SPG and the IOOS DMAC Standards Process continued in the past year. Other documents were also reviewed for the SPG.

In support of the project on altimeter ocean data records for climate, the Argo profiling float data were analyzed to estimate steric height contribution to the global sea level changes from 2003-2008. The analysis was extended to the end of 2009. To distribute the altimeter data record to the community, Jacob finalized the metadata fields and changed the data file structure from binary to NetCDF to improve interoperability.

Objectives for the Coming Year

The primary focus for the coming year is to further analyze the ocean model results to investigate the impact of surface forcing and mixing on the oceanic thermohaline circulation. High-resolution limited area domains in the Atlantic, Indian and Pacific near-equatorial ocean basins are also planned. A combination of *in situ*, remotely sensed, and numerical model results will be used in the analyses. Effort will also be extended to develop the procedure for retrieval of SSS. This approach will use the forward model simulated brightness temperatures and the ancillary data sets. Jacob will continue to improve the Aquarius forward model and simulate the total brightness temperatures at the satellite in relevance to the retrieval algorithm development. In addition, he and his team will further analyze the Labrador Sea data to understand the observed temperature, salinity and current structure, and will be related to climatological and other *in situ* observations. In particular, the GEST investigator will further research the large horizontal variability seen in the expendable profiler data.

The NASA SPG-related activities will continue in the next year with a specific focus on standardizing the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) file format and the Climate and Forecast (CF) metadata model. The rigorous collaboration established between the NASA SPG and IOOS DMAC will also be maintained following the steps outlined in the collaboration document.

Jacob will continue to contribute to making the ocean surface topography data from space-borne radar altimeter data available for research by providing expertise on the data and metadata standards and preparing the data for distribution by the data center. In addition, the Argo steric height analysis will be continued as more profiling float data becomes available.

Task 614-91-320: **Capacity Building Program**

GEST Investigator: Richard (Rick) Lawford

Collaborators: David Toll (NASA), Chu Ishida (Japanese Aerospace and Exploration Agency), Toshio Koike (Univ. of Tokyo), Avinash Tyagi (WMO), Einar-Arne Herland (European Space Agency), Jared Entin (NASA), Anna Medico (CONAE), Douglas Cripe (GEO Secretariat), Sushel Unninayar (GEST), Lawrence Friedl (NASA), Zhong-bo Su (ITC), Kenneth Korporal (Canadian GEO), Greg Withee (USGS), Jennifer Lewis (NOAA), Carrie Stokes (US Aid), Walter Baethgen (IRI), Ted Engman (NASA), Maria Donosco (UNESCO), Luis DeGoncalves (INPE), Angelica Gutierrez-Magness (Univ. of Maryland, College Park), Álvaro Soldano (CONAE), Cecille Blake (PM's Office, Jamaica), Hugo Higalgo (Costa Rica), Jorge Pachecol (CONIDA), Noel Trejos (CATHALAC, Panama), Rudolph Williams (Belize Meteorological Service), Jose-Alberto Soto (Columbia), Hugo Berbery (Univ. of Maryland, College Park), Venkat Lakshmi (North Carolina)

Description of Research

This project is working toward the initiation of a capacity building program to develop tools for using Earth observation data in support of water management and to show the value of Earth observations in water resource management. The geographical focus for this program is Latin and Caribbean Americas. Linkages with existing efforts of members (Nations) and participating organizations in the Group on Earth Observations (GEO) will be essential components of the resulting program.

Accomplishments during the Reporting Period

Building upon an April 2008 agreement reached with representatives from US GEO and Canadian GEO to include this initiative under the emerging GEOSS in the Americas program, efforts in 2009 were focused on preparing for a large workshop on capacity building in the water sector. During 2009, Lawford committed a substantial part of his time for this task to organizing a workshop in Lima, Peru. He established a workshop committee, chaired a number of committee teleconference calls and negotiated travel support for workshop attendees with NOAA, NASA, Canada GEO (Environment Canada), CONIDA and UNESCO. It also led in the identification of speakers and the preparation and distribution of invitations. Approximately 60 people from more than15 countries in Latin and Caribbean Americas attended the workshop in December 2009. As evident in the list of conference presentations (*see Appendices at end of annual report*), Lawford gave several overviews and summary talks at the workshop. The workshop discussions resulted in a number of recommendations that are now being pursued by a working group that was formed by experts who participated in the workshop.

Additionally Lawford gathered information from agencies around the world who were working in Latin and Caribbean America in order to update the GEO Task sheet for Task WA-06-07a, which deals with Capacity Building for water management in the region. He also presented and discussed the progress on this activity at a number of international meetings as well as provided inputs to presentations given by others and to NASA information updates. The level of effort for this activity in 2009 was 0.15 FTE.

Objectives for the Coming Year

During the coming year, efforts will be directed toward a follow-up to the GEO Capacity Building meeting in South or Central America in order to document the information needs of water resource managers in Latin America, to summarize the services currently available in Latin America, and to initiate steps for building a sustained capacity development activity in the region. As a first step, a report for the Lima workshop will be compiled. In addition, approval is being sought for the follow-on working group to be recognized under GEOSS in the Americas as a permanent working group or Community of Practice.

Based on inputs received at this workshop, a GEOSS in the Americas Water Resources Capacity Building plan will be advanced. In addition, the activity will support the development and management of GEO Water Cycle Community of Practice and to the GEO Water SBA activities.

This task will expand to include other requirements in the coming year, such as the development of plans for an Evapotranspiration workshop and a white paper for NASA activities in international science and applications related to water resource management. In order to maintain progress on this task and to expand into other areas, the level of effort may need to be increased in FY 10-11.

Task 975-32-159: **Application of Air/Space-borne Radar to Atmospheric Remote Sensing**

GEST Investigator: Liang Liao

Collaborators: Robert Meneghini (GSFC, Code 613.1)

Description of Research

Simulations of dual-wavelength radar profiles in precipitating hydrometeors are essential to improve the accuracy of space-borne radar in inferring microphysical properties of hydrometeors. The validation of radar measurements and their algorithms for estimates of rain rate is also important to ensure the success of radar in mapping precipitation globally, such as TRMM PR and GPM DPR. This is usually achieved by employing the data taken from the instruments mounted on different platforms and comparing their common products. In addition, some fundamental studies are useful to understand radar scattering and propagation effects, which include computations of scattering fields from non-spherical and non-homogeneous particles, and effective dielectric constant of mixed-phase particles.

Accomplishments during the Reporting Period

Measurements and Simulations of X- and W-Band Radar Bright Band

In simulating the X- and W-band radar returns within the melting layer, a stratified-sphere model is used to describe the non-uniformly melting of single snowflakes during their descent through the 0^0 isotherm. With the use of the stratified-sphere particle model, the fractional water content is conveniently expressed as a function of the particle radius. As a result, the melting process, which starts at the snow surface and progresses to the center, can be realistically modeled. In each layer of the stratified sphere, the fractional water content is constant but is allowed to change from layer to layer. The effective dielectric constant in the layer of interest is computed by the CGFFT numerical method in accordance with its specified fractional water content. Expressing the fractional water content as an exponential function in particle radius, and using the Yokoyama and Tanaka melting layer model, the radar bright-band profiles are simulated and subsequently compared to the X- and W-band Doppler radar measurements. While excellent agreement is found at X-band, persistent offsets exist between the model and measured results at W-band. These offsets, however, can be reasonably explained by the attenuation caused by cloud water and water vapor at W-band. This is confirmed by the comparisons of the radar profiles made in the rain regions where the unattenuated W-band reflectivity profiles can be estimated through the X- and W-band Doppler velocity measurements. Additionally, the simulated unattenuated rain profiles at W-band agree well with those from the retrieval of the Doppler measurements. Despite the difficulty in describing microphysical properties of hydrometeors in the melting layer, Liao's simulations of the radar bright band made at X- and W-bands appear to be fairly accurate and suggest the usefulness of the stratified-sphere scattering model as well as the effective dielectric constants derived from mixed-phase particle realizations. The bright-band model developed through this study has the potential to be used effectively for both radar and radiometer algorithms relevant to the TRMM and GPM satellite missions.

Study on Feasibility of Dual-Wavelength Radar for Identification of Hydrometeor Phases

To develop an algorithm for the Ku- and Ka-band dual-wavelength spaceborne radar for the identification of hydrometeor phase state, such as snow, melting snow (mixed-phase) and water, the GEST researchers start with model simulations that are focused on snow and rain. As the rain and snow particle size distributions can be described by an exponential function, theoretical computations of the radar signatures at Ku- and Ka-bands are performed using both a constant snow density (invariant with particle size) and variable snow density (size dependent); note, snow and rain can usually be

clearly distinguished. The data taken from the NASA JPL APR-2 Ku- and Ka-band airborne radar during the Wakasa Bay experiment are employed to check the model simulations and also to assess the feasibility of the dual-wavelength radar technique for the identification of hydrometeor phase. Having superimposed the data collected in stratiform rain onto the theoretical computations, the GEST investigator found that the radar measurements are generally consistent with the model simulations for snow and rain. When compared with measurements, better agreement is obtained using fixed snow density than variable snow density. An analysis of the two-dimensional PDF from snow, rain and mixed-phase data indicates that snow can be easily distinguished from rain and mixed-phase hydrometeors if the radar reflectivity factor at Ku-band is greater than 18 dBZ; rain, however, is not always separable from mixed-phase data. In stratiform rain, the region of overlap occurs at ranges near the lower boundary of the melting layer where the snow melting is nearly complete. Apart from this overlap region, the separation between the regions of rain and mixed phases appears feasible. To develop a fully functional radar algorithm, an investigation is needed into an optimal selection of the radar parameters that effectively separates different phase regions. To achieve this, a further study will be undertaken, which will include an analysis of dual-wavelength radar measurements and the model computations under various microphysical conditions, as well as an exploration of convective storm in which an obvious bright-band is absent. The development of an effective dual-wavelength method to distinguish the rain, snow and mixed-phase hydrometeors will be an important step toward an accurate, efficient DPR profiling algorithm.

Scattering Computation of Snow Aggregates
Liao investigated the effective dielectric constant and scattering properties of snow aggregates produced by the developed ice crystal growth model. The model-generated snowflakes are able to replicate most of the observed snow-crystal morphology. They, however, appear in highly complicated shapes and structures that require a fairly large amount of pixels (or cells) in order to compute their scattering parameters and effective dielectric constants. To fulfill this study, the CGFFT computation will be carried out by using the NASA supercomputer system (http://www.nccs.nasa.gov).

Objectives for the Coming Year

Liao will continue his research on a variety of topics associated with airborne and space-borne weather radar analysis generally and the TRMM Precipitation Radar (PR) and GPM Dual-Wavelength Precipitation Radar specifically. The work will include single- and dual-wavelength radar analysis of hydrometeor profiles, simulation of polarimetric radar signatures in rain and snow, retrieval of the microphysical properties and characteristic parameters of drop size distribution using data from dual-wavelength airborne weather radar, and the validation of the TRMM standard products using ground-based measurements.

Task 923-32-162: **Development of Atmospheric Correction Algorithm for MODIS, and Algorithm Analysis for Land Surface and Atmospheric Products for VIIRS**

GEST Investigator: Alexei Lyapustin

Collaborators: Yujie Wang (GEST)

Description of Research

Lyapustin's main objective is to develop an advanced algorithm for simultaneous retrievals of aerosol properties and surface bidirectional reflectance from EOS MODIS imaging spectrometer.

The contemporary paradigm of remote sensing from the whisk-broom low-orbit sensors (AVHRR, MODIS etc.) is pixel-based and relies

on a single-orbit data. It produces a single measurement for every pixel characterized by two main unknowns, AOT and surface reflectance. This lack of information constitutes a fundamental problem of the remote sensing which cannot be solved without either *a priori* assumptions, *e.g.* about spectral regression coefficients for the Dark Target method (Levy *et al*., 2007; Vermote and Kotchenova, 2008), or ancillary data, such as a global surface reflectance database for the Deep Blue method (Hsu *et al.*, 2004). The approximate nature of these *a priori* constraints and use of common simplifications in the radiative transfer model, such as the Lambertian model of surface reflectance, limit the accuracy and/or applicability of the current operational aerosol/atmospheric correction algorithms.

Accomplishments during the Reporting Period

Lyapustin and Wang have developed a new Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm for MODIS (Lyapustin and Wang, 2009). It uses a time-series approach and image-based (rather than pixel-based) processing to perform simultaneous retrievals of atmospheric aerosols and surface spectral bi-directional reflectance/albedo without empirical assumptions typical of current operational algorithms. The new algorithm is generic and works over vegetated regions of the Earth as well as over bright deserts. The aerosol retrievals are performed at a high-resolution of 1 km, which is highly requested in different science and application disciplines, such as Air Quality/Urban Pollution. In snow-covered regions, MAIAC provides an estimate of the snow grain size and sub-pixel snow fraction. MAIAC has an advanced cloud mask (CM) and an internal dynamic land-water-snow classification, which helps an algorithm to choose a processing path in changing conditions. MAIAC has been extensively tested on the local and regional scales.

Objectives for the Coming Year

Supported by NASA EOS and GOES-R grant funding, the researchers' effort will be focused on the following tasks. First, they plan to resolve remaining algorithm issues, namely implementing retrievals over inland water bodies and coastal regions; adding full polarization correction; finalizing global aerosol climatology for operational processing; and removing relatively small but systematic aerosol retrieval biases over bright surfaces. They will develop an operational version of MAIAC compatible with MODIS Adaptive Processing System (MODAPS) and demonstrate operational feasibility of algorithm. MAIAC products will be validated, and aerosol validation will continue based on AERONET data. Surface reflectance/albedo will be validated with AERONET-based Surface Reflectance Validation Network (ASRVN) data record, and available ground measurements (through established collaborations with groups of N. Coops and T. Hilker (Canada), A. Gitelson (Nebraska), E. Dutton (SurfRad) and others). They will also perform an operational evaluation of MAIAC in MODAPS and conduct a systematic comparison study of MAIAC and MOD09/MCD43 surface reflectance products, as well as adapt *MAIAC* for geostationary GOES imager.

Task 974-52-200: **NASA Energy and Water Cycle Study (NEWS) Science Integration Team (NSIT), and the International Global Energy and Water Experiment (GEWEX)**

GEST Investigator: Robert A. Schiffer

Description of Research

In 2003, NASA established the NASA Energy and Water-cycle Study (NEWS), whose long-term grand challenge is to document and enable improved, observationally based, predictions of water and energy cycle consequences of Earth system variability and change. NEWS serves as the primary interface and liaison with other NASA water and energy cycle related system components, and is charged with integrating the results of the NEWS investigations within the overall NASA Earth Science Program. However, recognizing that, the broad objectives of energy and water cycling-related climate research extend well beyond the purview of any single agency or program, and call for the support of many activities that are matched to each agency's respective roles and missions. Therefore, to achieve the ultimate goal of credible global change predictions and applications across all significant scales, NEWS continues to seek collaborations with other Federal and international agencies, the scientific community-at-large and private industry. The NASA Associate Administrator for Earth Science appointed Schiffer as a charter member of the NEWS Science Integration Team with responsibilities for scientific planning and programmatics.

WaterNet, which serves as an Applications node for NEWS, is intended to improve and optimize the sustained ability of water cycle researchers, stakeholders, organizations and networks to interact and harness and extend NASA research results to augment decision support tools and meet national needs. Schiffer's Co-I responsibilities focused on aviation-related applications. WaterNet was concluded in 2009, and a final report will be issued in 2010.

The International GEWEX Project Office (IGPO) was established in 1990 in response to a request from the World Meteorological Organization (WMO) to the United States to support an international project office in Washington, D.C. for the World Climate Research Programme's (WCRP) Global Energy and Water Cycle Experiment (GEWEX). The key role of the IGPO is to provide focus for the scientific direction of GEWEX with the senior level leadership and staff necessary to integrate the efforts of the numerous participating scientists. Through a well-structured organization with the strategic planning and a milestone driven roadmap, the international funding agencies can have confidence in the contributions of GEWEX to climate research. Schiffer's support to the Global Energy and Water Experiment (GEWEX) consists of scientific and administrative activities aimed at enhancing efficiencies of national and international participation in myriad field campaigns and global data acquisition efforts.

Accomplishments during the Reporting Period

Several specific NEWS activities were undertaken by Schiffer, such as assisting in the overall project's scientific and implementation planning and management, particularly developing and updating the Science Implementation Plan. Schiffer's specific accomplishments include a leadership role in the development of a phased research program exploiting current capabilities, integrating improvements in the observation-prediction system, and leading to a comprehensive end-to-end water cycle prediction system; providing external international coordination linkages with relevant activities including the WCRP Global Energy and Water Cycle Experiment (GEWEX), the Integrated Global Water Cycle Observations (IGWCO) theme of the Integrated Global

Observing Strategy (IGOS), and the Global Earth Observation System of Systems (GEOSS); assisting in developing performance metrics for evaluating scientific progress and reporting project accomplishments; supporting monitoring ongoing NEWS scientific investigations by serving as a designated point of contact for the project with selected investigators; and, contributing to research solicitation development and proposal review processes, including his participation as a member of NEWS peer review panels. Schiffer plays the central role in updating NEWS scientific requirements, coordinating the peer review process for selecting additional NEWS investigations, and serving as a principal editor of the NEWS Implementation Plan.

Throughout 2009, the NEWS project has been working on how to refine a team approach to tackling integration. In response to science community feedback, NEWS is attempting to create a structure that allows for consistency from existing NEWS activities, and at the same time welcomes the new NEWS PIs and their projects. To these ends, the project created four NEWS working groups that build off all the projects and the previous NEWS question-based groups. The principle objective of the 2009 Science Team meeting, held in December, was to become aware of project accomplishments, identify the integration needs and make the needed connections within four main working groups: Drought and Flood Extremes; Evaporation and Latent Heating; Water and Energy Cycle Climatology; Modeling and Water Cycle Prediction. Two co-chairs for each working group have been selected to lead these efforts. To be successful, the NEWS team must partner and coordinate with water & energy cycle research and application activities going on at other organizations within NASA, nationally, and internationally.

During 2009, Schiffer assisted the IGPO by preparing a new proposal to NASA, which was subsequently approved as a new 5-year task under the UMBC/NASA Cooperative Agreement.

Objectives for the Coming Year

Schiffer's primary NEWS objectives include assisting NASA Headquarters in formulating a new Integration/Management model for NEWS Implementation. The Implementation strategy will reflect recent NASA programmatic decisions that are forcing reconsideration of the timeline for achieving the long-term NEWS goal of documenting and enabling improved observation-based predictions of the water and energy cycle consequences of Earth system variability and change. Emphasis will be on community-wide integration of science results.

The principal goal of the new working groups will be to propose and implement the development of scientific papers that integrate various NEWS research within the working group topic. The working groups are expected to coordinate and integrate NEWS PI science investigations, to liaison with relevant flight missions and NASA Research and Analysis Programs, to implement an annual assessment of progress in meeting NEWS scientific requirements, and to contribute to periodic Implementation Plan (IP) updates. In addition the working groups are encouraged to promote/lead integrated scientific journal publications, to prepare annual progress summaries, and to conduct regularly scheduled teleconferences. The working groups are encouraged to assist in planning and organizing annual Science Team meetings and sessions at national meetings (*e.g.* AMS, AGU). In support of these working groups, the project planned the annual NEWS meeting around the working groups, with significant science discussion breakouts.

In 2010, particular emphasis will be given to resolving issues including working group restructuring (recognizing the central role of modeling), project management and working group leadership arrangements (post NSIT), setting research priorities for future proposal solicitations, exploring opportunities for expanded interagency/international coordination, participating in future NASA hydro-meteorological relevant flight missions, and assessing progress in meeting NEWS IP Phase-1 objectives.

Schiffer will continue to provide scientific and administrative support to the International GEWEX project, and assist in planning and coordinating the 2nd Pan-GEWEX Meeting to be held in Seattle, Washington in August 2010. He will provide support to Panels in implementing the Hydrologic Applications Project (HAP) and CEOP Phase II and LandFlux, implement the GEWEX Roadmap with respect to the WCRP Implementation Document and the conclusions from the Legacy document, and support GEWEX Extremes activities. He will also coordinate WCRP monsoon research (with CLIVAR) and WCRP extremes research (with CLIVAR, US CLIVAR), as well as strengthen agency support for GEWEX; and provide support to GEO and IGWCO as required.

Task 614-90-316 **Earth Science Data Records of Global Forest Cover Change**

GEST Investigators: Joseph Sexton, John Townshend (PI)

Collaborators: Jeff Masek, Robert Wolfe, Bin Tan, Feng Gao, Eric Brown de Coulston, Doug Morton, Greg Ederer (all of GSFC 614); John Townshend, Chengquan Huang, Saurabh Channan, Raghu Narasimhan, Eric Vermote, Kwan Song, and Do-Hyung Kim (all of UMD); Dean Urban, Jennifer Swenson, and Alex Pfaff (all of Duke University); Conghe Song and Todd BenDor (both of University of North Carolina); Dalia Amor and Fernando Colchero (both of Max Planck Demographic Institute, Germany), Cesar Delgado (CESEL Ingenieros, Peru), James Westervelt (U.S. Army Corps of Engineers), Rebecca Bartel (University of Georgia).

Description of Research

Sexton's research focuses on analyzing ecosystem dynamics in space and time, and more immediately, creating the datasets needed to do so. This includes converting decades of satellite images into time-serial maps of forest and other "land-cover" types as well as using air- and space-borne laser and radar technology to map vertical forest structure over large areas. These maps are used for studying and managing a wide and increasing array of ecosystem services, including watershed health, biodiversity, and carbon sequestration.

Accomplishments during the Reporting Period

After completing his doctoral degree in Ecology at Duke University in April 2009, Sexton began his employment with GEST in June 2009. His accomplishments were thus heavily weighted toward publishing his dissertation research and other standing projects while he shifted his focus onto specifically GEST-related research. In early 2009, two of his papers were published (Sexton *et al.*, 2009, Whitehurst *et al.*, 2009), which described forest structural measurement and land-cover change analysis methodologies for his future work with GEST. These were followed later in the year by a paper describing the application of his multi-temporal image processing methods to monitoring the habitat of an endangered butterfly over 25 years of ecosystem change. During FY 09-10, he and coauthors also prepared and submitted a paper describing the application of these methods to urban growth modeling; this paper has been accepted for publication (BenDor *et al.*, in press). Three other papers, all in review, are expected to be published in FY 10-11.

This wide range of topics opened many opportunities for service as a peer reviewer. During the past year, Sexton reviewed papers for the following journals: *Remote Sensing of Environment, Canadian Journal of Remote Sensing, Remote Sensing, Biological Conservation,* and *Journal of Biogeography*.

Sexton's principal project with GEST has been the Global Forest Cover Change (GFCC) Project, under the NASA program "Making Earth Science Data Records for Use in Research Environments" (MEaSUREs). This project will use satellite images from 1975, 1990, 2000, and 2005 to monitor forest cover change between those times, over entire surface of the Earth, and at 30-meter horizontal resolution (90-meter resolution in 1975). On this project, Sexton began in the role of developing the accuracy assessment methodology and later moved toward greater responsibility and oversight of the scientific underpinnings of the methodology.

Sexton is also collaborating on a project studying biome boundary shifts in response to decadal-scale changes in temperature and precipitation.

Objectives for the Coming Year

Sexton will complete the transition from dissertation-related to GEST projects during the coming year. His first responsibility will be to edit and write the GFCC project's Algorithm Theoretical Basis Document, the primary documentation for the project and the basis for the project's review by NASA experts. His own initiatives include expanding the community of those responsible for "training" the GFCC and other land-cover classifications from its current fragmented and local configuration outward to a web-based consortium of local experts; increasing the accessibility of Landsat data by developing a meta-database documenting the >6-million-image archive of images held by the US Geological Survey; and, piloting early applications of multi-temporal land-cover datasets, including a novel chronosequence approach for predicting the potential carbon sequestration capacity of large landscapes based on remotely sensed data.

Task 974-44-184: **Evaluation and Correction of Satellite-based Precipitation Measurements for LIS and AFWA**

GEST Investigator: Yudong Tian

Collaborators: Christa Peters-Lidard (co-PI, GSFC 614.3), John E. Eylander (AFWA), Robert Adler (UMCP)

Description of Research

For many applications, a better understanding of the error characteristics in precipitation measurements and forecasts is critical, such as flood monitoring and early warning, water resource management, agriculture and climate change. Tian's current research examines and documents a wide range of precipitation measurements and forecasts, including those from ground-based, satellite-based and numerical weather prediction (NWP) models. He also studies the impact of the errors on flood forecasts, and devises approaches to correct or reduce errors in precipitation estimates or forecasts.

Accomplishments during the Reporting Period

For satellite-based precipitation estimates, Tian and colleagues have developed an error decomposition scheme to separate errors in precipitation estimates into three independent components: hit biases, missed precipitation and false precipitation. This decomposition scheme reveals more error features and provides a better link to the error sources than conventional analysis, because in the latter these error components tend to cancel one another when aggregated or averaged in space or time. The scheme is validated with ground-based CPC gauge and Stage IV radar data, and applied to five leading satellite-based precipitation datasets: AFWA, TMPA/3B42, TMPA/3B42RT, CMORPH and PERSIANN.

Their analysis reveals that all three products detected strong precipitation (> 40 mm/day) well, but with various biases. The products tend

to over-estimate in summer and under-estimate in winter, plus they missed a significant amount of light precipitation (< 10 mm/day). They also found that hit biases and missed precipitation are the two leading error sources. In summer, positive hit biases dominate the total errors, especially for CMORPH and PERSIANN. The gauge correction used in TMPA/3B42 greatly reduced the hit biases and false precipitation. Also, in winter, missed precipitation over mountainous regions and the Northeast, presumably snowfall, poses a common challenge to all five datasets. Over the Rocky Mountains, for example, winter misses contribute to 100% of the total under-estimate biases.

More recently, Tian and colleagues have collaborated with scientists in Japan to study a newer satellite-based dataset called GSMaP, where the new CPC unified gauge analysis is used as the reference data. The evaluation shows that GSMaP does well in capturing the spatial patterns of precipitation, especially for summer, and that it has better estimation of precipitation amounts over the eastern than over the western CONUS. Meanwhile, GSMaP shares many of the challenges common to other satellite-based products, including underestimates in winter and overestimates in summer. In winter, GSMaP has on average 50% less precipitation over the western and 33% less over the eastern continent, whereas in summer it has about 75% and 25% more estimated precipitation over the two respective regions. Most of the summer overestimates (winter underestimates) are from an excessive (insufficient) number of strong events (> 20 mm/day).

Finally, Tian and colleagues have developed and tested a new approach to reduce biases in satellite-based estimates in real time. Currently, satellite-based precipitation estimates exhibit considerable biases, and there have been many efforts to reduce these biases by merging surface gauge measurements with satellite-based estimates. Most of these efforts require timely availability of surface gauge measurements. The newly proposed approach does not require gauge measurements in real-time; instead, the Bayesian logic is used to establish a statistical relationship between satellite estimates and gauge measurements from recent historical data. This relationship is then applied to real-time satellite estimates when gauge data are not yet available. This new scheme was tested over the U. S. with six years of precipitation estimates from two real-time satellite products and a gauge analysis dataset. The first four-year period was used as the training period to establish a satellite-gauge relationship, which was then applied to the last two years as the correction period, during which gauge data were withheld for training but only used for evaluation. This approach showed satellite biases were reduced by 70-100% for the summers in the correction period.

For precipitation forecasts from numerical weather prediction (NWP) models, the GEST investigator has evaluated the skills and errors of precipitation forecasts from NASA's GEOS5 model against the satellite-based, gauge-corrected precipitation estimates, TMPA 3B42, over the land surface. GEOS5, among other NWP models such as ECMWF and GFS, is shown to have the lowest biases in precipitation. Still, GEOS5 systematically over-estimates global precipitation by approximately 50%.

Objectives for the Coming Year

Along with NOAA CPC scientists, Tian will work on integrating new methods to blend remotely sensed precipitation observations with surface gauge-based precipitation measurements to create an improved analysis of precipitation in near real-time. In addition, he will implement and evaluate new methods to utilize regional and global precipitation climatologies for interpolating *in situ* surface precipitation measurements in orographic regions to further improve AFWA's precipitation analysis.

To reduce the errors in NWP precipitation and their impacts, Tian has explored various correction schemes on GEOS5 forecasts. He will implement his findings to adjust the intensity distribution of the global precipitation field to match that of the satellite-based observations, either globally or regionally, to support applications in early flood warning.

Task 923-32-162: **Validate MODIS Surface reflectance product with ASRVN system and Algorithm Analysis for Land Surface and Atmosphere products**

GEST Investigator: Yujie Wang

Collaborators: Alexei Lyapustin (Sponsor)

Description of Research

The main objective of Wang's research is two-fold: first, to produce a well-calibrated long-term surface reflectance data record around available AERONET stations for the algorithm analysis and product validation (ASRNV dataset); second, to analyze and validate the newly developed Multi-Angle Implementation of Atmospheric Correction (*MAIAC*) algorithm.

The AERONET-based Surface Reflectance Validation Network (ASRVN) has been in development for the past six years. An operational processing system, ASRVN receives MODIS TERRA and AQUA data from MODAPS and MISR data from NASA Langley for AERONET locations, and AERONET aerosol and water vapor data. It then performs an accurate automated atmospheric correction, creating individual sensor records of surface bidirectional reflectance. Spectral surface BRF and albedo are primary ASRVN products generated in gridded format at a resolution of 1 km for the areas of 50×50 km^2 for over 100 AERONET stations globally.

The contemporary paradigm of atmospheric correction algorithms developed for instruments such as MODIS and AVHRR are pixel-based and depend on only single-orbit data. It produces a single measurement for every pixel characterized by two main unknowns, AOT and BRF, which raises a fundamental concern: the remote sensing problem cannot be solved without either *a priori* assumptions or ancillary data. These *priori* constraints are approximate, and limit the accuracy and/or applicability of the current operational aerosol/atmospheric correction algorithms. On the contrary, the *MAIAC* algorithm is an algorithm for simultaneous retrieval of the aerosol optical thickness and surface bidirectional reflectance from MODIS. It uses the time-series of gridded, geo-located and calibrated L1B MODIS measurements, and an image-based (rather than pixel-based) processing. If the researchers consider that the surface changes much slower than measurement frequency and the AOT varies over a rather large scale, the number of measurements will be more than the number of unknowns, which becomes a solvable problem.

Accomplishments during the Reporting Period

In the year 2009, the investigator's effort, in collaboration with Dr. Lyapustin, was mainly focused on three objectives: further improvement of ASRVN algorithm; testing and analyzing MAIAC algorithm components including cloud mask algorithm, aerosol retrieval, and atmospheric correction; and validating MODIS surface reflectance with the ASRVN system.

Wang continuously has worked on improving the quality of the ASRVN dataset by filtering noise from residual clouds and spatially variable aerosols. An image-based algorithm has been implemented to identify surface reflectance retrievals with high noise. A new HDRF product has been added to the ASRVN product list.

The MAIAC algorithm is being extensively tested. Wang has performed a large-scale test of the MAIAC algorithm over different locations such as Africa, the Arab peninsula, Northwestern America, and the Amazon area. Wang also worked on the algorithm testing on the continental level. Preliminary continental US BRF, aerosol and cloud mask products have been created. Through the collaboration with USDA forest service, he has also migrated MAIAC algorithm to the USDA MODIS direct readout system for air quality monitoring.

Wang also conducted an intensive comparison of ASRVN products with MODIS surface reflectance (MOD09) and surface BRDF (MCD43) products. He found that uncompensated atmospheric scattering caused by the Lambertian model used in the MODIS surface atmospheric correction algorithm systematically biases the retrieved surface reflectance. The magnitude of biases grows with the amount of scattering in the atmosphere, *i.e.* at shorter wavelengths and at higher aerosol concentration. This error propagates into the MODIS BRDF/albedo algorithm, slightly reducing the magnitude of overall reflectance and anisotropy of BRDF, and results in a small negative bias of spectral surface albedo. An assessment for the GSFC (Greenbelt, USA) validation site shows the albedo reduction by 0.004 in the near infrared, 0.005 in the red, and 0.008 in the green MODIS bands.

Objectives for the Coming Year

Wang's and Lyapustin's objectives for the coming year include developing an operational version of MAIAC compatible with MODIS Adaptive Processing System (MODAPS) and demonstrating the operational feasibility of algorithm, as well as validating MAIAC products. Aerosol validation will continue based on AERONET data. Surface reflectance/albedo will be validated with AERONET-based Surface Reflectance Validation Network (ASRVN) data record and with available ground measurements (through established collaboration with groups of N. Coops and T. Hilker (Canada), A. Gitelson (Nebraska), E. Dutton (SurfRad) and others). They will also perform an operational evaluation of MAIAC in MODAPS and conduct a systematic comparison study of MAIAC and MOD09/MCD43 surface reflectance products.

Task 614-73-251: **Provide Analysis of Synthetic Aperture Radar data of Antarctic and Greenland for Glaciological Research**

GEST Investigator: Boris S. Yurchak

Collaborators: Waleed Abdalati (PI, CIRES, Colorado University)

Description of Research

Changes in snow, firn, and ice characteristics near the marginal zones of the Greenland Ice Sheet (GrIS) are indicative of variations in mass balance under conditions of climate change. To examine this variability, Yurchak and Abdalati apply cross-correlation analysis of the RadarSat-1 SAR data acquired at the end of 1997 and 2007 ablation seasons to the marginal zones of Northwest Greenland with the aim of determining the displacement pattern of the snow cover due to the a shift in the equilibrium (or snow) line elevation. Usually, the cross-correlation technique (*e.g.*, Scambos *et al.*, 1992) is used to assess glacier movement by tracking the displacement of slowly varying features in the glacier surface. In this case, they apply the cross-correlation technique not to detect the physical movement of snow and ice, but rather to identify a geographic shift in metamorphic processes as expressed in SAR backscatter characteristics. The origin of snow backscatter change due to the metamorphic processes was interpreted in terms of the developed enhanced semi-empirical model (ESEM) (Yurchak, 2009a), which exploits the so-called "slice" approach and takes into account the changes of statistical characteristics of the snow microstructure under snow densification.

The current research is focused on grounding the methodology of the interpretation of radar signatures from the thick snow based on the 'slice" approach and determining the areas within the GrIS impacted with metamorphic processes.

Accomplishments during the Reporting Period

The spatial-ordered SAR backscatter displacement pattern has been found within Hayes Peninsula hilly area in the northwest part of the GrIS. The displacement pattern has been compared with the ICESat-derived Digital

Elevation Model of Greenland (DEM) of the area selected. Yurchak and Abdalati find that the pattern has corresponded to relief features in the elevation data. A complementary analysis of the so-called normalized Snow Depth (nSD) field, retrieved from SAR backscatter data for November 1997 and 2007, also indicates this similar shift in metamorphism pattern. The nSD technique exploits the fact that, for areas where the snow depth is less than the penetration depth and yet is still significant to produce notable volume backscatter, the return signal is sensitive to changes in the snow microstructure profiles. They have found that nSD "displacement" is also related to relief features as well. The backscatter field displacement obtained from the cross-correlation analysis and nSD displacements are consistent with one another, and they demonstrate "movement" mainly uphill. This movement is not a physical movement of the firn, but rather an up-slope propagation of the metamorphic processes, as the snow line has risen and temperatures have increased.

In accordance with the ESEM, the backscatter from snow is governed not only by particle size distribution function but also the fluctuations of particle concentration and their sizes at scales much less than the radar wavelength. This contribution is described by the deviation factor, which is the function of particle number fluctuation and particle size variation coefficient. The researchers found that the observable backscatter features are caused by snow metamorphism, which is characterized by the densification of the firn. This process is accompanied with increasing the density of snow (Li *et al.*, 2007). In turn, the snow density fluctuations at centimeter scales decrease with the increasing mean density (*e.g.*, Gow, 1968), an that results in the fading of the particle concentration variation. As a consequence, the backscatter and nSD are diminished also in areas impacted by the metamorphic process.

Results of these estimations have been presented at the AGU 2009 meeting (Yurchak and Abdalati, 2009). Thus, the joint analysis of SAR data in conjunction with the elevation data of Greenland's marginal hill areas can improve the understanding of the cause of the snow metamorphism and provide insight into critical climate change features in remote Arctic regions.

Methodological questions regarding the radar sounding of thick snow cover, which have not been analyzed in literature, are considered in (Yurchak, 2009b). In particular, the condition of complete burial of the probing radar pulse into snow medium, the assessment of volume component of the backscatter coefficient including the concept of the normalized snow depth, the enhanced semi-empirical model of the volume component of the backscatter coefficient based on the "slice" approach, and the spectral model of the backscatter have been considered.

Objectives for the Coming Year

The main objective will be the comparison of radar data obtained on the margins of the GrIS and other sites with thick snow cover with the available *in situ* data about snow characteristics to continue the improvement of the ESEM for a more detailed interpretation of the radar backscatter over selected areas within the coastal zone of the GrIS. A specific objective is the focusing of the "slice" approach on the layered feature of the GrIS snow cover.

Task 900-37-172: **Implementation of the algorithm to derive the fraction of PAR absorbed by chlorophyll ($FAPAR_{chl}$) and leaf water content (LWC) for MODIS, EO-1 Hyperion and HyspIRI images**

GEST Investigator: Qingyuan Zhang

Collaborators: Elizabeth Middleton (GSFC, Code 614.4), Hank Margolis (Université Laval, Canada)

Description of Research

In this project, Zhang applies the two new algorithms for MODIS, Hyperion and HyspIRI, respectively. First, he applies the algorithms for 500m MODIS images (MOD09A1 and MYD09A1) to get 500m $FAPAR_{chl}$ and LWC for selected CO_2 flux tower sites. Zhang atmospherically corrects the L1R Hyperion images to get hyper-spectral surface reflectance product, and then spectrally combines the bands to get 30m MODIS-spectral-like images. He uses the algorithms for the 30m images and gets $FAPAR_{chl}$ and LWC products. Zhang conducts prototype studies for HyspIRI, and he uses the 30m L1R Hyperion images to scale up and get 60m HyspIRI-spatial-like images. He atmospherically corrects the L1R 60 m HyspIRI-like images to get the hyper-spectral surface reflectance HyspIRI product, and then spectrally combines the bands to get 60m MODIS-spectral-like images. Finally, Zhang uses the algorithms for the 60m images, resulting in $FAPAR_{chl}$ and LWC products.

Accomplishments during the Reporting Period

The MODerate Resolution Imaging Spectroradiometer (MODIS) has seven (of 36) spectral bands for land study: red (620–670 nm, band 1), blue (459–479 nm, band 3), green (545–565 nm, band 4), near infrared (NIR_1, 841–875 nm, band 2; and NIR_2, 1230–1250 nm, band 5), and the short-wave infrared ($SWIR_1$, 1628–1652 nm, band 6; and $SWIR_2$, 2105–2155 nm, band 7). Zhang has developed a method to derive $FAPAR_{chl}$ and LWC products using MODIS 8-day composite reflectance products (MOD09A1 and MYD09A1), a coupled canopy-stem-leaf-soil radiative transfer model and a Markov Chain Monte Carlo (MCMC) approach. The $FAPAR_{chl}$ product was first validated for the Southern Old Aspen site in Canada. Zhang combined five years of flux, meteorological, and MODIS-derived $FAPAR_{chl}$ from the tower site. $APAR_{chl}$ and $APAR_{canopy}$ were computed by linking $FAPAR_{chl}$, $FAPAR_{canopy}$ and flux tower based incident PAR. He found that LUE_{chl} matched well with LUE_{tower} both at magnitude and at phase, while LUE_{canopy} did not, which is a very important finding for global carbon cycle studies. Using $FAPAR_{chl}$ and LUE_{chl} to estimate terrestrial GPP will significantly improve the accuracy of estimated GPP.

The MODIS-based $FAPAR_{chl}$ and LWC algorithms are also used for other flux tower sites for algorithm tests. The algorithms use a more realistic model of canopy optical characteristics, provide output of a frequency of distribution of the fourteen variables, utilize all seven MODIS land bands (the existing product only uses two bands), provide a direct measure of uncertainty, explicitly handle variability in view/sun angles, and provide an improved estimate of GPP, with a much higher spatial resolution using direct measurements and is physically based. The MODIS $FAPAR_{chl}$ and LWC products will be tested and validated against the tower flux measurements.

Zhang developed algorithms for EO-1 Hyperion images; note, the EO-1 Hyperion is the only available hyperspectral sensor in space. He used the Atmosphere Removal Algorithm (ATREM) to atmospherically correct Hyperion L1R images, spectrally combined the Hyperion bands, and gets seven MODIS-like spectral bands. He then applies the algorithms for the 30m MODIS-spectral-like images. He has also

applied the algorithms for the Harvard Forest in MA and the Douglas-Fir site in Canada.

Zhang also began a prototype study of $FAPAR_{chl}$ and LWC for the HyspIRI mission by using Hyperion images as a base to simulate the VISIR part of HyspIRI to obtain 60m hyperspectral images, atmospherically correcting the 60m images, and applying the $FAPAR_{chl}$ and LWC algorithms for the 60m images.

Objectives for the Coming Year

Zhang's first objective is to draft manuscripts to publish the results of $FAPAR_{chl}$ and LWC of the MODIS, Hyperion and HyspIRI images. The second objective is to write a proposal in response to NASA's "Terra and Aqua Science" to suggest the $FAPAR_{chl}$ product be a new MODIS product, to promote usage by the whole community. His third objective is to write a proposal in response to NASA's "Remote Sensing Theory" regarding the studies of the theoretic advances of the $FAPAR_{chl}$ and LWC algorithms. Zhang's fourth objective is to expand the applications of the $FAPAR_{chl}$ and LWC algorithms to field–acquired measurements from 2008 at the USDA cornfield.

Heliophysics Division, Solar System Exploration Division
(Code 660-699)

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GEST Highlight: Operation Ice Bridge Flies the Crane Glacier

Christopher Shuman

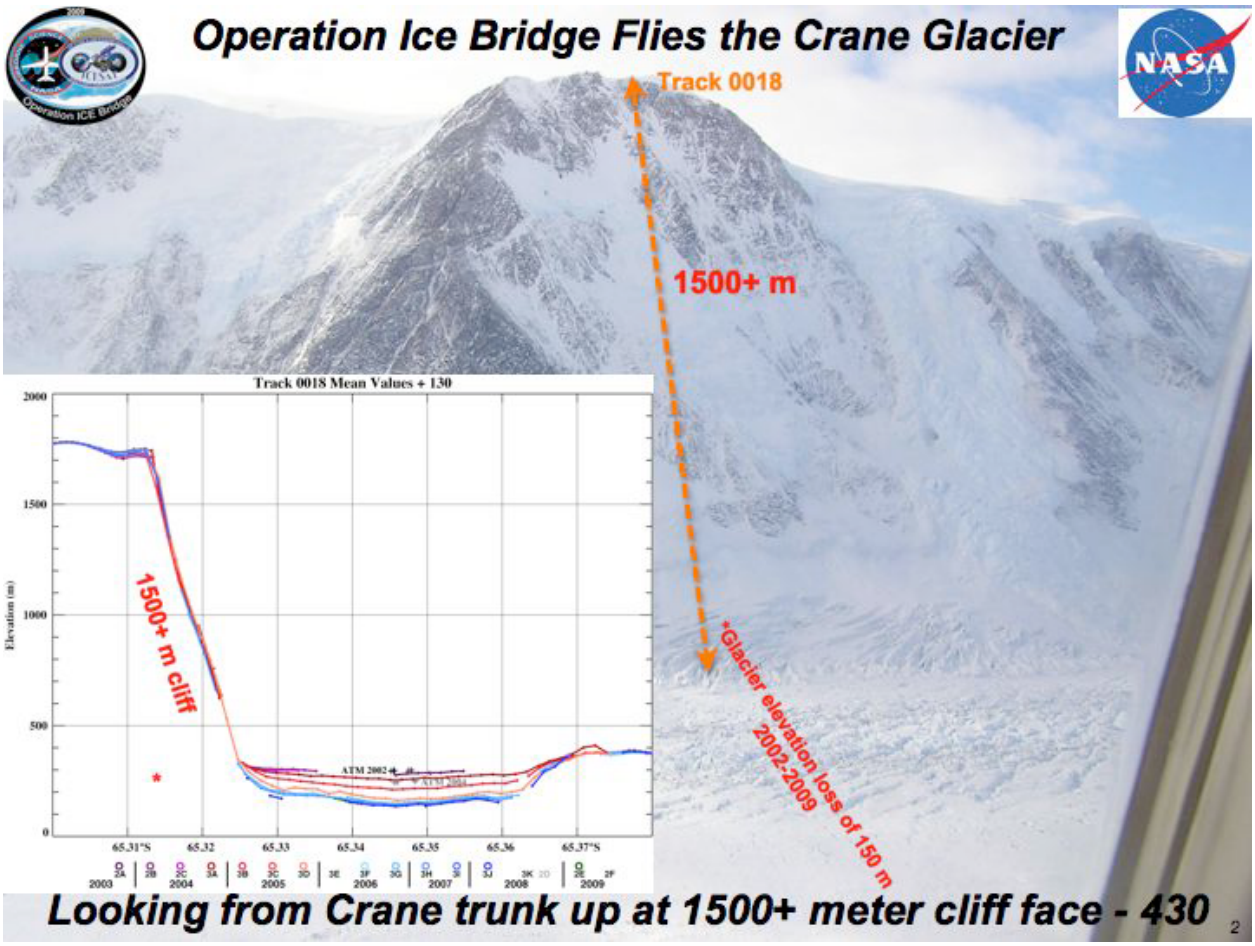

Figure: Operation Ice Bridge flights on the NASA DC-8 aircraft from Punta Arenas, Chile, are enabling continued collection of altimetry data along the Crane Glacier and over other areas of the Antarctic Peninsula and the West Antarctic coastline. Since the breakup of the nearby Larsen B Ice Shelf in early 2002, elevation losses exceeding 150 m have been documented adjacent to this impressive cliff face by a combination of Ice, Cloud, and land Elevation Satellite (ICESat) and Airborne Topographic Mapper (ATM) elevation data (*see inset*). This long-range flight profiled the Crane Glacier including its large southern branch on October 31, 2009.

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Task 699-71-247: **Numerical Modeling of Planetary Magnetospheres and Exospheres**

GEST Investigator: Mehdi Benna

Collaborators: Paul. R. Mahaffy (GSFC 699), Wayne T. Kasprzak (GSFC 699), James A. Slavin (GSFC 670), Menelaos Sarantos (GEST/UMBC), Edward Settler Jr. (GSFC 673)

Description of Research

This research aims to better understand the magnetospheres of the planets and the small bodies of the solar system and to improve spaceborne mass-spectrometry instruments used to study these environments. On the scientific level, the magnetosphere of Mercury and its interaction with the solar wind was studied using a new numerical model. The resulting predictions of this model were used to help understand the data returned by the MESSENGER spacecraft during its first two flybys of Mercury. This model is also being utilized to study the atmosphere of Enceladus and support the CASSINI mission. On the technical level, substantial progress was made in the modeling and design of the LADEE-NMS and the MAVEN-NGIMS mass-spectrometers. Progress was also made on the Simulator for the Sample Analysis at Mars Instrument (SAM). This simulator will serve as a science-planning tool during SAM operations on Mars and will allow the science team to optimize the use of all the capabilities of this complex instrument.

Accomplishments during the Reporting Period

This research is multidisciplinary and combines both scientific and technical skills. During the reporting period, Benna focused on modeling the magnetospheres of planets and icy moons, which are the target of most of the planetary missions. The objective was to help understand, through these models, the environments where spaceborne mass-spectrometers operate, and thus, to provide a better theoretical background for the interpretation of the collected data. Benna also focused on studying new designs to improve the performance of quadrupole and Time-of-Flight mass-spectrometers (QMS) and their dependent systems. This class of mass-spectrometers has always been a cornerstone of major space missions (Giotto, Contour, Nozomi, Cassini, MSL, etc.).

On the scientific level, the GEST investigator completed the validation of the new advanced magnetohydrodynamic (MHD) model MESS-3D that simulates the magnetosphere of Mercury and its interaction with the solar wind. His involvement with the MESSENGER mission as participating scientist allowed him to use this model to study in more detail the magnetospheric data obtained during the spacecraft’s two flybys of Mercury, January 14 and October 6, 2008. The results showed a good agreement between the models and the data collected by the MESSENGER magnetometer (MAG) and the ion spectrometer (FIPS) for the spatial variation of a variety of parameters (density, velocity, and temperatures of ions).

Benna extended these models to study the interaction between the atmosphere of Enceladus and the magnetosphere of Saturn. The resulting model (ENCAM-3D) is being validated in order to investigate more precisely the structure of Enceladus' tenuous atmosphere in light of recent data recorded by several CASSINI instruments. The initial results of this research led him to confirm the hypothesis that a neutral plume emission from the southern polar terrain of the moon is the source of the density peaks detected by the Ion Neutral Mass spectrometer (INMS) and the Dust analyzer (CDA) instruments.

On the technical level, the GEST investigator supported the design and fabrication phases of the LADEE-NMS and the MAVEN-NGIMS mass-spectrometers by providing an end-to-end ion-optics model of both instruments. These models were critical in providing input and guidance during the mechanical and electrical

designs. These models will also be used during the calibration and testing phases. Benna also made substantial progress in the design and validation of the SAM Instrument Simulator (SAMSIM). This Simulator can generate thermal, power and gas flow analysis and will serve as a science-planning tool during the instrument operations on Mars. This tool is currently being validated in conjunction with the instrument testing and calibration phase. Additionally, Benna is involved in designing two new-generation mass spectrometers. The first instrument, led by Dr. Edward Sittler, Jr. (NASA-GSFC), is an ion-neutral 3D Time-of-Flight mass spectrometer tailored to determine the astrobiological potential of Europa. The second instrument, led by Thomas Zurbuchen (University of Michigan), is an improved design of Quadrupole Mass-Spectrometers (QMS) that uses a novel operational mode to obtain improved isotopic measurements over a larger mass range with high-heritage sensors.

Objectives for the Coming Year

On the scientific level, Benna will continue supporting the MESSENGER mission and will provide magnetospheric models of Mercury to plan the orbit insertion in March 2011. He will also use these models to help extract a better estimation of the intrinsic magnetic field for Mercury's dynamo from the Mercury flybys data. Furthermore, he will continue his modeling effort in the framework of the CASSINI mission by providing an improved model of the environment of Enceladus and its interactions mechanisms with the magnetosphere of Saturn.

On the technical level, Benna will continue his support to the LADDE-NMS and MAVEN-NGIMS through the integration and testing phase. He will support the SAM instrument as it goes through calibration and testing by providing control system analysis to the SAM integration team. Benna also will characterize and provide performance models for the two new-generation mass spectrometers that are being developed by NASA-GSFC and by the University of Michigan.

Task 612-71-248: **Coupling Between Mercury's Exosphere and Magnetosphere and the Study of Planetary Magnetospheres**

GEST Investigator: Scott A. Boardsen

Collaborators: James A. Slavin (GSFC 670.0), Eun-Hwa Kim and Jay Johnson (Princeton Plasma Physics Laboratory-PPPL), Torbjörn Sundberg (Space and Plasma Physics, School of Electrical Engineering, Royal Institute of Technology, Stockholm, Sweden), Nick Omidi (Solana Sci. Inc., Solana Beach, Ca), Menelaous Sarantos (GEST, GFSC 674.0), Mehdi Benna (GEST, GSFC 699.0), Pavel Trávníček (UCLA Institute of Geophysics and Planetary Physics)

Description of Research

The GEST investigator studies plasma waves, plasma structures and their interaction with particles in planetary magnetospheres. His current research focus is on the analysis and interpretation of ultra-low frequency (ULF) waves detected at Mercury by the magnetometer flown on the MESSENGER spacecraft. He is studying the role these waves play in energy transfer within plasmas and as a diagnostic of magnetospheric processes and composition. He is also examining the interrelationship between Mercury's magnetosphere and ions, mainly Na+, created by the ionization of Mercury's exosphere by analysis of *in situ* measurements and MHD and hybrid simulations. Boardsen is studying high frequency Kilometric Continuum (KC) radiation generated in the Earth's magnetosphere, and he works on other Earth-oriented missions.

Accomplishments during the Reporting Period

Boardsen performed a study comparing ULF waves observed near the proton cyclotron

frequency in Mercury's magnetosphere during the January 14, 2008 (M1) flyby, (for which the magnetosphere was quiet), and the September 29, 2008 (M2) flyby (for which the magnetosphere was highly disturbed). He published his findings in *Geophysical Research Letters* (Boardsen *et al.* 2009). While the ULF waves observed during M2 had similar polarization properties, they exhibited much stronger wave amplitudes and no frequency drift compared to those observed during M1. The reasons for the observed variations in frequency and polarization properties are not clear and multiple scenarios have been proposed. One possible scenario is that these waves are either due to field line resonances or cavity modes. Boardsen continued to collaborate with the theorists Dr. Kim and Dr. Johnson at the PPPL, who are experts in modeling field line resonances. Another possibility is that these waves are generated by local plasma instabilities due to the large planetary loss cones expected in the ion distribution functions at Mercury. The investigator started exploring this possibility using cold and hot plasma wave tracing and instability analysis in a loss cone environment.

The investigator analyzed MESSENGER October 6, 2009 Mercury Flyby (M3) magnetometer data. Kelvin-Helmholtz (K-H) waves driven by solar wind flow around plantery magnetospheres were observed during the inbound magnetopause crossing. Studying K-H waves at Mercury provides a unique opportunity due to large ion Larmor radius effects in a small magnetosphere and low Alfvénic mach numbers due to Mercury's close proximity to the Sun, influences which aren't easily and haven't been observed at other planetary magnetospheres. Working with Torbjörn Sundberg (graduate student candidate whose Ph. D. thesis topic is K-H at Mercury), Boardsen performed an analysis of these waves and presented the results of this analysis at AGU this past fall. These magnetopause surface waves could be the primary source of low frequency waves observed in the interior of Mercury's magnetosphere and an important mechanism for the transport of solar wind plasma into the magnetosphere.

Boardsen provided science support to members of the MESSENGER science team. He worked with Dr. Slavin on analyzing magnetic flux loading/unloading observed in Mercury's magnetotail during M3: the magnetic flux loading-unloading was estimated to transfer 30-100% of magnetic flux from Mercury's dipole field into its tail; at Earth, transfers of 12% maximum have been observed. The results of this study were submitted to *Science* (Slavin *et al.*, 2010).

Objectives for the Coming Year

Boardsen will submit his preliminary findings on K-H waves during M3 to a peer-reviewed journal. He will modify his analysis code in preparation for orbital insertion of MESSENGER about Mercury on March 18, 2011. His work on the analysis and interpretation of ULF waves at Mercury, including wave propagation and growth rate studies, will continue. Boardsen will search for ion cyclotron waves in MESSENGER magnetometer data during the cruise phase between M3 and orbital insertion of March 13, 2011, and will work on analyzing the output of both hybrid and MHD simulations of Mercury's magnetosphere. He plans to publish his findings in the appropriate peer reviewed journals, and he will write and submit to the appropriate journal the case studies of atypical high frequency Kilometric Continuum radiation.

Task 673-97-337: **Plasma in the Saturnian Magnetosphere and Its Interactions with Icy Satellites**

GEST Investigator: Matthew H. Burger

Collaborators: Edward C. Sittler, Jr. (PI, GSFC 673), Rosemary Killen (GSFC 695)

Description of Research

The interactions between planetary magnetospheres and the surfaces of planets and satellites produce tenuous neutral clouds and exospheres that supply the raw material for plasma in the planetary magnetospheres. Spacecraft observations provide the most effective method of studying these features. The primary goal of this work is to use a combination of *in situ* measurements by the Cassini Plasma Spectrometer (CAPS) and other instruments onboard the Cassini mission to Saturn, ground-based observations, and numerical modeling to understand the distribution of plasma and neutrals in Saturn's magnetosphere and their interactions with the geologically active moon Enceladus. In addition, numerical modeling is used to interpret observations of Mercury's exosphere by the MESSENGER spacecraft.

Accomplishments during the Reporting Period

The Cassini spacecraft began orbiting Saturn in 2004 and its current mission will not end until 2017. One of the most exciting discoveries of the Cassini mission has been the detection of jets of water gas and ice grains at the south pole of Saturn's moon Enceladus. These jets emanate from warm cracks in the surface of this small (500 km diameter), icy object, and suggest the possibility of a sub-surface reservoir of water. Observations by Burger and his colleagues place constraints on source mechanisms for the jets. Modeling of the chemical evolution of Enceladus, assuming expected elemental abundances, suggests that the sodium concentration in a sub-surface ocean would be high. However, observations of the gas plume and the torus of gas around Saturn formed from the plume failed to detect emission from sodium gas, indicating that the source is significantly depleted in sodium relative to a proposed ocean source (Schneider, *et al.* 2009). Observations of solid ice grains ejected from Enceladus, which make up <10% of the total plume material, did reveal the presence of sodium (Postberg, *et al.* 2009, *Nature*). Together, the two sets of observations point to a plume source which enriches the grains in sodium and leaves the gas depleted.

The Enceladus jets produce a torus of neutral water around Saturn that is narrowly confined to Enceladus' orbital distance from Saturn. Clouds of neutral O and OH much larger than this torus have also been observed by the Hubble Space Telescope and Cassini. This cloud is likely formed by a charge exchange between H_2O and water group ions (H_3O^+, H_2O^+, OH^+, O^+) in Saturn's magnetosphere, which produces fast neutrals that spread farther out into Saturn's magnetosphere. One question is whether these charge exchange reactions occur in the neutral torus or in the jets close to Enceladus. The charge exchange must occur at speeds lower than the expected magnetospheric corotation speed so that the fast neutrals produced do not escape Saturn entirely. Although plasma is slowed as it flows through the jets, increasing the probability of producing non-escaping neutrals, modeling of the ion-neutral interaction in the torus by the GEST investigator has shown that most of the neutrals forming the extended cloud are formed in the torus. This happens because the charge-exchange cross sections are largest at low speeds, and, despite the large mean velocity of the ions, most of the neutral production is at the low end of the ion speed distribution (Burger, 2009).

The exosphere of Mercury has been observed by the MESSENGER spacecraft during three flybys of the planet, and will be explored extensively during the orbit phase of the mission which begins in 2011. The complex and time-variable morphologies of different species in Mercury's exosphere have been observed with the Mercury Atmosphere and Surface Composition Spectrometer (MASCS) on MESSENGER and interpreted using numerical modeling of the interactions of the exosphere with Mercury's surface, the solar wind, and the solar radiation environment. The observations have resulted in the discovery of magnesium and have produced high spatial resolution maps of magnesium, sodium, and calcium, both close to the planet and in a tail extended away from the sun (McClintock, *et al.*, 2009). Modeling of the sodium observations has found that it is ejected from Mercury's surface by photon-stimulated desorption (PSD), a process by which sodium in the topmost monolayers of surface grains is

ejected by solar UV radiation. Enhancements in the sodium emission near Mercury's poles are likely produced by the ion-enhanced diffusion of sodium from the interior of the grains to their surfaces. Normally, PSD rapidly depletes sodium from the grain surfaces. However, in the polar cusps of Mercury's magnetosphere, solar wind ions are free to precipitate onto the surface, and can increase the amount of sodium available for desorption, producing enhancements in the emission.

Burger has also contributed to several book chapters on satellite atmospheres in the outer solar system. These include a review chapter by Johnson *et al.* (2009) in the University of Arizona Press publication *Europa* on modeling Europa's tenuous oxygen atmosphere, and two chapters in the upcoming Springer book *Moons of the Outer Solar System: Exchange Processes Involving the Interiors*, one on observing and one on modeling satellite atmospheres.

Goals for the upcoming year relate to understanding the plasma distribution in Saturn's magnetosphere and the interaction between plasma and the atmospheres of satellites and planets in the solar system. The first goal is to improve the ion moments calculations in the CAPS data based on the method developed by Ed Sittler. This will be used to understand the density, temperature, and bulk velocity of plasma in Saturn's inner magnetosphere and its interaction with Saturn's satellites. Second, the previously developed model of Mercury's exosphere will be used to understand observations of calcium emission by MESSENGER, which show significant morphological differences from the sodium observations which have been previously studied. Third, development will begin on a model of the interactions between Jupiter's magnetospheric plasma, Europa's ionosphere, and Europa's atmosphere in support of a theory proposal submitted to the Hubble Space Telescope (Space Telescope Science Institute).

NASA Grant: **Analysis of the Earth's and planetary gravity fields and geophysical applications (NNX08AH89G)**

GEST Investigator: Shin-Chan Han

Collaborators: David Rowlands, Scott Luthcke, Richard Ray, Frank Lemoine, Jeanne Sauber, Erwan Mazarico (GSFC 698), In-Young Yeo (Univ. of Maryland), Hyungjun Kim, Taikan Oki, Pat Yeh (Univ. of Tokyo), Douglas Alsdorf (Ohio State Univ.)

Objectives for the Coming Year

Description of Research

The satellite gravity measurements such as Gravity Recovery And Climate Experiment (GRACE) are sensitive to mass re-distribution on the Earth surface and interior with a spatial resolution of some hundreds km and temporal resolution of 10 days or so. For the case of geophysical mass variation with known temporal frequency (*e.g.*, tides), it is possible to study such phenomena even with a sub-daily interval. The major goal of this investigation is to optimally process the satellite tracking data to analyze the hydrological mass fluxes over the large river basins, the ocean tides over the coastal areas and polar regions, and the solid earth dynamics related to the coseismic change and postseismic relaxation caused by large earthquakes.

Accomplishments during the Reporting Period

Terrestrial water storage in the Amazon basin and its surrounding areas is studied by exploring the instantaneous measurements of distance changes between two satellites from the GRACE mission. The surface water in the channels and floodplains can be significant in weighing total water storage. Its magnitude can be as large as soil moisture perturbing the motions of the satellites to a detectable amount by the onboard

instrument. The river runoff routing simulations indicate the effective velocity throughout the Amazon basin over the years is about 30 cm/s with significant seasonal change. The lower velocity, during rising stages and peak water season, and the faster velocity, during falling stages, are delineated from the observations. The backwater effects may impact such seasonal change on the overall flow velocity. Direct assimilation of GRACE tracking data can contribute to land surface dynamic processes by resolving the time scale of transport in rivers and streams.

The localized mass anomalies inferred from GRACE ranging measurements were assimilated into a hydrodynamic model to improve tidal solutions around Antarctica for the M2, S2, and O1 constituents. The variational approach used accounts for the spatial averaging of tidal elevations implicit in the mass anomaly parametrization used for the GRACE tidal analysis, as well as the spatial correlation of errors in the resulting estimates. The inverse solution shows better agreement with independent station tide measurements around Antarctica, and it reduces cross-over residuals for ICESat laser altimeter data over the Filchner-Ronne and Ross Ice Shelves, demonstrating that GRACE data can provide useful constraints for improving hydrodynamic tidal models at high latitudes.

The problem associated with the large data gap on the farside of the Moon is addressed by constructing a high-resolution global gravity model. By localizing the power law constraint and making it effective only within the farside and limb regions, Han mitigates the undesired power-limiting effect on the nearside. Compared to the solution estimated from the Lunar Prospector and other satellite tracking data with the globally applied power law, the locally constrained solution shows significant improvement of the nearside gravity estimates. Around the areas dominated by craters in the southern hemisphere of the nearside, the correlation with topography approaches nearly 0.95 and the admittance converges to 100 – 110 mGal/km and up to a spherical harmonic degree of 130, while the globally-constrained solutions distort starting at a degree of 90. The proposed analysis can benefit the science and operation of other existing and future planetary missions and enhance the geophysical interpretation of the gravity field.

Objectives for the Coming Year

The validation of the static and time-variable gravity fields from GRACE data products will continue. Han and his colleagues also plan to exploit the GRACE observations of cosiesmic gravity change to infer the subduction zone geometry (fault dip angles), which is hardly resolved from the traditional data such as distant geodetic (GPS) measurements and seismic waveforms. They will update the estimates of the postseismic gravity changes, especially to improve the steady-state viscosity of the asthenosphere from the longer GRACE time-series, and update the ocean tide estimates, including K1 components with the longer GRACE time-series. Various global ocean tide models such as GOT4.7, FES2004, and TPXO7 will be tested and validated. They will explore the feasibility of estimating (temporally and spatially variable) the surface water flow velocity directly from the GRACE tracking data, and study what the GRACE Follow-On mission would contribute to for the earthquake associated deformation and time-variable gravity changes. Han and his team plan to analyze various seismic P- and S- wave and geodynamic models to estimate the best *a priori* 3D coefficients and corresponding covariance, test various velocity-density conversion models, analyze the correlations among the long wavelength signals of geopotential, geomagnetic potential, and seismic wave-based CMB models to develop the best *a priori* CMB topography coefficient estimates and corresponding covariance. In addition to the Earth gravity analysis, the tracking data from the satellites orbiting the Moon and Mars will be investigated to obtain improved gravitation models for the Moon and Mars.

Task 673-94-324: **The Magnetospheric Multiscale (MMS) mission: a NASA Solar-Terrestrial Probe Project**

GEST Investigator: Kyoung-Joo Hwang

Collaborators: Melvin Goldstein (PI, GSFC 673), Michael Hesse (GSFC 670); John C. Dorelli and Adolfo Figueroa-Vinas (GSFC 673); Martin Goldman and David Newman (Univ. of Colorado, Boulder); M. A. Shay, M. Swisdak, Jim F. Drake (UMCP)

Description of Research

The Magnetospheric Multi-Scale (MMS) mission, to be launched in 2014, will use Earth's magnetosphere as a laboratory to study the microphysics of magnetic reconnection, a fundamental plasma-physical process that converts magnetic energy into heat and the kinetic energy of charged particles as a result of global magnetic topology changes. MMS will investigate how the energy conversion that occurs in magnetic reconnection accelerates particles to high energies and what role plasma turbulence plays in reconnection events. MMS pre-launch researches the use of existing data from multi-spacecraft mission, *Cluster*, and the application of either analytical or simulation techniques to processes occurring in the ion and electron diffusion regions near the reconnecting magnetic fields, which help provide in-depth understanding of the physics of magnetic reconnection as well as important implications for the MMS design.

Accomplishments during the Reporting Period

The parallel electric field (often called a double layer) associated with the generation of electron phase-space holes is one important and prevalent physical process in space, and has been highlighted as its effect on the magnetic reconnection was repeatedly reported (Cattell *et al*., 2005). The computational study using a kinetic *Vlasov* simulation code, partly developed and fully modified by the GEST investigator, proposed a new self-consistent model about the development and evolution of the parallel electric field and associated particle energization via electron phase-space holes, and this work was published in *Geophysical Research Letters.*

Hwang performed an intense data analysis on the Earth's magnetospheric phenomena using the Cluster and THEMIS spacecrafts. Three main topics of her research were electron behavior near the reconnection X-line (where reconnection is initiated), Kelvin-Helmholtz (KH) waves at the Earth's magnetopause, and dipolarization front (DF) event in the Earth's magnetotail.

Hwang reported Cluster observations of multiple X-line structures in Earth's magnetotail current sheet, and showed that a second X-line is formed and developed within about 17 seconds. The initiation and magnetic topology reconfiguration associated with magnetic reconnection are thought to occur in a small electron diffusion region, which is found within a much larger ion diffusion region. Although ion diffusion regions have been identified by their Hall magnetic and electric field geometry, the electron diffusion region is difficult to identify observationally, primarily because of its small scale size. The GEST investigator identified both ion and electron diffusion regions by examining a Walén relation for ions and electrons separately and together with field and particle signatures. In particular, she found agyrotropic electron distributions accompanied by super-Alfvénic electron outflows and enhanced high-energy electron fluxes, in the electron diffusion region. These signatures correspond well to previous numerical studies (Shay, 2007).

The GEST investigator analyzed and reported well-developed KH waves at the flank magnetopause during southward IMF conditions, which is unusual from the observational point of view. The observation indicates that KH activities under southward

IMF might have more temporal or intermittent nature, which explains the preferential *in situ* detection of KH waves under northward IMF conditions. Along the boundary of KH waves, evidences for the reconnection phenomenon are found. This study was submitted to the *Journal of Geophysical Research.*

Hwang also investigated a series of the depolarization front observed by Cluster in the near-midnight current sheet. These DFs were presumably generated by a bursty reconnection that occurred tailward of Cluster from the observation of associated earthward fast flows. Each DF was followed by local magnetic disturbances, indicating a magnetic fluctuation generated by the impact of the DF. The GEST investigator proposed that an interchange of unstable DF might have caused the deformation of the mid-tail magnetic topology, which generates significant field-aligned currents, and possibly powers the auroral arc during the substorm processes. This study is to be submitted to the *Journal of Geophysical Research*.

Objectives for the Coming Year

Hwang's primary objectives are consistent with the primary MMS physics objectives, especially focusing on the microphysics in the electron scale length: what kinetic processes are responsible for the magnetic reconnection, how the reconnection is initiated and what microphysics influence its initiation and temporal variations, what energization mechanism heats and accelerates particles, and what role plasma turbulence plays in reconnection events. Based on their preliminary investigation on the reconnection events, and their further effort of finding reconnection events observed by Cluster and other spacecraft, Hwang and her team will seek answers for those questions. First, they will continue to investigate electron and ion three-dimensional distribution functions measured in the different locations within the reconnection site. Second, the observation will be compared with three-dimensional PIC simulation results for better understanding of kinetic processes responsible for the reconnection initiation and evolution. Third, they will investigate properties of turbulent reconnection, which indicates how the energy conversion between fields and particles are mediated throughout reconnection processes. Reconnection is initiated in a small diffusion region, but its consequences lead to large-scale magnetospheric phenomena, such as DFs, substorms, and a solar wind entry into the Earth's magnetosphere at the dayside near-subsolar magnetopause, cusps, and well-developed KH waves. They will continue investigating these various magnetospheric phenomena using multi-spacecraft data and global MHD simulation codes.

Task 670-94-328: **Solar Wind-Magnetosphere Coupling and Substorm Dynamics at the Earth and Mercury**

GEST Investigator: Suzanne M. Imber

Collaborators: James Slavin (GSFC 670), Guan Le (GSFC 674)

Description of Research

Magnetic reconnection is the primary mechanism for energy and flux transfer from the solar wind into the magnetosphere. The location and rate of reconnection at the dayside magnetopause are thought to be primarily controlled by solar wind parameters, such as the orientation and strength of the interplanetary magnetic field. Prolonged reconnection at the dayside magnetopause leads to flux buildup in the magnetotail lobes, and this increased pressure causes the cross-tail current sheet to thin and reconnection between the two oppositely directed tail lobes to begin, leading to a decrease of the magnetic flux in the lobes. The cycle described above is called the substorm cycle and has been studied for decades using ground-based magnetometers, and more recently radars, all-sky cameras and spacecraft data.

Accomplishments during the Reporting Period
During this period, research into the reconnection taking place in the near-Earth magnetotail was carried out at Goddard Space Flight Center. This research was primarily focused on utilizing data from the new THEMIS mission to investigate flux ropes and travelling compression regions (TCRs). THEMIS is a constellation of five spacecraft in equatorial orbits such that the apogee of each spacecraft lies in the range ~10-30 R_E. Every four days a major conjunction takes place so that all of the spacecraft are aligned down the tail. These multi-point measurements enable the evolution of travelling magnetic structures to be investigated.

Flux ropes are magnetic structures made up of twisted magnetic field lines, which are thought to be formed by reconnection at multiple locations in the near-Earth tail. They have been observed travelling both Earthward and tailward in the plasma sheet by previous satellite missions. Due to their formation mechanism, they are known to be related to substorms; however, the exact sequence of events making up the complex substorm phenomena is still hotly debated. Travelling compression regions (TCRs) are signatures of lobe compression, thought to be due to large flux ropes travelling Earthward or tailward.

A database of flux ropes and TCRs observed in THEMIS data was generated and this allowed the statistical location of the near-Earth reconnection site to be determined. The dependence of the upstream solar wind conditions on the location of the reconnection site was also investigated. Case studies of multiple flux rope events were identified for future study. This work was presented at the GEM meeting in Snowmass, Colorado and IAGA meeting in Sopron, Hungary in August 2009.

The dependence of the near-Earth neutral line on solar activity was investigated using Geotail data. Flux ropes and TCRs were identified in two years of data at the extremes of the solar cycle, and the results show both solar cycle dependence (mainly related to the differences in solar wind conditions during the solar cycle) and an interesting asymmetry in the dusk-dawn location of the reconnection site. Imber gave an oral presentation of this work at the Fall AGU meeting in San Francisco, CA in December.

Imber received a University of Leicester College of Science award in 2008 for her Ph.D. thesis, titled “Reconnection under Northward Interplanetary Magnetic Field”. She will be awarded with a medal from the university and then will give a 30-minute public lecture on her thesis material in May 2010.

Objectives for the Coming Year
Case studies of multiple flux ropes/TCRs identified in both Geotail and THEMIS spacecraft data will be further studied in order to determine whether it is possible that flux ropes are coalescing or splitting as they travel Earthward or tailward. Various theories have been suggested following the development of magnetohydrodynamic models; however, no *in situ* measurements have confirmed the theories.

Imber and colleagues also plan to study the spatial scale of the northward IMF current systems at Earth using a combination of the three spacecraft Space Technology 5 (ST5) mission and the SuperDARN radars.

Task 674-84-294: **Collisionless Reconnection Simulation and Detector Response Study**

GEST Investigator: Alex Klimas

Collaborators: Michael Hesse (PI, GSFC 674), Melvyn Goldstein (PI, GSFC 673), Seiji Zenitani (ORAU at GSFC 674), Adolfo Figueroa-Viñas (GSFC 673)

Description of Research

Collisionless magnetic reconnection is a ubiquitous process that plays an important role in the dynamics of many space, laboratory, and astrophysical plasma systems. Because it is a complicated nonlinear process, much of what has been learned about collisionless reconnection has come from simulation studies. From these studies, a "Hall reconnection model" has emerged as the generally accepted paradigm for this process. Recently, however, simulations done with open, rather than the traditional periodic boundary conditions have challenged the Hall reconnection model. The purpose of this task is to modify an available electromagnetic 2 ½-dimensional particle-in-cell (PIC) reconnection simulation code to incorporate open boundaries and then to investigate this recent challenge to the Hall reconnection model using the modified code.

The Magnetospheric Multiscale Mission is an upcoming four spacecraft mission designed to study collisionless reconnection in Earth's magnetosphere. Selected output from this simulation study is to be used to analyze the response of the Fast Plasma Investigation (FPI) electron and proton spectrometer instrument to be flown on that mission.

Accomplishments during the Reporting Period

A new, and far more general, algorithm for open boundaries in PIC simulation codes has been developed. Klimas and colleagues impose a zero normal gradient on the particle distributions at each of the boundaries; in addition, compatible boundary conditions are imposed on the electromagnetic field at the open boundaries. A zero gradient on the normal component of the electric field has been introduced into a Langdon-Marder-type iterative algorithm (*Langdon*, 1992) that is used to correct this initial choice to account for charge density at the boundary. Further, the conditions, zero normal gradient for the tangential magnetic field and divB=0 for the normal component, are imposed on an implicit solver for the electromagnetic field. These choices lead to the smooth passage of electromagnetic structures (magnetic islands, outflow jets, etc.) through the boundaries with no trace of charge buildup near the boundaries or anywhere else on the computational grid.

The new open boundary construct has been applied to the inflow boundaries of the simulation domain in the reconnection simulation code. A pair of multiprocessor work stations are being used for running simulations. The most time consuming portion of the simulation code has been successfully parallelized using the OpenMP paradigm. The code has been further modified to allow for the imposition of an out-of-plane electric field to drive the reconnection in a manner that mimics the effect of the cross-tail potential imposed on Earth's magnetotail by the solar wind. A sequence of reconnection simulations under various driving strengths has been carried out to investigate the response of the reconnection rate to the variable driver. The results from these simulations are under study and a paper to be published in *Physics of Plasmas* is in preparation.

The available methods for extracting, analyzing, and visualizing particle distributions from the reconnection simulation results have been extended for application to the FPI detector response study. The particle distributions have been rescaled to represent real particle fluxes and rebinned to agreement with the expected phase space response of the detectors. The response of the detectors to particle fluxes from selected regions of the simulation results are under investigation.

Objectives for the Coming Year

Because of the closed boundary conditions used, earlier PIC reconnection simulation studies have been limited to short runs that have not reached the time-scales of most physical systems. A principal objective for this open boundary simulation study is to extend the simulation runs to these physical time-scales. In principle, this extension should be possible using the presently available code; however, two problems have been encountered that must be overcome: first, the total number of particles on the simulation grid declines steadily to unacceptably low values as runs proceed; the inflow boundary conditions do not supply a sufficient number of particles;

second, some very slowly moving active reconnection sites can reach the outflow boundaries of the simulation domain, where they stall and then lead to large unphysical disturbances that spread, thereby destroying the validity of the simulation. Simulation objectives for the upcoming year are to overcome these problems, to extend the simulation runs to physical time-scales, and to continue with the examination of the Hall reconnection model at these time-scales.

The available methods for extracting, analyzing, and visualizing particle distributions from the reconnection simulation results have been extended for application to the FPI detector response study. The next step is to provide these capabilities in a user-friendly format to researchers in the reconnection simulation community as well as to FPI detector developers. An interactive page at the Community Coordinated Modeling Center (CCMC) web site will be developed for this purpose. Users will choose among a collection of simulation results for both modeling and theoretical studies as well as assistance in detector development.

Task 672-109-377 **Wind Magnetic Field Investigation**

GEST Investigator: Andriy Koval

Collaborators: Adam Szabo (PI, GSFC 672)

Description of Research

The simulation or modeling of the propagation of an interplanetary shock in the heliosphere, its interaction with planetary magnetospheres, and its particle acceleration effectiveness are dependent on the shock parameters, such as the front orientation, propagation speed, Mach number, as well as the angle between the shock normal and the magnetic field. The interplanetary shock kinetic structure is also defined by these parameters. Furthermore, for a shock moving in the non-uniform solar wind, these parameters are expected to be functions of both time and location; thus, their precise determination at different locations is essential to fully characterize the shock.

Accomplishments during the Reporting Period

A study of interplanetary shock shapes was performed on shocks observed by multiple spacecraft in the solar wind. The shock parameters were calculated locally from magnetic field and plasma measurements of individual spacecraft. To calculate the shock parameters, a program with a graphical user interface was developed in the Interactive Data Language (IDL) that allows fast and intuitive shock parameter determination from measurements of a number of spacecraft using different techniques. Possible complex shock shapes with small and large scale curvatures of the shock surface were demonstrated based on an example of shock observed by six spacecraft. To systematically estimate the shock front deviation from planarity on different scales, ~ 70 shocks observed by multiple spacecraft in the solar wind were analyzed. The results indicate significant deviation of shock shapes from widely used planarity assumption. On the scales perpendicular to the shock normal up to ~ 50 R_E, the minimum radius of curvature is in the range from the lower limit of the technique to ~ 400 R_E. It increases with perpendicular separation and reaches the range of ~ 400 R_E to ~ 1000 R_E for the perpendicular separation of ~ 100 R_E to ~ 150 R_E, with the absolute minimum of the shock curvature radius of ~ 400 R_E on these scales.

To study kinetic structures of interplanetary shocks and to find the kinetic structure dependence on previously determined local shock parameters, Koval is developing a new technique to improve calibration of the Wind Magnetic Field Investigation (MFI) that will produce 11(22) vector/sec high time resolution data product necessary for such study. In the current stage, the improved technique results in

significantly decreased spin noise in the data as compared to the original calibration technique.

Objectives for the Coming Year

Koval's first objective is to complete the new technique to improve the calibration of the Wind spacecraft MFI 11/22 vector/sec high time resolution data product. Second, the data product for the whole mission will be reprocessed using the newly developed technique. Third, scientific research on kinetic structures of solar wind discontinuities and, in particular, interplanetary shocks will be performed using the data.

NASA Grant: **Tide and Influence of the uncertain model parameters on constraining Earth's surface and interior model from satellite observations (NNX08AH89G)**

GEST Investigator: Choon-Ki Lee

Collaborators: Shin-Chan Han (GSFC 698)

Description of Research

Observations from satellites such as GRACE and ICESat recently have played very important roles in understanding the Earth's surface and interior process. The uncertainties of theoretical (mathematical) Earth models are analyzed for various geophysical applications of satellite observation. In determining the accuracy in ocean tidal computations based on hydrodynamics, the bathymetry is the most important factor. Lee and Han explored the relationship between the bathymetry and its effect on the surface via ocean tides by non-linear inversion schemes of the tidal measurements from ICESat laser altimetry. The accuracy of mantle viscosity derived from global geoid observations is also dependent on the uncertainty in the seismic tomography model used as a model constant. Lee analyzed the effect of the noise in the tomography model on constraining mantle viscosity, which was then minimized by the total least squares approach.

Accomplishments During the Reporting Period

As previously stated, the bathymetry is the most important factor in determining the accuracy in ocean tidal computation based on the hydrodynamics. The bathymetry underneath the ice shelves in Antarctica, including the Ross Ice Shelf (RIS), is poorly known. While there have been considerable recent improvements in ocean bathymetry from satellite data, the bathymetry underneath the RIS is not covered and still relies on coarsely-spaced water column depth measurements from the 1970s. Lee and Han formulated the relationship between the bathymetry and its effect on the surface via ocean tides and explored non-linear inversion schemes of the tidal measurements from ICESat laser altimetry. The ocean tides are computed to be larger in magnitude than the measured tides in most of the ice shelf; consequently, the bathymetry inversion is followed in a way that it reduces the computed tidal amplitudes comparable to the measurements. The inversion results from independent measurements of various ICESat campaigns consistently indicate that the bathymetry is deeper westwards and shallower near the middle of the ice front, with respect to the initial bathymetry widely used in the community. The new bathymetry inverted from ICESat data reconciles the tidal prediction with most of the *in situ* tidal measurements available on the RIS. The hydrodynamic tidal prediction adopting the optimized bathymetry yields performances comparable to other assimilative tide models, such as GOT 4.7, TPXO 7.1, and CATS2008a.

The simulation and actual data analysis for the mantle viscosity estimation from the uncertain 3D density structure (constrained by seismic tomography models) and the noisy geoid observations were presented. The analysis is based on computing the misfit (cost) functions established in the sense of the (usual) least square (LS) and the total least square (TLS) method; the latter approach is particularly interesting, because the error caused by the uncertainty in seismic tomography models on the geoid is typically much larger than the noise in the geoid measurements. Most studies

disregard the effect of the uncertain model parameters such as density structure and obtain the solutions by way of minimizing the noise in the geoid observations. The simulations show the uncertainty in the density model can cause biases in the viscosity estimates, if it is not taken into account in the inversion process. The viscosity solutions tend to underestimate the magnitude of the geoid in order to minimize the cost function reflecting the noise in the observations. The TLS method redefines the cost function, including the effect of the uncertainty in the model parameter such as density as well as the data noise. The solutions that minimize both effects turn out to be less biased and more consistent with the spectral bands of the observations in the simulations. From the actual satellite geoid data analysis with a simple three-layer structure (upper mantle, transition zone, and lower mantle) for viscosity parameterization, the TLS viscosity solutions indicate the distinction between upper mantle and transition zone viscosities is not statistically significant, unlike the solutions based on the LS methods. The researchers' viscosity model ignores the mantle compressibility, the layered convection, the effect of layer thickness variation, and the other surface observables, such as surface topography and plate velocity.

Objectives for the Coming Year

In 2010, the bathymetry underneath the RIS will be analyzed in the context of geostatistical estimation. The seismic measurement of water column thickness and ice thickness will be interpolated by the kriging method. The correction from bathymetry inversion reflects the effect of bathymetry correction averaged over each inversion block. Using the inverted water column depth as a spatially varying local mean, a residual kriging will be performed to integrate the seismic measurement and the bathymetry inversion result.

The uncertainties in the seismic tomography model will be more realistically analyzed using a rigorously derived covariance matrix for the seismic tomography model from global seismologists (the previous work was based on the statistically derived covariance matrix from the seismic tomography models more commonly used). The covariance matrix, directly derived from the resolution and uncertainty of the global seismic tomography inversion, is then to be applied to the full TLS approach.

Task 673-90-315: **Study of the Interaction Between Space Objects and Plasma Flow: 3D Hybrid/Kinetic Simulation**

GEST Investigator: Alexander S. Lipatov

Collaborators: Edward C. Sittler (PI, GSFC 673), Richard E. Hartle (GSFC 673), John F. Cooper (GSFC Code 672)

Description of Research

This research focuses on the three basic problems of the space plasma dynamics: the hybrid-kinetic simulation of the Solar Probe Plus spacecraft interaction with the solar wind; hybrid simulation of the interaction of Saturn's plasma with Titan's environment (Cassini - T9 encounter); and the hybrid-kinetic simulation of the Jovian plasma torus interaction with Europa. The objective of the research is to model the kinetic plasma interaction between the Solar Probe spacecraft and the solar wind perihelion. The main issue is the plasma wake that forms around the spacecraft and its effects on the Plasma Wave Instrument (PWI). A kinetic approach is necessary to account for the range of solar wind plasma conditions expected during the mission, where ion gyroradii are generally much larger than the spacecraft, while electron gyroradii are typically of spacecraft size near the Sun and much larger than the spacecraft near 1 AU. Understanding Titan's interaction with Saturn's rotating magnetosphere is very complex with non-stationary kinetic plasma processes, and it is necessary to analyze the Cassini observations (*e.g.*, Cassini Plasma Spectrometer (CAPS), (Sittler *et al.*, 2005; Hartle *et al.*, 2006, Sittler *et al.*, 2009; Sittler *et al.*, 2010)) with a

physically meaningful model such as Lipatov's advanced kinetic-fluid (hybrid code) model (*e.g.*, Lipatov, 2002). The understanding of the interaction of Jovian plasma torus with the atmosphere and the surface of Europa is very important in the course of future missions. Te researchers' numerical modeling will provide important information about the interaction processes between the thermal/energetic plasma and atmosphere and the surface of Europa. One goal of this research is to produce a map of the particle fluxes at Europa's surface. These models will be used in future missions to Europa to study the composition of the surface.

Accomplishments during the Reporting Period

The first part of the project studies the spatial distributions of the thermal and energetic particles in the plasma environment (plasma wake) of spacecraft (Solar Probe), their velocity distributions and the electromagnetic waves. The model results are essential in developing the design strategy of the PWI, including orientation of the antenna and particle instruments planned for the future Solar Probe mission. Lipatov has developed 3D and 2.5D hybrid models of the plasma environment near Solar Probe with a realistic configuration of the spacecraft. The main effort during the past year was the study of the solar wind plasma dynamics near the SP Plus spacecraft at the distance r = $9.5R_{sun}$ and realistic electron betas $\beta_e = 0.3$. The modeling demonstrates the formation of the whistler and, at a later time, the Alfv'en wing directed by the interplanetary magnetic field. A 3D simulation (meshed with 301x301x401 grid points and 80×10^9 macro-particles) needs five months of runs on the NAS Supercomputer "SGI-Columbia" with multi-parallel processing (OpenMP). The code was optimized for massively parallel computation: using the Open Multi-Processing (OpenMP), and using the hybrid environment - Message Passing Interface (MPI) along the computational nodes and the Open Multi-Processing (OpenMP) inside the node. The MPI/OpenMP version of the researchers' code was designed under the project between Code 673 and the Information and Visualization Office (GSFC). Lipatov is currently testing this MPI/OpenMP version of code with previous OpenMp version. He is also performing the 2.5D simulation that provides a much longer simulation with higher space resolution. He is currently working on the boundary condition that may reduce the electric field oscillations near the *SP*+bus.

The second part of the project studies the spatial distributions of the neutral and ionized gases in the plasma environment of Titan, mass loading processes, pickup acceleration inside the exosphere and formation of magnetic barrier, ionopause and induced magnetotail. For the first time, the hybrid code model can account for the transition of plasma characteristics that range from a finite-gyro-radius description far from the Moon to the collisional plasma of the ionosphere. One essential result of this modeling effort is the description of the ion phase space distribution and the moments in the interaction region of Titan. Lipatov developed a Particle-Ion–Fluid-Ion–Fluid Electron method of kinetic ion-neutral simulation code. This multi-scale combined (fluid–kinetic) numerical method allows researchers to use more realistic plasma models at Titan, taking into account charge-exchange, photo-ionization and electron impact ionization processes. Lipatov also studied Titan's plasma environment in the case of Cassini T9 encounter. The background ions H and pickup ions H^+, H_2^+, CH_4^+, N_2^+, and ionospheric ions (M=28) are described in a kinetic or drift-kinetic approximation, where the electrons are approximated as a fluid (Lipatov, 2002; Lipatov *et al.*, 2005; Lipatov and Combi, 2006). In this research, he considered the multi-scale spatial structure for plasma and electromagnetic field, and the velocity distribution of ions that results from the coupling between background ions and pickup ions. Special attention was given to the comparisons of their numerical results with Cassini (CAPS) observations (*e.g.* Sittler, Hartle, *et al.*, 2005; Hartle, Sittler *et al.*, 2006; Sittler *et al.*, 2008, Sittler *et al.*, 2009, Sittler *et al.*, 2010). He also estimated the mass loading rate for T9 encounter, energy input to upper atmosphere from ambient and pickup ions, and the T9 encounter with two crossings. The comparison of the simulation with observed data demonstrated a good agreement in total density,

but further development of the model is needed to improve an agreement in the magnetic field and bulk velocity (Lipatov, Sittler, Hartle *et al.*, 2010).

Lipatov also worked on a 3D hybrid simulation of the interaction between the Jovian plasma torus and Europa in collaboration with J.F. Cooper (GSFC Code 672) for the third part of his project. He studied a global plasma structure near Europa and the fluxes of the incoming and pickup ions on the surface of Europa (Lipatov, Cooper, *et al.*, 2009). The computations were supported by the NASA Advanced Supercomputing (NAS) Division (SGI - Columbia and Pleiades (NASA Ames Research Center), Projects: SMD-09-1110 (Europa), SMD-09-1124 (Titan), and SMD-09-1125 (Solar Probe).

Objectives for the Coming Year

The first and main objective is to continue the 3D hybrid simulation on the large scale of the plasma environment near Titan, including the fluid model for ionosphere in absence of Saturn's oxygen. The CAPS ion measurements during the T9 and other flybys through the induced magnetic tail of Titan were recently analyzed and reveal that the principal component of the background plasma is H^+, and H^+_2 with no evidence for O^+. Lipatov's second objective is to continue 3D hybrid simulation on the large scale of the plasma environment near Europa and to start the Lunar project. Finally, he plans to begin a 3D kinetic simulation on the large/small scales of the plasma environment near the Solar Probe Plus spacecraft for the parameters of the solar wind at the distance $9.5R_{sun}$. These simulations may serve as an expert system in the future design of the Solar Probe Plus spacecraft.

Task 690-107-368 **Remote Sensing of CO_2 and Other Atmospheric Compositions**

GEST Investigator: Jianping Mao

Collaborators: Jim Abshire (GSFC 690), Jay Herman (JCET/UMBC), Randy Kawa (GSFC 613), Clark Weaver (GEST)

Description of Research

Global high spatial and temporal resolution remote sensing of atmospheric CO_2 concentration is greatly desired for global and regional carbon studies. The biggest challenge for CO_2 remote sensing is to achieve the high-precision science measurement requirement (~ 1 ppmv or 0.3% on regional scales) so that such measurement will be valuable to reduce uncertainties about carbon sources and sinks. GSFC is developing an active laser approach for global atmospheric CO_2 concentration measurement from space as a candidate for NASA's future carbon mission ASCENDS - the Active Sensing of CO_2 Emissions over Nights, Days, and Seasons. This pulsed laser approach provides several advantages with respect to passive approaches and other laser techniques toward high-precision measurement of CO_2 from space. The main goal of this task is to support this ongoing development.

Accomplishments during the Reporting Period

Spectroscopy is a great challenge for CO_2 remote sensing. An updated spectroscopy database, HIgh-resolution TRANsmission molecular absorption database (HITRAN) 2008 version, was used in radiative transfer calculations and evaluated in comparison with an earlier version, HITRAN 2004. Substantial differences were found between the two databases in both CO_2 band at 1.57 μm and O_2 A-band at 0.76 μm used for CO_2 concentration measurements. These differences are mainly due to the line center position updates in the new database.

Water vapor effects on both CO_2 and O_2 measurements were investigated. It was found that water vapor partial pressure could cause

significant line broadening and result in a major retrieval error. The variable water vapor could also remarkably modify CO_2 concentration with regard to dry air from time to time. Therefore, accurate water vapor profile data in addition to atmospheric temperature profiles are needed as ancillary information to achieve high-precise CO_2 concentration measurement. Previous studies totally underestimated water vapor's impact on this measurement.

Surface reflectance affects a sensor's signal-to-noise ratio, retrieval error and calibration and validation strategy. Data from the ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) library were used to analyze the spectral dependence of surface reflectance in the shortwave lengths. Global MODIS nadir BRDF-adjusted surface reflectance near CO_2 and O_2 bands were then analyzed and, together with the Fresnel reflection over water as a function of surface wind speed, incorporated in the mission study simulations. It shows that measurement over mid- and high-latitude oceans may be noisy, particularly over southern hemisphere oceans, where surface wind speed is large and surface reflectance is low in all wavelengths. Reflectance in CO_2 wavelengths is also low over snow/ice, particularly over permanent ice caps, *e.g.*, Greenland and Antarctic, where good retrievals of CO_2 are difficult to achieve.

GSFC's CO_2 laser sounder had a number of airborne experimental flights. Data analyses for December 2008 engineer flights and August 2009 science flights were performed, and their retrievals were compared to *in situ* measurements. These flights demonstrated great sensor's measurement capability, consistent performance and good agreement with *in situ* data. Meanwhile, some issues were identified for future improvement.

Ground-based remote sensing of CO_2 plays a critical role in studying local and regional carbon cycles and validating satellite measurements. The feasibility of using AERONET-type moderate spectral resolution (~ 10 nm) sensors to measure CO_2 at both 1.57 and 2.06 μm bands was studied, and the researchers found that much higher spectral resolution (~ 0.1 nm) is needed for 1 ppmv measurement precision. A new high spectral resolution sensor is currently under development for this purpose.

Five-year (2005-2009) daily L2 OMI UV reflectance at 340 nm data were generated, providing a key data set in constructing a satellite UV reflectance climate data record since 1978. This data set has high spatial resolution and showed good agreement with other data sets, *e.g.*, SeaWiFS and SBUV. The data will be used for further studies about aerosols and clouds signals, their inter-annual and intra-annual variability, their relationship with ENSO, and loss of glacier in the polar region during the period.

Objectives for the Coming Year

Mao's first objective is to continue the mission simulation studies for the future NASA CO_2 space mission, ASCENDS, using lidar measurements. Second, the researchers will continue to support the atmospheric spectroscopy and performance analysis for the GSFC CO_2 and O_2 lidar. Third, they plan to explore new measurements and missions for planets' atmospheric composition. Meanwhile, researchers will continue the planetary UV reflectance climate data record construction and analysis.

Task 612-67-235: **Solar Wind and Magnetospheric Environment**

GEST Investigator: Jan Merka

Collaborators: Adam Szabo (PI, GSFC 672), Tom Narock (GEST), Yongli Wang (GEST), Shing Fung (GSFC 672), David Sibeck (GSFC 674)

Description of Research

Finding and retrieving space physics data is still a rather daunting task, even when the data are publicly available on the Internet. The space physics data environment consists of thousands of relatively small and many large datasets and, in principle, a web search engine should be able to find them. Unfortunately, the relevance scoring methods successful in a web environment, such as Google's PageRank method, are not suitable for space physics data sets because most resources are singular observations that are not linked to other resources. As a solution, Virtual Observatories (VxOs) are under development within the space physics community.

Merka leads the development of the Virtual Magnetospheric Observatory (VMO) and closely collaborates with Dr. Szabo in leading the development of the Virtual Heliospheric Observatory (VHO). These two VxOs share a common architecture design and efforts oriented toward a structured data search of magnetospheric and heliospheric data, respectively. The VMO and VHO web interfaces aim to provide unified, easy-to-use portals for magnetospheric and heliospheric data discovery and delivery.

The Virtual Wave Observatory (VWO) team led by Dr. Fung relies on Merka's experience in the VxO design in order to reuse and implement proven VMO/VMO features and components.

Furthermore, together with Dr. Wang and Dr. Sibeck, Merka works on a generalized 3-D magnetosheath specification model dependant on many solar wind and geophysical parameters. His contribution is the bow shock modeling.

Accomplishments During the Reporting Period

The NASA-funded domain-oriented Virtual Observatories aim to provide a single point of discovery of data and related resources for particular space physics domains. A Virtual Observatory (VxO) is a suite of software applications on a set of computers that allows users to uniformly find, access, and use resources (data, software, document, and image products, and services using these) from a collection of distributed products and service providers. A VxO typically includes registries based on a metadata model, front-end applications, and connections to data providers. In particular, the Virtual Magnetospheric Observatory (VMO) serves magnetospheric data, while the Virtual Heliospheric Observatory (VHO) serves heliospheric data.

The VHO/VMO do not use actual data granules (files) for answering queries because they rely on metadata conforming to the SPASE data model. In fact, the SPASE model has been adopted by the NASA-funded VxOs as a standard for describing resources in order to facilitate data search and retrieval across the space physics data environment. Without SPASE metadata, the VHO/VMO middleware would not work, so the researchers are actively participating in the SPASE development. These efforts lead to the release of a significantly improved SPASE model version 2.0.0, released on April 29, 2009, and continued with several bug-fix releases up to the version 2.0.2, released on November 20, 2009. The 2.0* model line incorporates significant changes in the SPASE model necessitated by the VxO findings and is expected to be the primary SPASE version used within the VxO environment.

The VHO/VMO middleware was created as an interconnected collection of components that keep track of and process metadata, and answer

data queries via a web interface and, in the future, an Application Programming Interface (API). All harvested metadata are stored in a registry before ingestion into a PostgreSQL database. During 2009, the middleware was continuously updated to reflect developments in the SPASE model and its anticipated future directions. The most significant design change was the implementation of SPASE Query Language (SPASEQL) for passing queries and results both internally and externally. However, this change brought increased query processing complexity and slowed down processing times; thus, further optimization work is necessary.

The VHO/VMO teams developed and deployed a prototype of a query language for exchanging queries and results among VxOs and related services. This SPASEQL has been accepted by the VxO and SPASE communities as an important common and unifying element of the VxO environment because its adoption would lead to a standardized information exchange of SPASE and SPASE-related information. The VHO/VMO interfaces now offer to save the queries and/or result sets in the SPASEQL format, and then import them or just the matching time intervals to populate new queries. Thus, it is possible, for example, to obtain results via the VMO, save them and then load them into the VHO as constraining time intervals for a heliospheric data search. Although the VMO and VHO are still under heavy development and lacking quite a number of data products, the GEST researcher attempted to increase the VxO research utility by adding spatial-temporal plots of results (matching time intervals) and demonstrate this feature on a THEMIS magnetotail study, which was presented at the 2009 AGU Fall Meeting.

Merka also collected and/or identified a large number of bow shock crossings from various spacecraft (currently 1009 for WIND, 11455 for IMP8, 1020 for Interball-1, 884 for MAGION-4, 2500 for HEOS-2, 813 for Geotail, 6660 for THEMIS 520 for Cluster) to be used for bow shock modelling that will result in a new generalized 3-D magnetosheath model.

Objectives for the Coming Year

The major task of the upcoming year will be the continuing internal and API implementation of the SPASE Query Language and collaboration with other VxOs, and the SPASE consortium on the data model and SPASEQL evolution. This will allow Merka to focus on speed optimization of data searches, interface usability improvements and a better integration of VMO/UCLA and VMO/GSFC search interfaces. Additional data products will be ingested in metadata registries and databases. The search functionality will be enhanced by allowing event queries using bow shock and magnetopause crossings, for example.

His next task will be to help the VWO group to implement their middleware based on the VMO/VHO results. Finally, a new bow shock model will be created from the extensive shock-crossing database collected.

Task 612-67-235: **Development of Virtual Observatories for Heliophysics**

GEST Investigator: Thomas Narock

Collaborators: Jan Merka (PI, GEST), Adam Szabo (GSFC 672)

Description of Research

The NASA Recommended Roadmap for Science and Technology 2005-2035 (http://sec.gsfc.nasa.gov/Roadmap_FINALsrc.pdf) places a focus on system science. There is a spotlight on looking at the Sun-Solar System connection as a comprehensive system and thus investigating the linked phenomena of the cosmos. In order to accomplish such a task, the data from a fleet of heliophysics spacecraft must be made to interoperate and be used as a collective whole. This is the task of the newly formed Virtual Observatory (VO) program within NASA Heliophysics. Specifically, the VO program has divided the spatial region into

sub-domains with a VO to serve as a single point of data access for each sub-domain; that is, each VO will unify its respective sub-domain and provide a one stop search and retrieval system capable of finding distributed and heterogeneous data. This task focuses on the magnetospheric community, their data, and ongoing efforts to deploy technical infrastructure that supports the VO program objectives.

Accomplishments during the Reporting Period

One of the prime objectives of the NASA Heliophysics data environment is to enable communication among the VOs, which will allow the discipline-specific VOs to be used as a collective whole. Such communications will enable researchers seamless online access to data that can be used to address global cross-disciplinary problems in Heliophysics. The community has tasked GEST personnel to develop and deploy a mechanism to enable this communication.

During this reporting period, the GEST researchers revised the software implementation of this communication based upon community feedback. Further, GEST personnel deployed this software at two of the Virtual Observatories, demonstrating cross-disciplinary searches over large quantities of data. Such demonstrations showed that previously conducted manual searches could now be done orders of magnitude faster. In addition, GEST personnel utilized the new communication software to connect VOs to other services within the community and further extended the search and retrieval capabilities for users.

Additionally, Narock and fellow researchers served as advisors to the nascent Virtual Waves Observatory (VWO) project. GEST personnel were specifically sought out for their expertise in designing and developing VO infrastructure. As a result, the GEST researchers were tasked with being Co-Investigators on the recently awarded VWO proposal. During this reporting period, GEST personnel conducted their first duties in this role by helping to design and build the foundations of the VWO.

Objectives for the Coming Year

During the coming year, Narock and colleagues will work to unify more pieces of the heliophysics data environment. They will deploy the newly defined communication standards at key points throughout the data environment. As GEST personnel are active researchers in the magnetospheric community, they will continue to identify new data products for the VO as well as use the VO to conduct magnetospheric research. Their aim is to increase the science that can be accomplished via VOs and to demonstrate their efficacy by using them in their own research.

Task 672-109-377 **Intergovernmental Personnel Act (IPA) Agreement**

GEST Investigator: Lynn Parnell

Description of Research

Parnell manages the day-to-day operations and an expansion (described below) of the NCCS HPC Center at NASA Goddard Space Flight Center. He is responsible for managing the NCCS budget, assigning work tasks to staff, and reporting to the CISTO Chief. Parnell leads the development and implementation of a comprehensive program management plan in consultation with other CISTO staff. He provides direct leadership and oversight to the Government Staff. In addition to his management duties, he leads and collaborates in background studies and the development of an Analysis of Alternatives (AA) for providing computing resources for Climate Simulation at GSFC. The AA considers advantages and disadvantages of existing strategy, proposes a range of feasible alternatives and explores advantages and disadvantages - cost, schedule, risks - associated with each alternative.

The NCCS is developing and implementing a strategic plan to vastly expand and extend support to NASA earth and space scientists. The expansion will increase the amount of HPC

compute cycles and data storage available. The extension will provide additional services to the user community in the areas of data publication and data analysis and visualization, particularly supporting extremely large data sets resulting from climate and weather simulation.

Accomplishments during the Reporting Period

Parnell began the IPA assignment as NCCS Lead in September. The assignment requires the transition of NCCS management duties previously performed by the GSFC CISTO Chief, allowing the latter to focus on strategic HPC, IS, Center and Agency issues and planning. A gradual transfer of management duties of NCCS operations was initiated to minimize disruption of critical NCCS work and support for ongoing earth and space computational science. Parnell's assumption of day-to-day operations and management of the NCCS has proceeded smoothly and effectively, as designed. Major contract support revisions have been accomplished and are continuing in consonance with CISTO directives for streamlining and refocusing operations to facilitate major expansion of computational resources within in-guide budgets. A substantial addition to HPC hardware was made using ARRA funding, resulting in almost 40% increases in processor core count and peak performance of the NCCS flagship HPC cluster, Discover.

The NCCS AA development task progressed as planned, producing preliminary results which include assessment of alternative organizational and operational approaches of four other major HPC centers having similar missions to that of the NCCS. An evaluation workshop was conducted to gather consensus opinions from external, as well as NASA internal, experts in management of HPC centers. Results of the workshop include preliminary decisions regarding preferred organizational and operational alternatives and a decision to hold another evaluation workshop with external stakeholders and HPC customer focus.

Objectives for the Coming Year

Parnell's first objective is to complete the assumption of management duties of the NCCS from the CISTO Chief. Second, the revision of option years two and three of the operations support contract will be completed. He will also lead the integration of the SIVO support contract into the CISTO and/or NCCS will be undertaken. Another major expansion in computational hardware for the Discover cluster will be completed and plans for long-term growth in high end computing hardware, storage systems and software will be developed. Finally, development of the expanded and refocused charter of the NCCS will be completed.

NASA Grant:	**Dynamics of eastern Mediterranean, Sea Level and altimetry Calibration-validation (DynMSLaC) (NNG05GO31G)**
NASA Grant:	**Global Sea Level in a Changing Climate: Reference Frames, Data Analysis, and Interpretation (NRA-03-OES-03 funding Kuzmicz's Task)**
NASA Grant:	**GRACE applications for TRF development and fundamental physics tests (NNH06ZDA001N-GRACE**
NASA Grant:	**Eastern Mediterranean Altimetry Calibration Network (e-MACnet) (NNX08AR50G)**
Task 698-112-394:	**Design and Optimization of NASA's Future Space Geodetic Networks in Support of GGOS**
GEST Investigator:	Erricos Pavlis
Collaborators:	Magdalena Kuzmicz-Cieslak, (GEST/JCET); Keith Evans (JCET); Peter Hinkey, Abhijit Patil, and Bhushan Sonawane, Pavan Kumar and Chandra Kumar Holenarasipur Suresh (undergraduate student assistants)

Description of Research

The research of Pavlis and his team focuses on the application of SLR, VLBI, GPS, and altimetry in Earth science covering many, often overlapping areas. They excel in analyzing SLR, VLBI and GPS data for the development and maintenance of global terrestrial reference frames and mean sea level time series. They lead an international team to design NASA's future space geodetic tracking networks and now spend 75% of their effort on this subject alone. Pavlis and his team, in collaboration with the Nat. Tech. University of Athens, Greece, have established and operate in the Aegean area six facilities for sea level monitoring, altimeter calibration and environmental observation for weather, oceanography and climate research, contributing to GLOSS and MedGLOSS.

Accomplishments during the Reporting Period

Pavlis chairs the International Laser Ranging Service's (ILRS) Analysis Working Group and Refraction Study Group. He is also a member of the Steering Committee for IAG's (Int. Assoc. of Geodesy) Global Geodetic Observing System (GGOS), the ILRS Governing Board and Central Bureau, the Int. Earth Rotation and Reference Frame Service (IERS) Directing Board, as well as Science Coordinator for the GGOS Bureau of Networks and Communications and Associate Editor of the journal *Celestial Mechanics and Dynamical Astronomy*.

During the past year, Pavlis and his team delivered an improved SLR product for the development of the new International Terrestrial Reference Frame 2008 (ITRF2008). The final version was submitted to ILRS and IERS in August 2009. In September 2009, Pavlis organized a ILRS workshop focused on the SLR tracking of GNSS targets for reference frame development, in Metsovo, Greece, bringing together all of the operators of current and future navigation constellations.

Pavlis and his team continue their collaboration with an international group of scientists and engineers seeking an improved measurement of the relativistic "frame-dragging" effect using a third cannonball satellite (LARES) that the group designed for the Italian Space Agency (ASI). The first LARES Int. Workshop was co-organized with the Italian team in July 2009 in Rome, Italy. LARES is now completed and

awaiting launch with a tentative date in late 2010 or early 2011.

Under the OSTM program, they continued with full operations at the KASTELI facility, including the connection to METEOSAT and the EUMETSAT web-based database. They have now instrumented four more sites in the eastern Mediterranean area, with only one left to complete the Eastern Mediterranean Altimetry Calibration Network (*e*-MACnet). Work on the Mean Sea Level (MSL) project focused on the assessment of geocenter errors on MSL variability.

The optimization of the future NASA tracking networks continued with simulations focused on developing a strategy that will use SLR-tracked GPS satellites to improve reference frame stability and disseminate the ITRF with sufficient accuracy to meet the requirements for MSL and climate change studies. Results were presented at the 2009 IAG Scientific Assembly in Buenos Aires, the Fall 2009 AGU meeting, the 2009 European Geosciences Union general assembly, the GGOS Retreate in January 2010, and several other meetings and seminars. Work now focuses developing a tracking scenario that will assure the quality of the results and comply with the tracking restrictions imposed by the U.S. Air Force. Additionally, Pavlis' team contributed in the authorship of chapters of two international publications (Pavlis *et al.*, 2009) that focus on GGOS and its role in MSL monitoring and studies of climate change.

Objectives for the Coming Year

As part of an ILRS Analysis Center, Pavlis and his team will continue to operate their automated weekly and daily data analysis and quality control, and generate annual contributions. Also, they will extend their solutions to include the new SLR targets that they reprocessed from historical data, extending the record to the early years of SLR tracking (ca. mid-1970s). This product will be submitted to ILRS and IERS for evaluation. They will continue to extend their analysis of GRACE data for temporal variations of gravity and test them in the reanalysis of SLR data in preparation for a new reanalysis.

They will continue their project collaboration eMACnet/GAVDOS with their European partners, and the routine operation of their six facilities. A paper detailing the results is in preparation for a special 2010 issue of *Marine Geodesy*. The final site will be deployed in 2010 and all communication packages will be upgraded in 2010, pending the recommendations from a EUMETSAT workshop that Pavlis will attend in March 2010. In the coming year, Pavlis will organize two workshops, the first associated with the LARES mission and a second one focused on the SLR tracking of GNSS targets for reference frame development.

Task 612-74-254: **Ionospheric Modeling**

GEST Investigator: Antti Pulkkinen

Collaborators: Michael Hesse (PI, GSFC 674); Maria Kuznetsova, Lutz Rastätter, Natalia Buzulukova (GSFC 674); Risto Pirjola and Ari Viljanen (Finnish Meteorological Institute, Finland); Ben Damsky and Luke Van der Zel (Electric Power Research Institute)

Description of Research

Geomagnetically induced currents (GIC) that affect the normal operation of long technological conductor systems on the ground, such as high-voltage power transmission systems, are one of the manifestations of space weather. The increasing dependence of humankind on technological systems, both on the ground and in space, emphasizes the importance of harnessing an understanding of the physical processes in the near-space to applications that can benefit the society. The core elements of such applications

are space weather forecasts, which are pursued in this research.

In this activity, an ambitious first-principles-based GIC forecasting system is being developed in collaboration with the North American power transmission industry. The forecasting system utilizes a large pool of state-of-the-art space physics models (hosted at NASA/GSFC) that enable propagation of the information obtained from the solar observations to the surface of the Earth, where GIC in individual power transmission system nodes are estimated. With the help of collaborators from the Electric Power Research Institute (EPRI), GIC estimates will be coupled to the so-called SUNBURST decision tool used by the North American power transmission industry. Also, the economic value of the forecasting system will be quantified. The GEST activity constitutes the central part of the Solar Shield project funded by NASA's Applied Sciences Program.

Accomplishments during the Reporting Period

The integration of the Solar Shield output to the SUNBURST decision support tool was completed during year 2009. The integrated system was presented and discussed during the Solar Shield team's visit to Tennessee Valley Authority (TVA) in Chattanooga, TN. TVA provided feedback on the experimental forecasting system that has been running 24/7 since February 2008. Further, Pulkkinen generated a Solar Shield project website that can be accessed at ccmc.gsfc.nasa.gov/Solar_Shield.

The baseline work on coupling the kinetic inner magnetospheric models to global MHD models was completed and the results were reported in the two papers published in peer-reviewed journals. The next step in this line of work includes extending the Solar Shield system to include the lower latitude ionospheric output from the inner magnetospheric models. Further, Pulkkinen studied geomagnetically induced current phenomenons at the low latitudes with Japanese colleagues.

The GEST investigator spent a substantial amount of time supporting the Geospace Environment Modeling 2008-2009 Challenge. In the Challenge, systematic and quantitative evaluations of different geospace circulation modeling approaches were carried out. To facilitate an unambiguous and objective interpretation of the Challenge results, a particular focus was placed on systematic metrics-based analyses. The primary goals of the evaluations carried out in the Challenge were to address differences between various modeling approaches, evaluate the current state of geospace models, demonstrate effects of model coupling and grid resolution, encourage collaborations, and facilitate further model improvements. Pulkkinen has submitted two manuscripts about the work done in the Challenge to peer-reviewed scientific journals.

In July 2009, a team at NASA GSFC's Space Weather Laboratory was awarded a grant through NASA's Innovative Partnerships Program to study the space weather needs of NASA robotic mission operations. The GEST investigator was Co-I in the team. The key objective of the project was to develop a document that outlines NASA robotic mission operations requirements for specification and assessment of space environment conditions. To accomplish the objective, Pulkkinen organized a two-day workshop on September 16-17, 2009 at GSFC, and he was the lead author of the requirements document prepared as a result of the workshop.

In addition to participation in power grid- and NASA operator-related activities, the GEST investigator supported Space Weather Laboratory's work with the US Air Force Weather Agency. In this role, in collaboration with UMBC's Department of Computer Science and Electrical Engineering, Pulkkinen created a novel machine vision-based technique to model Coronal Mass Ejections (CMEs). This new CME modeling tool will be used in a semi-operational fashion in the work with the US Air Force. The tool is documented in a paper that was published in the peer-reviewed *Solar Physics* journal.

Objectives for the Coming Year

The GEST investigator will continue supporting Space Weather Laboratory's collaborative

activities with NASA mission operations, US Air Force and electric power transmission industry. A significant portion of this work will involve transitioning newly developed scientific products into semi-operational space weather regime. The work will require coordination between modeler, customer and service provider (such as Space Weather Laboratory) activities.

Pulkkinen will continue to work on using ionospheric output from the inner magnetospheric models in power grid operations-related applications. This will include new theoretical work on dealing with asymmetric magnetospheric situations and integration of the inner magnetospheric output into the Solar Shield system. This theoretical work will be published in a peer-reviewed journal.

Additionally, Pulkkinen will continue to pursue the public outreach aspect of the space weather research via popular articles and possible space weather-related shows like that on SoS. He will continue to look for new opportunities to supervise and mentor students interested in space weather research and in natural sciences.

Task 670-108-374 **Modeling neutrals and ions that are generated from collisionless exospheres of planetary bodies**

NASA Grant **DREAM: Dynamic Response of the Environment At the Moon**

GEST Investigator: Menelaos Sarantos

Collaborators: James A. Slavin (GSFC 670.0), Rosemary M. Killen (GSFC 693.0), Mehdi Benna (GEST, GSFC 699.0), Scott A. Boardsen (GEST, GFSC 674.0), Matthew H. Burger (GEST, GSFC 693.0), Stefano Livi (Southwest Research Institute), William E. McClintock (University of Colorado), David Shriver (UCLA), Pavel Travnicek (UCLA)

Description of Research

The specification of the Moon's rarified exosphere is one of two major objectives of this multi-institutional team of experts funded by the NASA Lunar Science Institute. As a Co-Investigator, Sarantos quantifies the relative contributions by the solar wind, ultraviolet photons, and micrometeorites in producing the lunar exosphere. Following their validation with telescopic observations of sodium, exospheric models are used to estimate the abundances of other undetected exospheric constituents and to determine the chance of their discovery with *in situ* and remote sensing spectrometry data from orbit. Results are important both for mission planning and for interpretation of the expected measurements.

Accomplishments during the Reporting Period

In a study that appeared in *Icarus*, Sarantos and co-aauthors demonstrated that solar wind ions create an enhancement in volatile sodium atom release from the lunar surface. Sarantos and co-authors analyzed a large set of ground-based telescopic sodium exosphere observations and compared the observed sodium intensity, corrected for geometrical effects, to the prevailing UV photon and solar wind environment during the time of the observation. The dominant sodium release process is called photon-stimulated desorption (PSD), where an incident solar UV photon is energetic enough to break the sodium/regolith bond, releasing the sodium into free space. It was found that, when the Moon was in the terrestrial magnetotail (low ion concentration environment), sodium intensity levels closely matched the levels expected from models of the PSD process. However, when the Moon was in the solar wind (high ion concentration environment), the exospheric sodium intensity levels increased by factors of 2–3 above the levels that can be explained by photon–stimulated desorption. The researchers concluded that the solar wind ions are enhancing the desorption process by weakening the existing sodium/regolith bonds or increasing sodium levels by sputtering from multi-charged ions. The study included an

assessment of the contributions to sodium by impacts, but excluded the effects on source rates of atoms rebounding upon contact with the surface. This effect will be studied next.

In a follow-up study, Sarantos simulated the expected release processes for several undetected lunar exospheric constituents. His results indicate that, within uncertainties in the micrometeroid influx and the sputter yield, impact vaporization and ion sputtering contribute equally to the release of exospheric refractories (*e.g.*, Mg, O, Ca, Al, Fe, Ti) for fluxes typical of the solar wind at 1 AU. Consequently, several microphysical parameters describing the interaction of exospheric particles with the surface can be determined from an orbital platform such as the proposed Lunar Atmosphere and Dust Experiment Explorer (LADEE) mission. Counts and/or radiance for species that do not condense from gas to solid states following hypervelocity impacts should vary by a factor of two as the Moon enters and then exits the Earth's magnetosphere. In contrast, species for which condensates or molecules form will exhibit steeper variations during passages through the magnetosphere, as they will be dominated by the sputtering source which varies by a factor of ten. The modeled phase space density of exospheric neutrals revealed that, as a result of the collisionless nature of the exosphere, detection of sputtered ejecta with neutral mass spectrometry is possible only for off-ram pointings. This is contrary to thermalized ejecta, which are best observed by pointing the LADEE neutral mass spectrometer toward the ram direction. Convolution of the model density with the instrument response function for different boresights shows that sodium from photon-stimulated desorption and oxygen from impacts should yield detectable counts for integration times ≥ 200 s.

Objectives for the Coming Year

Sarantos will conclude his simulations regarding the detectability of lunar exospheric constituents by the LADEE probe and submit them for peer review. Similar to the work done for neutral mass spectroscopic measurements, best-pointing scenarios will be assessed for the line-of-sight measurements and compared to the "background" of coronal zodiacal light and, closer to the horizon, exospheric dust scattering. The investigator will then re-examine the agreement between telescopic sodium observations and his models by including refinements, such as multiple "hops", that particles may experience following their interaction with the lunar surface. He will integrate his models with those by other team members in an effort to build "Supermodels" of the lunar environment that will treat the lunar plasma, dust and exosphere components self-consistently.

Task 674-110-384 **Ionosphere-Thermosphere Models at Community Coordinated Modeling Center**

GEST Investigator: Ja Soon Shim

Collaborators: Michael Hesse (PI, GSFC 674); Maria M. Kuznetsova, Anna Chulaki, Lutz Rastaetter (GSFC 674)

Description of Research

The Community Coordinated Modeling Center (CCMC) is a multi-agency partnership that hosts a set of state-of-the-art space science models ranging from the solar atmosphere to the Earth's upper atmosphere. The CCMC provides access of the models to the scientific community through a web-based and Runs on Request system by which researchers can readily request simulations to conduct scientific studies for time intervals of interest and a broad range of conditions. The CCMC also provides a variety of modern, visualization and analysis tools to enable users to work with the output of requested model runs. Model output can be specifically tailored for easy comparison with

observational data to facilitate data analysis and model validation. Using the ionospheric and/or thermospheric measurements, the ionosphere-thermosphere models at CCMC, such as CTIP (Coupled Thermosphere Ionosphere Plasmasphere) Model, USU-GAIM (Utah State University-Global Assimilation of Ionospheric Measurements), TIE-GCM (Thermosphere Ionosphere Electrodynamic General Circulation Model) and SAMI2 (Sami2 is Another Model of the Ionosphere), and new models to be hosted in the near future will be tested and validated.

Accomplishments during the Reporting Period

The NCAR (National Center for Atmospheric Research) Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) is a comprehensive, first-principles, three-dimensional, non-linear representation of the coupled thermosphere and ionosphere system that includes a self-consistent solution of the low-latitude electric field. The model solves the three-dimensional momentum, energy and continuity equations for neutral and ion species at each time step, using a semi-implicit, fourth-order, centered finite difference scheme, on each pressure surface in a staggered vertical grid. It has 29 constant-pressure levels in the vertical, extending from approximately 97 km to 500 km in intervals of one-half scale height, and a 5° x 5° latitude-longitude grid, in its base configuration. The TIE-GCM model has been installed on the CCMC computers by the GEST investigator and the model is ready to be used by the community for scientific studies.

In order to compare performances of available ionospheric models at CCMC, 3D simulation results of USU-GAIM, TIEGCM, and CTIP during AGU storm (December 14-15, 2006) have been obtained. In particular, global electron density at a height of 350km as a function of geographic latitude and longitude, and electron density at 270° longitude as a function of height and geographic latitude were derived by three models and compared with each other. For the simulation, time dependent input parameters were used. The results show noticeable differences. One main reason for the differences is that the USU-GAIM model is capable of assimilating data from a variety of data sources, including *in situ* electron densities from satellites, bottomside electron density profiles from ionosondes, and total electron content (TEC) measurements between ground receivers and the GPS satellites, while the other two models do not assimilate the ionospheric measurements. To better understand the possible cause of the differences among them, further investigations using the ionospheric measurements will be carried out.

Objectives for the Coming Year

Shim's first goal is to provide CCMC users with access to the TIE-GCM model through a web-based Runs on Request system. Second, the latest versions of the existing ionospheric models will be provided to the scientific community, for example CTIPe (Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics), which is the latest version of CTIP and will be running in real time at CCMC. In addition, the researchers plan to host new ionospheric models including GITM (Global Ionosphere-Thermospere Model) and JPL/USC GAIM (*Jet Propulsion Laboratory/ University of Southern California)* Global Assimilative Ionosphere Model). Finally, the validation study will be performed by comparing model results with the ionospheric measurements, such as electron density, neutral density, and total electron content.

Task 698-83-285: **Swath Laser Altimetry Instrument Incubator Program and Ice Sheet Research**

GEST Investigator: Christopher A. Shuman

Collaborators: Dr. David J. Harding (PI, GSFC 698); Scott Lutkcke (GSFC 698), Dorothy K. Hall and Joey Comiso (GSFC 614.1), Phillip Dabney and Bryan Blair (GSFC 694), Michelle Hofton (UMCP), and Vijay P. Suchdeo (Sigmaspace at NASA/GSFC)

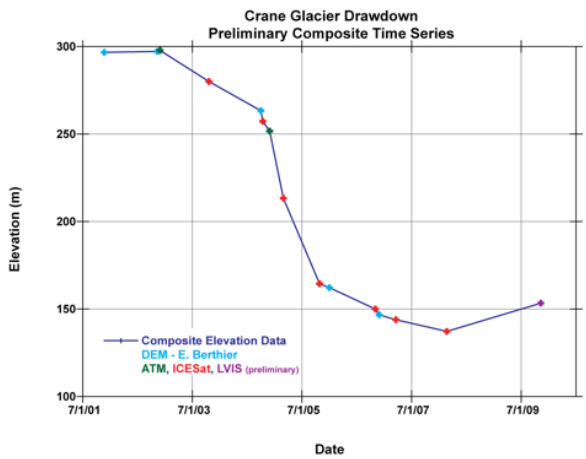
Description of Research

Last year's Instrument Incubator Program effort (CS D. Harding, PI) was completed in 2009, in which Shuman supported laser testing of the Slope Imaging Multi-Polarization Lidar (SIMPL) including the vexing question of green (532 nm) vs. infrared (1064 nm) laser energy penetration into snow and ice samples. Both breadboard and operational instrument testing were conducted at GSFC, and flight testing on the NASA Lear 25 aircraft was conducted over a variety of terrain near NASA Glenn Research Center (GRC). Further use of SIMPL data is anticipated in support of the ICESat-2 SDT activity as well as Operation Ice Bridge (OIB, in 2010). In addition to participating in the planning for long-range aircraft flights over Antarctica on the NASA DC-8 in support of the Land, Vegetation, and Ice Sensor (LVIS) for OIB, Shuman helped acquire data on a number of flights from Punta Arenas, Chile, including a large outlet glacier he has been studying for many years. In addition, he has continued to study ICESat altimetry data over large subglacial lakes in Antarctica. Supported by independent multi-year GPS data from Vostok Station, Shuman has identified a residual received energy altimetry error (up to ~20 cm) due primarily to waveform saturation that persists in the latest ICESat-1 data. Temperature studies for locations in Greenland are another area of ongoing activity. Additional work on ice sheet, ice cap, ice shelf, and outlet glacier proposals (currently and expected to be funded) support the above activities as well as producing high-quality science results, presentations, and publications. An education and outreach component in support of these activities at meetings and through press materials is also expected.

Accomplishments During the Reporting Period

Shuman's research shows dramatic drawdown on the Crane Glacier (Antarctic Peninsula) over 2001-2009. A combination of elevation data from the Ice, Cloud, and land Elevation Satellite (ICESat), Airborne Topographic Mapper (ATM), imagery-derived DEMs, and additional data from the Land, Vegetation, and Ice Sensor (LVIS) data show how this large glacier's elevation has responded over time – losing over 150 m in elevation and only recently regaining some elevation near its new terminus position - possibly due to recently more extensive sea ice conditions in the area (see graphic below). These substantial losses have progressed up the Crane Glacier's drainage, suggesting that the entire system has responded to downstream events; this result was updated at the Fall AGU meeting during a talk. Repeated mapping of the LVIS coverage in this area on the DC-8 in late 2010 will enable a full flow system assessment, something that has not been possible to date with other altimetry data. For context, Crane Glacier currently flows directly into the Southern Ocean but the Larsen B ice shelf restrained it until that feature substantially collapsed in early 2002 (Scambos *et al.*, 2004). Nearby and similarly-sized glaciers that still flow into the remnant of the Larsen B (Flask and Leppard Glaciers) do not show similar ice elevation changes indicating the importance of ice shelf 'back stress' on glacier flow and ice sheet mass balance. This analysis has been expanded through the use of a colleague's ASTER/SPOT DEM differencing with the DEMs calibrated by the ICESat and ATM altimetry data. The LVIS data was acquired during Operation Ice Bridge long-range flights from Punta Arenas, Chile on November 5, 2009. Shuman is supporting the DESDynI Working

Group and the ICESat-2 SDT to help them develop a 3-year minimum, 5-year optimum mission plan in order to capture such dynamic glacier changes.



Sadly, it now appears that ICESat-1's last operational laser expired in October 2009. With its final operational periods in 2008-2009 complicated by partial track patterns and/or very low transmit power, further efforts have also been made to understand the ICESat-1 time series and its inherent elevation biases over the past year. As part of the ICESat-1 Precision Range Determination (PRD) study group, the unresolved elevation error due to a received energy detector saturation problem, initially demonstrated at Lake Vostok, has now been extended through ICESat's last operation period (2F). In addition, Shuman's analyses of ICESat data have confirmed that East Antarctica's subglacial Lake Vostok is not changing in elevation; this result was updated at the Fall AGU meeting. Crucially, the Lake Vostok 'no elevation change' result has been independently confirmed by multi-station GPS data from 2000-2008 operating near Vostok Station. The reason this result from ICESat is a significant accomplishment is Shuman and colleagues are now using the Vostok area's ~zero elevation change to calibrate and validate the 2003-2009 ICESat data. Detailed studies of the ICESat data reveal received energy-dependent accuracy variability up to ~20 cm that still impact the accuracy of elevation change trends that are the basis of the ice sheet mass balance assessments, the mission's ultimate goal (http://icesat.gsfc.nasa.gov/). The PRD activity, led by Dr. Harding with significant help from Vijay Suchdeo, has provided guidance to engineers developing the ICESat-2 mission.

In addition, a mass balance study that has been presented and published shows that a small ice cap in NW Iceland, Drangajökull, has been lowering, although the trend is poorly defined due to seasonal variations in accumulation/ablation and altimetry losses due to clouds. This study uses a combination of ICESat repeat profiles from 2003-2008 and an April 2005 ground traverse GPS-derived DEM. This research documents factors that challenge the utilization of ICESat data such as steep slopes and frequent cloud-cover.

A paper that progressed through peer-review to publication last year documenting temperature changes and melt extent increases across Greenland (Hanna *et al.*, 2008) is being extended with multi-sensor and multi-station AWS data. This is a continuation of temperature trend studies in Greenland that was begun at the GISP2 site in the 1990s and continues with the CDR work led by Dorothy Hall and supported by Joey Comiso. In addition, the ongoing refinement of ICESat's altimetry data will enable better characterization of East Antarctica's 'megadune' features. The effort to understand the accumulation variation from upwind dune face to the zero-accumulation backslope, as well as the speed with which these antidune features migrate, began with Fahnestock *et al.*, (2000) and continues using ICESat data on a newly funded ROSES 2009 proposal.

Finally, although developmental issues delayed the SIMPL IIP project's ultimate success, the initial breadboard laser unit's data against the earth, snow, and ice samples acquired in the project have helped define green (532 nm) vs. infrared (1064 nm) laser penetration into snow and ice samples. Ground and flight tests have confirmed its theoretical abilities to discriminate target types, and flight tests have obtained swaths of elevation data in two wavelengths and at two polarizations on the NASA Glenn Learjet 25. The goal of retrieving elevations at the decimeter accuracy level from a variety of

natural targets including vegetation covered land, open water, lake ice, and snow-covered ground has been achieved. Funding is being pursued that will advance the overall concept toward polar aircraft missions including Operation Ice Bridge flights and eventually space-based operations.

Objectives for the Coming Year

The primary science goal for the coming year will be submitting several ongoing activities for publication, including the Crane Glacier drawdown story, and the recently funded ROSES 2009 proposal on the geometric character of East Antarctica's megadune features. In addition, Shuman's objectives continue to include a significant PRD component in support of the final release (33) of ICESat-1 data given that the mission concluded altimetry operations in 2009. A specific goal of the PRD activity is addressing the residual error due to waveform saturation and publishing an explanation. This error, a function of detector performance degradation at higher-than-expected received energy levels, has significant consequences for the ICESat-1 mission goals, as well as the usage of this data as a 'baseline' for Operation Ice Bridge and the planned ICESat-2 and the DESDynI missions (http://www.nap.edu/catalog.php?record_id=11820). In addition, further testing of an effective 40 Hz 'cloud filter' for use in Antarctica and Greenland, as well as over smaller ice masses, remains a high priority activity. Both of these efforts should enable improved use of ICESat-1 data for mass balance studies as well as help to develop performance characteristics of the NRC Decadal Survey's ICESat-2 and DESDynI laser sensors.

Further activities in support of flight instruments are likely, including participation in planned Greenland and Antarctic long-range altimetry flights for Operation Ice Bridge. Additional proposals and investigations of available cloud-impacts on laser altimetry data are also likely. Finally, the funded CDR proposal (D. Hall, PI) is enabling development of temperature records from AVHRR and MODIS IR sensors across Greenland. Shuman is revisiting the Greenland Summit composite temperature record and plans to extend it back through the 1980s and forward to 2010 (Shuman *et al.*, 2001).

Task 698-103-352 **Investigation of non-tidal ocean signals in land observatory and satellite magnetic measurements**

GEST Investigator: Kumar Singh

Collaborators: Weijia Kuang (GSFC 698), Terence Sabaka (GSFC 698), Alexei Kuvshinov (ETH Zurich, Switzerland)

Description of Research

A central goal of the project regarding electromagnetic induction of the non-tidal ocean flow is to model the ocean variability using a high-resolution ocean model, for approximately 10 years, and correlate the signals with observatory magnetic data. The static part of the ocean-generated magnetic fields is difficult to separate from the crustal magnetic field. However, the accuracy of the crustal magnetic fields has considerably increased in the past decade, owing to better data and processing techniques. Considering the fact that the geomagnetic field models will undergo drastic improvements in accuracies and resolution with the arrival of magnetic data from the upcoming Swarm mission, it is imperative to model and remove the non-tidal part of the ocean magnetic signals from satellite and observatory magnetic data. Hence, modeling and detecting the magnetic fields of the non-tidal ocean motion in land- and satellite-based magnetometer records is important.

Accomplishments during the Reporting Period

The importance of the 3-D electromagnetic induction modeling effort is to understand the ocean variability of a regional current from a high-resolution (0.25° x 0.25°) ocean model. The selected region of study is the Kuroshio,

which is the western boundary current of the north Pacific. The current originates north of Taiwan and continues along the eastern coast of Japan. The monthly mean of the north and east components of the Kuroshio ocean current velocity field are obtained from the global OCCAM (Ocean Circulation and Climate Advanced Modelling project) oceanic circulation model produced by National Oceanography Centre, Southampton. The monthly magnetic anomalies between 1986 and 2002 are computed in a spherical Earth model with a 3-D EM induction model. The temporal variation in the strength of the vertical component of the magnetic field induced by the Kuroshio Current is approximately ±8 nT at the ocean surface. The calculated magnetic signals are weak in comparison to the strong residuals (10-20 nT) in the magnetic observatory data. The spatial variation over eastern Japan along the Kuroshio currents show magnetic anomaly features 2-5 degrees wide.

As the ground magnetic observatories could not detect ocean-induced magnetic anomalies, their flow-generated magnetic fields depend on electrical conductivity-weighted flow integrals and thus have the potential to provide these critical constraints. The altitude of the Global Hawk platform (20 km) is ideal for resolving mesoscale (10-100 km) features, and thus offers a unique opportunity to explore the potential of magnetic methods for ocean remote sensing. The simulation studies, such as those demonstrated here, will help extract the motion induction signals and will not only support the lithosphere imaging of the Earth's crust, but will also pave the way to develop new capabilities for magnetic remote sensing of mesoscale ocean flows. The results were presented at the AGU Fall Meeting in San Francisco, CA in December 2009. A manuscript is being prepared to submit the results to the leading geophysical journal.

In addition, in 2009, Singh has published as author and co-author in many international journals the studies related to the interpretation of Earth's lithosphere in terms of structure, detectability was analyzed with a flight simulation study. Singh's study also indicates that motion-induced magnetic anomalies are very sensitive to ocean current model resolutions. Flight simulation studies along the eastern coast of Japan for an altitude of 20 km were done to detect the measurability of the induced signals. The 20 km altitude for simulation studies was selected due to the proposed flying altitude of NASA's Global Hawk aircraft with the Venture Class missions supported by NASA to study and explore the Earth's tectonic features at wavelengths not explored earlier. The results obtained from the simulation studies showed that the weak induced signals from the Kuroshio currents, largely undetected in ground observatories, could be detected at the altitudes. Although the results were computed using synthetic data computed from a global comprehensive magnetic field model, it showed that aeromagnetic surveys are very promising in detecting these weak signals.

The implications for detecting spatial-temporal variability of ocean signals are multifold. The composition and dynamics of tectonic units from satellite magnetic data.

Objectives for the Coming Year

Singh's first objective is to modify and implement the ocean flow and induction model and reassess the conductivity properties of major oceanic currents of the world. Since higher resolution models (*e.g.* 1/12° and higher) are now available, it may require simulations to be carried out on massively parallel computing systems, thus code porting and modification across different computing platforms. Second, he plans to perform exploratory studies on geomagnetic constraints to oceanic flow models. In particular, he will identify the differences between the simulation results (from various oceanic flow models) and those to be obtained from surveys (to be planned as a venture class mission). The results will provide the needed geomagnetic constraints.

Task 699-105-358 **Extraction of organic matter from martian analogs and application to future in situ missions to Mars**

GEST Investigator: Fabien Stalport

Collaborators: Paul Mahaffy (PI, GSFC 699); Daniel Glavin and Jennifer Eigenbrode (GSFC 699)

Description of Research

The search for organic compounds at Mars is a primary objective to determine if a prebiotic chemistry or even biology emerged on this planet. To support this quest, laboratory studies are necessary for defining *in situ* experimental strategies. One of the best strategies is to investigate the organic matter diversity, and concentration from martian analog samples. The Svalbard Islands (North Pole), the Atacama desert, Rio Tinto and JSC Mars 1 (a martian stimulant soil) represent the best martian-like environments on Earth since the climate is arid/hyper arid. The extraction of organic compounds from these analogs using a wet chemical one-step derivatization method is similar to the extraction protocol that will be used by the Sample Analysis at Mars (SAM) experiment on the Mars Science Laboratory (MSL). The objective is to demonstrate the capability for extracting trace levels of organic compounds from martian-like environments and the potential of this technique for discriminating between organic molecules of abiotic or biotic origin on Mars.

Accomplishments during the Reporting Period

While one step derivatization, often used in laboratories, has never been performed in space, an automatic derivatization system compatible with space constraints will be onboard the SAM instrument in 2011 (Cabne *et al.*, 2004) and also part of the Rosetta mission in 2014 on its way to Comet 67 P/Churyumov-Gerasimenko (Thiemann and Meierhenrich, 2001). This wet chemistry step has been added to advance the organic detection capabilities beyond Viking mission (1976). Indeed, the pyrolysis of samples at high temperatures can volatilize solid organics from natural samples; nevertheless, the pyrolysis technique can fragment some complex organic compounds into smaller volatile fragments that may be difficult to interpret by mass spectrometry (*e.g.* simple amines). In addition, even chemical compounds that do not fragment can be hard to extract and analyze by chromatographic techniques. Polar organic compounds that contain labile hydrogen are typically of low volatility, due to their tendency to self-associate or to associate with polar liquids or solid media (such as martian samples or even the stationary phase of the chromatographic columns) through hydrogen bond formation (Rodier *et al.*, 2001; Buch *et al.*, 2003; Rodier *et al.*, 2005). The one step derivatization is an interesting alternative to extract more polar organic compounds and will minimize their decomposition during direct pyrolysis. Derivatization increases polar analyte volatility and solubility in non-polar fluids; therefore, one-step derivatization reactions are of tremendous importance for *in situ* analysis of polar organic compounds, including amino and carboxylic acids.

Several methods for chemical derivatization have been proposed for spaceflight and employed for laboratory experiments. N-methyl-N-(tert-butyldimethylsilyl)-trifluoroacetamide (MTBSTFA), a silylating agent, and tetramethylammonium hydroxide (TMAH), a reagent used to effect the thermochemolysis reaction (chemical reaction at high temperatures), have been targeted since they react with a wide range of molecules (amines, acids, alcohols, amino acids, sugars, lipids, proteins, kerogens), give a sensitive response in MS, and fulfill space-flight requirements, including temperature and radiation stability. Several samples from Atacama and Svalbard have been investigated. Experiments have essentially focused on derivatization and extraction by MTBSTFA. The extraction of

organics from biogenic carbonates from Svalbard has been successful; amino acids have been extracted from these samples. Conversely, the extraction of organics from samples from Atacama, Rio Tinto and JSC Mars 1 was not conclusive. The mineralogy of these samples has been pointed in order to understand these results. Rio Tinto and Atacama samples are more or less rich in water: Rio Tinto soil is mainly composed of hydrated sulphates, and hydrated phyllosilicates are present in the Atacama samples. MTBSTFA is very sensitive to the presence of water. Hence, these data indicate that MTBSTFA preferentially reacts with water molecules. For JSC Mars 1 samples, the presence of oxides could explain the total degradation of MTBSTFA and then its capacity for extracting organic molecules. Preliminary experiments also have been performed on Rio Tinto soil by TMAH extractions. Initial results indicate that TMAH is not affected by the presence of water such as MTBSTFA. Carboxylic acids and hopanoids have been extracted.

Objectives for the Coming Year

Stalport's first objective is to develop a new procedure for extracting organics from Atacama, Rio Tinto and JSC Mars 1 samples by MTBSTFA derivatization. A pyrolysis step will be added in order to sublimate and condense organics from these samples into a "cold finger". Then derivatization by MTBSTFA will be attempted directly on these organic molecules. The derivatization by TMAH will be also performed on Atacama, Svalbard and JSC Mars 1 samples. Finally, new samples from the Antarctic Dry Valleys (South Pole) will be added. The Antarctic Dry Valleys also represent one of the best martian-like environments on Earth, since the climate is cold and arid/hyper arid like on Mars. These samples represent different environments and different mineralogies, and the organic content is expected to vary considerably.

NASA Grant:	**Mapping Lunar Surface Electric Fields and Characterizing the Exospheric Dust Environment (NNX08AM76G)**
Grant:	**Observational and Theoretical Constraints on Lunar Surface and Dust Charging Processes (SA5568-11215)**
Grant:	**Lunar Surface Charging and Dust Transport during Extreme Space Weather Events (SA56609-11504)**
NASA Grant:	**Lunar Potential Determination using Apollo-Era Data (NNX08BA32G)**
NASA Grant:	**NLSI Dynamic Response of the Environment at the Moon (DREAM) (NNX09AG78A)**
NASA Grant:	**Optical Scattering Processes Observed from the Moon: Measurements, Models and Implications (NNX09AO79G)**
GEST Investigator:	Timothy J. Stubbs
Collaborators:	Yongli Wang (GEST), Michael R. Collier (695), William M. Farrell (695), David A. Glenar (New Mexico State University/ 693), Richard R. Vondrak (690), Rosemary M. Killen (695), H. Kent Hills (Adnet Systems, Inc./690.1), Jasper S. Halekas (UC Berkeley), Gregory T. Delory (UC Berkeley/NASA Ames Research Center), Denis T. Richard (San José State University /NASA Ames Research Center), Anthony Colaprete (NASA Ames Research Center), Joseph. M. Hahn (Space Science Institute), John Marshall (SETI Institute4).

Description of Research

The various investigations of the near-lunar space environment aim to understand how solar irradiation and the ambient plasma environment at the Moon result in the surface becoming electrically charged, and, in turn, how this drives the transport of charged dust. The resulting exospheric dust is believed to scatter sunlight to produce the “lunar horizon glow” (LHG) that was reported during the Apollo era. A predictive modeling code, which simulates LHG and exospheric atomic emission lines in the presence of coronal and zodiacal light, is continuing to be developed. These phenomena likely occur on all airless regolith-covered bodies in the Solar System. This work is also important for lunar-based science and exploration activities, since the charged dust is known to be a nuisance, and could potentially be a hazard. Stubbs is a Participating Scientist with the Lunar Reconnaissance Orbiter (LRO) mission, and is affiliated with the Cosmic Ray Telescope for the Effect of Radiation (CRaTER) instrument team. As part of the LRO science team, he will map surface electric fields and characterize exospheric dust. He is also a member of the NASA Lunar Science Institute’s Dynamic Response of the Environment At the Moon (DREAM) team.

Accomplishments during the Reporting Period

A major milestone in the LRO-funded work has been reached with the development of the codes for calculating optical and plasma shadowing using digital elevation models (DEMs) produced from Lunar Orbiting Laser Altimeter (LOLA) topographic data. (Note, these codes can be adapted for use with other planetary and asteroidal DEMs.) The “plasma shadow” refers to a reference boundary for models of the lunar wake (expansion of plasma into the void formed in the solar wind downstream of the Moon). In addition, two different wake models have also been implemented, one that assumes the ambient plasma has a Maxwellian distribution function,

and another that assumes a Kappa distribution function. For the initial analysis of the influence of topography on the optical shadowing, plasma and surface charging environments, the time of the LCROSS impact at the South Pole was used as a test case. The resulting predictions for the optical shadowing at the impact site, as well as its visibility from the Earth, were supplied to the LCROSS team to assist with their analysis. So far, only relatively basic surface charging equations and the simpler Maxwellian wake model have been coupled with the DEM in order for the effects associated with each element to be readily distinguished and understood. More complicated surface charging and wake models will be included in the future (*e.g.*, including the secondary emission of electrons from the surface).

Stubbs has been assisting the LRO project team with planning the spacecraft maneuvers required for off-nadir pointing of the LRO cameras (LROC) and the Lyman Alpha Mapping Project (LAMP) instrument toward the limb in order to observe LHG during the Science Phase of the mission. Partly as an effort to help support such observations, he has been working with colleagues to develop a predictive code to simulate the optical scattering that will be observed at the Moon. This code has been used to make LHG predictions for the LADEE Ultraviolet Spectrometer (UVS) and the star tracker cameras that will orbit the Moon onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission. These predictions indicate that they will be able to detect LHG and distinguish it from both the bright background of coronal and zodiacal light (CZL), and the dominant emission lines from exospheric sodium. The LHG predictions were based on dust concentration estimates from Apollo era observations, which contributed the largest uncertainties in these predictions. The LADEE star tracker camera predictions will serve as a useful guide for the LROC observations of LHG, which will also be observing from 50 km altitude with broadband imagers (*i.e.*, the Narrow Angle Cameras (NAC) and the Wide Angle Camera (WAC)).

It has been suggested that the star tracker cameras on the Clementine mission also observed LHG, although this has been difficult to prove conclusively for several reasons, including the presence of the bright CZL background. The predictive code for simulating the optical scattering observed at the Moon includes the best available CZL map, which is based on a combination of observations from the Clementine star tracker cameras and sub-orbital rockets. Therefore, this predictive code is also being used to re-analyze the Clementine star tracker data in order to try to extract any LHG signal from the CZL background. Initial results indicate that there may be a weak LHG signal, but an assessment of the sources of scattered light within the star tracker cameras themselves needs to be carried out before any LHG detections can be made.

In support of possible dust detections by CRaTER, Stubbs has been investigating the dust environment at the Moon using results from the radio occultation experiments performed by the Soviet Luna 19 and 22 missions, which indicated the presence of a lunar ionosphere at the limb with a peak electron concentration of ~1000 cm^{-3} at a tangent height of ~10 km. These somewhat controversial electron measurements are far too high to be explained by any well known mechanisms, such as photo-ionization of exospheric neutrals. More recently, the Japanese Kaguya mission has made similar measurements that appear to be broadly consistent with the Luna observations. It has been suggested that charged exospheric dust might be accompanied by a substantial number of electrons, which could contribute to these high electron concentrations. Using the exospheric dust concentrations inferred from Apollo 15 coronal photography, he has estimated the concentration of electrons that would be associated with these photo-charged dust grains, which are referred to as “dust-electrons”. From a comparison of the various electron populations at the Moon with the Luna 19 observations, it appears that dust-electrons are the most likely dominant contributor to these high electron concentrations.

Significant progress has been made with the lunar surface charging studies using data from

the Suprathermal Ion Detector Experiment (SIDE) packages deployed on the surface during Apollo missions in combination with Lunar Prospector (LP) Electron Reflectometer (ER) data obtained from orbit. These datasets are complementary since SIDE is better suited to inferring surface potentials on the dayside, while LP ER is able to infer them on the nightside, and they overlap in the region around the terminator. Results from the analysis of the SIDE data indicate that there is a positive enhancement in the dayside surface potential as the Moon crosses the Earth's bow shock on the dawn flank from the magnetosheath to the foreshock region in the solar wind. This appears to be caused by an increase in the secondary emission of electrons from the surface due to a population of solar wind electrons that have been heated and accelerated by the bow shock. The LP ER data, meanwhile, has been used to investigate the surface charging and the secondary emission of electrons from the lunar surface on the nightside. In this case, these phenomena are highly dependent on how the incident plasma is processed in the wake region that forms downstream of the Moon.

Objectives for the Coming Year

In the coming year, most of the funding support for Stubbs will come from LRO, and so his focus will remain on the development of a comprehensive lunar surface charging model and the integration with the shadowing models and associated DEMs. This will also include the dissemination of the results from this coupling, as well as the fundamental improvements and enhanced scope of the surface-charging model. This will also be supported by the analysis of SIDE and LP ER data, as well as by activities related to the NLSI DREAM team. Stubbs will also continue to develop dust transport models, which will complement the search for LHG in images from the Clementine star tracker cameras.

Task 674-92-321: **CCMC Solar and Heliospheric Modeling**

GEST Investigator: Aleksandre Taktakishvili

Collaborators: Michael Hesse (GSFC 674), Peter MacNeice (GSFC 674), Maria Kuznetsova (GSFC 674), Antti Pulkkinen (GEST), Lutz Rastätter (GSFC 674)

Description of Research

CME is an ejection of material from the solar corona that can be detected remotely with a white-light coronagraph. The most severe geomagnetic storms are caused by CMEs that reach the Earth as ICMEs. ICMEs may disrupt the Earth's magnetosphere. They can result in damage to satellites, disruption of radio transmissions, damage to electrical power transformers and power outages. Knowing the arrival time of a CME and the magnitude of impact is very important in predicting space weather.

Scientific models are important tools in understanding physical processes in the solar system. The advantage of scientific modeling is that it provides a global view of a studied phenomenon. This is not possible using only satellite or ground observations. Models are used for space weather operators' applications and for forecasting. It is essential that the scientific community, operational users, and model developers are aware of model capabilities and limitations. Modeling results depend on the input parameters; therefore, it is very important to estimate the robustness of the model performance dependence on the uncertainty in the input parameters.

In this activity, the researchers performed uncertainty estimations for the ENLIL/Cone model predictions of arrival of CME shocks at Earth's orbit and the magnitude of impact on the magnetosphere. ENLIL/Cone model has two components: cone model for halo CMEs - an analytical method to determine the angular width, propagation orientation and radial velocity of halo CMEs using the SOHO satellite LASCO/C3 coronograph images (the method was developed and implemented at the CCMC by the GEST investigator); ENLIL - a time-

dependent 3D MHD model of the heliosphere, developed by D. Odstrcil. The results of the simulation are compared with the ACE satellite observations and the model robustness is studied.

Accomplishments during the Reporting Period

In the previous reporting period, Taktakishvili performed a systematic study of the physics-based ENLIL cone model results for 14 fast CME events (Taktakishvili *et al.*, 2009). The focus was on the arrival time of the ICME shock and the magnitude of the ICME impact on the magnetosphere, characterized by the magnetopause standoff distance. In the current reporting period, the GEST investigator studied the dependence of the CME shock arrival time and the magnitude of impact on the uncertainty in the input parameters: initial velocity of CME, cone angular radius, and CME material initial density. Three CME events from the previously modeled 14 CMEs were chosen: 1) "high" speed CME event of December 13, 2006; 2) "moderate" speed CME event of April 6, 2001; 3) "low" speed CME event of April 15, 2002. Each of the input parameters was varied by the factor of approximately 2. The influence of this variation on the model results was explored, as well as the influence of spatial resolution. The researchers found that uncertainty in the CME initial speed and CME cone angular width are the most important and second important parameters, respectively, for CME shock arrival time and magnetopause standoff distance. The uncertainty in CME density has the least influence on the model predictions. The window of uncertainty due to the approximately two-fold uncertainty in the input parameters was (-8, 8) hours for the arrival time, regardless of the CME initial speed. For the magnetopause standoff distance, the window of uncertainty is almost 2Re. They also found that the shock arrival time varies as a function of the model spatial resolutions used, while the magnetopause standoff distance is largely independent of resolution. A manuscript describing this work was submitted and accepted for publication in *Space Weather* (Taktakishvili *et al.*, 2010).

Taktakshivili transferred to NOAA the package of WSA/ENLIL/Cone model software for testing and future implementation as a forecasting tool for operations. This work is under progress. The significant accomplishment of this activity is that it connects the CME modeling to the end-user.

He collaborated with A. Pulkkinen and T. Oates in developing cone model parameters extraction routine from LASCO C3 images, based on pattern recognition scheme. The first paper on this issue was published in *Solar Physics* (Pulkkinen *et al.*, 2009).

The PI conducted validation of the solar-heliosphere part of the U. Michigan SWMF, available at the CCME. The results have been communicated to the model developers. This feedback is very important for the model improvement. The preliminary results on these studies were presented at the SHINE-2009 and 2009 Fall AGU conferences, and the corresponding publication is under preparation.

He also worked on the real-time implementation of the SWMF-solar-heliosphere model at the CCMC. This work is under progress. With already existing ENLIL real time simulation, this allows ensemble forecasting of the solar-heliosphere conditions.

The GEST investigator supervised a Ph.D. student from Denmark (Thea Falkenberg), who presented a paper at the 2009 Fall AGU conference and submitted a paper to *Space Weather* (Falkenberg *et al.*, 2009). Also, he gave a talk on Solar-Heliosphere models at CCMC at the Director's seminar of the NASA/GSFC Heliophysics Division.

Objectives for the Coming Year

Using ENLIL/Cone model, CME events that caused 35 most severe recent geomagnetic storms will be studied and modeled. The results of this work will provide important feedback to the model developers and operators. A paper will be prepared for publication in a scientific journal.

The work on the ensemble modeling of the background solar wind conditions at the Earth orbit, using the ENLIL and SWMF runs will be

continued using real time simulation. The validation of the modeling results will be continued. A paper will be prepared for publication in a scientific journal.

He will work on the validation of cone model parameters extraction routine from LASCO C3 images, based on pattern recognition scheme developed together with A. Pulkkinen and T. Oates. The work will be published in a scientific journal. Additionally, he will supervise and mentor summer students coming to CCMC and will continue to work on the public outreach aspect of the space weather research.

Task 915-50-193a: **Laboratory Investigations on Electrical Discharge and Methane Destruction in the Martian Atmosphere**

Task 915-50-193b: **VAPoR (Volatile Analysis of Polar Regolith)**

Task 915-50-193c: **Development of a Laser Desorption Mass Spectrometer and a Precision Subsampling System for Mars**

GEST Investigator: Inge L. ten Kate

Collaborators: Paul R. Mahaffy (PI, GSFC 699); Daniel P. Glavin (GSFC 699); William B. Brickerhoff (GSFC 699)

Description of Research

Methane has been detected in the martian atmosphere by means of different, independent techniques, from orbit (Formisano *et al.*, 2004) as well as earth-based telescopes (Krasnopolsky *et al.*, 2004). Different theories have been proposed to explain the variability in the amount of methane in the martian atmosphere. One proposed mechanism that could destroy methane is breakdown through electric discharge. This discharge could be induced by electric fields generated by dust particle interaction in dust storms and dust devils (Farrell, Delory, and Atreya, 2006). The primary focus of this research is to experimentally test these theoretical models in a dedicated simulation facility, not only focused on destruction of methane but also on formation of new species, *e.g.*, hydrogen peroxide.

VAPoR (Volatile Analysis of Polar Regolith) has been selected as one of the suitcase-sized instruments in the framework of the Lunar Sortie Science Opportunities.

VAPoR is a pyrolysis mass spectrometer for evolved gas analysis designed for both robotic and human missions, to analyze volatile species in the lunar regolith using a pyrolysis oven and a miniaturized time-of-flight mass spectrometer.

A laser desorption mass spectrometry instrument (LDMS) is currently under development at GSFC. The LDMS will be used to analyze rock samples, consisting of drill fines for their chemical and mineralogical composition. The fines are obtained using the precision subsampling system (PSS), under development as well, which uses a dentist drill-like drill to precision drill samples in the order of several milligrams from different layers in rock cores and samples, in order to distinguish between the different mineral phases in the rock. The PSS will furthermore consist of a sample transportation system that is currently being designed.

Accomplishments during the Reporting Period

Dust facility

In 2008, a simulation facility was developed and built to simulate dust devils in a martian atmosphere, and to measure the effect of the dust interaction and the electric field built up due to this interaction on the composition of this atmosphere. An internally mounted electrometer

is used to measure the electric field built up through the interaction between the dust particles. In this chamber, experiments were performed where Mars soil analogues, the JSC-1 Mars analogue (Allen *et al.*, 1998) and Salten Skov (Nørnberg *et al.*, 2009) were agitated with a rotating fan to create dust circulation. Further experiments were performed in which the dust was agitated by puffing gas onto the dust, lifting up the dust. The latter approach appeared to be the most successful in generating electric fields and was further explored. Preliminary results have been acquired with this method and were presented at the 2nd European Planetary Science Conference, September 2009. Experiments performed in 2006 on the discharge between spherical electrodes in a Martian atmosphere have been compiled in a manuscript and submitted to *Advances in Space Research*.

VAPoR
Using the breadboard developed in 2008, several samples have been analyzed and a manuscript is in press at *Planetary and Space Science*. A field version of VAPoR was built and successfully deployed during the International Lunar Surface Operation - In-Situ Resource Utilization Analog Test, January 2010 on Mauna Kea, HI. Funding for this field-testing was successfully obtained through the Field Science Analogue Testing program, a new program under ROSES. Results of this field-testing are being compiled in a manuscript for a peer-reviewed journal.

PSS
PSS work mainly consisted of more drill testing and designing a Mars simulation chamber for prototype testing. The chamber is currently being assembled and will be operational for testing in mid-2010. The PSS system and test results were presented as a conference paper at the Earth & Space 2010 Conference.

LDMS
Clay minerals have been discovered on the Martian surface, and on earth these minerals have been suggested to be deposits of organic compounds. Therefore a project has been initiated, within the LDMS testing campaign, to investigate the instrument capabilities by obtaining scientific data on the absorption of organic compounds onto clay minerals. First experiments included the detection of pure tryptophan, and tryptophan ground with Ca-montmorrillonite and kaolinite. Results of these experiments were presented at the annual fall meeting of the American Geophysical Union, December 2009.

Objectives for the Coming Year
LDMS: Ten Kate will participate in clay-organics adsorption experiments and analyze two organic compounds (tryptophan, phenylalanine) adsorbed onto two clays (Ca-montmorrillonite, kaolinite). She will define further work based on these outcomes, and plans to draft a related manuscript.
VAPoR: The GEST PI will prepare a manuscript on Mauna Kea field-testing. She will also prepare and deploy a field unit at AMASE field-testing campaign in Svalbard, Norway, and set up collaboration with Dr. Fabien Stalport (GEST/GSFC) on analyzing carbonates. She plans to review and revise a draft of the carbonate study paper.
Dust facility: Ten Kate will finish experiments with the puffing system, and then define possible further work.

Task 674-106-360: **Characteristics of Flux Transfer Events**

NASA Grant: **Generalized 3-D Magnetosheath Specification Model (NNX09AP16G)**

NASA Grant: **ST5 Automating Electron Density Determinations from Magnetospheric Dynamic Spectra (NNX06AH07G)**

Task 673-87-302: **Characterizing the Composition of Large Mid-latitude Topside-ionospheric/plasmapheric Gradients**

Task 674-106-370: **Establishing Links Between Solar Wind and Topside-Ionospheric Parameters**

SA 5568-11215: **Observational and Theoretical Constraints on Lunar Surface and Dust Charging Processes**

GEST Investigator: Yongli Wang

Collaborators: David Sibeck (PI, GSFC 674), Masha Kuznetsova (GSFC 674); Jan Merka (GEST), Scott Boardsen (GEST), Homa Karimbadi (UCSD), Tamara Sipes (SciberQuest); Phillip Webb (Inst. For Defense Analyses), Leonard Garcia (Wyle); Robert Benson (PI, GSFC 673); Timothy Stubbs (PI, GEST), Erwan Mazarico (ORAU)

Description of Research

In 2009, Wang worked on various topics in Moon environment, magnetosheath and magnetopause dynamics, and inner magnetosphere environment. He worked on several new NASA projects: one to build a complete and advanced flux transfer event database to study the statistical properties of this important solar wind-magnetosphere interaction phenomenon; one to build a state-of-the-art magnetopause, bow shock, and magnetosheath empirical models using machine learning techniques; one to establish links between solar wind and top-side ionosphere; one to automatically determine electron density using five years of IMAGE satellite power spectra observations; one to characterize the composition of large mid-latitude topside-ionospheric/plasmaspheric gradients; and, one to calculate the sunlight and solar wind shadowing and surface charging on the surface of the Moon. Meanwhile he also provided data support for Space Technology 5 satellite observations.

Accomplishments during the Reporting Period

Related to the NASA project regarding flux transfer event (FTE) statistics, Wang constructed a big observational database including the most recent satellite observations near the magnetopause. A systematic survey of the database had begun which will produce the largest, most consistent, and most complete FTE database to address many long lasting problems about FTE.

For the NASA project to build the state-of-the-art magnetopause, bow shock, and magnetosheath empirical models using machine learning techniques, Wang built a large observational database of magnetosheath and bow shock in addition to the above-mentioned magnetopause database. A systematic survey of the database had begun which will produce the largest, most consistent, most complete magnetopause-crossing database for magnetopause modeling. Dr. Jan Merka, his team member, also built a big bow shock crossing database. Modeling of the magnetopause using the new database and machine learning techniques had begun and extremely promising results were obtained.

For the NASA project related to automatically determining electron density using five years of

IMAGE satellite power spectra observations, Wang took over the PI-ship of the project from Dr. Phillip Webb in April, and led the project until its completion by the end of 2009. During the last phase of the project and with great help from Dr. Webb, the team added an important identification mechanism, Z-mode wave, in the automatic identification procedure. A new electron density database was created after that with major improvements relative to the older version of the database. A new manual correction program was developed by Wang for large-scale checking and manual correction of the new database. The resulting database has been posted on CDAWeb, NASA Virtual Wave Observatory, and Spacephysics.org.

In the NASA project to characterize the composition of large mid-latitude topside-ionospheric/plasmaspheric gradients, Dr. Wang provided technical support for the team members in ionogram inversion using the Jackson's program. He also provided important support for a summer student who used the program in his research. The major limitations of the Jackson's program in these applications made Wang decide to create a brand new program to totally replace it for future investigations.

In the NASA project to establish links between solar wind and top-side ionosphere, a brand new ionogram inversion tool was developed by Wang from scratches to replace the Jackson's problems which is 40 years old. Many restrictions of the old tool were removed and the new tool provides a lot of flexibility including using new field models and handling complex geometries. This new tool will be used extensively by the project team to perform ionogram analysis and study the dependence of top-side ionosphere on solar wind conditions.

In the NASA project to calculate the sunlight and solar wind shadowing and surface charging on the surface of the Moon, Wang worked with Dr. Timothy Stubbs and developed from scratches a new Moon sunlight and solar wind shadow model. The new model can use various Moon Digital Elevation Maps (DEMs), from ULCN to the most recent Kaguya and LRO LOLA DEMs, and it is the most accurate model currently available for sunlight shadow calculations because various refined techniques were used to account for many factors usually neglected by other models. It is also the only available model for solar wind shadow calculations, which has been used successfully for Moon surface charging and other related investigations led by Dr. Stubbs. In addition, Wang also worked with Dr. Stubbs to provide support for other team members for their related research and mission, including LCROSS.

Objectives for the Coming Year

In 2010, Wang will work with Dr. Sibeck and other team members to continue progress in building the new FTE database and will make statistical investigation using the new database to address many major questions related to FTE. He will also work on the magnetopause, bow shock, and magnetosheath modeling; the final model products will be available to the scientific community by the end of this year. The new technique developed in the earlier phase of this study will be further refined and expanded so that it can be used in other fields in space physics. Wang will also work with Dr. Benson and other team members to use the new ionogram inversion tool to systematically study the plasma properties of ionosphere and plasmasphere, as well as their relation to the solar wind conditions. A major upgrade of the large Alouette/ISIS digital topside ionogram database used by the team will also be conducted to allow more streamlined data access for the follow-up investigation. As a Co-I of a newly funded NSF project, Wang will work with Dr. Richard Denton at Dartmouth College and provide data support for magnetospheric electron density modeling. In addition, Wang will continue working with Dr. Stubbs and other team members on Moon shadow and surface charging related modeling work. The model has been implemented to Vesta, and other space bodies as planned, and there would be major work related to that if a new proposal that involves Wang and Dr. Stubbs can be funded.

Global Energy and Water Cycle Experiment (GEWEX) Project

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Task 971-32-161: **International Global Energy and Water Cycle Experiment (GEWEX) Project; International GEWEX Project Office (IGPO)**

GEST Investigator: Petrus (Peter) J. van Oevelen, Richard (Rick) Lawford

Collaborators: Tom Ackerman (University of Washington), Pavel Groisman (National Climate Data Center), Jin Huang (NOAA), Chu Ishida (Japanese Aerospace and Exploration Agency), Toshio Koike (University of Tokyo), Riko Oki (Japanese Aerospace and Exploration Agency), Annukka Lipponen (United Nations Educational Scientific and Cultural Organization), Alice Aureli (United Nations Educational Scientific and Cultural Organization), William Rossow (City University of NY), Robert Schiffer (GEST), Paul Try (Science and Technology Corporation), Gilles Sommeria (WMO/IPCC Secretariat), Ronald Stewart (University of Manitoba), Vladimir Ryabinin (World Climate Research Programme), Ghassem Asrar (World Climate Research Programme), Avinash Tyagi (World Meteorological Organization), Charles Vorosmarty (City College of NY), Yuping Yan (Beijing Climate Center), Olga Zolina (University of Bonn), Wolfgang Grabs (World Meteorological Organization), Sam Benedict (Coordinated Energy and Water Cycle Observations Project), Arthur Askew (International Association of Hydrological Sciences), Pavel Kabat (International Geosphere-Biosphere Programme), Susanna Eden (Univ. of Arizona), Einar-Arne Herland (European Space Agency), Jan Polcher (Laboratoire de Météorologie Dynamique du CNRS), Dennis Lettenmaier (University of Washington), Eric Wood (Princeton University), Christian Jakob (Monash University, Melbourne), Howard Cattle (CLIVAR), Jared Entin (NASA), Lydia Gates (Center for Research on Environment and Water), John Pomeroy (University of Saskatchewan), Anna Medico (CONAE), Anni Reissell (iLEAPS), Bill Kustas (USDA), Norman Miller (University of Berkley), Ruby Leung (Pacific Northwest Laboratory), David Toll (NASA), Paul Houser (George Mason University), Ana Nunes (Scripps Institute of Oceanography), Douglas Cripe (GEO Sectretariat), Sushel Unninayar (GEST), Lawrence Friedl (NASA), Zhong-bo Su (ITC), Diego Pietro Fernandez (ESA), Marc LeBlanc (James Cook University, Cairns)

Description of Research

The Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP) brings together a significant component of the world climate community in joint initiatives to advance understanding of the coupled hydrologic and atmospheric processes on a global scale and to apply global water cycle understanding, observations and models to the problems of climate and water resources around the world. Scientists from over 45 countries participate in major GEWEX projects aimed at quantifying the hydrologic cycle and energy fluxes by means of global measurements of atmospheric and surface properties; modelling the global water cycle and its role in the climate system; developing the ability to predict the variations of global and regional hydrologic processes and water resources and their response to environmental change; and fostering the development of observational techniques, as well as data management and assimilation systems. GEWEX activities involve understanding and modelling land-atmosphere coupling and cloud system processes, global data set development, water resource applications and the effective use of Earth Observations in climate science.

During 2008, van Oevelen served as Director of the International GEWEX Project Office (IGPO), which is responsible for coordinating

the activities of the GEWEX project and its interactions with WCRP and other global and national environmental programs, as well as space agencies and other research and operational groups. This position provides management, service and coordination functions for more than 1,500 scientists worldwide who are working on the water and energy cycle science, and it supports the information and management needs of WCRP. Staff support in the IGPO is provided through the Science and Technology Corporation (STC); Scientific Advisory services are provided by Drs. Paul Try and Robert Schiffer.

During the past year, van Oevelen co-led two WCRP cross-cuts—one on monsoons and one on Extremes—and served on the executive board of the Science Committee for the Integrated Global Water Cycle Observation (IGWCO) theme of the Integrated Global Observing Strategy (IGOS) Partnership, which currently is folded into the Group on Earth Observations (GEO). He also served as task leader for one task in the 2007–2009 GEO Work Plan and represented WCRP on the GEO Capacity Building Committee. He is co-chair of the International Soil Moisture Working Group (ISMWG), one of the driving forces in the establishment of a global soil moisture *in-situ* network. He serves on the organizing committee of the 2nd American Meteorological Society (AMS) Conference on International Cooperation, scheduled to be held during the AMS Conference in Atlanta in January 2010.

Lawford continues to support the IGPO. He maintains his links with the GEWEX Extremes activity through his part-time position as the Network Manager for the Canadian Drought Research Initiative (DRI) being led by McGill University and the University of Saskatchewan. He serves as task leader or co-leader for two tasks in the 2007–2009 GEO Work Plan and represented WCRP on the GEO User Interface Committee during 2008, also serving as the WCRP delegate to the GEO Plenary in Romania. Lawford also accepted an invitation to serve as a member of the GWSP Science Committee in 2008.

The research undertaken within GEWEX is directed at the development and application of planetary Earth science and observations to the problems of the world climate and to understand the global water cycle and its role in the supply of the world's water resources. In particular, efforts are directed at producing consistent descriptions of the means, variability and trends of the Earth's energy and water cycle variables, along with the generation of data sets for the development and validation of climate and hydrologic models and an understanding of the factors that account for temporal and spatial variations in these variables over weather to climate time scales. Metrics of scientific success include an improved ability to close regional and global water budgets through better observation and modelling capabilities and the expanded use of satellite data in climate programs, Numerical Weather Prediction (NWP) forecasts and decision support systems.

GEWEX is an interdisciplinary study that requires close collaboration between meteorology, hydrology, atmospheric chemistry, oceanography and other disciplines to be successful. The principal tools used in this research involve the derivation and analyses of data sets derived from satellite and *in-situ* data combined with state-of-the-art assimilation and modelling systems. GEWEX predictability studies and prediction system developments emphasize the contributions of land surface and cloud processes to water cycle predictability and rely on the use of mesoscale atmospheric models, coupled land atmosphere models, cloud resolving models and hydrologic models. The development of improved parameterizations depends on process understanding derived from field studies. GEWEX contributes to the development of global observation and data systems through the Coordinated Energy and Water-cycle Observations Project (CEOP).

GEWEX places a strong emphasis on increasing the understanding of how energy and water cycle processes contribute to climate feedbacks. Studies of the role of clouds, precipitation and land surface processes in the climate system are undertaken to understand and quantify feedback processes in the climate system. To improve

parameterizations, GEWEX collaborates with model developers in a cycle of model evaluation and improvement. GEWEX provides key data sets through targeted field projects that are used in the evaluation of the models over a range of conditions. Field data are organized on web sites to facilitate the evaluation of models by the modellers themselves. In addition, the value of these improvements is assessed in collaborative studies with the water resource and applications communities.

The Director's role is to provide guidance and advice on the programmatic aspects of these activities and to direct the office that coordinates research activities, plans for future activities and meetings, coordinates implementation, helps to synthesize results and establishes processes for making the results useful for different communities. The information and synthesis roles are facilitated by the GEWEX web site (www.gewex.org), the organization of scientific meetings and conferences, teleconference calls and the preparation of overview and review articles for different publications and conference presentations. The program is promoted through the GEWEX Newsletter and through participation in committees involved in the development of observational systems. In addition, van Oevelen facilitated opportunities for GEWEX projects by liaising with potential funding agencies. Within the framework provided by the program, he applied his expertise to promote research aimed at a better understanding of regional and global water resource issues and to the development of better Earth Observation systems (especially space-based systems) that could support GEWEX science.

Accomplishments During the Reporting Period

As IGPO Director, van Oevelen provides overall support for the GEWEX program in terms of organizing workshops, meetings and conferences; maintaining the website; publishing a regular Newsletter; overseeing preparations and setting the agenda for the GEWEX Scientific Steering Group (SSG) annual meeting; preparing minutes of meetings; and writing reports and articles to inform the science community about the project. He was responsible for the documents from these meetings and ensured that they were acted upon in a timely way. He assisted in coordinating the implementation of GEWEX aerosol and climate responsibilities as well as new GEWEX projects such as LandFlux and the Hydrologic Applications Project (HAP). During the past year, he continued to support implementation of the merger of the Coordinated Enhanced Observing Period and the GEWEX Hydrometeorology Panel into the new Coordinated Energy and Water Cycle Observations Project (CEOP) that occurred in 2007, which involved participating in several CEOP meetings and encouraging the further development of ideas for the GEWEX Roadmap. The GEWEX Roadmap was further developed as a framework for accountability and planning and was updated during the year to reflect progress and new aspirations of other GEWEX Panels.

The IGPO Director supported the chair of the GEWEX SSG by contributing to the preparation of a number of science and programmatic talks, reports to the Joint Scientific Committee (JSC—includes the World Meteorological Organization (WMO), the International Council of Scientific Unions (ICSU), and the International Oceanographic Commission (IOC)) and Academy reviews, and drafted letters of recommendation for programs and requests for visas and travel support. He also supported the chair of the GEWEX SSG and the chairs of GEWEX Panels by assisting in the development of meeting minutes and by negotiating and/or carrying out follow-up activities on action items arising from meetings. Support to the SSG also included coordination of preparations for the GEWEX SSG-21 meeting in Irvine, California in terms of overseeing the logistics and meeting facilities and developing and providing briefings, agendas, written material and assignments for SSG members. He also organized the GEWEX-Climate Variability and Predictability Project (CLIVAR) Joint Executive meeting held in Silver Spring, Maryland.

In response to an invitation from the NRC (National Research Council)/NAS (National Academy of Science), Lawford continues to

serve on an NAS committee established to provide a review of the WATERS project. WATERS is an initiative of the academic hydrologic and hydraulics communities to develop major scientific infrastructure for future research.

An agreement was developed with the Integrated Land Ecosystem-Atmospheric Processes Study (iLEAPS) program to hold a joint meeting of the Sixth International Global Energy and Water Cycle Conference and consequently both projects agreed to hold the conference in Melbourne, Australia from August 24-28, 2009. Several teleconference calls have been held to organize meeting details. A website for this meeting has been set-up as well as a site to submit abstracts. Sponsorship for the meeting is being pursued with numerous organizations. Furthermore, several side meetings are being organized such as CEOP Panel Meeting, LandFlux meeting, GLASS meeting and an Early Career Scientists Workshop.

In the scientific community, van Oevelen promoted GEWEX during 2008 by organizing workshops and scientific sessions at international conferences. In particular, a session related to GEWEX and WCRP efforts on extremes was organized for the Fall American Geophysical Union (AGU) meeting in San Francisco, California. In addition, Lawford helped to organize a GEWEX workshop on Extremes held in Vancouver, Canada.

In April 2008, during the European Geophysical Union meeting, van Oevelen organized a special preparatory workshop along with the European Space Agency (ESA) on a new Support to Science Element called WACMOS (Water Cycle Monitoring from Space) and attracted about 40 people. In addition, he informed the scientific community about GEWEX goals and activities by providing more than 25 seminars and talks on GEWEX activities at universities and international and national science conferences and meetings. This was supplemented by 5 presentations on GEWEX by Lawford at international science meetings.

Van Oevelen provided GEWEX and water cycle input to a number of documents and questionnaires from such organizations as GEO, ESA and the European Science Foundation (ESF). In addition, he reviewed proposals for the National Aeronautics and Space Administration (NASA) and ESA and articles for AGU, AMS and Elsevier journals. He prepared GEWEX documentation and reports—including those on the Extremes and Monsoon cross-cut activities—for meetings of the WCRP JSC and the GEWEX SSG. He also served on the Technical Evaluation Board of ESA for water cycle-related tender. Lawford reviewed several manuscripts for AMS and the Canadian Water Resources Journal and proposals for the National Oceanic and Atmospheric Administration (NOAA) and NASA, and served on a NASA Review Panel.

During the past year, van Oevelen continued to strengthen links between GEWEX and other WCRP core projects, in particular CLIVAR. In preparation for the next JSC meeting, a large amount of preparatory material is being produced, most notably a so-called legacy document that will serve as the basis for the future of WCRP and its core projects.

Through the IGPO, van Oevelen provided support for the GEWEX program by overseeing the preparation of four newsletters during the past year. Newsletter themes during 2008 included precipitation, GEWEX Modelling and Prediction Panel (GMPP) activities and a CEOP special issue that can also be seen as a commemorative issue for Dr. John Roads. The Director continued to guide other outreach activities including the maintenance of the GEWEX web site, which includes recent news, GEWEX document archives, background on GEWEX, meeting calendars and logistics, opportunities for employment, and more. The IGPO continues to recognize the contributions of its community as Lawford led in the preparation of an obituary for Dr. John Roads that was published in the November issue of the *Bulletin of the American Meteorological Society*.

During the past year, the IGPO continued to contribute to GEO as a topic leader for water

activities. Updated inputs were provided to 2007–2009 Work Plans. In addition, Lawford served on the Committee that reviewed GEO Targets and contributed to the definition of tasks in the 2009–2011 Work Plan.

Objectives for the Coming Year

During 2010, it is expected that the IGPO's priorities will include (but not be limited to) providing support to panels in implementing new initiatives (such as HAP, aerosols and climate, LandFlux and the new CEOP); further implementing the GEWEX Roadmap; supporting the WCRP Strategic Plan and Legacy Document; developing a GEWEX Phase II Brochure highlighting achievements over the past 7 years; leading and strengthening the WCRP Monsoon Cross Cut (with CLIVAR); leading and strengthening the WCRP Extremes Cross Cut (with CLIVAR); supporting ESA by establishing requirements for the Data User Elements Programme; supporting WACMOS and participation as chair of the advisory board; strengthening agency support for GEWEX; and providing support to the organization of the Sixth International Global Energy and Water Cycle Science Conference.

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Goddard Visiting Fellows Program

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NASA Goddard Visiting Fellows Program

The Goddard Earth Sciences and Technology Center (GEST) and the NASA Goddard Earth Sciences Directorate solicited qualified Ph.D. scientists for collaboration in scientific research relating to the observation, analysis and modeling of physical processes within the earth-atmosphere system, and to relevant global change issues. Selected candidates were appointed as Visiting Fellows to pursue independent research in collaboration with scientists in the Laboratories within the Earth Sciences Directorate, and they have full access to NASA computing facilities and other resources at either the Goddard Space Flight Center (GSFC) in Greenbelt, MD or at the Goddard Institute for Space Studies in New York, NY. This solicitation was aimed at all levels from post-doctoral to senior scientists, particularly university faculty interested in sabbatical arrangements.

Research interests in the Earth Sciences Directorate include attaining knowledge and understanding of the components of the Earth system through experimental and theoretical studies using NASA technology, information science, and space observations. The approach includes instrument, algorithm and model development involving remote sensing and *in situ* measurements. GEST sought candidates for collaboration in scientific research in one of the following research theme areas of the Division:

· Aerosols
· Carbon Cycle
· Clouds and Precipitation
· Polar Climate Change
· Terrestrial Water
· Weather and Short-term Climate Forecasting

One of our 2008-2009 candidates finished his term in 2009. Dr. Kurtulus Ozturk, Senior Meteorologist, Turkish Meteorological Service. Dr. Ozturk arrived at GSFC in September 2008 and stayed for a one-year sabbatical at Code 613.1 to work with Dr. Tokay and the TRMM ground validation group. An expert in rain rate sensing, Dr. Ozturk learned techniques that can be used for TRMM GV in Turkey when he returns to his home country.

The Application period for the GVF closes in February of each year (at the end of the period covered by this report). We reported on 2009-10 candidates in last year's report and update those selections here. ***The selections for the 2009-10 program were:***

- Asst. Prof. Wenge Ni-Meister, Department of Geography, Hunter College of the City University of New York. Dr. Ni-Meister obtained her Ph.D. from Boston University in 1997 in Remote Sensing. Dr. Ni-Meister works in the area of land-atmosphere interactions and numerical modeling. She is studying the exchange of carbon dioxide with the biosphere. She is working with Drs. K. Jon Ranson, J. Bryan Blair, Forrest Hall, and Guoqing Sun to continue her vegetation lidar modeling work to assess the mission requirements for the Ice, Cloud, and land Elevation Satellite-II (ICESat-II) and the Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI) missions. Dr. NiMeister arrived in August 2009 and stayed on the GVF until August 2010. She is continuing to work with Dr. Ranson on a visiting appointment.

- Dr. Miguel Roman, SUNY Albany. Dr. Roman was offered a GVF post-doctoral position but declined in favor of the NASA Post-Doctoral Program.

- Dr. DeZheng Sun, CIRES, University of Colorado. Dr. Sun obtained his Ph.D. from MIT in 1992 and works on large-scale climate change models which link sea surface temperatures to the effects

on cloud and aerosols in the Earth system. Dr. Sun studies the effects the El Nino has on long-term climate and studies how is effect is modeled in GCMs. Dr. Sun conducted his research at GEST in March-September 2010.

- Dr. Chien Wang, Principal Research Scientist, Department of Earth and Atmospheric Sciences, MIT. Dr. Wang is the Yoram Kaufman Visiting Fellow for 2009-10. Dr. Wang's area of research is in aerosol-cloud-precipitation and physics/chemistry of atmospheric aerosols and clouds using numerical modeling and NASA satellite data. Dr. Wang started his visiting position with GEST in September 2009 and stayed through August 2010.

Six applications were received for the 2010-11 program. The candidates were discussed and ranked by a selection committee of Drs. Starr, Hoff, Richards, and Halverson. ***The 2010-2011 accepted candidates are:***

- Peter Adams, Carnegie Mellon, to work with Ralph Kahn in 613.2. Professor Adams is an expert in the modeling of atmospheric aerosols and proposed four tasks to work with Dr. Kahn: (1) modeling the uptake of water as a function of relative humidity, (2) enhanced corrections for aerosol size in the aerosol index (AI) and (3) classification of AI and AOD behavior by regions globally.

- Olivier Paulius, NYU, to work with Antonio Del Genio at GISS. Dr. Paulius is spending his research time at GISS to further interactions with GISS modelers on cloud interactions and precipitation prediction in large scale climate models.

- Antti Arola, FMI, to work with Nick Krotkov and P. K. Bhartia, 613.3. Dr. Arola proposed to work on SO_2 and aerosols with Dr. Krotkov but had to decline the invitation for 2010-11 because of work related issues at his home institution.

- Dirceu Luis Herdles, INPE, Brazil, to work with Arlindo DaSilva, GMAO. Dr. Herdies proposed to aid the GMAO in assimilation of aerosols in the GEOS-5 model with particular interest in South American fires.

- Juan-Carlos Antuna, Spanish citizen working in Cuba to work with Judd Welton, 613.1, and Lorraine Remer in 613.2. Dr. Antuna is a lidar expert and has been involved for several years in organizing lidar efforts in the Caribbean and in Latin America. He proposed a network called ALINE for this region.

Again this year, these appointments are sabbatical arrangements for the visitors. In the section below, we include the report of Dr. Chien Wang.

Raymond Hoff
Director

Task 900-37-172: **Climate effects of anthropogenic absorbing aerosols**

GEST Investigator: Chien Wang

Collaborators: William Lau (NASA/GSFC), Lorraine Remer (NASA/GSFC), J. Vanderlei Martins (JCET)

Description of Research

Anthropogenic aerosols affect the radiative balance of the Earth-atmosphere system by scattering or absorbing sunlight, by acting as cloud condensation nuclei (CCN) or ice nuclei (IN) and thus modifying the optical properties and lifetimes of clouds, and by altering the local atmospheric thermodynamic status and thus cloud formation and dissipation. These direct and indirect effects influence the strength of not only the anthropogenic forcing but also the feedback of climate system. Quantifying the roles of aerosols in climate system is still challenging.

Absorbing anthropogenic aerosols, mainly black carbon, are among the strongest particulate absorbing matters of solar radiation in the atmosphere. Such absorption can lead to a consistent thermo heating to the atmosphere and hence affect local thermodynamic structure. Previous studies have revealed that the local heating of BC aerosols could affect the formation clouds over certain regions and, perhaps most importantly, also alter large-scale circulation and thus impact on convection and precipitation distance from BC source regions.

To understand the mechanisms and strengths of the climate impacts of anthropogenic aerosols, an interactive aerosol-climate model has been developed at MIT based on the Community Climate System Model (CCSM) of NCAR. Its rather sophisticated aerosol module describes the size, chemical composition, as well as the mixing states of various sulfate and carbonaceous particulate matters. The major research during Wang's visit at Goddard is to better our knowledge of the climatological distribution of absorbing aerosols and to further reveal several key processes behind the climate effects of BC aerosols. The research will combine the modeling efforts at MIT and Goddard with data analyses based on various NASA satellite retrievals as well surface observations using several unique techniques and data.

Accomplishments during the Reporting Period

One major task of the current research of absorbing aerosol-climate interaction is to minimize the large model-observation discrepancy of particulate absorption strength and to assess the modeled global 3-D absorbing aerosol fields. For this purpose Wang has developed a Kalman-filter based inverse modeling framework at MIT based on the offline version of his team's aerosol-climate model. They have applied this framework to optimize the emissions of BC aerosols by minimizing the model-observation discrepancy of absorbing aerosol optical depth (AAOD). During the reporting period, extensive efforts to further this research have been carried out collaborating with several colleagues at Goddard. These have led to the screening and utilizing of MISR AAOD with the help of Dr. Ralph Kahn, and a better selection of AERONET data with the help of AERONET group. These data in addition to NOAA ground station data have been used to process the inverse modeling. The preliminary result of this research was reported at AGU's 2009 Fall Meeting (Jeong, G.-R., C. Wang, N. Mahowald, M. Rigby, J. V. Martins, and L. A. Remer, 2009: The assessment of climatology of 3D absorbing aerosol field with integration of aerosol-climate model and ground as well as satellite remote sensing measurements, 2009 AGU Fall Meeting, December, San Francisco, CA.)

During the reporting period, Wang has also been able to continue his research in several other directions. These include an effort to study the climate impact of the seasonality of biomass-burning-emitted carbonaceous aerosols (BBCA);

a further in-depth analysis of the sensitivity of this modeled effect to the emissions of BC from 5 major regions of the world; and an analysis on the dynamical mechanism behind the absorbing aerosol impact on Indian summer monsoon system.

Objectives for the Coming Year

He will continue to study the impact of absorbing aerosol on tropical precipitation in particular various monsoon system. Research will be conducted to further theoretical understanding of the aerosol forcing mechanisms. Another major effort in the coming year is to summarize several research activities, including inverse modeling and BBCA climate impact.

Educational Programs

NASA Graduate Student Summer Program & Summer Institute in Earth Sciences

Exploring Earth Seminar Series Presents

A Tour of Earth System Science in 3D Using "Science On A Sphere"

Dr. Jeffrey Halverson

Associate Professor, Geography and Environmental Systems, UMBC

July 31 10:30 AM
GSFC Visitor Center

GEST
Goddard Earth Sciences and Technology Center

JCET

Educational Programs

GEST has continued to be active in education and mentorship, with successful programs that provide "once in a lifetime" experiences to a host of students.

Graduate Student Summer Program (GSSP)

The GSSP program sponsored by NASA's Earth Science division encourages graduate students in the Earth sciences to conduct genuine research at GSFC for a ten-week duration that can be incorporated into their graduate thesis. The program is open to students in a Masters or Ph.D. program. Each applicant must submit a proposal of the research they would like to carry out while at GSFC, and propose a GSFC mentor or research team they would like to work with. Students could be placed at any of the three Goddard institutions: GSFC in Greenbelt, Maryland, Goddard Institute for Space Studies (GISS) in New York, NY, and Wallops Flight Facility (WFF) in Wallops Island, Virginia.

The GSSP 2009 summer program ran from June 1 to August 7, 2009. Eight students were selected to participate in GSSP 2009 and seven completed the program. The student population included four doctoral students and four Master's students. All eight students worked at GSFC in Greenbelt, MD and all were matched with a GSFC mentor.

Students were housed on-campus at the University of Maryland, College Park and were shuttled to GSFC daily. Individual meetings were conducted with each student after the first week of the program to monitor their progress, the mentor relationship, and project comprehension. These meetings were followed up by visits to students at their workstations throughout the program. A weekly "brown bag" lunch was held for all students to get together and discuss their research.

The GSSP Seminar Series featured experts in various areas of Earth Sciences. These seminars were scattered throughout the program and were approximately 1.5 hours in length. The series culminated in a presentation covering all areas of the Earth Sciences at the Goddard Visitor Center by Dr. Jeffrey Halverson, who utilized data projected on the Science on a Sphere. The seminars were well attended by GSSP students, students from other summer programs, and GSFC scientists among others.

A variety of other educational and social events were held during the summer, including a tour of NASA Goddard, networking events, poster sessions, and a farewell dinner in Annapolis.

Students' final presentation seminars were held on the last day of the program. Each student gave a 20-minute seminar on the work completed this past summer, and time was given for question and answer. The presentations were well attended by all students, mentors, and other GSFC and UMBC personnel. The students' last requirement was to submit a paper to GEST, all of which are available for public view on the GEST website: http://gest.umbc.edu/student_opp/2009_gssp_reports.html.

The students reported positive relationships with each other and their mentors. In particular, two students have extended his graduate research with his summer mentors. All students participated in research that will be utilized in their theses.

Below is a list of the projects completed during GSSP 2009. Names marked with an asterisk indicate GEST faculty members.

2009 GSSP Alumni Project Reports

Title	Student	Mentor(s)
Analysis of Errors Associated with the Estimation of Smoke Emission Rates from Satellite Fire Radiative Power Measurements over North America	K. G. Thishan Dharshana, University of Wisconsin-Milwaukee	Dr. Charles Ichoku
Atmospheric Transport of Patagonian Dust and Its Influence on Marine Biological Activity in the South Atlantic Ocean	Matthew Johnson, North Carolina State University	Dr. Santiago Gasso*
Phenology-Climate Dynamics in Response to Changes in Land and Water Use Practices in Central Asia	Jahan Kariyeva, University of Arizona	Drs. Lahouari Bounoua and Marc Imhoff
Impact of High Resolution Land Surface Initialization on Convection along the Sierra Madre Occidental	Wendilyn Kaufeld, University of Illinois at Urbana-Champaign	Dr. Christa Peters-Lidard
Hydrological Modeling of the Rio Grande Basin	C. Prakash Khedun, Texas A&M University	Dr. John D. Bolten
Southwestern U.S. and Northwestern Mexico Dust Storm Modeling Through Moderate Resolution Imaging Spectroradiometer Data: A Machine Learning Perspective	Pablo Rivas Perea, The University of Texas El Paso	Dr. James C. Tilton
Contribution of Aerosol-Cloud-Vegetation Interactions to the Hydrological Cycle during the Amazonian Biomass Burning Season	John E. Ten Hoeve, Stanford University	Dr. Lorraine Remer
2006 Heat Wave over California - Preliminaries to a Modeling Study	Aude Valade, University of California, Davis	Dr. Joseph Santanello

Summer Institute in Earth Sciences (SIES)

In 2009, the Summer Institute in Earth Sciences (SIES) program was managed by GEST under the program management of Valerie Casasanto. In addition, Dr. Ali Tokay (UMBC's Joint Center for Earth Systems Technology (JCET), Code 613.1) served as selection committee Chair and Dr. Jeffrey Halverson, Associate Director of JCET, served as advisor to the summer programs.

The SIES 2009 summer program, sponsored by the Earth Sciences Division of the NASA Goddard Space Flight Center, ran from June 1 to August 7, 2009. The program is designed to introduce undergraduate students majoring in all areas of the physical sciences to research opportunities in the atmospheric, biospheric, and hydrospheric sciences, both theoretical and experimental. The program is directed primarily at undergraduates who are in their junior year at the time of application. 2009 was the first year the program format was slightly changed: in order to maximize the time that students could work with their mentors, students selected their mentor projects ahead of time using the Education Office on-line application system. Previously, the first week of the 10-week

program was spent listening to mentor presentations and selecting summer projects.

The 2009 program included 10 students from universities across the United States. In addition to students' summer research projects, a variety of other educational and social events were held during the summer, including a tour of NASA Goddard, networking events, poster sessions, and a farewell dinner in Annapolis.

Students' final presentation seminars were held on the last day of the program. Each student gave a 15-minute seminar on the work completed this past summer, and time was allotted for question and answer. The presentations were well attended by all students, mentors, and other GSFC personnel. Names marked with an asterisk indicate GEST faculty members.

2009 Summer Institute in Earth Sciences Final Presentations

Title	Student	Mentors
Comparison of the NASA GEOS-5 Model to MPLNET Aerosol Data	Bryon J. Baumstarck, Rocky Mountain College	Dr. Peter Colarco/613.1
A Study of Algorithms used in Dual-Frequency Weather Radar	Anuraj (Justin) Chakraborty, University of Maryland, Baltimore County	Dr. Robert Meneghini/613.1
Driving Forces Behind Himalayan Glacial Melt	Brandon Cottom, University of Maryland, Baltimore County	Dr. Eric Wilcox/613.2
An Observational Study of the Connection between Boundary Layer Structure and Precipitation in the U.S. Great Plains	Melissa Dawson, University of Oklahoma	Dr. Andrea Molod*/610.1
Assessing the Accuracy of Land Cover Estimates for Earth Satellite Applications	Ryan Max, University of Maryland, Baltimore County	Dr. Eric Brown de Colstoun*/614.4
Factors that Affect Smoke Plume Injection Heights	Catherine May, University of Nebraska – Lincoln	Dr. Charles Ichoku/613.2
Correlation of AIRS CO and MODIS AOD over the northern hemisphere from June-August 2008	Kiran Quraishi, University of Maryland, Baltimore County	Dr. Allen Chu*/613.2
NLDA Drought Monitors: Precipitation Deciles and the Palmer Drought Severity Index	Vishana Ramdeen, Rutgers University	Dr. David Mocko/613.2
Variations of Rainfall in India	Tiffany Townsend, Oregon State University	Dr. Randy Koster/610.1 & Dr. Matt Rodell/614.3
Comparison of Satellite-Based Ocean Heat Content Estimates with Argo Measurements	Brian Young, Indiana University-Purdue University Indianapolis (IUPUI)	Dr. Paolo deMatthaeis*/614.6 & Dr. Daniel Jacob*/614.2

GEST Student Summer Interns

GEST hosted eight self-directed summer interns working with GSFC mentors on specific projects in the Earth and Space Sciences. These interns performed actual science research and presented their results at the end of the Program. The educational levels of the students ranged from high school through graduate. Many of these students were housed along with the GSSP summer students and the JCET summer interns.

GEST Graduate Fellowship

Mr. James Travis was awarded a one-year GEST Graduate Fellowship in August 2009. Mr. Travis is working on his PhD in the Mathematics/Statistics Department of UMBC. He has been working with his advisors, Dr. Anindya Roy and Dr. Prasun Kundu, on statistical properties of rainfall. The focus of Mr. Travis' PhD research is on further developing a spectral model of precipitation to obtain a unified description of second moment statistics obtained from radar and rain gauges and to develop novel parameter estimation methods for these models.

During the fellowship, Mr. Travis performed an analysis of the second moment statistics of time-averaged rain gauge data (TRMM standard products 2A56) collected from a gauge network located at a NASA TRMM ground validation site near Melbourne, Florida. The work will be presented at the AGU 2010 Fall Meeting in San Francisco, CA.

Mr. Travis also explored the probability of zero rainfall using an alternating renewal series approach on the NASA TRMM data set. This work will be presented at the 2010 Joint Statistical Meetings in August 2010.

Short-Term Visitors

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Short-Term Visitors

The Short-Term Visiting Scientist (STVS) program, managed by Ms. Valerie Casasanto, facilitates collaboration between scientists at GSFC and those at other research institutions to support science research and education at GSFC, WFF and GISS, field locations and external conferences. This program has hosted a wide variety of visitors, from graduate students to research support staff to senior researchers. Many of our visitors are invited speakers for established seminar series, while the younger visitors typically come to GSFC for hands-on training or to obtain data for their own research at their home institution.

GEST facilitated the visits of approximately 152 short-term visiting scientists in the reporting period. Those scientists who visited GSFC or other locations under the auspices of GEST included:

Visitor's last name	Visitor's first name	Affiliation	Code Visiting
		Museum Educators Workshop (20 people to GSFC)	100.0
		8th Workshop on Adjoint Model Applications in Dynamic Meteorology (7 people to Tannersville, PA)	610.1
		GMAO Board Meeting (5 people to GSFC)	610.1
		GEWEX Meeting (15 people to Australia)	610.6
Abdalati	Waleed	University of Colorado-Boulder	614.1
Akkraoui	Amal	McGill University	610.1
Alekseev	Igor	Moscow State University	670.0
Amediek	Axel	DLR	690.0
Appleby	Graham	NERC Space Geodesy	
Atlas	David	Retired NASA Scientist	613.0
Auligne	Tom	NCAR/MMM	610.1
Barahona	Donifan	Georgia Tech	613.2
Barros	Ana	Duke University	610.0
Bateni	Moji	MIT	610.1
Bayr	Klaus	Keene State College	614.1

Visitor's last name	Visitor's first name	Affiliation	Code Visiting
Beita Guerrero	Victor Hugo	Universidad Nacional	613.3
Belenkaya	Elena	Moscow State University	670.0
Burton	Aaron	Porland State University	699.0
Cazorla	Maria		613.3
Chow	Judith	Desert Research Institute	613.2
Christian	Hugh	NSSTC	610.0
Chu	Tao	MRSL Unv. Of Mass	613.1
Cohen	Judah	AER, Inc.	614.3
Cook	Kerry	University of Taxas	610.1
Dai	Aiguo	NCAR	
Davis	Anthony	JPL	
De Goncalves	Luis	NPP Fellow	614.3
Dempsey	Logan	U. of Pennsylvania	610.0
Dharshana	Thishan	University of Wisconsin-Milwaukee	613.2
Dirisu	Afusat	NASA GSFC	613.1
Draper	Clara	University of Melbourne	610.1
Engelen	Richard	ECMWF	610.1
Felder	Martin	ZSW	613.3
Ferguson	Craig	Princeton University	614.3
Findell	Kirsten	Princeton	614.3
Forno	Ricardo	University of San Andres	613.1
Fouilloux	Ann	ECMWF	610.1
Fu	Joshua	U. of Tennessee	613.2
Fu	Rong	University of Texas-Austin	613.0
Gabriel	Philip	Colorado State University	613.2

Visitor's last name	Visitor's first name	Affiliation	Code Visiting
Garcia Leal	Julio	Student from Columbia	614.3
Garnier	Anne	Université Pierre et Marie CURIE	
Gibert	Claude	ECMWF	610.1
Glocer	Alex	ORAU	670.0
Golden	Kenneth	University of Utah	610.0
Goniadzki	Dora		614.3
Gupta	Pawan	University of Alabama	613.3
Gutierrez	Angelica	NOAA	614.3
Ham	Yoo-Geun	Seoul National Univeristy	610.1
Herdies	Dirceu	INPE	614.3
Honkonen	Ilja		674.0
Houser	Paul	George Mason University	
Howat	Ian	School of Earth Science	614.1
Hu	Yongtao	Georgia Institute of Tech	613.2
Huang	Hsin-Yuan	UCLA	613.0
Hughes	Eric	University of Maryland College Park	610.6
Jochum	Markus	NCAR	610.1
Jones	Dylan	University of Toronto	610.1
Kang	In-Sik	Seoul National Univeristy	610.1
Karpowicz	Bryan	Georgia Institute of Technology	600.0
Khain	Alexander	The Hebrew Univeristy of Jerusalem	613.1
Kidd	Christopher	University of Birmingham-Ebgbaston	610.1
Krabill	William	Krabill & Krabill	614.1
Kummerow	Chris	Colorado State University	587.0
Lapeta	Bozena	Institute of Meteorology	610.1

Visitor's last name	Visitor's first name	Affiliation	Code Visiting
Liang	Lusheng	University of Illinois at Urbana-Champaign	613.2
Lin	Neng-Heui	Nat'l Central U.	613.2
Maggioni	Viviana	University of Connecticut	610.1
Mahowald	Natalie	Cornell University	613.0
Maslowski	Wieslaw	Naval Postgraduate School	614.1
McLaughlin	Dennis	MIT	610.1
Mensah	Julius	Hydrological Services Dept.	614.3
Miller	Robert	Oregon State University	610.1
Mo	Kingtse	NOAA	610.1
Montilla	Elena	Universidad de Valladolid	613.1
Munchak	Joe	Colorado State Univerisy	613.1
Park	Sang Jong	Seoul National Univeristy	610.1
Parnell	Lynn	UMBC	610.6
Petty	Grant	University of Wisconsin	613.1
Pierce	Jeffrey	Dalhousie University	613.2
Qian	Yun	Pacific Northwest National Lab	613.3
Randel	Bill	NCAR	613.0
Rogan	Brian	Foundation for Earth Science	
Ruane	Alex	NASA GISS	613.2
Saavedra	Pablo	University of Bonn	587.0
Samsonov	Andrey	St. Petersburg University	674.0
Sarantos	Menelaos	ORAU	670.0
Satoh	Masaki	University of Tokyo	613.1
Schindler	Karl		674.0
Shige	Shoichi	Kyoto University	613.1

Visitor's last name	Visitor's first name	Affiliation	Code Visiting
Shuyi	Chen	University of Miami	613.1
Stoyanova	Silvia	UMBC	130.0
Studinger	Michael	Lamont-Doherty Earth Observatory Columbia U	614.1
Sun	Wen-Yih	Purdue	613.2
Thorncroft	Chris	University at Albany	610.1
Trejos Castillo	Noel	Water Center for Humid Tropics	614.3
Tremolet	Yannick	ECMWF	610.1
Tumbulto	Jacob	Volta Basin Authority, Burkina Faso	614.3
Turk Katircioglu	Filiz	UMBC GEST	674.0
Van Oevelen	Peter	GEWEX Project Office	610.1
Vargas	Fernando	University of San Andres	613.1
Volkamer	Rainer	University of Colorado	613.3
Wang	John	Niagara University	613.0
Wango	Ted	University de Cocody-Abidjan	614.3
Wiessenger	Scott		130.0
Williams	Rudolph		614.3
Wolfram	Elian	CEILAP Lidar Group	613.1
Yang	Young-Min	Seoul National Univeristy	613.1
Zaratti	Francesco	University of San Andres	613.1
Zhang	Chidong	University of Miami	613.0

GEST’s short-term visiting scientist program continues to grow by including other GSFC codes and proves to be a needed service to the Earth and Space Sciences communities.

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APPENDICES

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Chin, M., H. Yu, R. Ferrare, A. Omar, and D. Winker (2009), Comparisons of aerosol types and associated lidar ratios between CALIOP data and GOCART model, CALIPSO/CloudSat Science Team meeting, Madison, WI, 28-31 July.

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Cumbane, J. J., C. K. Gatebe, M. D. King, and H. J. Annegarn (2009), Exploring radiance vertical profiles to investigate atmospheric aerosol stratification by combining measurements and modeling, IGARSS, Cape Town, South Africa, 12-17 July.

Curran, R., (2009), NASA Earth System Science at 20 Years, Washington, DC, 22-24 June.

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Engman, E., D. Toll, R. Lawford, H. Berbery, L. Gustavo de Goncalves, V. Lakshmi, and J. Hendrickx (2009), NASA Support of Capacity Building with an Emphasis in Latin America, World Water Forum, Istanbul, Turkey, March.

Erlich, D. (2009), GEWEX Radiation Panel Meeting Bonn, Germany, 13-16 October.

Errico, R. M. (2009), A proposal to organize a new workshop series to address current controversies in the atmospheric sciences, presentation at the 8th Workshop on Adjoint Model Applications in Dynamic Meteorology, Tannersville, PA, 20 May.

Errico, R. M. (2009), Atmospheric data assimilation, seminar at Virginia Polytechnic Institute, Blacksburg, VA, 23 October.

Errico, R. M. (2009), Design and validation of observation system simulation experiments at NASA's Global Modeling and Assimilation Office, seminar at the University of Reading, Reading, England, 17 November, *invited*.

Errico, R. M. (2009), Design and validation of observation system simulation experiments at NASA's Global Modeling and Assimilation Office, seminar at European Centre for Medium-Range Weather Forecasts, Reading, England, 16 November.

Errico, R. M. (2009), Fundamentals regarding the use of adjoint models in dynamic meteorology, tutorial at the 8th Workshop on Adjoint Model Applications in Dynamic Meterorology, Tannersville, PA, 17 May, *invited*.

Errico, R. M. (2009), Introduction to Adjoint Models, invited lecture at the Summer Colloquium on Data Assimilation sponsored by the Joint Center for Satellite Data Assimilation, Stevenson, WA, 13 July.

Errico, R. M. (2009), Issues regarding the assimilation of precipitation observations, invited lecture at the Summer Colloquium on Data Assimilation sponsored by the Joint Center for Satellite Data Assimilation, Stevenson, WA, 15 July.

Errico, R. M. (2009), The design, validation, and applications of observing system simulation experiments (OSSEs), SED Director’s seminar at NASA, Greenbelt, MD, 6 November.

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Errico, R. M. (2010), Atmospheric predictability, presentation at the workshop on Exploring Complex Dynamics in High-Dimensional Chaotic Systems, the Max Planck Institute for the Physics of Complex Systems, Dresden, Germany, 28 January, *invited*.

Errico, R. M. (2010), Status and short-term plans for the GMAO OSSE and why we are developing the OSSE the way we are, seminar at the Joint Center for Satellite Data Assimilation, Camp Springs, MD, 17 December.

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Farrell, W. M., G. T. Delory, R. M. Killen, R. P. Lin, J. S. Halekas, S. Bale, D. Krauss-Varban, R. R. Vondrak, M. R. Collier, J. Keller, T. Jackson, R. Hartle, M. Hesse, M. Sarantos, R. Elphic, A. Colaprete, T. J. Stubbs, D. M. Hurley, J. Marshall, R. Hodges, D. A. Glenar, W. Paterson, H. E. Spence, L. Bleacher, H. Weir, M. Horanyi, M. Dube, M. Hyatt, J. Kasper, and Y. Saito (2009), Dynamic Response of the Environment At the Moon (DREAM): A NLSI team exploring the solar-lunar connection, 2nd Annual Lunar Science Forum, NASA Lunar Science Institute, NASA Ames Research Center, Moffett Field, CA, 21–23 July.

Farrell, W. M., J. S. Halekas, T. J. Stubbs, G. T. Delory, R. M. Killen, M. R. Collier, R. R. Vondrak, and T. L. Jackson (2010), Plasma flow past an obstacle: Advances derived from lunar applications, 1st Workshop on Lunar Dust, Plasma and Atmosphere: The Next Steps, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, 27-29 January, *invited.*

Farrell, W. M., T. J. Stubbs, J. S. Halekas, G. T. Delory, M. R. Collier, and R. R. Vondrak (2009), The anticipated electrical environment within permanently shadowed lunar craters, 2nd Annual Lunar Science Forum, NASA Lunar Science Institute, NASA Ames Research Center, Moffett Field, CA, 21–23 July.

Fogt, R. L., J. Perlwitz, S. Pawson, and M. A. Olsen (2009), Intra-annual Relationships Between Polar Ozone and the SAM in Observations and a Chemistry Climate Model, MOCA-09 Joint Assembly, IAMAS and IAPSO and IACS, Montreal, Canada, 19-29 July.

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Gao, S., S. Chiu, R. Chokngamwong, and C.-L. Shie (2009), Trends in oceanic evaporation retrieved from the Goddard Satellite-based Surface Turbulent Fluxes based on SSM/I v6 (GSSTF2b) Dataset, 2009 AGU Fall Meeting, San Francisco, CA, 14-18 December.

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Gassó, S. (2009), Dr. Koren, or How I Learned to Stop Worrying and Love "Torturing Data", Aerocenter Seminar, GSFC, Greenbelt, MD, 24 April, *invited*.

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Gassó, S. (2009), Insights from an observed event of long range transport of dust from Patagonia: Implications for ice-core studies and the iron-fertilization hypothesis, NOAA Air Resources Lab, Silver Spring, MD, 2 April, *invited*.

Gassó, S. (2009), Report and Progress of the Aerosol-Ocean Interactions Working Group, ACE Meeting, Santa Fé , NM, August.

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Gassó, S., Z. Ahmad, C. McClain, and O. Torres (2010), Satellite observation of marine productivity and marine aerosol using a combination of OMI and MODIS products, AGU Ocean Sciences Meeting, Portland, OR, February.

Gatebe, C. K. (2009), Characterization of Aerosol and Surface BRDF in Southern African from Airborne Measurements during SAFARI 2009, IGARSS, Cape Town, South Africa, 12-17 July.

Gatebe, C. K. (2009), Characterization of Aerosols and Bidirectional Reflectance Distribution Function from Airborne Radiation Measurements, poster presentation at NASA Mission

Planning: the Aerosol, Clouds and Ocean Ecosystem (ACE) Workshop, La Posada de Santa Fe Hotel, Santa Fe, NM, 5-7 August.

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Giles, D.M., B.N. Holben, S.N. Tripathi, T.F. Eck, W.W. Newcomb, I. Slutsker, R.R. Dickerson, A.M. Thompson, S.-H. Wang, and R.P. Singh (2009), Aerosol Properties Observed on the Mesoscale and MODIS Aerosol Optical Depth Comparisons during the 2008 Pre-monsoon TIGERZ IOP in Kanpur, India, *Eos Trans. AGU, 90*(52), Fall Meet. Suppl., Abstract A13K-06, San Francisco, CA, 14-18 December.

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Glenar, D. A., T. J. Stubbs, and R. R. Vondrak (2009), A reanalysis of Apollo light scattering observations, and implications for the distribution of lunar exospheric dust, P23C-1264, 2009 Fall AGU meeting, San Francisco, CA, 14–18 December.

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Goldstein, M. L.. K.-J. Hwang, Ensang Lee, and J. S. Pickett (2009), Cluster observation of multiple Dipolarization Front (DF) events deforming mid-tail magnetic topology as a cause of a substorm auroral arc, paper presented at 2009 AGU Fall meeting, San Francisco, CA, 14-18 December.

Guenther, B., F. DeLuccia, J. Xiong and R. Murphy (2010), Overview Comparison VIIRS to MODIS, A Physics Discussion on Reflected Solar Bands, presented to the American Meteorological Society, Atlanta, GA, 18 – 21 January.

Guenther, B., F. DeLucia, J. Xiong, and R. Murphy (2009), Overview Comparison VIIRS to MODIS, A Physics Discussion on Reflected Solar Bands, paper presented at the American Geophysical Union Fall Meeting, San Francisco, CA, 14 – 18 December.

Halekas, J. S., G. T. Delory, R. P. Lin, W. M. Farrell, T. J. Stubbs, and M. R. Collier (2010), Lunar surface charging: Current understanding and next steps, 1st Workshop on Lunar Dust, Plasma and Atmosphere: The Next Steps, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, 27-29 January.

Halekas, J. S., G. T. Delory, T. J. Stubbs, W. M. Farrell, and R. P. Lin (2009), Developing a predictive capability for lunar surface charging during solar energetic particle events, #1357, Lunar and Planetary Science Conference XL, Lunar and Planetary Institute, Houston, TX, 23–27 March.

Han, M., S. A. Braun, and C. R. Williams (2009), A study of a landfalling winter cyclone over the US west coast, NASA Precipitation Measurement Missions Science Team Meeting, Salt Lake City, UT, 26-30 October.

Han, M., S. A. Braun, and C. R. Williams (2009), Precipitation and cloud microphysics evaluation for a landfalling winter storm using a mesoscale model, 34th Conf. on Radar Meteorology, Amer. Meteor. Soc., Williamsburg, VA, 5-9 October.

Harding, D. J., *et al.* (2009), Single photon, dual-color, polarimetric laser altimeter measurements of lake ice properties, poster presentation 2009 AGU Fall Meeting, San Francisco, CA, 14-17 December.

Heaps, W.S., E. Georgieva, and W. Huang (2009), Broadband Lidar technique for precision CO_2 measurement, AGU Fall meeting, San Francisco, 14-18 December.

Heymsfield, G. M., L. Li, M. Vega, S. Rodriguez, P. Racette, and L. Tian (2009), NASA Goddard High-Altitude Radars – Past, present, and future, AMS 34th Conference on Radar meteorology, Williamsburg, VA, 5-9 October.

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Hulot, G., E. Thébault, N. Olsen and K. Hemant (2009), Predicting crustal secular variation, ESA 2nd Swarm Science Meeting, GFZ, Postdam, 24-26 June.

Hwang, K.-J., M. M. Kuznetsova, F. Sahraoui, M. L. Goldstein, E. Lee, and G. K. Parks (2009), Kelvin-Helmholtz waves under southward IMF conditions, paper presented at 2009 AGU Fall meeting, San Francisco, CA, 14-18 December.

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Kiang R. K., H. N. Safi, F. A. Adimi, and R. P. Soebiyanto (2009), Toward malaria early warning in Afghanistan using remote sensing, presented at 58th Annual American Society of Tropical and Medical Hygiene Meeting, Washington DC, 15-17 November.

Kiang, R. K., F. A. Adimi, and R. P. Soebiyanto (2009), Roles of remote sensing and GIS in avian and pandemic influenza surveillance and risk prediction, presented at 137th American Public Health Association Annual Meeting, Philadelphia, PA, 7-11 November.

Kim, D., H. Huang, Y. Tang, S. Lu, P. Lee, M. Tsidulko, J. McQueen, M. Chin, T. Diehl, A. daSilva, P. Davidson, I. Stajner, and W. Stockwell (2009), The Global Dust Modeling System of the NOAA/NWS National Centers for Environmental Protection, Fall AGU, San Francisco, CA, 14-18 December.

Kim, D., H.-C. Huang, Y.-H. Tang, S. Lu, P. Lee, M. Tsidulko, J. McQueen, M. Chin, T. Diehl, A. da Silva, P. Davison, I. Stajner, and W. R. Stockwell (2009), The Global Dust Aerosol Modeling System at the National Centers for Environmental Prediction, 8th AeroCom Workshop, Princeton, NJ, 5-7 October.

Kim, M.-K., K.-M. Lau, W.-S. Lee, and K.-M. Kim (2009), Effect of aerosol radiative forcing on the seasonal variation of snow over the northern hemisphere, AGU Fall Meeting, San Francisco, CA, 14-18 December.

King, T. A., J. Merka, T. Narock, R. Walker, and L. Bargatze (2009), Registry framework: Front-to-back, Earth and Space Science Informatics Workshop, University of Maryland, Baltimore County, 3-5 August.

King, T. A., J. R. Thieman, D. A. Roberts, and J. Merka (2009), Recent advances of the SPASE data model, oral presentation at the 2009 EGU General Assembly, Vienna, Austria, 19-24 April, EGU2009-12576, (oral).

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Korth, H., B. J. Anderson, J. A. Slavin, S. A. Boardsen, S. M. Krimigis, R. E. Gold, R. L. McNutt, S. C. Solomon, C. L. Johnson, and M. E. Purucker (2009), Overview of magnetic field observations from MESSENGER's third flyby of Mercury, *Eos Trans. AGU, 90*(52), Fall Meet. Suppl., Abstract P24A-03.

Koval, A., and A. Szabo (2009), Multi-spacecraft observations of interplanetary shock parameters, poster presentation at the AGU Fall Meeting, San Francisco, CA, 14-18 December.

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Krotkov, N., C. Lee, R. Martin, K. Pickering, J. Witte, S. Carn, K. Yang, G. Carmichael, C. Wei, D. Streets, Q. Zhang, R. Dickerson, and C. Li (2009), OMI measurements of SO_2 pollution over Eastern Chinain 2005 - 2008, Atmospheric Composition Constellation (ACC) Meeting, Frascati, Italy, 15-17 June.

Krotkov, N., K. Yang, S. Carn, A. Krueger, K. Pickering, J. Witte, C. Li, R. Dickerson, C. Wei, C. Lee, R. Martin, G. Carmichael, D. Streets, Q. Zhang, and E. Hughes (2009), New discoveries enabled by OMI SO_2 measurements, EOS Aura Science Team Meeting, Leiden, The Netherlands, 14-17 September.

Krotkov, N., M. Schoeberl, K. Yang, S. Carn, and G. Morris (2009), Trajectory modeling of Kasatochi eruption plume compared with OMI SO_2 observations, EOS Aura Science Team Meeting, Leiden, The Netherlands, 14-17 September.

Krueger, A., N. Krotkov, and K. Yang (2009), Comparison of GOME-2 and OMI sulfur dioxide retrievals, Atmospheric Science Conference, Barcelona, Spain, 7-11 September.

Kurylo, M.J. (2009), A SPARC Success Story: An Update on the Initiative on the Role of Halogen Chemistry in Polar Stratospheric Ozone Depletion, presentation at the 17th Session of the Scientific Steering Group for the Stratospheric Processes and their Role in Climate (SPARC) Project of the World Climate Research Program, Kyoto, Japan, October.

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Kurylo, M.J. (2009), An Update on the SPARC Initiative on the Role of Halogen Chemistry in Polar Stratospheric Ozone Depletion, presentation at the Meeting of the NASA Panel for Data Evaluation, Billerica, MA, October.

Kurylo, M.J. (2009), Can the NDACC Working Group Structure Serve as a Guide to GRUAN Implementation?, presentation at the 1st GRUAN Implementation and Coordination Meeting, Norman OK, March.

Kurylo, M.J. (2009), From the Laboratory to the Stratosphere: Constructing a Bridge Between Science and Policy, Hillebrand Prize Address, American Chemical Society – Chemical Society of Washington, Greenbelt, MD, March.

Kurylo, M.J. (2009), Status of the 2010 WMO/UNEP Scientific Assessment of Ozone Depletion, presentation at the Meeting of the International Steering Committee of the Network for the Detection of Atmospheric Composition Change, Geneva, Switzerland, September.

Kurylo, M.J. (2009), The Interface Between 2009 and 2010 Data Recommendations and the 2010 WMO/UNEP Scientific Assessment of Ozone Depletion, presentation at the Meeting of the NASA Panel for Data Evaluation, Billerica, MA, October.

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Kurylo, M.J. (2009), The Role of Suborbital Research in Addressing NASA's Mandate in Atmospheric Composition, presentation at the NASA Earth System Science @ 20 Symposium, National Academy of Sciences, Washington, DC, June.

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Labow, G., J. Herman, D. Larko, L. Huang, J. Mao, and W. Qin (2009), Cloud and Aerosol Amounts as a Function of Time of Day as Measured by TOMS, SeaWiFS and SBUV Instruments, *Eos Trans. AGU, 90(52)*, Fall Meet. Suppl., Abstract A54C-07.

Lau, K.-M., K.-M. Kim, Y.C. Sud, and G. K. Walker (2009), A GCM study of the effects of radiative forcing by Saharan dust on the water cycle and climate of the West Africa and the Atlantic, Gordon Research Conference on Radiation and Climate, New London, NH, 5-10 July.

Lau, K.-M., M.-K. Kim, K.-M. Kim, and W.-S. Lee (2009), Changes in snow cover and water cycle over the Tibetan plateau induced by absorbing aerosols, AGU Fall Meeting, San Francisco, CA, 14-18 December.

Lau, K.-M., Y.P. Zhou and H. –T. Wu (2009), Have tropical cyclones been feeding more extreme rainfall? PMM science meeting, Salt Lake City, UT, 26-29 October.

Lawford, R. (2009), Toward a GEO Water Cycle Community of Practice, World Water Forum, Istanbul, Turkey, 16-21 March.

Lawford, R. (2009), Earth Observation Programs in support of Water Cycle Understanding and Applications, Spring AGU Meeting, Toronto, May.

Lawford, R. (2009), NAS Review of WATERS, Washington DC, 15-16 June.

Lawford, R. (2009), Toward a GEO Water Cycle Community of Practice, GTN-H Meeting, CUNY, New York, NY, 7-10 July.

Lawford, R. (2009), WaterNet Meeting, CUNY, New York, NY, 13 -14 August.

Lawford, R. (2009), GEO and its Water Cycle Societal Benefit Area (SBA), CEOP Meeting, Melbourne Australia, 19-21 August.

Lawford, R. (2009), Global Water System Project SSC, Stellenbosch, South Africa, 17-19 October.

Lawford, R. (2009), Update on the Water Cycle Community of Practice, GEO UIC Committee Meeting, Washington, DC, November.

Lawford, R. (2009), Recent Advances in GEO Water Cycle Activities, Fall AGU Meeting, San Francisco, CA, December.

Lawford, R. (2009), Introduction to GEO and its Water Cycle Societal Benefit Area, Latin and Caribbean Water Cycle Capacity Building Workshop, Lima, Peru, December.

Lawford, R. (2009), Global Environmental Programs and their potential contributions to Capacity Building in Latin America and Caribbean America, Latin and Caribbean Water Cycle Capacity Building Workshop, Lima, Peru, December.

Li, F., R. S. Stolarski, and S. Pawson (2009), Narrowing of the upwelling branch of the Brewer-Dobson circulation in the lower stratosphere, paper presented a the 15th American Meteorological Society Conference on Middle Atmosphere, Stowe, VT, 11 June.

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Liang, Q., R. S. Stolarski, S. R. Kawa, J. E. Nielsen, J. M. Rodriguez, D. R. Blake, E. L. Atlas and L. E. Ott (2009), Finding the missing stratospheric Bry: A global modeling study of CHBr3 and CH2Br2, *Eos Trans. AGU*, Fall Meet. Suppl., Abstract A43A-0218.

Liao, L., and R. Meneghini (2009), A Study on Identification of Phase States of Hydrometeors for GPM DPR, *Precipitation Measuring Mission Science Meeting*, Salt Lake City, UT, 26-29 October.

Liao, L., and R. Meneghini (2009), Effective Dielectric Constant of Melting Snow and Simulation of Radar Bright Band, European Geosciences Union General Assembly 2009, Vienna, Austria, 19-24 April.

Liao, L., and R. Meneghini (2009), Snow Detection and Estimation from Ku- and Ka-Band Dual-Wavelength Radar, *The 34th Conference on Radar Meteorology*, Williamsburg, VA, 5-9 October.

Lin, C. Y., J. Chang, C.-H. Zy, A. Chin, D. A. Chu, and S. Liu (2009), Characteristics of Springtime Profiles and Sources of Ozone in the Low Troposphere Over Northern Taiwan, AS16-A012 *Proceedings of 6th Annual General Meeting, Asian Oceanic Geosciences Society*, Singapore, 11-15 August.

Lin, P.-L., D. Chen, W.-K. Tao, J. J. Shi, and M.-Y. Chang (2009), The Impact of Microphysics and Model Resolution on Precipitation Processes Associated with Typhoon Morakot, 2009 Conference on Mesoscale Convective Systems (MCSs) and High-Impact Weather/Climate in East Asia (ICMCS-VII), Seoul National University, Seoul, Korea, 11-13 November.

Lin, X., and A. Y. Hou (2009), Evaluation OF AMSU-B rainrates against TMI/SSMI/AMSR-E estimates using TRMM PR and ground measurements as references, EGU General Assembly 2009, Vienna, Austria, 20-25 April.

Linthicum, K.J., S.C. Britch, J. Clark, D. Ng'onga, F. Ngere, C. Kibet, A. Anyamba, W.W. Wynn, M. Farooq, V.L. Smith, C.A. Robinson, J.C. Dunford, and T. Walker (2009), Reducing Sand Fly Numbers in Leishmania Endemic Regions in Kenya with Insecticide Treated Camouflage Screening, presented at the Annual Meeting of the American Mosquito Control Association in New Orleans, LA, 5-9 April.

Lipatov, A.S. (2009), From Fluid/Particle Toward Complex Particle Kinetic Models, paper presented at ISSS - 9, Paris, France, 3-10 July, *invited*.

Lipatov, A.S. (2009), Titan's Plasma Environment for T9 Encounter: 3D Hybrid Simulation and Comparison with Observations, Heliophysics Science Division: Directors's Seminar, NASA Goddard Space Flight Center, Greenbelt, MD, May.

Lipatov, A.S., and J.F. Cooper (2010), Hybrid kinetic modeling of the Lunar plasma environment: Past, present and future, paper presented at Lunar Dust, Atmosphere and Plasma - 2010 workshop, Boulder, CO, 20-22 January.

Lipatov, A.S., E.C. Sittler, and R.E. Hartle (2009), Titan's plasma environment for T9 and T18 encounters: 3D hybrid simulation and comparison with observations, paper presented at EGS General Assembly, Vienna, Austria, 19-24 April.

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Lipatov, A.S., E.C. Sittler, R.E. Hartle, and D.G. Simpson (2009), Saturn's magnetosphere interaction with Titan for T9 encounter: 3D hybrid simulation and comparison with CAPS's observations, paper presented at Fall AGU Meeting, San Francisco, CA, 13-18 December.

Lipatov, A.S., J.F. Cooper (2009), Europa's Plasma Environment: 3D Hybrid kinetic simulation, paper presented at ISSS - 9, Paris, France, 3-10 July.

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Lipatov, A.S., J.F. Cooper, and W.R. Paterson (2009), Europa's Plasma Environment: 3D Hybrid kinetic simulation, paper presented at European Planetary Science Congress 2009, Potsdam, Germany, 13-18 September.

Livingston, J., *et al.* (2009), Validation of satellite overland retrievals of AOD at northern high latitudes with coincident measurements from airborne sunphotometer, lidar, and in situ sensors during ARCTAS, AGU *90*(52), *Fall Meet. Suppl.*, Abstract A43A-0154.

Lyapustin, A. (2009), Bidirectional Reflectance of Snow (Spring ARCTAS'08 campaign), and Snow Grain Size Retrievals from MODIS, ESA internal review meeting, Noordwijk, Netherlands, 28 August, *invited*.

Lyapustin, A. (2009), Using time series for aerosol retrievals from MODIS, Seminar at the Max Planck Meteorological Institute, Hamburg, Germany, 13 August.

Lyapustin, A. (2009), Using time series for aerosol retrievals from MODIS, Seminar at Institute of Environmental Physics, Bremen University, Bremen, Germany, 14 August.

Lyapustin, A., (2009), A time series technique for aerosol retrievals from MODIS, WE-Heraeus Seminar: Determination of atmospheric aerosol properties using satellite measurements, Bad Honnef, Germany, 17-19 August, *invited*.

Lyapustin, A., and Y. Wang (2009), A time series algorithm for simultaneous retrieval of atmospheric aerosol and surface bidirectional from MODIS, oral presentation at the European Geophysical Union, Vienna, Austria, 19-24 April.

Lyapustin, A., and Y. Wang (2009), A time series technique for aerosol retrievals from MODIS, poster presentation, Fall AGU, San Francisco, CA, 14 -18 December.

Lyapustin, A., and Y. Wang (2009), Analysis of MAIAC algorithm for the US NAVY and USDA Forest Service applications, oral presentation, NASA Applied Science Air Quality Meeting, Washington, DC, 17-19 October.

Lyapustin, A., and Y. Wang (2009), Multi-Angle Implementation of Atmospheric Correction for MODIS: ATBD, presentation for NASA HQ ATBD Panel Review, Washington, DC, 22 October.

Lyapustin, A., and Y. Wang (2009), Validation of Surface Reflectance IP for VIIRS, Presentation at VIIRS Land Validation Meeting, UMCP, College Park, MD, 8-9 October.

Lyapustin, A., C. K. Gatebe, R. Kahn, R. Brandt, J. Redemann, P. Russell, M. D. King, C. Pedersen, S. Gerland, R. Poudyal, A. Marshak, Y. Wang, C. Schaaf, D. Hall, and A.

Kokhanovsky (2009), Analysis of Snow BRF from Spring-2008 ARCTAS Campaign, MISR Science team meeting, Pasadena, CA, 11-12 December, *invited*.

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Lyapustin, A., T. Hilker, F. Hall, Y. Wang, N. Coops, G. Drolet, T. A. Black (2009), Evaluation of MAIAC atmospheric correction using photochemical reflectance index (PRI), 4th global vegetation workshop, Missoula, MT, 16-19 June.

MacNeice, P., and A. Taktakishvili (2009), Systematic Independent Validation of Inner Heliospheric Models, SHINE conference, Wolfville, NS, Canada.

Mahaffy, P.R., R.R. Hodges, M. Benna, D.N. Harpold, W. K . Kasprzak, J.W. Kellogg, and T.T. King (2009), Neutral Mass Spectrometer under Development for the Lunar Atmosphere and Dust Environment Explorer (LADEE) Mission, 40th Lunar and Planetary Science Conference, Woodlands, TX, 23-27 March.

Mahanama, S. P. P., R.D. Koster, R.H. Reichle and D. P. Lettenmaier (2009), Contribution of Soil Moisture Information to Streamflow Prediction in the Snowmelt Season: A Continental-Scale Analysis, 6th International Scientific Conference on the Global Energy and Water Cycle, Melbourne, Australia, 24-28 August.

Mao, J., and the Goddard CO_2 Laser Sounder team (2009), Global CO_2 Measurement from Space: Passive vs Active, 1st International Symposium on Atmospheric Light Scattering and Remote Sensing, Xi'an, China, 13-17 July, *invited*.

Mao, J., C. Weaver, and J. Joiner (2010), Assessment of GOSAT Radiance Responses to the Lower Atmospheric CO_2 Concentration Change and Impact of Aerosols and Clouds on CO_2 Concentration Retrievals, paper presented in the 2nd Greenhouse gases Observing SATellite Principal Investigators Meeting, Kyoto, Japan, 28-29 January.

Mao, J., S. R. Kawa, J. B. Abshire, and J. Herman (2010), Global Measurement of CO_2 from Space: Challenges and Perspectives, paper presented in the 6th International Workshop on Greenhouse Gas Measurements from Space, Kyoto, Japan, 26-27 January.

Marshak, A., R. Cahalan, T. Várnai, G. Wen, and W. Yang (2010), Enhanced clear sky reflection near clouds: what can be learned from it about aerosol properties?, MODIS/VIIRS Science Team Meeting, Washington, DC, January.

Marshak, A., Y. Yang and S. P. Palm (2009), Revisiting the Blowing Snow Issue for the Forward Scattering Range Delay Problem, ICESat Science Team Meeting, Boulder, CO, 8-9 April.

Marshak, A., Y. Yang and S. P. Palm and and W. J. Wiscombe (2009), Atmospheric range delay from ICESat: an update, Joint ICESat/Cryosat2 Meeting, Reykjavik, Iceland, 22-26 June.

Marshak, A., Y. Yang, S. P. Palm, and W. Wiscombe (2009), Effect of clouds on the ice sheet altimetry accuracy for the ICESat-II photon counting system, ICESat-II Science Definition Team Meeting, Greenbelt, MD, 6-7 October.

Massie, S., F. Wu, N. A. Krotkov, P. F. Levelt, D. A. Chu, *et al.* (2009), Observations of SO_2, NO_2, CO, and aerosol over central China, EGU 2009 Session, AS3.8, Megacities, 19-22 April.

Masterton, S., D. Gubbins, K. H. Singh, D. Ivers, D. Müller, and D. Winch (2009), The prediction of lithospheric magnetic anomalies using the inversion of magnetisation data for vector spherical harmonics, 11th *IAGA Scientific Assembly*, Sopron, Hungary, 23-30 August.

Masuoka, P., T.A. Klein, H. Kim, D.M. Claborn, N. Achee, R. Andre, J. Chamberlin, K. Taylor, J. Small, A. Anyamba, M. Sardelis, and J. Grieco (2009), Modeling and analysis of mosquito and environmental data to predict the risk of Japanese encephalitis, ASPRS Annual Conference, Baltimore, MD, 9-13 March.

Matsui, T., W. Tao, H. Masunaga, C. D. Kummerow, W. S. Olson, N. Teruyuki, M. Sekiguchi, M. Chou, T. Y. Nakajima, X. Li, J. Chern, J. J. Shi, X. Zeng, D. J. Posselt, and K. Suzuki (2009), Goddard Satellite Data Simulation Unit: Multi-Sensor Satellite Simulators to Support Aerosol-Cloud-Precipitation Satellite Missions, *Eos Trans. AGU, 90(52)*, Fall Meet. Suppl., Abstract A21D-0268.

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Matsui, T., W.-K. Tao, H. Masunaga, C. D. Kummerow, W. S. Olson, N. Teruyuki, M. Sekiguchi, M. McCarty, W., R. Errico, M. McGill, R. Yang, R. Gelaro, and M. Rieneker (2009), The Development and Simulation of Doppler Wind Lidar Measurements and Assimilation Methodologies in Preparation for ADM-Aeolus and 3D-Winds, 8th International Workshop on Adjoint Applications in Dynamic Meteorology, Tannersville, PA, 18-22 May.

McCarty, W., R. Errico, M. McGill, R. Yang, R. Gelaro, and M. Rieneker (2009), Preliminary Efforts to Simulate and Assimilate DWL Observations at the GMAO, 32nd Meeting of the Working Group on Space-Based Lidar Winds, Wintergreen, Virginia, 16-19 June.

McCarty, W., R. M. Errico, M. McGill, R. Yang, R. Gelaro, and M. Reinecker (2009), The development and simulation of doppler wind lidar measurements and assimilation methodologies in preparation for ADM-Aeolus and 3D-winds validation of the new GMAO OSSE system, presentation at the 8th Workshop on Adjoint Model Applications in Dynamic Meteorology, Tannersville, PA, 19 May.

McClintock, W. E., M. Benna, E.T. Bradley, M.H. Burger, N.R. Izenberg, R.M. Killen, M.C. Kochte, M. Lankton, N. Mouawad, S.C. Solomon, A.L. Sprague, and R.J. Vervack (2009), Exploring Mercury's Surface-bound Exosphere with the Mercury Atmospheric and Surface Composition Spectrometer: An Overview of Observations during the Three MESSENGER Flybys, 2009 AGU fall meeting, San Francisco, CA, 14-18 December.

Melville, K., T. Farnham, and S. Hoban (2009), Study of the Collimated Jets in the Deep Space 1 Images of Comet 19P/Borrelly, 41st Annual Meeting of the Division of Planetary Sciences of the American Astronomical Society, Fajardo, Puerto Rico, 4-9 October.

Meneghini, R., and L. Liao (2009), An Integral Equation Method for Dual-Wavelength Radar Data using a "soft" constraint, The 34th Conference on Radar Meteorology, Williamsburg, VA, 5-9 October.

Merka, J., A. Szabo, R. J. Walker, T. W. Narock, T. A. King, and J. Faden (2009), Symbiosis of data archives and virtual observatories, *Eos Trans. AGU, 90* (52), Fall Meet. Suppl., Abstract SM33B-1571.

Merka, J., A. Szabo, R. Walker, T. Narock, T. King, and J. Faden (2009), Symbiosis of Data Archives and Virtual Observatories, 2009 Fall AGU Meeting, San Francisco, CA, 14-18 December.

Merka, J., A. Szabo, T. W. Narock, R. J. Walker, T. King, J. A. Slavin, S. Imber, H. Karimabadi, and J. Faden (2009), An example of using the Virtual Heliospheric and Magnetospheric Observatories for a substorm study, EGU General Assembly 2009, Vienna, Austria, 19-24 April, EGU2009-12642.

Molnar, G. I., and J. Susskind (2009), Interrelations of AIRS/AMSU-Derived Anomalies and Trends of Temperature, Water vapor, Clouds and OLR, 2009 AGU Fall Meeting, San Francisco, CA, 14-18 December.

Morris, G.A., H. Akimoto, Y. Kanaya, M. Takigawa, J. Hirokawa, F. Hasebe, M. Fujiwara, K. Ishida, K. Miyagawa, M. R. Schoeberl, E. Celarier, N. Krotkov, S. Christensen, N. Kellams, B. Lehmann, and T. G. Pietrzak (2009), An Examination of the Impact of Air from China on Air Quality in Hokkaido, Japan Before, During, and After the Beijing Olympics, poster presented at the Spring 2009 Joint Assembly Meeting, Toronto, Canada, 24-27 May.

Narock, T. W., J. Merka, and A. Szabo (2009), Toward a unified heliophysics data environment, *Eos Trans. AGU, 90(52*), Fall Meet. Suppl., Abstract SH51B-1286.

Narock, T., and V. Yoon (2009), Context and Subjectivity in Semantic e-Science, 2009 Fall AGU Meeting, San Francisco, CA, 14-18 December.

Narock, T., J. Merka, and A. Szabo (2009), Toward a Unified Heliophysics Data Environment, 2009 Fall AGU Meeting, San Francisco, CA, 14-18 December.

Narock, T., V. Yoon, J. Merka, and A. Szabo (2009), Semantic e-science in space physics - A case study, *Eos Trans. AGU, 90*(22), Jt. Assem. Suppl., Abstract IN24A-02.

Narock, T., V. Yoon, J. Merka, and A. Szabo (2009), Semantic e-Science in Space Physics - A Case Study, American Geophysical Union Joint Assembly, Toronto, Canada, May.

Noblet, A., F. Stalport, P. Coll, and C. Szopa (2009), Evolution of Organics of Astrobiological Interest under Simulated Martian Environmental Conditions, American Astronomical Society, DPS (Division for Planetary Sciences), Fajardo, Puerto Rico, 4-9 October.

Norris, P., and L. Oreopoulos (2009), Using ARM data to model cloud overlap with copulas, poster presented at the Nineteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting, Louisville, KY, 30 March–4 April.

Norris, P., A. da Silva, and L. Oreopoulos (2009), Statistical cloud parameterizations and their constraint with satellite data: Plans for cloud data assimilation in the NASA Global Modeling and Assimilation Office's GEOS-5 data assimilation system, AFWA Cloud Analysis Workshop, National Center for Atmospheric Research, Boulder, CO, 1-3 September.

Olsen, M. A., A. R. Douglass, M. R. Schoeberl, J. M. Rodriquez, and Y. Yoshida (2009), Lower Latitude Contribution to the Extratropical Ozone Budget Through Laminar Transport, 2009 Joint Assembly, American Geophysical Union, Toronto, Canada, 24-27 May.

Olsen, M. A., A. R. Douglass, M. R. Schoeberl, J. M. Rodriquez, and Y. Yoshida (2009), Lower Latitude Contribution to the Extratropical Ozone Budget Through Laminar Transport, UTLS Community Workshop, NCAR, Boulder, CO, 19-22 October.

Olsen, M. A., A. R. Douglass, M. R. Schoeberl, J. M. Rodriquez, and Y. Yoshida (2009), Inter-annual Variability of Ozone in the Winter Lower Stratosphere and the Relationship to Laminar Transport and Mixing, 2009 AGU Fall Meeting, San Francisco, CA, 14-18 December.

Olson, W. S., M. Grecu, T. L'Ecuyer, M. Bosilovich, C.-L. Shie, and W.-K. Tao (2009), Precipitation and latent heating distributions derived from active and passive microwave observations, NASA/NEWS Annual Science Team Meeting, Columbia, MD, 2-3 December.

Ott, L. E. (2009), The impact of convective transport on trace gas distributions simulated by the GEOS-5 AGCM, presented at Harvard University, Boston, MA, 8 May.

Ott, L. E., and S. Pawson (2009), The impact of stratosphere-troposphere exchange on surface CO_2 mixing ratios studied with the GEOS-5 AGCM, presented at the 2009 AGU Fall Meeting, San Francisco, CA, 18 December.

Palm, S. P., A. Marshak, Y. Yang, J. Spinhirne, and T. Markus (2009), The Influence Of Arctic Sea Ice Extent On Polar Cloud Fraction And Vertical Structure And Implications For Regional Climate, 10th Conference on Polar Meteorology and Oceanography, Madison, WI, 18-21 May.

Pan, X., B. Huang, and J. Shukla (2009), The Impact of the Mean Climate on the ENSO Simulation and Prediction, paper presented at AMS 89th Annual Meeting, Phoenix, AZ, 15 January.

Pavlis, E. C., (2009), SLRF2008: The ILRS Reference Frame for SLR POD Contributed to ITRF2008, OST Mission Science Team meeting, Seattle, WA, 22-24 June.

Pavlis, E. C., (2010), "Earth's gravity field models for testing general relativity", 1st Workshop on *Theory and Model for the New Generation of the Lunar Laser Ranging Data*, ISSI, Bern, Switzerland 16-19 February.

Pavlis, E. C., K. Evans, B. Beckley, X. Frantzis, S. P. Mertikas, P. Milas, and D. Paradissis, (2009), OSTM/JASON-2 Cal/Val Results From The Eastern Mediterranean Altimeter Calibration Network – *e*MACnet, EGU2009-6608, Vienna, Austria, 19-24 April.

Pavlis, E. C., K. Evans, et al., (2009), OSTM/JASON-2 Cal/Val Results From The Eastern Mediterranean Altimeter Calibration Network – *e*MAC*net*, OST Mission Science Team, Seattle, WA, 22-24 June.

Pavlis, E. C., M. Kuzmicz-Cieslak, J.-P. Boy, and P. M. Hinkey, (2009), Improved modeling approaches toward the mm SLR, EGU2009-6584, Vienna, Austria, 19-24 April.

Pavlis, E. C., V. Luceri, C. Sciarretta, and R. Kelm, (2009), The ILRS contribution to ITRF2008, EGU2009-6564, Vienna, Austria, 19-24 April.

Pavlis, E. C., V. Luceri, C. Sciarretta, R. Kelm, (2009), "The ILRS Reanalysis 1983 – 2009 Contributed to ITRF2008", *Eos Trans. AGU, 90*(52), Fall Meet. Suppl., Abstract G11B-0629.

Pawson, S., P. Xu, A. R. Douglass, M. A. Olsen, S. Strahan, J. E. Nielsen, N. McKee, M. Sienkiewicz, and K. Wargan (2009), Assimilating EOS-Aura OMI and MLS Data in GEOS-5, EOS Aura Science Team Meeting, NASA, Leiden, The Netherlands, 14-17 September.

Petrenko, M., M. Chin, Q. Tan, and T. Diehl (2009), Biomass burning emission height in global aerosol model, simulations vs. satellite measurements, Fall AGU, San Francisco, CA, 14-18 December.

Pippin, M., J. Fishman, D. Neil, L. Cowen, J. Geiger, J. Murray, N. Prasad, P. Lucker, S. Bedka, C. Thornton, J. Szykman, J. Herman, A. Cede, N. Abuhassan, D. Martins, A. Jensen, D. Doughty, A. Thompson, S. Kondragunta, T. Beck, D. Deslover, W. Feltz, E. Olson, R. Knuteson, and C. Scott (2009), Overview of the NASA Langley Chemistry and Physics of the Atmospheric Boundary Layer Experiment (CAPABLE), AGU 2009, San Francisco, CA, 14-18 December.

Poudyal, R., C. K. Gatebe, and E. Wilcox, Effect of ship wake on ocean glint reflectance, poster presentation at the 2009 AGU Fall Meeting, A41D-0151, San Francisco, CA, 14-18 December.

Pulkkinen, A. (2009), Avaruussää, presentation at the Planetary Association Seminar Series, Kajaani, Finland, 1 September, *invited*.

Pulkkinen**,** A. (2009), Geospace models: What works and what does not?, NASA GSFC Heliophysics Science Division Director's Seminar, 21 August, *invited*.

Pulkkinen, A. (2010), CCMC's V&V Report: Magnetosphere/Ionosphere Models, CCMC Workshop, Key Largo, FL, 25-29 January, *invited*.

Pulkkinen, A. (2010), Usage of modern physics-based models in space weather forecasting: current capabilities and future prospects, Embry-Riddle Aeronautical University, Daytona Beach, FL, 2 February, *invited*.

Pulkkinen, A., A. Taktakishvili, and T. Oates (2009), Automatic determination of the conic coronal mass ejection model parameters, George Mason University, Space Weather Laboratory, 30 September, *invited*.

Pulkkinen, A., A. Taktakishvili, and T. Oates (2009), Automatic determination of the conic coronal mass ejection model parameters, paper presented at the Fall AGU, San Francisco, CA, 14-18 December.

Pulkkinen, A., A. Taktakishvili, D. Odstrcil and W. Jacobs (2009), Novel approach to geomagnetically induced current forecasts based on remote solar observations, paper presented at the Space Weather Workshop, Boulder, CO, 28 April - 1 May.

Pulkkinen, A., L. Rastätter, M. Kuznetsova and A. Chulaki (2009), GEM Challenge: ground magnetic field perturbations, invited presentation at the GEM 2009 Summer Workshop, Snowmass, CO, 21-26 June.

Pulkkinen, A., M. Hesse, S. Habib, F. Policelli, B. Damsky, L. Van der Zel, D. Fugate, and W. Jacobs (2009), Solar Shield – Forecasting and Mitigating Space Weather Effects on High-Voltage Power Transmission Systems, IEEE Seminar Series, TVA, Chattanooga, TN, 10 December, *invited*.

Pulkkinen, A., M. Kuznetsova, A. Ridley, J. Raeder, D. Weimer, R. Weigel, M. Wiltberger, G. Millward, L. Rastätter, M. Hesse, H. J. Singer and A. Chulaki (2009), GEM 2008-2009 Challenge: ground magnetic field perturbations, Mini GEM Workshop, San Francisco, CA, 13 December, *invited*.

Randles, C. A. (2009), Accuracy of radiative transfer schemes in global modeling: The AeroCom A2 TROP/ARCTIC Experiment, paper presented at 8th International AeroCom Workshop, Princeton, NJ, 5-7 October.

Randles, C. A., P. R. Colarco, A. da Silva, A. M. Colarco, and R. C. Govindaraju (2009), Aerosol direct and semi-direct Effects on Cimate in Asia in the NASA GEOS-5 Model, poster presentation, 2009 Fall AGU Meeting San Francisco, CA, 14-18 December.

Ray, R.D., B.D. Beckley, J. Boy, S.D. Jacob, F.G. Lemoine, S.B. Luthcke, and N.P. Zelensky (2009), Global Mean Sea Level during 2004-2008 from Jason, GRACE, and Argo: A Discussion of Systematic Errors, paper presented at the AGU Fall Meeting, San Francisco, CA, 14-18 December, *invited*.

Reale, O., S. Schubert, and M.-I. Lee (2009), Assessing the representation of tropical cyclones in global models, ICTP Workshop on high-resolution modeling, Trieste, Italy, August (presentation given remotely).

Reale, O., W. K. Lau, E. Brin, E. Liu, J. Susskind, L.P. Riishojgaard, M. Fuentes, and R. Rosenberg (2009), AIRS impact on tropical cyclone analysis and forecast over the Atlantic, Pacific and Indian Oceans, AIRS Science Team Meeting, Greenbelt, MD, October.

Reich, J., J. Cox, R. Davila, A. Parsons, M. Kuznetsova, D. Berrios, M. Hesse, A. Pulkkinen, P. MacNeice, M. Maddox, L. Rastätter, and A. Taktakishvili (2009), AFWA-CCMC Partnership to Augment USAF Space Weather Forecasting Capabilities, paper presented at the Fall AGU, San Francisco, CA, 14-18 December.

Retscher, C., M. M. Yan, and I. Boyd (2009), AVDC Status/Plans, Aura Science Team Meeting, Leiden, NL, 14-17 September.

Richard, D. T., D. A. Glenar, S. S. Davis, T. J. Stubbs, and A. Colaprete (2010), Modeling of light scattering by non-spherical lunar dust grains, 1st Workshop on Lunar Dust, Plasma and Atmosphere: The Next Steps, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, 27-29 January.

Richard, D. T., D. A. Glenar, T. J. Stubbs, S. S. Davis, and A. Colaprete (2009), “But still, like dust, I'll rise”: Scattering signatures of complex lunar particulates, 2nd Annual Lunar Science Forum, NASA Lunar Science Institute, NASA Ames Research Center, Moffett Field, CA, 21–23 July.

Richards, E., P. Masuoka, D. Brett-Major, M. Smith, T. Klein, H.C. Kim, A. Anyamba, and J. Grieco (2009), The relationship between mosquito abundance and rice field density in South Korea, Force Health Protection Conference, Albuquerque, NM, August.

Rueda, L.M., T.L. Brown, H.C. Kim, T.A. Klein, D.H. Foley, A. Anyamba, M. Smith, J. Pike, and R.C. Wilkerson (2009), Habitats, seasonal occurrence and distribution models of Anopheles mosquito vectors and related species (Culicidae, Diptera) from South Korea, 5th International Society for Vector Ecology Congress, Antalya, Turkey, 11-16 October.

Rueda, L.M., T.L. Brown, H.C. Kim, T.A. Klein, D.H. Foley, A. Anyamba, M. Smith, and R.C. Wilkerson (2009), Species composition, habitats and distribution of potential malaria vectors and associated species of from South Korea, 75th Annual Meeting, The American Mosquito Control Association, New Orleans, LA, 5-9 April.

Ryan, F., and L. A. Parnell (2009), Multi-core Electromagnetic Propagation Simulation, paper presented at 2009 Department of Defense High Performance Computing Modernization Program (HPCMP) Users Group Conference, San Diego, CA, 15-19 June.

Salawitch, R. J., T. P. Canty, T. P. Kurosu, K. Chance, Q. Liang, *et al.* (2009), Airborne, Ground-based, and Satellite Measurements of BrO during ARCTAS and ARCPAC, *Eos Trans. AGU*, Fall Meet. Suppl., AbstractA32B-07.

Salustro, C.E., N.C. Hsu, and M.J. Jeong (2009), Validation of MODIS Deep Blue aerosol products over bright surfaces, *Eos Trans. AGU*, *90*(52), Fall Meet. Suppl., Abstract A11C-0114.

Sarantos, M., and J. A. Slavin (2009), On the possible formation of Alfvén wings at Mercury during encounters with coronal mass ejections, EGU2009-10447, EGU General Assembly 2009, Vienna, 19-24 April.

Sarantos, M., J. A. Slavin, M. Benna, R. M. Killen, W. E. McClintock, J. M. Raines, S. C. Solomon, D. Schriver, and P. Travnicek (2009), Sodium and Magnesium Neutral and Ion Species at Mercury: Simulations and Comparison to MESSENGER Observations, 2009 AGU fall meeting, San Francisco, CA, 14-18 December.

Sarantos, M., J. A. Slavin, M. Benna, T. H. Zurbuchen, S. M. Krimigis , D. Schriver, P. Trávnícek, and S. C. Solomon (2009), Comparison of models for Mercury's pickup ions with MESSENGER measurements for northward and southward IMF, EGU2009-9742-2, EGU General Assembly 2009, Vienna, 19-24 April.

Sarantos, M., J.A. Slavin, M. Benna, S.A. Boardsen, T. Zurbuchen, T. Krimigis, D. Schriver, and S. Solomon (2009), Comparison of Models for Mercury's Pickup Ions with MESSENGER Measurements for Northward and Southward IMF, 2009 EGU general assembly, Vienna, Austria, 19-24 April.

Sarantos, M., R.M. Killen, M. Benna, A.S. Sharma, and R.E. Hartle (2009), The Lunar exosphere: expectations for LADEE measurements, 2009 EGU General Assembly, Vienna, Austria, 19-24 April.

Sarantos, M., J.A. Slavin, M. Benna, R. M. Killen, W.E. McClintock, J. M. Raines, S. C. Solomon, D. Schriver, and P. Travnicek (2009), Sodium and magnesium neutral and ion species at Mercury: Simulations and comparison to MESSENGER observations, 2009 Fall AGU Meeting, abstract #P21A-1209, San Francisco, CA, 14-18 December.

Sarantos, M., R. M. Killen, R.E. Hartle, M. Benna, and A. S. Sharma (2009), The Lunar Exosphere: observations, models, and expectations for LADEE measurements, NASA 2009 Lunar Science Forum, NASA Ames Research Center, CA, July.

Schmidt, K. S., E. Bierwirth, P. Pilewskie, J. Redemann, R. Brandt, A. Lyapustin, C. Gatebe, C. Schaaf, and R. Kahn (2009), Airborne measurement of surface albedo in Alaska, poster presentation at the 2009 AGU Fall Meeting, San Francisco, CA, 14-18 December.

Schmidt, S., P. Pilewskie, M. King, G. Wind, L. Tian, S. Platnick, and T. Arnold (2009), Apparent absorption of solar radiation in heterogeneous tropical cirrus clouds, EGU General Assembly, Vienna, 19-24 April.

Schriver, D., P. Travnicek, J. Paral, J. A. Slavin, M. Sarantos, B. J. Anderson, H. Korth, T. Zurbuchen, D. Baker, M. Benna, R.M. Killen, W. E. McClintock, G. C. Ho, S. M. Krimigis, R. L. McNutt, and S. C. Solomon (2009), Particle Transport and Acceleration in Mercury's Magnetosphere during the MESSENGER Flybys, 2009 Fall AGU Meeting, abstract #P24A-07, San Francisco, CA, 14-18 December.

Schroeder, P. C., A. Szabo, A. Davis, G. Ho, J. Kasper, J. Merka, T. Narock, J. Raines, K. Rash, D. A. Roberts, and J. Vandegriff (2009), Providing data in a virtual world, EGU General Assembly 2009, EGU2009-5824, Vienna, Austria, 19-24 April.

Selkirk, H. (2009), The Water Vapor Tape Recorder in High Vertical Resolution: A Comparison of Balloonsonde Measurements from Costa Rica with MLS, oral presentation to the MOCA-09 Joint Assembly, Montréal, Quebec, 28 July.

Selkirk, H. (2009), Toward Modeling the Variability of Ozone Observed in the Deep Tropical Upper Troposphere, oral presentation to the AGU Joint Assembly, Toronto, Ontario, 27 May.

Selkirk, H. (2010), Ozone & water vapor structures in the UT/LS during MOHAVE, oral presentation to the MOHAVE 2009 workshop, NOAA ESRL, Boulder, CO, 11 February.

Sellitto, P, F. Del Frate, D. Solimini, C. Retscher, B. Bojkov, P. K. Bhartia (2008), Neural Network Algorithms for Ozone Profile Retrieval from ESA-Envisat SCIAMACHY and NASA-Aura OMI Satellite Data, IGARSS, Boston, MA, 6-11 July.

Sessions, W., *et al.* (2009), Transport Simulations of Carbon Monoxide and Aerosols from Boreal Wildfires during ARCTAS using WRF-Chem, AGU *90*(52), *Fall Meet. Suppl.*, Abstract A43A-0226.

Sexton, J.O., (2009), Vertical structure, horizontal cover, and temporal change of the North Carolina Piedmont (1985 – 2005), Nicholas School of the Environment, Duke University, Durham, NC, 24 April.

Sexton, J.O., (2009), Vertical structure, horizontal cover, and temporal change of the North Carolina Piedmont (1985 – 2005), Brown Bag Lunch seminar, Goddard Space Flight Center, Greenbelt, MD, November.

Shen, B.-W., W.-K. Tao, J.-D. Chern, and R. Atlas (2009), Scalability improvements in the NASA Goddard multiscale multicomponent modeling framework for tropical cyclone climate studies, paper presented at International Conference for High-Performance Computing in ASIA-Pacific Region 2009, Proceedings, pp. 249-256. Kaohsiung, Taiwan, 2-5 March.

Shie, C.-L., L. S. Chiu, R. Adler, I-I Lin, E. Nelkin, J. Ardizzone and S. Gao (2009b), The recently revived and produced Goddard Satellite-based Surface Turbulent Fluxes Version-2b (GSSTF2b) dataset, 2009 AGU Fall Meeting, San Francisco, CA, 14-18 December.

Shie, C.-L. (2009c), A recently revived global air-sea surface turbulent fluxes - the newly produced Goddard Satellite-based Surface Turbulent Fluxes Version-2b (GSSTF2b) dataset: Validation & findings, NASA/NEWS Annual Science Team Meeting, Columbia, MD, 2-3 December.

Shie, C.-L., L. S. Chiu, R. Adler, I-I Lin, E. Nelkin, J. Ardizzone, S. Gao, R. Chokngamwong, P. Xie, and F.-C. Wang (2009d), The recently revived and produced Goddard Satellite-based Surface Turbulent Fluxes Version-2b (GSSTF2b) dataset, NASA/NEWS Annual Science Team Meeting, Columbia, MD, 2-3 December.

Shie, C.-L. (2009e), Recently revived global air-sea surface turbulent fluxes - the newly produced Goddard Satellite-based Surface Turbulent Fluxes Version-2b (GSSTF2b) dataset: Review & findings, UMBC/GEST All Hands Meeting, Greenbelt, MD, 5 November.

Shie, C.-L. (2009f), Reviving the Goddard Satellite-based Surface Turbulent Fluxes (GSSTF), dataset: Review and preliminary findings, NASA/GSFC Code 613.1 Branch Meeting, Greenbelt, MD, 2 September.

Shie, C.-L., L. S. Chiu, R. Adler, I-I Lin, P. Xie, E. Nelkin, and R. Chokngamwong (2009g), Reviving the Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) dataset: Preliminary findings, the 6th Intl. Sci. Conf. on the Global Energy and Water Cycle, Melbourne, Australia, 24-28 August.

Shie, C.-L., L. S. Chiu, R. Adler, P. Xie, I-I Lin, E. Nelkin, R. Chokngamwong, F.-C. Wang, S. Bruan, and L. Wu (2009h), Reviving the Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) dataset: Preliminary results and findings, JOINT SYMPOSIA, Joint Assembly, MOCA-09, Montréal, Québec, Canada, 19-24 July.

Shie, C.-L., *et al.* (2009i), The Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) dataset: review and prospects, The Science Jamboree, NASA/GSFC, Greenbelt, MD, 25 June.

Shie, C.-L. (2009j), Reprocessing of Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) dataset for Global Water and Energy Cycle Research, GES DISK MEaSUREs Working Group (MWG) Meeting, Lanham, MD, 29-30 April.

Shie, C.-L., L. S. Chiu, S. Gao, R. Chokngamwong, R. Adler, I-I Lin, E. Nelkin, J. Ardizzone, P. Xie, and F.-C. Wang (2010c), A recently revived and global air-sea surface turbulent fluxes dataset – the newly produced GSSTF2b: Validations and findings, 2010 AGU Ocean Science Meeting, Portland, OR, 22-26 February.

Shim, J. S. and L. Scherliess (2009), Climatology of plasmaspheric TEC obtained from Jason-1, 2009 Fall AGU Meeting, San Francisco, CA, 14-18 December.

Shim, J. S., M. M. Kuznetsova, M. Hesse, A. Chulaki, and L. Rastaetter (2010), Ionosphere-Thermosphere Models at Community Coordinated Modeling Center, 2010 Air Force Orbital Resources Ionosphere Conference, Dayton, OH, 12-14 January.

Shuman, C. A. (2009), LVIS data and Greenland calibration of ICESat-1 data, PARCA Meeting, Seattle, WA, 29 September - 2 October.

Shuman, C. A., *et al.* (2009), Multi-sensor Assessment of Crane Glacier Drawdown 2002-2009, Larsen B Embayment, Antarctica, oral presentation, 2009 AGU Fall Meeting, San Francisco, CA, 14-17 December.

Shuman, C.A. (2009), Ice Cores, Glaciology, Subglacial Lakes, ICESat, and The International Polar Year, Freshman Global Warming seminar, UMBC, Baltimore, MD, 2 April.

Shuman, C.A. (2009), PoDAG Meeting, Boulder, CO, 13-16 October.

Shuman, C.A. (2009), seminar at PSU's Geography Department and informal talk to PSU's Cryosphere Research Group, Pennsylvania State University, State College, PA, 16-17 April, *invited*.

Shuman, C.A., *et al.* (2009), Detection of surface-elevation change on Drangajökull, Iceland, Eastern Snow Conference, Niagara-on-the-Lake, Ontario, Canada, 10-11 June.

Shuman, C.A., *et al.* (2009), DESDynI Mission Working Group meeting, Pasadena, CA, 8-9 June.

Shuman, C.A., *et al.* (2009), Empirical Correction of Residual Error in the ICESat-1 Altimetry Time Series at Lake Vostok, poster presentation – 2009 AGU Fall Meeting, San Francisco, CA, 14-17 December.

Shuman, C.A., O. Sigurðsson, R.S. Williams, Jr., and D.K. Hall (2009), Elevation Change of Drangajökull, Iceland from Cloud-Cleared ICESat Repeat Profiles and GPS Ground-Survey Data, Proceedings of the Eastern Snow Conference, Niagara-on-the-Lake, Ontario, Canada, 9-11 June.

Sibeck, D. G., and J. Merka (2009), Active missions and the VxOs with THEMIS as an example, *Eos Trans. AGU, 90*(52), Fall Meet. Suppl., Abstract SH54A-02.

Singh, K. H., and A. Salem (2009), Imaging geological structures of the Red Sea from thermal and aeromagnetic data, 11th *IAGA Scientific Assembly*, Sopron, Hungary, 23-30 August.

Singh, K. H., W. Kuang, and T. Sabaka (2009), Understanding Lunar remanent field through magnetization and dynamo mechanism, *NLSI Lunar Science Forum*, NASA Ames Research Center, Moffett Field, CA, 21-23 July.

Singh, K. H., W. Kuang, T. Sabaka, and A. V. Kuvshinov (2009), Oceanic magnetic anomalies induced from Kuroshio currents, *AGU 90*(52), Fall Meet. Suppl., *Abstract 0738*, San Francisco, CA, 14-18 December.

Slavin, J. A., B. J. Anderson, D. Baker, M. Benna, S. A. Boardsen, C. L. Johnson, G. Gloeckler, R. E. Gold, R. M. Killen, H. Korth, S. M. Krimigis, W. E. McClintock, R. L. McNutt, M. E. Purucker, M. Sarantos, D. Schriver, S. C. Solomon, A. L. Sprague, R. J. Vervack, T. Zurbuchen, and P. Travnicek, (2009), Mercury's atmosphere and magnetosphere: MESSENGER third flyby observations, *Eos Trans. AGU, 90*(52), Fall Meet. Suppl., Abstract P24A-01, *invited.*

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Smirnov, A., B.N. Holben, D.M. Giles, N.T. O'Neill, I. Slutsker, T.F. Eck, P. Croot, A. Macke, S.M. Sakerin, T.J. Smyth, G. Zibordi, T. Zielinski, N.B.Nelson, P.K. Quinn, K. Voss, Y. Courcoux, N.R. Nalli, E. Joseph, D. Covert, S.Belanger, C. MacLellan, L. Bariteau, and R. Dunn (2009), Maritime Aerosol Network as a component of AERONET – a satellite validation tool over the oceans, *Eos Trans. AGU, 90*(52), Fall Meet. Suppl., Abstract A11C-0099, San Francisco, CA, 14-18 December.

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Susskind, J., and G. I. Molnar (2009), Comparison of Anomalies and Trends of OLR as Observed by CERES and Computed from Geophysical Parameters Derived from Analysis of AIRS/AMSU Data, Fall 2009 CERES Team Meeting, Fort Collins, CO, 4-6 November.

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van Oevelen, P. (2009), Workshop on Monitoring Soil Moisture and Soil Temperature, Oak Ridge, TN, 5 March.

van Oevelen, P. (2009), Third Meeting of the International Soil Moisture Working Group (ISMWG), Lisbon, Portugal 10-11 March.

van Oevelen, P. (2009), 30th Session of the WCRP Joint Scientific Committee, University of Maryland, College Park, MD, 6-9 April.

van Oevelen, P. (2009), European Geophysical Union, General Assembly, Vienna, Austria,19-24 April.

van Oevelen, P. (2009), H-SAF Workshop, Vienna, Austria, 14-15 May.

van Oevelen, P. (2009), CLIVAR SSC, Madrid, Spain, 19-22 May.

van Oevelen, P. (2009), SMAP Science Algorithms and Cal/Val Workshop, Oxnard, CA, 9-11 June.

van Oevelen, P. (2009), GPM International Planning Meeting, Paris, France, 15-19 June.

van Oevelen, P., D. Erlich, and R. Lawford (2009), Third GEWEX Coordinated Energy and Water Cycle Observations Project (CEOP) Meeting, Melbourne, Australia, 19-21 August.

van Oevelen, P. (2009), Joint iLEAPS/GEWEX Early Career Scientists Workshop, Melbourne, Australia, 20-22 August.

van Oevelen, P. (2009), GEWEX/Global Land/Atmosphere System Study (GLASS) Meeting, Melbourne, Australia, 22 August.

van Oevelen, P., and D. Erlich (2009), Joint GEWEX/iLEAPS Workshop on Landflux, Melbourne, Australia, 23 August.

van Oevelen, P., D. Erlich, and R. Lawford (2009), Water in a Changing Climate: Progress in Land-Atmosphere Interactions and Energy/ Water Cycle Research--Parallel GEWEX and iLEAPS Science Conferences with Joint Sessions, Melbourne, Australia, 24-28 August.

van Oevelen, P. (2009), GEWEX Seminar at NOAA/CPO, Silver Spring, MD, 20 October.

van Oevelen, P. (2009), 24th session of the Working Group on Numerical Experimentation (WGNE) to be held with the 10th session of the GEWEX Modelling and Prediction Panel (GMPP), Offenbach, Germany, 3-7 November.

van Oevelen, P. (2009), Earth Observation and Water Cycle Science—Toward a Water Cycle Multi-mission Observation Strategy, ESA/ESRIN, Frascati, Italy, 18-20 November.

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van Oevelen, P., and R. Lawford (2009), Fall AGU, San Francisco, CA, 14-18 December.

Vasel, B.A., J. Borgeld, M. Ives, T. Conway, A.. Karion, M.L. Fischer, A.E. Andrews, C. Sweeny, B. Andrews, S.J. Oltmans, B.J. Johnson, L.C. Patrick, and T. Berkoff (2009), NOAA ESRL Atmospheric Research Operations in California, AGU Fall Meeting, San Francisco, CA, 14-18 December.

Vicente, G., W. Schroeder, A.J. Krueger, K. Yang, S.A. Carn, N.A. Krotkov, M. Guffanti, and P. Levelt (2009), The NOAA-NASA OMI/GOME-2 Near-Real-Time Monitoring System of Volcanic SO_2 and Aerosol Clouds, AGU Fall Meeting, San Francisco, CA, 14-18 December.

Walker, R. J., T. King, J. M. Weygand, J. Merka, L. F. Bargatze, P. Chi, J. Mafi, T. W. Narock, R. L. McPherron, and S. Joy (2009), The science centered approach of the Virtual Magnetospheric Observatory, EGU General Assembly 2009, Vienna, Austria, 19-24 April, EGU2009-11061.

Wang, H., S. Schubert, M. Suarez, and R Koster (2009), The physical mechanisms by which the leading patterns of SST variability impact U.S. precipitation, paper presented at the Eighth Workshop on Decadal Climate Variability, St. Michaels, MD, 13 October.

Wang, N., R. R. Ferraro, K. Gopalan, W. Tao, and J. J. Shi (2009), Improvement of Cold Season Land Precipitation Retrievals Through The Use Of WRF Simulations and High Frequency Microwave Radiative Transfer Model, AGU 2009 Fall Meeting, San Francisco, CA, 14-18 December.

Wang, Y., A. Lyapustin, A. Huete, E. Vermote, and C. Schaaf (2009), Validation analysis of MODIS surface reflectance/BRDF/Albedo products using ASRVN data set, 4th global vegetation workshop, Missoula, MT, 16-19 June.

Wang, Y., D. G. Sibeck, S. A. Boardsen, H. Karimabadi, and T. Sipes (2009), A New 3D Asymmetric Magnetopause Model with New Consistent Magnetopause Crossing Database and Machine Learning Techniques, *Eos Trans. AGU, 90*(52), Fall Meet. Suppl., Abstract SM13A-1598.

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Wen, G., A. Marshak, and R.F. Cahalan (2009a), 3D Radiative Effects of Vertically Extended Clouds on Reflectance and Aerosol Optical Thickness Retrieval in Nearby Clear Regions from MODIS and ASTER Images over the ARM SGP Site, IAMAS, Montreal, Canada, 19-29 July.

Wen, G., A. Marshak, T. Varnai, C. Chiu, and R.F. Cahalan (2009b), CALIPSO and CloudSat help to improve Aqua MODIS aerosol retrieval in A-Train Constellation, The Second International Conference on Aerosol Science and Global Change, Hangzhou, China, 18-21 August.

Wilcox, E. and C. K. Gatebe (2009), Bidirectional Reflectance Distribution Function from Airborne Radiation Measurements, poster presentation at NASA Mission Planning: 2nd HyspIRI Science Workshop, Sheraton Hotel, Pasadena, CA, 11-13 August.

Yang, K., X. Liu, N. Krotkov, A. Krueger, S. Carn and P. K. Bhartia (2009), Atmospheric Science Conference, Barcelona, Spain, 7-11 September.

Yang, K., X. Liu, N.A. Krotkov, A.J. Krueger, S.A. Carn, E.J. Hughes, S.G. Desouza-Machado, and L. Strow (2009), Measuring Volcanic Emissions Using Hyper-spectral UV Observations from Satellite, AGU Fall Meeting, San Francisco, CA, 14-18 December.

Yang, R., and R. M. Errico (2009), Validation of the new GMAO OSSE system, presentation at the 8th Workshop on Adjoint Model Applications in Dynamic Meterorology, Tannersville, PA, 19 May.

Yang, Y. (2009), Clouds observed by ICESat: liked by some, disliked by others, Climate and Radiation Branch, NASA/Goddard Space Flight Center, 18 November.

Yang, Y., A. Marshak, J. C. Chiu, and W. J. Wiscombe (2009), Retrieving optical depth for optically thick clouds from the Geoscience Laser Altimeter System (GLAS) onboard ICESat, 89th Annual Meeting of the American Meteorological Society, Phoenix, AZ, 11-15 January.

Yang, Y., A. Marshak, T. Várnai, and W. J. Wiscombe (2009), Properties of thin clouds observed by ICESat and CALIPSO over ice sheets and their impact on ice altimetry

measurements, 89th Annual Meeting of the American Meteorological Society, Phoenix, AZ, 11-15 January.

Yang, Y., A. Marshak, T. Varnai, S. P. Palm, and W. Wiscombe (2009), Study of Properties of Thin Cloud and Blowing Snow and their Potential Effects on Surface Altimetry for the ICESat-II Mission, Gordon Research Conference on Radiation and Climate, New London, NH, 5-10 July.

Yang, Y., and A. Marshak (2009), The Impact Of Clouds On Ice Surface Measurements From Space-Borne Lidars, 30th Asian Conference on Remote Sensing, Beijing, China, 18-23 October.

Yasunari, T. J., P. Bonasoni, P. Laj, K. Fujita, E. Vuillermoz, A. Marinoni, P. Cristofanelli, F. Calzolari, R. Duchi, G. Tartari, and K.-M. Lau (2009), Estimation of black carbon deposition from particulate data in the atmosphere at NCO-P site in Himalayas during pre-monsoon season and its implication to snow surface albedo reduction, AGU Fall Meeting 2009, San Francisco, CA, 14-18 December.

Yu, H. (2009), Satellite-model integrated studies of aerosol long-range transport and climate impacts, Laboratory for Atmospheres, NASA GSFC, Greenbelt, MD, 13 May, *invited*.

Yu, H., M. Chin, D. Winker, A. Omar, Z. Liu, C. Kittaka, and T**.** Diehl (2009), Global Aerosol Vertical Profiles from CALIPSO Lidar and GOCART Model, 8th AeroCom Workshop, Princeton, NJ, 5-7 October.

Yu, H., M. Chin, D. Winker, A. Omar, Z. Liu, C. Kittaka, and T. Diehl (2009), Global view of aerosol vertical distributions from CALIPSO lidar measurements and GOCART simulations: Regional and seasonal variations, CALIPSO/CloudSat Science Team meeting, Madison, WI, 28-31 July.

Yu, H., M. Chin, Q. Tan, Y. Hu, S. Kondragunta, P. Ciren, and B. N. Holben (2009), Aerosol spatial and temporal variations in a coastal area: Implications for GEO-CAPE measurements, NASA GEO-CAPE Workshop, Columbia, MD, 22-24 September.

Yu, H., M. Chin, Q. Tan, Y. Hu, S. Kondragunta, P. Ciren, C. Xu, and B.N. Holben (2009), Aerosol spatial and temporal variations over a coastal area: Implications for geostationary satellite measurements, *EOS Trans.*, AGU Fall Meeting, San Francisco, CA, 14-18 December.

Yu, H., Y. Hu, M. Chin, Q. Tan, S. Kondragunta, and P. Ciren (2009), Aerosol accumulation controlled by coastal meteorology over southern California: modeling and observations, Second Intl. Conf. of Aerosol Science and Global Change, Hangzhou, China, 19-21 August.

Yurchak, B.S., and W. Abdalati (2009), Evaluation of shifts in snow metamorphism patterns by joint analysis of RadarSat-1 and ICESat-1 data, *Eos Trans. AGU, 90*(52), Fall Meet. Suppl., Abstract C51B-0467.

Zeng, X., W.-K. Tao, M. Zhang, A. Y. Hou, S. Xie, S. Lang, X. Li, D. Starr, and X. Li (2009), Meridional Variation in the Radiative Forcing from Doubling the Current Ice Nuclei Concentration, IAMAS-IAPSO-IACS 2009 Joint Assembly, Montreal, Canada, 19-29 July.

Zhang, Y., R. Fu, H. Yu, and R. Dickinson (2009), A regional climate model study of how biomass burning aerosol impacts lands-atmosphere interactions over Amazon, Gordon Research Conference, New London, NH, 5-10 July.

Zhou, Y. (2009), Study the weather and climate systems from satellite observations of cloud, radiation and precipitation, Satellite Meterological Center, China Meteorological Administration, Beijing, China, 5 November, *invited*.

Zhou, Y.P., K.–M. Lau, O. Reale, and R. Rosenberg (2010), AIRS impact on precipitation analysis and forecast of tropical cyclones in a global data assimilation and forecast system, AMS annual meeting, Atlanta, GA, 18-21 January.

Grant Proposals and Status

(sorted by funding agency, proposal title)

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Modeling and observational studies of moisture in the upper troposphere and lower stratosphere and the climatic effects of aviation	ACCRI	Henry Selkirk (GEST)	Lesley Ott (GEST), Craig Benson (GEST), plus Richard Stolarski and Anne Douglass (GSFC 613.3), Steven Pawson, (NASA), and Luke Oman (JHU)	Awarded
A New Look at the Radiative Regime of Extended Clouds from Airborne Measurements	CRDF / RFBR	Irina Melnikova (Russian Academy of Sciences); Charles Gatebe (GEST)		Pending
DoD-GEIS utilization of remotely sensed satellite data to monitor and forecast Rift Valley fever and other vector-borne disease outbreaks and data and analysis support to other GEIS research projects.	DoD-GEIS	Assaf Anyamba (GEST)	Compton J. Tucker (GSFC 614), Kenneth J. Linthicum (USDA/CMAVE)	Awarded
Remote Sensing Analysis Support to NAMRU-3 Surveillance and Risk Assessment of Rift Valley Fever in Egypt and Hemorrhagic Fever with Renal Syndrome in Eastern Europe	DoD-GEIS	Assaf Anyamba (GEST)		Awarded
European Risk Study of Geomagnetically Induced Currents	EU FP7	A. Viljanen (Finnish Meteorological Institute)	A. Pulkkinen (GEST), plus other international collaborators	Pending
Geospatial Risk Assessment Model of environmental contamination of produce by Enteric Pathogens	FDA	Assaf Anyamba (GEST)	Wendy Feneselle, David Oryang (FDA), Matthew Smith (SSAI/GSFC)	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Validation of VIIRS Land EDRs Using AERONET-based Surface Reflectance Validation Network (ASRVN)	IPO – NOAA	A. Lyapustin (GEST)	Y. Wang (GEST); Collaborator: I. Laszlo	Awarded
Study of the Effects of Dust Radiative and Microphysical Properties on Energy Budget and Precipitation Using A-Train Satellite Measurements and a Cloud-Resolving Model	NAMMA	D. Allen Chu (GEST)	Sergio DeSouza-Machado (JCET), Chung-Lin Shie (GEST)	Awarded
A Combined EOS Data and GEOS-Chem Modeling Study of the Direct Radiative Forcing of Volcanic Sulfate Aerosols	NASA	J. Wang (UNL)	K. Yang (GEST), S. Carn (MTU)	Awarded
A Combined Satellite Radar-Radiometer Precipitation Algorithm for TRMM and GPM, Based upon Ensemble Filtering	NASA	M. Grecu (GEST)	W. S. Olson (JCET), L. Tian (GEST)	Awarded
A Comprehensive Science and Operational Evaluation of Algorithm MAIAC for MODIS Land Processing	NASA	A. Lyapustin (GEST)	Y. Wang (GEST), S. Korkin (GEST), B. Tan (ERT); Collaborator: R. Wolfe (GSFC)	Pending
A Cross-Calibrated Multi-Platform Ocean Surface Wind Velocity Data Set for Meteorological and Oceanographic Applications	NASA	Robert Atlas (NOAA)	Joseph Ardizzone and Juan Carlos Jusem (both GSFC 613)	Awarded
A global modeling of nitrate and ammonium at present day and the year 2050: Implication for atmospheric radiation, chemistry, and ecosystems	NASA	Huisheng Bian (GEST)	Hongbin Yu and Qian Tan (both GEST); Mian Chin (GSFC 613.3)	Awarded
A Sensitivity Study of the Spectral and Polarizing properties of Biogenic Marine Aerosols	NASA	Santiago Gassó (GEST)		Pending
A Study of Winter Precipitation over Complex Terrain Using NASA	NASA	Mei Han (GEST)	C. Peters-Lidard, T. Matsui (GEST), C. Williams, D. Kingsmill, J. Sippel	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Satellites, HMT Observations and Numerical Simulations				
A Study of Winter Precipitation Systems Using TRMM and Numerical Simulations	NASA	Scott Braun (GSFC 613.1)	Mei Han (GEST)	Awarded
Advanced forecasting system for mitigating the solar effects on civil aviation	NASA	Antti Pulkkinen (GEST)	Kent Tobiska (Space Environment Technologies), Christopher Mertens (NASA Langley Research Center), Fritz Policelli (GSFC)	Not Funded
Advanced MHD modeling of the magnetosphere of Mercury to support the Messenger mission	NASA	Mehdi Benna (GEST)		Awarded
Aerosol-Monsoon Water Cycle Interactions	NASA	William Lau (NASA)	Jainn J. Shi (GEST), Wei-Kuo Tao, Kyu-Myong Kim (GEST)	Awarded
Analysis of Aura data and aircraft data from the Aura Validation Experiment	NASA	Paul Newman (GSFC 613.3)	Leslie Lait (GEST), Randolph Kawa (GSFC 613.3), Peter Colarco (GSFC 613.3), Mark Schoeberl (GSFC 613.3), Hushieng Bian (GEST)	Awarded
Analysis of Titan's Interaction with Saturn's Magnetosphere using Cassini Titan Flyby Data and Kinetic-Fluid Mode and fluid-kinetic model	NASA	Edward C. Sittler (GSFC 673)	Richard E. Hartle (GSFC 673), John F. Cooper (GSFC 672), Alexander S. Lipatov (GSFC 673), Steve Brecht (Bay Area Res.), Matt Burger (NPP-UMBC), Andrew Coates (International, UK), Cesar Bertucci (International, UK)	Awarded
Assessing and Improving GEOS-5 Aerosol Products Using the CALIPSO Vertical Feature Mask	NASA	Ellsworth Welton (GSFC 613.1)	Lesley Ott (GEST), Peter Colarco (GSFC 613.3), Andrea Molod (GEST)	Pending
Automatic detection and three-dimensional characterization of coronal mass ejections: application to physics-based ensemble space weather predictions.	NASA	Antti Pulkkinen (GEST)	T. Oates (UMBC), A. Taktakishvili (GEST)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Characteristics of extreme precipitation events, and modulation by climate variations	NASA	Willam K.-M. Lau (GSFC), Yaping Zhou (GEST)	Wei-Kuo Tao (GSFC), Huey-Tzu Wu (SSAI)	Awarded
Characterization of Aerosols and Bidirectional Reflectance Distribution Function from Airborne Radiation Measurements Over Snow, Sea Ice, Tundra, and Clouds	NASA	Charles K. Gatebe (GEST)		Awarded
Characterizing aerosol types and transport through an integrated analysis of CALIPSO and A-train data with global models	NASA	Mian Chin (GSFC 613.3), Hongbin Yu (GEST)	Qian Tan (GEST), Thomas Diehl (GEST), Ralph Kahn (GSFC 613.2), Richard Ferrare (LaRC), Ali Omar (LaRC)	Pending
Climate- and Fire-induced Vegetation, Agricultural and Albedo Change in Northern Eurasia: Consequences to Gases, Aerosols and Radiative Fluxes	NASA	Amber Soja (NASA Langley)	P. Stackhouse (NASA Langley), N. Tchebakova and E. Parfenova (both of Sukachev Institute of Forestry), I. Sokolik (GA Tech), M. Chin (GSFC), Q. Tan (GEST), H. Shugart (UVA), J. Shuman (UVA), L. Oman (GSFC)	Pending
Climate Change Science Program through Intergovernmental Personnel Act appointment	NASA	Robert J. Curran (NASA/GSFC)		Awarded
Continuing studies of chemistry-climate interactions	NASA	Jose M. Rodriguez	Anne R. Douglass (GSFC 613.3), Mark A. Olsen and Susan E. Strahan (both GEST)	Awarded
Design and Optimization of NASA's Future Space Geodetic Networks in Support of GGOS	NASA	Erricos C. Pavlis, institutional PI (GEST)		Awarded (current)
Detecting three-dimensional magnetic reconnection in Earth's magnetosphere: A Cluster investigation	NASA	John Dorelli	Kyoung-Joo Hwang (GEST)	Pending
Development and application of infrastructure for observing system simulation	NASA	Ronald Errico (GEST)	Ronald Gelaro and Arlindo Da Silva (both of GSFC 610)	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
experiments at the Global Modeling and Assimilation Office				
Development of well-calibrated multi-sensor surface reflectance data record	NASA	A. Lyapustin (GEST)	Y. Wang (GEST); Collaborators: L. Remer (GSFC), B. Holben (GSFC), S. Ackerman (UW), R. Myneni (BU)	Awarded
Discover-AQ	NASA	James Crawford	Kenneth Pickering (GSFC), Bruce Anderson (NASA LaRC), Pawan Bhartia (GSFC), Gao Chen (NASA LaRC), D. Allen Chu (GEST), Ronald Cohen (U. Berkeley), Glenn Diskin (NASA LaRC), R. Ferrare (NASA LaRC), A. Fried (UCAR), Jay Herman (GEST), Ray Hoff (JCET), and 10 more	Pending
Effects of biomass burning on Asian Monsoon water cycle and climate	NASA	William K. Lau (GSFC 613)	P. Colarco (GSFC 613), A. DaSilva (GSFC 610), B. Holben (GSFC 614), C. Hsu (GSFC 613), C. Justice (UMD), K. M. Kim (GEST), GSFC 613), C. Mian (GSFC 613), Y. Sud (GSFC 613), W. Tao (GSFC 613), S.-C. Tsay (GSFC 613), E. Wilcox (GSFC 613), and T. J. Yasunari (GEST)	Not Funded
Emission and transport of tropospheric SO2: studies of impacts on air quality and radiative forcing by combining satellite observations and GEOS-Chem modeling	NASA	K. Yang (GEST) and N. Krotkov (GEST)	X. Liu (GEST, now at Smithsonian-Harvard), Jun Wang (UNL), D. Henze (UCB), R. Martin (DAL.CA)	Not Funded
EOS and NPP satellite data fusion to develop a long term record on aerosol absorption	NASA	Omar Torres (Hampton Univ.)	Santiago Gassó (GEST)	Awarded
Establishing Links Between Solar-Wind and Topside-Ionospheric Parameters	NASA	Robert Benson (GSFC)	Yongli Wang (GEST), Dieter Bilitza (GMU), Shing F. Fung (GSFC), Prof. Xueqin	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
			Huang (UML), Vladimir A. Osherovich (RITSS), Prof. Bodo Reinisch (UML)	
Estimating uncertainty in tropospheric composition and transport from assimilation of carbon monoxide data	NASA	Andrew Tangborn, (JCET)	Lesley Ott (GEST), Wallace McMillan (JCET), Ivanka Stajner (Noblis, Inc.)	Not Funded
Exospheres and Extended Neutral Clouds of Io and Europa	NASA	Fran Bagenal (University of Colorado)	Peter Delamere, Nicholas Schneider, Melissa McGrath, Matthew Burger (GEST)	Not Funded
Extracting the essence of cloud horizontal and vertical variability from CloudSat for the benefit of Large Scale Models	NASA	Lazaros Oreopoulos (GSFC 613.2)	Peter Norris (GEST)	Pending
Forecast and Analysis of the Transport of Aerosol and Carbon Monoxide using GEOS-5/GOCART and MODIS/AIRS Satellite Measurements During ARCTAS	NASA	D. Allen Chu (GEST)	Juying Warner (JCET), Huisheng Bian (GEST), Mian Chin (GSFC), Lorraine Remer (GSFC), Peter Colarco (GSFC)	Awarded
FY 10 Work Plan on GEO-CAPE Aerosol Science	NASA	Mian Chin (GSFC 613.3), Hongbin Yu (GEST)	Qian Tan (GEST), Yan Zhang (GEST), P.K. Bhartia (GSFC 613.3), Shobha Kondragunta (NOAA NESDIS)	Awarded
Generalized 3-D magnetosheath specification model	NASA	Yongli Wang (GEST)	D. Sibeck (GSFC 674), J. Merka (GEST), S. Boardsen (GEST), H. Karimabadi (UCSD), T. Sipes (SciberQuest, Inc.)	Awarded
Heavy ion effects on plasma transport at Mercury	NASA	Jay R. Johnson (Princeton)	Eun-Hwa Kim, Scott Boardsen (GEST)	Pending
Heterogeneous chemical reactions on PSCs and cirrus and their impact on ozone in the UTLS	NASA	Craig Benson (GEST)		Not Funded
Hybrid kinetic Model for Europa Surface and Atmospheric Interaction with	NASA	John F. Cooper (GSFC 672)	Alexander S. Lipatov (GEST), Steven Brecht (Bay Research Corp.), Robert E.	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Jovian Magnetosphere			Johnson (Univ. of Virginia), Mau C. Wong (JPL NASA), Murthy Gudipati (JPL NASA)	
Impact of emissions and long-range transport on the Arctic atmospheric composition and climate	NASA	Mian Chin (GSFC 613.3)	Huisheng Bian (GEST), Thomas Diehl (GEST), Qing Liang (GEST), Qian Tan (GEST), Hongbin Yu (GEST)	Not Funded
Improve EPA's AIRNow Air Quality Index Maps with NASA Satellite Data	NASA	Phil Dickerson (EPA)	D. Allen Chu (GEST), Jassim Al-Saadi (NASA/LaRC), Randall Martin (Harvard), James Szykman (EPA), Chieko Kittaka (SSAI), Shobha Kondraqunta (NOAA), John White (EPA), Scott Jackson (EPA), Calvin Beck (NOAA)	Awarded
Improved Ice and Mixed-Phase Precipitation Models for Combined Radar-Radiometer Retrieval Algorithm Applications	NASA	William Olson (JCET)	Mircea Grecu (GEST), Lin Tian (GEST), Kwo-Sen Kuo, and Benjamin Johnson (JCET)	Awarded
Improving forecasts of flood-producing precipitation caused by landfalling tropical cyclones with a global data assimilation and forecasting system	NASA	Oreste Reale (GEST)	Yaping Zhou (GEST), W. K. Lau (NASA), J. Susskind (NASA), Lars Peter Riishøjgaard (NOAA)	Not Funded
Improving Water Quality Management: Use of Earth Observations in SPARROW	NASA	Molly Macauley (RFF)	Anne Nolin (Oregon State Univ.), Qingyuan Zhang (GEST), Richard Smith (USGS), Jhih-Shyang Shih (RFF)	Awarded
Integrated Multi-mission Ocean Altimeter Data for Climate Research	NASA	Richard Ray (GSFC)	Brian Beckley (SGT), Scott Luthcke (GSFC), Frank Lemoine (GSFC), S.D. Jacob (GEST)	Awarded
Integration of NASA Climate research in community education on climate change through involvement in the GLOBE Student Climate	NASA	Charles K. Gatebe (GEST)	Robert Cahalan (NASA/GSFC)	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Research Campaign (SCRC).				
Interaction of Saharan dust and Atlantic ITCZ using Cloudsat-Calipso and A-train	NASA	W. K. Lau (NASA)	A. DaSilva (NASA), K.-M. Kim (GEST), T. Matsui (GEST), O. Reale (GEST), E. Wilcox (NASA)	Pending
Interaction of Vesta with the Space Environment	NASA	Timothy J. Stubbs (GEST)	Wang (GEST), Glenar (New Mexico State Univ.)	Pending
Interactions between tropical biomass burning, clouds, precipitation and land use changes on a regional scale	NASA	Lorraine Remer (GSFC 613.2)	Vanderlei Martins (JCET), Ilan Koren (JCET), Hongbin Yu (GEST), Graham Feingold (NOAA)	Not Awarded
Investigating the influence of biomass burning aerosols on clouds and precipitation	NASA	Jonathan H Jiang	Xiaowen Li (GEST), Hui Su, Steven Massie, Mark Schoeberl, plus others	Pending
Investigation of Satellite QPE and Hydrologic Validation in Complex Terrain Basins	NASA	E. N. Anagnostou (U. Conn)	M. Grecu (GEST), Y. Hong (OU)	Awarded
Ion Neutral 3D Mass Spectrometer to Determine Astrobiological Potential of Europa	NASA	Edward Sittler (GSFC 673)	N. Paschalidis (APL), R. Hartle (GSFC 613), W. Kasprzak (GSFC 699), M. Benna (GEST), P. Mahaffy (GSFC 699), J. Cooper (GSFC 612), and D. Chornay (GSFC 673)	Awarded
Ion-Neutral Data and 3-D Hybrid Kinetic Modeling for Heliosheath-Interstellar Interactions at the Heliopause	NASA	John F. Cooper (GSFC 672)	Edward C. Sittler (GSFC 673), Matt. Hill (JHU APL), Michael R. Collier (GSFC 673), Nand Lai (GSFC 672), Robert B. Dekker (JHUAPL), Alexander S. Lipatov (GSFC 673)	Not Funded
Light Scattering by Complex Lunar Dust Grains	NASA	Denis T. Richard (San Jose State Univ. / NASA Ames)	Stubbs (GEST), Glenar (New Mexico State Univ.), Davis (NASA/ARC)	Pending
Lunar-Analog Resource Exploration of the VAPoR Instrument at the Mauna Kea basaltic craters	NASA	Inge L. ten Kate (GEST)		Awarded
Mapping SO2 emissions with NASA AURA Ozone Monitoring Instrument (OMI)	NASA	Nickolay Krotkov (GEST)	Arlin Krueger (JCET), S. Carn (JCET, now MTU), R.	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
and GOCART model for air quality and climate science			Dickerson (UMCP)	
MATISSE: A Multi-frequency Advanced Tomography Instrument to Explore the Internal Structure of Small-bodies	NASA	Mehdi Benna (GEST)	M. Deshpande (GSFC 555)	Pending
Melting ice, habitat change and nutrient flux: Hydrological, biogeochemical and biological linkages between the Copper River watershed and the coastal Gulf of Alaska	NASA	Santiago Gassó (GEST)		Pending
Microphysical and Radiative Properties of Midlatitude Cirrus: Modeling and Observation	NASA	Xiaowen Li (GEST)	Qian Tan (GEST), Tamas Varnai (JCET)	Pending
Modeling studies with Aura MLS Measurements	NASA	Charles Jackman	Anne R. Douglass (GSFC 613.3), Susan E. Strahan (GEST), David Lary (JCET)	Awarded
Multi-decadal variations of atmospheric aerosols: Sources, transport, and effects on surface radiation	NASA	Mian Chin (GSFC 613.3)	D. Allen Chu (GEST), Thomas Diehl (GEST), Hongbin Yu (GEST), Huisheng Bian (GEST), Peter Colarco (GSFC), David Streets (Argonne National Lab), Yun Qian (Pacific National Lab), Tom Kucsera (GEST)	Awarded
Multi-fluid modeling of the atmosphere of Enceladus and interaction with Saturn's magnetosphere	NASA	Mehdi Benna (GEST)	W. Kasprzak (GSFC 699)	Awarded
NASA Earth and Space: Online "Missions" for High School Learners with Accompanying Electronic Professional Development for Educators	NASA	Maureen McMahon (Anne Arundel County Public Schools)	Susan Hoban (GEST), Charles Wood (Wheeling Jesuit University)	Awarded
New Operational Mode for Space-Borne Quadrupole Mass-Spectrometers	NASA	Thomas Zurbuchen (Univ. of	B. Block (Univ. of Michigan), M. Benna (GEST), P. Mahaffy (GSFC	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
		Michigan)	699), and M. Rubin (Univ. of Michigan)	
Obtaining a 30 year aerosol record from satellite radiances	NASA	Clark Weaver (GEST)		Awarded
On the Nature and Predictability of Interannual to Decadal Changes in the Global Hydrological Cycle and Its Regional Impacts	NASA	Siegfried Schubert (GSFC 610.1)	M. Suarez, R. Koster, M. Rienecker, M. Helfand (all of GSFC 610.1); H. Wang, Y. Chang, Y. Vikhliaev (all of GEST)	Awarded
Optical Scattering Processes Observed from the Moon: Measurements, Models and Implications	NASA	Timothy J. Stubbs (GEST)	Glenar (New Mexico State University), Killen (695), Hahn (Space Science Institute)	Awarded
PALS Field Experiment Salinity Studies	NASA	S.D. Jacob (GEST)	David Le Vine (GSFC)	Awarded
Predicting the accumulation of meteorite-delivered organic molecules to the surface of Mars	NASA	Pamela G. Conrad	Inge L. ten Kate (GEST), Mark Allen (JPL); collaborators: William B. Brinckerhoff (GSFC 699), Jennifer Eigenbrode (GSFC 699)	Pending
Rapid development of a focused Virtual Magnetospheric Observatory and its integration with VxOs for S3C data	NASA	Jan Merka (GEST)	D. Sibeck (GSFC 674), A. Roberts (GSFC 672), G. Le (GSFC 674), W. Paterson (Hampton Univ., VA), H. Karimabadi (SciberQuest), T. Fritz (Boston Univ.), J. Faden (Cottage Systems), V. Angelopolous (Univ. of California, Berkeley)	Awarded
Research, Education, Application and Solution Network Cooperative Agreement Notice	NASA	Robert Atlas (NOAA)	Juan Carlos Jusem and Joseph Ardizzone (both GSFC 613)	Awarded
Satellite-Plasma Interactions of Io and Europa	NASA	Fran Bagenal (University of Colorado)	Peter Delamere, Nicholas Schneider, Matthew Burger (GEST), Melissa McGrath, Chris Paranicas	Pending
Solar Wins Interaction with Lunar Exosphere and Surface	NASA	John F. Cooper (GSFC 672)	Edward C. Sittler (GSFC 673), Richard E. Hartle (GSFC 613), Kent Hill (GSFC 609.1), Alexander S.	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
			Lipatov (GSFC 673)	
Spectral absorption properties of aerosols in the UV wavelengths	NASA	Nickolay Krotkov (GEST)	Zhanqing Li (UMCP/ESSIC), Jay Herman (GSFC)	Awarded
Spectral Bio-Indicators of Ecosystem Photosynthetic Efficiency II: Synthesis and Integration	NASA	Elizabeth M. Middleton (GSFC)	Qingyuan Zhang (GEST), Petya Entcheva Campbell (JCET), and others	Pending
Study of the Effects of Dust Radiative and Microphysical Properties on Precipitation and Energy Budget Using A-Train Satellite Measurements and a Cloud-Resolving Model	NASA	Chung-Lin Shie and D. Allen Chu (both GEST)	Liang Liao (GEST) and Amber Reynolds (GSFC 613.1)	Awarded
The Characteristics of Flux Transfer Events	NASA	David G. Sibeck (GSFC)	Yongli Wang (GEST), Masha Kuznetsova (GSFC)	Awarded
The development of tropospheric ozone data products from Aura OMI/MLS and their scientific evaluation	NASA	Jerry Ziemke (GEST)	Sushil Chandra (GSFC 613.3)	Awarded
The Global Modeling Initiative: Satellite data analyses and model sensitivity experiments to reduce uncertainties in chemistry climate modeling	NASA	Susan E. Strahan (GEST)	Anne R. Douglass (GSFC 613.3), Mark A. Olsen (GEST)	Awarded
The role and predictability of external and internal magnetospheric plasma processes driving auroral electric current fluctuations	NASA	Antti Pulkkinen (GEST)	Dimitrios Vassiliadis (West Virginia University)	Not Funded
The validation of Aura ozone measurements using cloud slicing	NASA	Sushil Chandra (GEST)	Jerry Ziemke (GEST)	Awarded
The Virtual Wave Observatory (VWO): A VxO for heliophysics data	NASA	Shing Fung (NASA/GSFC, Code 673)	J. Merka (UMBC/GEST), T. Narock (GEST)	Awarded
Tomographic Reconstruction of Mercury's Exosphere from MESSENGER Flyby Data	NASA	Menelaos Sarantos (GEST)	Collaborator: Rosemary Killen (GSFC, 693.0)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Ultra-Low Frequency Waves in Mercury's Magnetosphere	NASA	Scott Boardsen (GEST)	Eun-Hwa Kim, Jay R. Johnson	Pending
Understanding ozone between 500 hPa and 50 hPa	NASA	Steven Pawson	Anne R. Douglass (GSFC 613.3), Mark A. Olsen (GEST), Susan E. Strahan (GEST)	Awarded
Understanding the Processes Controlling the Atmospheric Transport of Trace Gases in the Upper Troposphere and Stratosphere	NASA	Paul Newman (GSFC 613.3)	Anne Douglass (GSFC 613.3), Mark Olsen (GEST), Jerry Ziemke (GEST), Leslie Lait (GEST), David Lary (JCET), Mian Chin (GSFC 613.3)	Awarded
Using Airborne Radar Measurements to Improve Physical Assumptions in DPR and GMI Algorithms	NASA	Gerry Heymsfield	Lin Tian (GEST), Lihua Li (GSFC)	Awarded
Using the GEOS-5 AGCM to Understand the Local and Global Effects of Extreme Fire-Induced Convective Events	NASA	Lesley Ott (GEST)		Pending
Variation in the Mesospheric, Stratospheric and Tropospheric Temperatures in Connection with Solar Activity and QBO	NASA	Young-In Won (Wyle Information Systems, LLC)	Thomas Hearty, In-Sun Song (GEST), Gordon Shepherd	Pending
Volatile Analysis by Pyrolysis of Regolith (VAPoR) in the Field for Planetary Resource Exploration	NASA	Daniel P. Glavin, Inge L. ten Kate (GEST)	Eric Cardiff (GSFC 597), Todd King (GSFC 541), Dustyn Roberts (Honeybee Robotics, Ltd.); Collaborators: William Brinckerhoff (GSFC 699), Jennifer Eigenbrode (GSFC 699), Stephanie Getty (GSFC 541), Paul Mahaffy (GSFC 699), Timothy Swindle (Lunar and Planetary Laboratory, Univ. of AZ)	Not Funded
Instrument Simulator Suite for Atmospheric Remote Sensing (ISSARS)	NASA - AIST	Simone Tanelli	T. Matsui (GEST)	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Aerosol-Cloud Interactions: How 3D Science Can Help to Correctly Interpret Satellite Data	NASA - EOS	Robert F. Cahalan (NASA/GSFC), Alexander Marshak (NASA/GSFC)	Guoyong Wen, Tamás Várnai, Frank Evans	Awarded
Study of the Influence of the Saharan Air Layer on Tropical Cyclone Intensity Using Data from Aqua Multi-Sensors and other "A-Train" Satellites	NASA – EOS	Liguang Wu (GEST) and Chung-Lin Shie* (GEST), as of Nov 2009	Scott Braun (GSFC 613.1), Chung-Lin Shie (co-PI until Oct 2009)	Awarded
Multispectral Scanner for BRDF, Albedo, Clouds and Aerosols: MSBACA	NASA – GSFC - IRAD	Eric Wilcox (GSFC)	Charles K. Gatebe (GEST)	Awarded
Optimization of NASA's Next Generation Global Geodetic Networks (60000 CPU hours)	NASA – HEC-09	E. C. Pavlis (GEST)		Awarded
Multiscale Study of the Role of Hot Towers in Hurricane Intensification	NASA - HSRP	Gerry Heymsfield	Lin Tian (GEST), Lihua Li (GSFC)	Awarded
Biomass burning and the Earth's Water and Energy Cycles: GEOS-5 Response to Satellite Derived Emissions	NASA - IDS	Arlindo da Silva (NASA)	Peter Colarco (NASA), Susanne Bauer (Columbia Univ.), Cynthia Randles (GEST), Louis Giglio (SSAI), Jamison A. Smith (Humboldt State Univ.)	Pending
A Space Weather Service for NASA's Robotic Missions	NASA – IPP	M. Hesse (GSFC)	A. Pulkkinen (GEST), plus other collaborators	Awarded
Response to Solar Spectral Variability on Decadal to Centennial Time Scales Wavelength and time dependence of solar forcing of Earth's atmosphere-ocean system.	NASA – LWS	Robert F. Cahalan (NASA/GSFC)	Guoyong Wen (GEST)	Pending
Constraining Uncertainty in Simulations of Tropospheric Composition: Implications for Prediction of Future Air Quality	NASA - MAP	Bryan Duncan (GSFC 613.3)	A. Molod (GEST)	Awarded
Convective Transport and	NASA -	Kenneth E.	Jainn J. Shi (GEST), Wei-	Awarded

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Wet Removal in the GEOS-5 CCM and GMI CTM	MAP	Pickering (GSFC)	Kuo Tao	
Use high-resolution satellite observation to evaluate and advance NASA modeling ability for weather and short-term climate	NASA - MAP	Wei-Kuo Tao	T. Matsui (GEST)	Awarded
Use of Cloud-Resolving Models to Improve the Simulation of Convective Precipitation and Diurnal Cycle in the NASA GEOS-5	NASA - MAP	Myong-In Lee (GEST)	T. Matsui (GEST)	Awarded
Integrated Modeling of Aerosol, Cloud, Precipitation and Land Processes at Satellite-Resolved Scales	NASA – MAP	Christa Peters-Lidard, Wei-Kuo Tao, Mian Chin	Jainn J. Shi and Toshihisa Matsui (both of GEST)	Awarded
Moist physics development for GEOS-5+ and GEOS-6 using a multi-model framework with satellite simulators	NASA – MAP	Julio Bacmeister	T. Matsui (GEST)	Awarded
Reprocessing of Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) Data Set for Global Water and Energy Cycle Research	NASA – MEASURES	Chung-Lin Shie (GEST)	Long S. Chiu (GMU) and Robert F. Adler (GSFC Code 613.1)	Awarded
Calibration and Analysis of Global Latent Heating Estimates Using Passive and Active Microwave Sensor Data	NASA - NEWS	William Olson (JCET)	Mircea Grecu (GEST) and Chung-Lin Shie (GEST)	Awarded
Biomass Burning Aerosol Forcing and Feedbacks: Toward a better understanding of how aerosol absorption impacts the surface energy balance and	NASA - NIP	Cynthia A. Randles (GEST)		Pending

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hydrologic cycle				
Extraction of organic matter from martian analogs and application to future in situ missions to Mars	NASA – NPP	Daniel Glavin	Fabien Stalport (GEST)	Not Funded
Airborne Measurements Of BRDF Over Snow, Ice And Clouds For Improving The Accuracy Of Altimetry Measurements	NASA - ROSES	Charles K. Gatebe (GEST)	Christopher Shuman (GEST)	Pending
Development of a Climate-Data Record of surface-temperature of the Greenland Ice Sheet for analysis of ice sheet surface energy balance	NASA - ROSES	Dorothy Hall (GSFC)	Christopher Shuman (GEST)	Awarded
Earth-Venture-1 Serpent: Magnetic signatures of Serpentinized Mantle and Mesoscale Oceanic Variability Along the Alaska/Aleutian Subduction Zone	NASA - ROSES	Michael Purucker	K H Singh (GEST), and many scientists and workers from several institutes/universities	Pending
Millimeter Laser Ranging to the Moon	NASA - ROSES	Sergei Kopeikin	E. C. Pavlis (GEST)	Pending
Study of polar clouds and blowing snow for climate research and in support of the ICESat altimetry measurements	NASA - ROSES	Alexander Marshak (GSFC 613.2)	Stephen Palm (SSAI, Co-PI), Warren Wiscombe (GSFC 613.2), Yuekui Yang (GEST)	Not Awarded
Using Refined ICESat-1 Altimetry to Investigate the Limits of Change Detection on the East Antarctic Plateau	NASA - ROSES	Christopher Shuman		Awarded
Comparisons of Observations with Simulations from 3D models: A Path to Improved Prediction	NASA – ROSES	Henry Selkirk (GEST) and Anne Douglass (GSFC 613.3)	Mark Olsen (GEST), Douglas Allen (NRL)	Awarded
Development of a miniaturized, low-power, low-cost gas correlation radiometer instrument for	NASA – ROSES	Emily Wilson (GSFC 554)	Elena Georgieva (GEST), Haris Riris (GSFC 694), William S. Heaps (GSFC 613.3), James Garvin (GSFC	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
mapping multiple trace gases on the 2016 Mars Science Orbiter			600), Peter Shu (GSFC 553), Catherine Marx (GSFC 551)	
Differential Radiometer Using Fabry-Perot Interferometric Technique for Precise Remote Sensing Determination of CO_2, O_2, H_2O and CH_4 Column Concentration	NASA – ROSES	William Heaps (GSFC 613.3)	Emily Wilson (GSFC 554), Elena Georgieva (GEST)	Pending
Effects of Giant Impacts in Early to Mid-Noachian on Sub-critical Martian Dynamos and Their Implications to Martian Remnant Magnetism	NASA – ROSES	Weijia Kuang	K H Singh (GEST), Weiyuan Jiang, James Robert	Pending
The Linkage between Arctic Sea Ice, Polar Cloud Fraction and Vertical Structure and Implications for Regional Climate	NASA – ROSES	Stephen Palm (SSAI)	Alexander Marshak (GSFC 613.2); Yuekui Yang (GEST)	Pending
Utilizing Antarctica's Largest Subglacial Lakes for Calibration and Validation of Baseline Satellite Altimetry Data	NASA – ROSES	Christopher Shuman (GEST)		Not Funded
Optimizing ICESat - II Science Contributions	NASA – ROSES ICESat-2 SDT	David Harding	Christopher Shuman (GEST), plus others	Not Funded
Improvements in Aerosol Microphysics, Radiation, and Chemical Interaction in the GEOS Chemistry-Climate Model: Applications to Atmospheric Brown Clouds	NASA – ROSES MAP	Peter R. Colarco (NASA)	Cynthia A. Randles (GEST), Bryan Duncan (NASA), Huisheng Bian (GEST)	Awarded
Analysis of MAIAC Algorithm for the US NAVY and USDA Forest Service Applications	NASA Applications Program	A. Lyapustin (GEST) and Brad Quayle (USDA Forest Service, RSAC)	Y. Wang (GEST), C. K Brewer (RSAC), B. Schwind (RSAC); Collaborator: J. Zhang (Univ. of North Dakota)	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
An investigation of interactions of Saharan dust and Atlantic ITCZ using Cloudsat-Calipso and A-train data	NASA CALIPSO Cloudsat	William Lau (NASA)	E. Wilcox, P. Colarco, M. Chin, A. da Silva, Kyu-Myong Kim, O. Reale (GEST), T. Matsui (GEST)	Pending
Incorporating Non-Spherical Ice Crystals within Simulations of CloudSat Reflectivity and a Single-Moment Microphysics Scheme	NASA CALIPSO Cloudsat	Andrew Molthan	T. Matsui (GEST)	Pending
Aquarius: Global Modeling of Sea Surface Salinity	NASA - Center for Computa-tional Sciences	S.D. Jacob (GEST)	D.M. Le Vine (GSFC)	Awarded
Push-broom Laser Altimeter Demonstration for Space-based Cryospheric Mapping	NASA - IIP	D.J. Harding (GSFC)	C. Shuman (GEST)	Awarded
A Multi-Scale Modeling System for Studying Convective and Synoptic Cloud Systems and their Associated Microphysical and Precipitation Processes, Rainfall, and Latent Heating Structures in support of the NASA Precipitation Measurement Mission (PMM)	NASA – Precipita-tion Measure-ment Mission	Wei-Kuo Tao	Xiaowen Li and Toshihisa Matsui (both GEST); Stephen Lang	Awarded
On the development of a Synthetic GPM Simulator	NASA – Precipita-tion Measure-ment Mission	Toshihisa Matsui (GEST)	Xiaowen Li (GEST), Wei-Kuo Tao	Awarded
NASA Standards Process Group	NASA - SGT	S.D. Jacob (GEST)		Awarded
Aerosol algorithm development support for GOES-R	NOAA	A. Lyapustin (GEST)	Y. Wang (GEST)	Awarded
Development of Subseasonal Ensemble Forecast Techniques	NOAA	Siegfried Schubert	M. Rienecker, M. Suarez (610.1); S-C. Yang (ESSIC), Y. Chang (GEST), M. Peña	Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
			(SAIC), Z. Toth (EMC), A. Vintzileos (UCAR)	
Interpretation of VIIRS Sensor Development, Calibration and Characterization for NPP Environmental Data Products	NOAA – NESDIS	Bruce Guenther (GEST)		Pending
Dynamics of eastern Mediterranean, Sea Level and altimetry Calibration-validation (DynMSLaC)	NRA 03-OES-05	Erricos C. Pavlis (GEST)		Awarded (current)
Determination of the True Ionospheric Currents and Conductances from Combined Ground- and Space-Based Observations	NSF	Antti Pulkkinen (GEST)	H. Korth (JHU/APL)	Pending
Development and evolution of Kelvin-Helmholtz waves in Earth's flank magnetopause and their effects on the inner magnetosphere: CLUSTER-THEMIS conjunctive studies with MHD simulations	NSF	Kyoung-Joo Hwang (GEST)	Hui Zhang (ORAU/GSFC 674)	Pending
Impact of Climate Change on a Land-Atmosphere Feedback	NSF	Andrea Molod (GEST)		Not Funded
Magnetospheric Electron Density	NSF	Dr. Richard Denton (Dartmouth College)	Yongli Wang (GEST)	Awarded
STEM Innovation Incubator	NSF	Nagaraj Neerchal (UMBC)	Susan Hoban (GEST), Manil Suri (UMBC), Maureen McMahon (Anne Arundel County Public Schools)	Pending
The estimation of analysis error characteristics using an observing system simulation experiment	NSF	Ronald Errico (GEST)	Runhua Yang (SSAI)	Awarded
The role and predictability of external and internal magnetospheric plasma processes driving auroral electric current fluctuations	NSF	Antti Pulkkinen (GEST)	Dimitrios Vassiliadis (West Virginia University)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Global Sea Level in a Changing Climate: Reference Frames, Data Analysis, and Interpretation	ROSES - 2006	R. D. Ray	E. C. Pavlis (GEST)	Awarded (current)
GRACE applications for TRF development and fundamental physics tests	ROSES – 2006	Erricos C. Pavlis (GEST)		Awarded (current)
Eastern Mediterranean Altimetry Calibration Network (e-MACnet)	ROSES - 2007	Erricos C. Pavlis (GEST)		Awarded (current)
LARES: LAser Relativity and Earth Science Satellite Mission	ROSES – 2007	E. C. Pavlis (GEST)		Awarded
Next Generation Models of Europa's Atmosphere and Ionosphere	Space Telescope Science Institute	Matthew Burger (GEST)	Timothy Cassidy, Melissa McGrath	Pending
Development of an Early Warning System to detect conditions of elevated populations of potential vectors of Rift Valley Fever (RVF) and other mosquito-borne emerging virus threats in the United States	USDA - ARS	Assaf Anyamba (GEST)	Compton J. Tucker (GSFC 614)	Awarded

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Biographies

Dr. Assaf Anyamba is an associate research scientist with the Goddard Earth Sciences Technology Center/University of Maryland-Baltimore County (GEST/UMBC) at NASA's Goddard Space Flight Center. He received his undergraduate degree from Kenyatta University, Nairobi, Kenya in Geography and Economics (1989) and a Masters degree in Geography from Ohio University, Athens (1992). He received his Ph.D. (1997) in Geography with focus on Remote Sensing of Land Surface Patterns of ENSO from Clark University, Worcester, MA. His research interests are in the extraction of interannual climate variability signals from remotely sensed vegetation measurements, drought pattern analysis, applications of remotely sensed data in agricultural monitoring, drought & famine early warning and the links between climate and disease outbreaks. His current work supports research and development for USDA/FAS-PECAD and USAID/FEWNET, DoD-GEIS, USDA/CMAVE and FDA Programs.

Ms. Kristi R. Arsenault received a Bachelor's of Science degree in geography and climatology from Arizona State University in May 1997. While at Arizona State, she interned at the NASA Mars Global Surveyor TES Laboratory for two years, working on the interplay between dust storms and the northern polar ice cap of Mars. After graduating, Ms. Arsenault attended Ohio State University in Columbus, Ohio, where she pursued a Master of Science degree in atmospheric sciences. Her graduate work involved investigating the role of air-sea interactions over the North Atlantic Ocean and their effects farther downstream over the Eurasian continent. Ms. Arsenault began working at NASA Goddard Space Flight Center full-time in early January 2001. Her main research at NASA Goddard has focused mainly on applying the latest research at NASA to water resource related issues. Her focus has been on how satellite and land surface models can be enhanced and integrated to improve energy and moisture budget estimations to help benefit other government agencies, like the Bureau of USBR. Currently, Ms. Arsenault is pursuing her Ph.D. degree in Climate Dynamics at George Mason University in Fairfax, VA.

Mr. Jefferson Beck joined GEST as Research Associate on July 21, 2008. He is completing his M.F.A. in Science & Natural History Filmmaking at Montana State University. He has a background in ecology and journalism, has taught science film workshops, and is now working in the Public Affairs Office with Wade Sisler.

Dr. Benita Bell received her doctoral degree in nutrition and chemistry from Howard University. Her bachelors and masters degrees are also in chemistry from UNC Chapel Hill and North Carolina A&T State University. Dr. Bell has taught chemistry at Howard University in the School of Allied Health Sciences, North Carolina Central University and Bennett College, where she was an Associate Professor of Chemistry and the Director of the Science, Technology, Engineering and Mathematics (STEM) Program. Dr. Bell was awarded a NASA Administrator's Fellowship position where she served as a NASA Fellow in the Office of Biological and Physical Research at NASA Headquarters in Washington, DC. There she developed a pilot clinical research study on soy isoflavones and their role in immunity and heart disease. Dr. Bell has also had corporate experience working with Johnson and Johnson and Smithkline in the medical and pharmaceutical sales industries. She has received numerous honors and awards, a few of which include the recipient of the Board of Trustees Faculty Teaching Excellence Award and the Division of Higher Education Exemplary Teacher of the Year Award. Dr. Bell is currently working at NASA Goddard Space Flight Center with the Minority University Space Interdisciplinary Network (MUSPIN) in the area of Astrobiology. She is the Co-Director of the Minority Institution Astrobiology Collaborative (MIAC). Her research interests are in the areas of astrobiology, science education and women's health.

Ms. Deborah Belvedere received a B.A. in Music Performance (Flute and Organ) from the State University of New York at Oswego. After graduating, Ms. Belvedere taught Music, played professionally

with the Divertimento Trio and co-owned and operated The Anchorage House Restaurant, a fine dining and catering establishment in South Carolina. In 1995 Ms. Belvedere joined the NASA/GSFC Climate and Radiation Branch, and in 2000 accepted an offer to work as a Program Coordinator with the Hydrological Sciences Branch, where she was instrumental in the planning, communication, coordination, and implementation of many large projects within the science community; specifically as a member of the NASA Energy and Water Cycle Study (NEWS) team, the Goddard Water and Energy Cycle Theme (GWET) activity, and the Global Energy and Water Cycle Experiment (GEWEX) Americas Prediction Project (GAPP). In 2006, as Assistant Director of the Center for Research on Environment and Water (CREW), she continued her work with the NEWS team, in addition to managerial duties and work as co-I on the NASA Applications funded project WaterNet, The NASA Water Cycle Solutions Network. Building upon these experiences brought Ms. Belvedere to her current position as the NASA Water and Energy Cycle Focus Area Liaison, working closely with NASA Program Manager, Dr. Jared Entin, and collaborators Dr. Paul Houser of George Mason University and Dr. Robert Schiffer, UMBC/GEST.

Dr. Mehdi Benna received his degree in Electrical Engineering from the Engineering School of Tunis (ENIT) in 1999. After obtaining a M.Sc. in Radio-wave Telecommunication from the University of Tunis in 2000, he received in 2002 a Ph.D. in Space Science from the University of Toulouse in France. From 2002 to 2003, Dr. Benna was an associate scientist at the Planetary and Terrestrial Geophysics Laboratory (CNRS) in France. In 2003, he came to NASA's Goddard Space Flight Center as an NRC postdoctoral fellow where he remained for three years. In 2006, he joined the Goddard Earth Science and Technology Center as an assistant research scientist. Dr. Benna's main research interest is the numerical modeling of planetary magnetospheres. Besides his scientific work, he uses his engineering experience to support the development of several space-borne instruments (Rosetta-CONSERT, MSL-SAM, NIGMS). His publications include papers on MHD modeling of comets and icy moons of the solar system, radiotomography techniques, and ill-posed inverse problems.

Dr. Craig Benson received a Ph.D. in Physical Chemistry (2002) from The George Washington University in Washington, DC, following a BA in Chemistry (1997) from Brandeis University in Waltham, MA. His doctoral dissertation concerns simulations of micron-sized water droplet behavior in high-temperature environments. After completing his Ph.D. studies, Craig worked for three years as a National Research Council Postdoctoral Research Associate at the Naval Research Laboratory Remote Sensing Department in Washington, DC, where he investigated numerical modeling of PSC formation mechanisms as a member of the POAM science team. Craig joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a Research Associate in 2006.

Mr. Timothy Berkoff is an Assistant Research Engineer with the University of Maryland's Goddard Earth Science and Technology Center. He has more than 20 years of experience with optical instrumentation and measurement analysis, and currently serves as the instrument manager for NASA's Micro-Pulse Lidar Network (MPLNET), a global network of lidar systems to provide long-term observations of aerosols and clouds. His background includes lidar, fiber-optic sensing techniques, interferometry, spectroscopic gas detection, tunable diode lasers, optical design, opto-electronics, and optical diagnostics. He has more than 15 peer-reviewed publications, numerous conference proceedings, and is an inventor on two patents in the field of optical sensing. Mr. Berkoff obtained a B.S. in Optics from the University of Rochester in 1988.

Dr. Huisheng Bian received a B.S. in atmospheric science from Nanjing University in 1985, a M.S. in 1988, and a Ph.D. from University of California, Irvine in 2001. From 1988 to 1995, she worked in Chinese Meteorological Academy as an assistant researcher, where her research interest was regional air quality modeling. Her Ph.D. work focused on improving, validating, and applying UCI global chemistry transport model for tropospheric ozone simulation, as well as on developing a module (Fast-J2) to accurately simulate stratospheric photolysis in global chemistry models. Upon graduation, Dr. Bian

became interested in atmospheric aerosols, their distribution and their photolytic and heterogeneous impacts on tropospheric chemistry. Her current major research interest involves improving and applying multiple CTMs to the atmospheric chemistry studies and providing mission planning and mission support.

Dr. Scott A. Boardsen is currently an associate research scientist at GEST. He received his B.S. in physics in 1981 from the University of Iowa, his M. S. in physics from the University of Iowa in 1984, and his Ph.D. in physics in 1988 also from the Univeristy of Iowa. His master thesis research was in laboratory plasma physics were he studied methods for improving the efficiency of ion propulsion engines. His Ph. D. research was in space plasma physics were he studied electrostatic ion cyclotron waves generated along the auroral field lines. Throughout his career he has worked on various topics in magnetospheric physics including studies of equatorial fast magnetosonic waves and their interaction with unstable ion distributions, auroral kilometric radiation, kilometric continuum radiation, plasmaspheric hiss and its relation to lightning, high latitude magnetic reconnection, and magnetopause modeling.

Dr. Matthew Burger received a B.A. in Physics from Rice University in 1996, and a M.S. and Ph.D. in Astrophysical and Planetary Sciences from the University of Colorado, Boulder, in 1998 and 2003, respectively. His Ph.D. thesis entitled "Io's Neutral Clouds: From the Atmosphere to the Plasma Torus," presented observations and numerical modeling of sodium and oxygen neutrals in Io's exosphere and extensive neutral clouds. From 2003 to 2005, he worked as a Postdoctoral Research Associate at the University of Virginia, Charlottesville, modeling the neutral clouds associated with the Jovian and Saturnian satellites. He began work as a NRC Research Fellow in 2005 and continued as a NASA Postdoctoral Fellow from 2006-2008. At GSFC, Dr. Burger worked with the Cassini Plasma Spectrometer team modeling interactions between Enceladus and the Saturnian magnetosphere. Since 2008, Dr. Burger has divided his time between GEST, working with CAPS data, and the University of Maryland, College Park, modeling Mercury's exosphere in support of the MESSENGER mission. In 2010, he will begin working full time with GEST.

Ms. Valerie Casasanto has been GEST's Program Coordinator since late 2005, where she has managed the Short-Term Visitor program, NASA's Graduate Student Summer Program in Earth Sciences and undergraduate Summer Institute in Earth Sciences program, GEST's self-directed interns, the GEST fellowship program, and the Goddard Visiting Fellows Program (since 2008). Her former work includes management of the International Space University's Summer Programs, and facilitating educational experiments on the Space Shuttle. She is currently a member of NASA Goddard's Education Implementation team, the International Astronautical Federation (IAF) Education and Outreach Committee, and NASA Goddard's Native American Advisory Committee.

Dr. Edward Celarier received B.S. degrees in chemistry and physics/astronomy (1981) from the University of Washington, in Seattle, and a Ph.D. in physical chemistry (1986) from the University of Toronto. He was a postdoctoral fellow at Princeton University (1986-1989). After that, he joined the chemistry faculty of Hampton University (Hampton, VA). In 1995, he began work with the Atmospheric Chemistry and Dynamics branch (now Code 613.3) at NASA Goddard Space Flight Center, working for Software Corporation of America, Hughes STX, and Stinger Ghafarian Technologies, Inc. In February 2008, he took his current position, as Associate Research Scientist, at the UMBC GEST Center, where he still works in Code 613.3. During his 15-year association with NASA, Dr. Celarier has worked in the area of measuring trace gases in the Earth's atmosphere using satellites and using ground-based instruments, particularly the measurement of ozone (O_3) and nitrogen dioxide (NO_2), using the TOMS instruments (O_3) and the Ozone Monitoring Instrument (OMI) on NASA's EOS-Aura satellite (NO_2). Dr. Celarier has also been responsible for the development and implementation of algorithms that produce publicly distributed data sets, including OMI NO_2 and the Surface Ultraviolet Exposure data set produced from TOMS data; the latter algorithm has also been implemented by the Finnish Meteorological Institute to produce a Surface Ultraviolet Exposure data product from OMI. He is also responsible for an Earth

surface ultraviolet reflectivity climatology data set, based on TOMS data, that is widely used for other trace gas retrieval algorithms. Finally, he has worked in the area of validation of satellite-based measurements of atmospheric trace gases and ultraviolet exposures, using ground-based measurements. In addition to his research work, Dr. Celarier has taught students from 3rd grade to university, as an assistant professor of chemistry at Hampton University, as a volunteer teacher for 4-H's Adventure in Science Program, supported by the National Institutes of Standards & Technology (NIST), and for workshops run by Dr. Dianne Robinson at Hampton University. He has also taught computer skills to high school students and clerical workers. Dr. Celarier has devised numerous hands-on science activities for students, and some of the students who have participated have gone on to develop some of these activities into science fair projects. At Hampton University, he revised the suite of experiments for the physical chemistry laboratory course, redesigning several experiments and introducing some novel ones. Dr. Celarier was a coauthor of a NASA-produced online textbook on stratospheric ozone. Dr. Celarier has recently been involved in educational projects for high school and university students at the Instituto Technológico de Monterrey Campus Guadalajara, focused on understanding the atmosphere and global warming and climate change.

Dr. Sushil Chandra is a Senior Research Scientist in GEST. His education culminated with a Ph.D. in Physics from Pennsylvania State University. Prior to his GEST appointment, he was a senior scientist at NASA GSFC where he conducted research in the fields of aeronomy, ionosphere, and many other aspects of atmospheric science. He has more than 100 refereed publications and many contributions to technical reports. Dr. Chandra was involved in the development of the first interactive ionosphere-atmosphere model. Later, he moved to stratospheric ozone research and made significant contributions to understanding the variability of ozone and temperature on different time scales ranging from ~27-day solar rotation period to long term trends. Currently, Dr. Chandra is involved in developing new methods for deriving tropospheric ozone from satellite data. This work has produced a unique ~30-year record of tropospheric column ozone in the tropics and has helped in the understanding of the seasonal and long term changes in the tropical troposphere including intra-seasonal, inter-annual, and decadal changes associated with the Madden Julian Oscillation, QBO, El Nino, La Nina, and solar cycle. He is PI and Co-I for several NASA funded proposals. He was a Co-I for the WINDII experiment on the UARS and was a member of the UARS Science Team from the very beginning of the UARS program. Dr. Chandra is currently an active science team member for EOS Aura OMI.

Dr. Yehui Chang received a BS in Physics from ECNU in 1982, and a Ph.D., in Geophysical Fluid Dynamics from the Florida State University in 1994. He took a lectureship in Physics in the Nanjing College of Economics from 1982 to 1987. From 1994 to 2001, he served as senior scientist in SAIC studying climate and its variability and predictability, the variability and predictability of the Madden-Julian Oscillation, extreme weather events, short-term climate and dynamical seasonal forecasting. His specific interest is in developing and applying mathematical, numerical and statistical methods to diagnose and characterize the complex climate systems and the system responses. Such methods are important not only in the detection and estimation of forced signals but provide a clue as to natural variability of a climate system and the accuracy of the data assimilation system. Dr. Chang's publications deal with EOF modeling, diagnostics of climate and the data assimilation system, dynamical seasonal prediction, the impact of ENSO on extratropical low frequency noise in seasonal forecasts and extreme weather events. Dr. Chang joined GEST in September 2001, as Associate Research Scientist at UMBC.

Dr. Jiun-Dar Chern received a BS from National Taiwan University in 1984 and a Ph. D. in Atmospheric Sciences in 1994 from Purdue University where he has developed the Purdue Mesoscale Model (PMM) and applied the model to study lee vortices, and winter cyclogenesis over the western United Stated. Form1995-2000, he worked as a Research Associate at Purdue University to develop the Purdue Regional Climate Model (PRCM) and snowpack and sea-ice models. The model has been applied to study the 1988 US drought, 1993 Midwestern flood, and 1998 flood in Eastern Asia. In 2000 he joined

UMBC/GEST and worked at the DAO, NASA/GSFC to improve the physical parameterizations of the fvGCM and the interface between the fvGCM and GEOS4 data assimilation system. In 2004 he joined the modeling group at Mesoscale Atmospheric Processes Branch to develop the Multi-scale Modeling Framework or superparameterization based on the fvGCM and 2D GCE models. His main research goal is to use NASA high-resolution satellite products for evaluating and improving the cloud microphysics schemes in CRM and the representation of moist processes in climate models.

Dr. D. Allen Chu received a BS in Atmospheric Sciences from the National Taiwan University in 1982 and a Ph.D. in Atmospheric Sciences from Georgia Institute of Technology. In 1989, he joined ISAMS (Improved Stratospheric and Mesospheric Sounder) team at NASA Langley Research Center where he worked on the ozone and nitric acid retrievals using ISAMS measurements as well as radiance simulations using line-by-line/broadband radiative transfer models. In 1996, he was recruited by MODIS (Moderate Resolution Imaging Spectroradiometer) aerosol team at NASA Goddard Space Flight Center to work on MODIS aerosol retrieval and lead quality assurance for the MODIS atmosphere products. In 2004, he joined the JCET of UMBC as an associate research scientist. Since then, he has been heavily involved in a number of projects including the application of MODIS AOD to air quality, evaluation of aerosol radiative forcing in a number of field campaigns (INTEX-NA, INTEX-B, NAMMA, and ARCTAS), study of dust radiative and microphysical process on precipitation and energy budgets over the tropical Atlantic Ocean, and intercomparison of model (e.g., GOCART, GEOS-CHEM, and CMAQ) and MODIS-derived aerosol properties. In 2007, he joined the GEST to continue his researches. He served as a PI of NASA INTEX-B, NAMMA, and ARCTAS programs, and EPA AMI pilot project.

Dr. Amelia Colarco obtained her M.S. in 1999 and her Ph.D. in 2003, from the Astrophysical and Atmospheric Science Department at the University of Colardo, Boulder, with a focus on *in situ* measurements of carbon dioxide in the upper troposphere and lower stratosphere. She worked for two years as a NASA contractor setting up a local boundary layer *in situ* CO_2 mixing ratio measurement in support of an on-going CO_2 LIDAR development effort at GSFC. Upon completion of her degree, Dr. Colarco was awarded a two-year NRC Research Associate Fellowship under Dr. John Burris, GSFC Code 613.3, to study the measurement requirements and potential benefits of a ground-based profiling CO_2 LIDAR. At the completion of this fellowship, Dr. Colarco began work under Arlindo da Silva focusing on assimilation of aerosol from satellite measurements with a global transport model.

Ms. Laurie Cook is an Instructional Design Specialist at GEST. She is currently working on her Doctoral Degree in Science Education at Morgan State University, with anticipated completion in 2010. She received an MEd. in Science Education from Salisbury State University in 1986, and an MS in Conservation Biology and Sustainable Development from the University of Maryland in 1996. Cook taught high school science in the public school system for 9 years. She taught developmental mathematics at Baltimore City Community College and environmental science at the Community College of Baltimore County. In October of 2005, Ms. Cook joined the GEST Information Science and Educational Technology Faculty Group to work on the educational implementation of a map sonification tool to allow NASA Earth science data to be accessible to blind learners. Her current research areas include improving education for blind students and minority students through the use of advanced technologies, and studying the effectiveness of electronic delivery of professional development for educators.

Dr. Robert J. Curran has served as senior staff scientist in the U.S. Global Change Research Program Office in Washington, DC since August 2005. He is seconded to this position from UMBC through an Intergovernmental Personnel Act agreement funded by NASA. In that position his responsibilities include development of all aspects of the annual report of the USGCRP entitled *Our Changing Planet*. Prior to joining USGCRP, Dr. Curran was Director of the Goddard Earth Sciences and Technology Center (GEST) at the University of Maryland, Baltimore County. Before joining UMBC he was a

Visiting Senior Scientist with the California Institute of Technology. Dr. Curran has over 12 years experience as a science program manager in the Earth sciences at NASA Headquarters. He also has 12 years experience as a research scientist associated with Earth and planetary science missions at the Goddard Space Flight Center. His main research interests are in understanding how clouds and aerosols interact with radiation and their roles in the Earth's climate. In addition to his experience within NASA, Dr. Curran has 6 years experience in industry, part of which was as project scientist with the Hughes Aircraft Corporation in its development of the Earth Observing System Data and Information System. His undergraduate degree (BS) major was in Physics from Creighton University. His graduate degrees (MS and PhD) were also in Physics with specialization in Atmospheric Physics and were from the University of Arizona.

Dr. Paolo de Matthaeis was born in Rome, Italy. He received the Laurea degree (Summa cum Laude) in Electrical Engineering from the University of Rome "Tor Vergata", Italy, in 1991. In 1993-1994 he was with the European Space Agency at ESTEC in The Netherlands under the Young Graduate Trainee program. In 1994-1995, he received a grant from the Italian Space Agency (ASI) to carry out research in the SIR-C/X-SAR data at the Remote Sensing Laboratory at the University of Rome "Tor Vergata". He earned the Doctor of Science degree in Electrical Engineering from The George Washington University in Washington, DC in 2005. He is currently working at the NASA Goddard Space Flight Center in Greenbelt, MD, as a Research Associate with the Goddard Earth Sciences and Technology Center (GEST) of the University of Maryland Baltimore County. His research interests include active and passive microwave remote sensing, with a focus on electromagnetic modeling of vegetation and sea surface. He is part of the Science Algorithms team for the Aquarius instrument, where he has been working on the radiometer and radar scatterometer simulators.

Dr. Marcianna P. Delaney received her B.S. in Marine Biology with a concentration in Physics at the University of North Carolina in Wilmington in 1994. She earned her M.Sc. and Ph.D. in Biological Oceanography at Memorial University of Newfoundland in St. John's, Newfoundland. Her graduate research for both degrees focused on the effects of small-scale turbulence on the marine microbial food web of a cold-ocean environment. She has turned her love of science into a career with the GSFC Office of Education as a scientist on staff. Dr. Delaney currently serves as the GSFC Digital Learning Network Team (DLN) Lead, in which she designs STEM content for interactive videoconferencing, actively teaches to students and teachers across the United States, and establishes partnerships across NASA for additional STEM collaboration on projects for e-Education. In addition to her extensive experience with teacher professional development, she is currently designing an on-line synchronous and asynchronous STEM PD course with blendedschools.net utilizing NASA science and engineering content. Most recently noted is the effort Dr. Delaney made on behalf of NASA Education in its relationship with Disney/Pixar, in which she secured the WALL·E partnership in the Space Act Agreement for the NASA DLN this past year.

Dr. Thomas Diehl received a M.S. in physics from the State University of New York at Stony Brook in 1990 while being on a fellowship, and a diploma in physics from the University of Tübingen, Germany, in 1992. From 1993 to 1994 he was a research fellow at the High Performance Systems Division at the Hewlett-Packard Company in Richardson, Texas. He received his Ph.D. in computational astrophysics from the Department of Astrophysics and Computational Physics at the University of Tübingen in 1996, where he was also a postdoctoral fellow from 1996 until 1997. During his time in Tübingen, he conducted research in the field of scalable parallel algorithms for the solution of elliptical PDE's and developed a model to investigate the magnetosphere of radio pulsars. He then spent four years at the German Climate Computing Center in Hamburg implementing efficient parallel versions of regional and global atmospheric climate models and developed a benchmark suite for the procurement of a high performance computing server. From 2001 to 2003, he was a research scientist at the Max Planck Institute for Meteorology in Hamburg, where he coupled chemistry modules to an AGCM. He used the coupled model

to investigate the climate-forcing impact of a global hydrogen economy, the impact of climate change on the chemical composition of the troposphere, and contributed to the development of a coupled model covering altitudes up to 250km. Dr. Diehl has been working at GSFC since 2004, first through an affiliation with SSAI, and since February 2005 with GEST. His current research focuses on aerosol modeling with the GOCART model and comparing model results with AERONET and satellite data.

Dr. Emmanuel P. Dinnat joined GEST as an Assistant Research Scientist in March 2007. He obtained his Ph.D in March 2003 from the Laboratoire d'Océanographie Dynamique et de Climatologie (LODYC), Paris, France. His doctoral dissertation was on remote sensing of sea surface salinity, and in particular, the effect of surface roughness. He was a research fellow with the European Space Agency at ESTEC where he worked on the Soil Moisture and Ocean Salinity mission from 2003 to 2005. In 2005, he joined the GSFC and started to collaborate with David Le Vine in code 614 on the development of retrieval algorithms for the mapping of the global salinity field from space under the NASA Postdoctoral Program. In 2006, he was the recipient of a NASA Outstanding Post-Doc/Research Associate Peer Award. In 2008, he was co-author on a paper that received the peer award for outstanding publication from the NASA-GSFC, Hydrospheric and Biospheric Sciences Laboratory. He is a member of the American Geophysical Union.

Mr. Thomas F. Eck received a BS in meteorology from Rutgers University in 1977 and an MS in meteorology from the University of Maryland (College Park) in 1982 where his major interests were in micrometeorology and atmospheric radiation. In 1981 he began work at Goddard Space Flight Center (GSFC) and has continued there (in association with the Biospheric Sciences Branch, Code 614.4) for more than 28 years, through to the present. During his career he was involved in algorithm development and data analysis for the Nimbus-7 cloud climatology project. He was also active in instrument calibration, field instrument deployment, and data analysis for the PARABOLA instrument project (plant canopy bi-directional reflectance), and analysis of AVHRR satellite data for water vapor retrievals. Beginning in 1992 and continuing through the present he has carried out instrument calibration and deployment, field experimentation, data analysis, and scientific research within the global Aerosol Robotic Network (AERONET) project. He has authored and co-authored over 95 papers in the refereed literature with recent emphasis on studies of the optical properties of atmospheric aerosols, especially from biomass burning, fossil fuel combustion, and coarse-fine mode mixtures and the attenuation of solar flux by aerosols.

Dr. Ronald Errico received a B.S. in physics from the University of Arizona in 1974, where he also took several graduate courses in meteorology. His Ph. D. in meteorology was received in 1979 from the Massachusetts Institute of Technology. With E.N. Lorenz as his advisor, his thesis entitled “The partitioning of energy between geostrophic and ageostrophic modes” examined the fundamentals of why the atmosphere is quasi-geostrophic. It won the department’s award for best thesis that year at the recommendation of Jules Charney. Applications of this thesis have continued throughout his career. After completing his degree, Ron joined the Advanced Study Program at the National Center for Atmospheric Research (NCAR) as a postdoc, followed by a staff appointment in 1981 within NCAR’s Large Scale Dynamics Section of its Atmospheric Analysis and Prediction Division. In 1994 he was appointed Senior Scientist in the Climate and Global Dynamics Division there. During his tenure at NCAR, Ron had sabbaticals from NCAR at the Naval Research Laboratory in Monterey from March 1989 to April 1990 and at ECMWF for 7 months in 1996. He left NCAR to join GEST and work at NASA’s Data Assimilation Office in July 2002. Since 1992, he has been chief organizer of 14 international workshops concerned with data assimilation, including 7 of the 8 International Workshops on the Application of Adjoint Models in Dynamic Meteorology. His past work has included examination of atmospheric balance, development and application of atmospheric adjoint models, atmospheric predictability, scale analysis, regional climate modeling, and data assimilation. This last includes design and application of observing system simulation experiments.

Mr. Ryan Fitzgibbons joined GEST as a Research Associate on July 7, 2008. He received his M.F.A. in Science & Natural History Filmmaking from Montana State University and has been a photographer/producer/director/editor of educational and corporate media. He has won an award from the North American Association for Environmental Education Film Festival. As an education producer at Goddard, he helps develop and produce video modules for NASA's Digital Learning Network as well as educational webcasts.

Dr. Melanie Follette-Cook received a BS in Biophysics from the University of Scranton in 2000, followed by an MS in Meteorology in 2002 and a Ph.D. in Atmospheric and Oceanic Science from the University of Maryland College Park in 2007. Her doctoral work focused on examining the distribution of ozone and water vapor in the upper troposphere/lower stratosphere using a variety of instruments and satellite platforms. From 2007 to 2009 she held a National Research Council postdoctoral research associateship at the Naval Research Laboratory (NRL) in Washington, DC. During her tenure at NRL, her research focused furthering her doctoral work as well as analyzing aerosol transport altitudes from pyroconvective biomass burning events. In June 2009, she joined the Goddard Earth Sciences and Technology Center at the University of Maryland Baltimore County as an assistant research scientist. Her current research centers on quantifying the variability of tropospheric trace gases in preparation for a proposed NASA geostationary satellite.

Mr. Robert Garner joined GEST as a Media Specialist in April 2007. He has a bachelor of arts in journalism from the University of Maryland, College Park, with a minor in astronomy. He currently attends the University of Maryland, College Park part-time in pursuit of a master's of library science degree. He is part of NASA Goddard's Public Affairs Office, and he splits his time between Web editing and the occasional feature story. Mr. Garner helps manage the Goddard Web site, and he maintains NASA's Hubble and Lunar Reconnaissance Orbiter mission sites. Additionally, Mr. Garner is the center's representative to the NASA Images project, which is working toward developing a comprehensive digital collection of important NASA photographs, images, videos and other visualizations available online.

Dr. Santiago Gassó received a M.S. in Applied physics at the University of Buenos Aires, Argentina, (1992), a M.S. (1997) and a Ph.D. (2001) in Geophysics at the University of Washington. During his PhD thesis work, Dr. Gassó worked with Prof. Dean A. Hegg on the analysis and derivation of aerosol optical and hygroscopic properties using remote sensing and in situ methods. He joined the GEST faculty in August 2001. He worked in the Climate and Radiation Branch at GSFC under the supervision of Dr. S. Tsay, in the development of a radiative transfer module for the Navy Aerosol Analysis Prediction Systems (NAAPS) aerosol transport model. Since 2004, Dr. Gassó is working independently on the transport of aerosols over South Atlantic basin and to Antarctica and looking for possible influences on phytoplankton. In addition, he is a member of the NPOESS Preparatory Project (NPP) and Ozone Monitoring Instrument (OMI) science team. He is currently working with Dr Torres (Hampton University) on the development and improvement of the retrieval of aerosol absorption properties with the OMI and MODIS detector. Other topics of interest are the study of dust in the South Hemisphere and its climate impacts and the study of the effect of volcanoes in clouds. In early 2009, he joined the science working group for the proposed satellite mission ACE (Aerosol, Clouds and Ecosystems). He leads the Aerosol-Ocean interactions working group.

Dr. Charles K. Gatebe received the B.Sc. (meteorology, mathematics, and physics) and M.Sc. (meteorology) degrees from the University of Nairobi, Kenya, in 1990 and 1994, respectively, and the Ph.D. degree in atmospheric sciences from the University of the Witwatersrand, South Africa, in 1999. He taught courses on air pollution using nuclear related techniques at the Institute of Nuclear Science, University of Nairobi from 1995–1998 and came to NASA GSFC in 1999 as a Resident Research Associate of the USRA. He is currently an associate research scientist in the GEST/UMBC based at GSFC. Over the last ten years, Dr. Gatebe has participated in many international field experiments. He

flew the NASA's CAR instrument aboard the University of Washington aircraft, Convair CV-580 during SAFARI 2000 and CLAMS 2001, and made measurements of surface BRDF over marine stratus clouds over the Atlantic Ocean off Namibian coast, African savannah (South Africa and Zambia), salt pans of Namibia and Botswana, and coastal waters and deep oceans in the western Atlantic Ocean off the US Coast. Between 2004 and 2005, he oversaw integration of the CAR onto a new platform, South Africa Weather Service aircraft, Aerocommander-690A and took measurements in Skukuza, South Africa in June 2005. He oversaw integration of the CAR on Sky Research aircraft, Jetstream-31 (J-31) from 2005–2006, and made measurements in Mexico during INTEX-B field experiment in 2006. Dr. Gatebe was the lead scientist on J-31 aircraft during CLASIC field experiment in Oklahoma in 2007 and the principal investigator for the CAR during the ARCTAS Mission in 2008. His past research experience includes developing a simple Gaussian model to estimate motor vehicle emissions from line sources (highways) in Nairobi, in situ measurements of aerosols and gases, and characterizing aerosol sources using measurements he sampled at a high altitude on the second highest mountain in Africa, Mt. Kenya and performed statistical and trajectory analysis to determine the sources region of pollutants. Currently, Dr Gatebe is interested in measurements of BRDF over different types of surfaces and remote sensing of aerosols and clouds to better understand their role in climate variability and change. He is also involved in the modification of the CAR instrument to have modern and additional capability for remote sensing of aerosol, surface, and clouds studies. Dr. Gatebe received the World Meteorological Organization Young Scientist Award in 2000 and was honored in 2007 by NASA GSFC's Climate and Radiation Branch for his outstanding scientific leadership in conducting airborne measurements to elaborate important surface and atmosphere radiative transfer functions and improve remote sensing retrievals of aerosols and clouds. He has also received NASA's Group Achievements awards in 2008 and 2009 for participating in the INTEX-B and ARCTAS field experiments, respectively.

Dr. Ritesh Gautam received his MS (2005) and PhD (2008) degrees from George Mason University (GMU) majoring in Atmospheric Science. After completion of his PhD, Gautam joined the GEST center at UMBC as a Research Associate in 2009 and is working on aerosol-radiation-climate effects at the NASA/Goddard Space Flight Center (GSFC). He has also previously been associated with GEST during 2005 as a graduate student summer intern working at the Climate and Radiation branch at GSFC. He has participated in two NASA/GSFC-led field experiments to study impact of aerosols on regional climate in Thailand (2006) and India (2009). His research interests include remote sensing of tropospheric aerosols and their climate effects as well as assessing their potential impacts on hydrological cycle. He has published peer-reviewed articles on aerosols (PhD, Postdoc) as well as on hurricanes (MS).

Dr. Elena M. Georgieva received her PhD in physics in 1998 from the University of Sofia. She was a research associate at Lasers and Optical characterization Laboratory, Georgetown University where she worked on nanoparticles characterization and correlation spectroscopy (01/2000 - 08/2001). Dr. Georgieva also was a research associate at NIST Center for neutron research and Johns Hopkins University (08/2001 - 07/2002). For four years she was a Senior Systems Scientist/Engineer at Science Systems and Applications and worked at Goddard Laser and Electro-optics branch on instrument development for measurement of atmospheric species (7/2002-05/2006). She has research experience in remote sensing, data analysis and validation, instrument development, spectroscopy, interferometry, 3-D imaging laser radar system and polarimetry. Previous positions held by Georgieva include Assistant Professor at the Institute of Applied Physics, Technical University of Sofia; Bulgaria (1995 - 1999); Graduate Research Assistant, Department of Physics, University of Sofia (1988 - 1994); Research Associate, Institute of Applied Mineralogy, Bulgarian Academy of Sciences, Sofia (1987 - 1988). She has 28 refereed publications and is a member of Optical Society of America and The International Society for Optical Engineering (SPIE).

Dr. Mircea Grecu received a B.S. degree from the Technical University of Civil Engineering, Bucharest, Romania in 1993, and a M.S. in civil engineering from the University of Iowa in 1996, followed by a

Ph.D. from the same university in 1999. After a Postdoctoral association with the University of Connecticut, he joined GEST in 2002. His research interests include: rainfall estimation from space and ground observations, assimilation of satellite observations in atmospheric and hydrologic models and short term atmospheric and hydrologic forecasting. Dr. Grecu is currently involved in the Tropical Rainfall Measuring Mission (TRMM) project in progress at the Mesoscale Atmospheric Processes Branch of NASA GSFC. His work is focused on the refinement and extension of algorithms for rain estimation from TRMM observations. Specifically, he investigates the combined use of active and passive microwave observations for rainfall estimation by employing radar and radiative transfer models in optimal estimation frameworks.

Dr. Bruce Guenther received a Ph.D. degree from the University of Pittsburgh, Pittsburgh, PA in Aeronomy in 1974. He was a NASA Goddard Space Flight Center employee from 1974 to 2001. Dr. Guenther was an Engineering Fellow in the Lockheed Martin organization from April 2001 to September 2002. He became affiliated with the Goddard Earth Sciences and Technology Center in October 2002 and continues to the present in this affiliation. He also serves as the Sensor Data Records Branch Head in the NPOESS Data Products Branch for NOAA-NESDIS in the Integrated Program Office as an Inter-Governmental Personnel Act transfer. Dr. Guenther's research and management highlights include the discovery of nearly constant presence of noctilucent clouds in the upper atmosphere over the summer poles, the presence of an NO absorption signature in the backscatter uv measurements at 255.5 nm on the Nimbus 4 BUV sensor, the introduction of a solar diffuser into the measurement paradigm for the MODIS EOS sensors and the delivery of the first MODIS L1b calibration data set to the EOS community. He has service as first EOS Project Scientist for the Terra Spacecraft and developed the strategy and provided first service as the EOS Project Scientist for Calibration and Data Product Evaluation.

Dr. Mei Han received her Ph.D. in Atmospheric Sciences from University of Illinois at Urbana-Champaign in 2004. She also holds an M.S. degree in Meteorology (1999) and a B.S. degree in Meteorology (1996) from Nanjing University, China. She joined GEST in January 2005. Her past research efforts has been using mesoscale models to study the dynamics of frontal circulations in wrapped wintertime extratropical cyclones and the mechanisms for fine scale banding and heavy snowfall. During her stay in GEST, she applies cloud-scale and mesoscale models for research into atmospheric precipitation systems with particular emphasis on model validation and evaluation using satellite and airborne remote sensing data. Her current research focuses on the dynamics, kinematics, and microphysics of frontal rainbands within extratropical cyclones.

Dr. Shin-Chan Han received a Ph.D. (2003) and a MS (2000) in Geodetic Science from Ohio State University (OSU), Columbus, OH, and a BS (1998) in Earth Science from Seoul National University, Seoul, Korea. His MS thesis is on absolute point positioning from Global Positioning System (GPS) and his Ph.D. dissertation is on the global and regional gravity recovery from satellite tracking data and geophysical applications. He worked for two years as a Postdoctoral Research Associate at the Space Geodesy and Remote Sensing Laboratory at OSU and for one year as a Research Scientist at the School of Earth Sciences as OSU. During this period, he gave several invited talks on Earth gravity field at Technische Universiteit Delft, University College London, University of Toronto, Texas A&M University, and Université Laval. In 2006, he joined the Planetary Geodynamics Laboratory at NASA Goddard Space Flight Center and the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. His main research interest is global and local, static and temporal gravity field determination of the Earth and planets and earthquake monitoring and modeling with the gravity observations. He has been publishing papers on gravity estimation theory, coseismic and postseismic deformation, hydrological mass variation over the large river basins, ocean tides in polar regions, GPS/INS, and gravity gradiometry.

Dr. Susan Hoban is a Senior Research Scientist at GEST. She received her Ph. D. in astronomy from the University of Maryland in 1989. She conducted research in cometary science at NASA Goddard Space Flight Center, first as a National Research Council fellow, then as part of USRA Visiting Scientist Program, from 1989 - 1993. In 1993, she began working on information systems for science and education. In 1996, Dr. Hoban received the NASA Special Service Award for her work on web-based educational outreach. Dr. Hoban joined the University of Maryland Baltimore County in the Computer Science and Electrical Engineering Department in 1996 as part of the Center of Excellence in Space Data and Information Science (CESDIS) at Goddard. From 1998-99 Dr. Hoban served as Acting Associate Director of CESDIS and from 1999 through the conclusion of CESDIS in 2000 as Acting Director. Her interests include scientific information systems, and information technologies for science, technology, engineering and mathematics (STEM) education. Dr. Hoban is the PI on the NASA's BEST Students (Beginning Engineering, Science and Technology) project that provides professional development for educators and curriculum support resources with a space exploration theme for engineering clubs for elementary and middle school students. The project also hosts engineering challenges and two-week summer bridge programs centering on lunar exploration for middle and high school students. Dr. Hoban has a particular interest in contributing to our nation's educators' understanding of STEM subjects. She serves on the STEM Council at UMBC and on the STEM Advisory Council for Anne Arundel County Public Schools.

Dr. Jingfeng Huang received a Ph.D. in remote sensing and hydrology in Civil Engineering (2006) from the University of Manchester, Manchester, United Kingdom, a MS in environmental hydraulics in Civil Engineering (2002) from the Hong Kong University of Science and Technology (HKUST), Hong Kong, China. He graduated with his first BS in environmental science and engineering (2000) and his secondary BS in economics and management (2000) from Tsinghua University, Beijing, China. He worked for three years as a Postdoctoral Associate at the Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami, where he expanded his expertise from environmental science, hydrology and hydraulics, to meteorology and atmospheric science, and developed his broad interests on climatic effects of aerosols. In 2009, he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. His research interests cover satellite aerosol data retrieval and algorithm development, multi-sensor data assimilation, covariability of aerosol and meteorological and climatic factors, and aerosol climatic effects. He is also heavily involved in the VIIRS aerosol product calibration and validation activities.

Dr. Kyoung-Joo Hwang received a B.S. degree from the Korea University in 1996, and a M.S. degree in the field of Space Physics from the Korea Advanced Institute of Science And Technology (KAIST) in 1999. She received a Ph.D. degree in Space Plasma Physics, specialized in the Auroral physics, from Dartmouth College in 2006. She worked two years as a Postdoctoral Research Assistant at the Laboratory of Atmospheric and Space Physics (LASP), University of Colorado at Boulder, Colorado, where she expanded her space physics knowledge both using data analysis and numerical simulations. In October 2008, she joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a research associate on the MMS pre-launch studies. Her research is focused on the microphysics of a scale length of the electron diffusion region in the magnetic reconnection, using Cluster PEACE data, as well as investigating the global phenomena occurring in the Earth's magnetosphere, such as substorms in the magnetotail, and Kelvin-Helmholtz waves at the dayside magnetopause.

Dr. Suzanne Imber received a Ph.D. in Space Plasma Physics in 2008 from the University of Leicester, in the UK, and an MSci from Imperial College, London in 2005. Her Ph.D. thesis work investigates the process of magnetic reconnection at the magnetopause during intervals of northward IMF, in particular determining the factors influencing the lobe reconnection rate, and presenting first observations of dual lobe reconnection using a combination of SuperDARN radar and spacecraft data. Immediately following her Ph.D. she joined the Goddard Earth Sciences and Technology Centre and is based at NASA Goddard

Space Flight Centre in Maryland. Her main focus of research is reconnection in the near-Earth tail, with a particular focus on multiple x-line reconnection and flux rope formation and evolution. She also serves on the Deputy Director's Council for Science at GSFC.

Dr. S. Daniel Jacob received a B.E. (Hons.) in Civil Engineering from the Madurai Kamaraj University, Madurai, India, a Masters degree in Ocean Engineering from Indian Institute of Technology, Madras, India. He worked for a few years at the Indian Space Research Organization analyzing Synthetic Aperture Radar data of ocean surface waves and other satellite data before pursuing a Ph.D. at the University of Miami. He was awarded his Ph.D. in Meteorology and Physical Oceanography from the University of Miami Rosenstiel School of Marine and Atmospheric Science in 2000. His dissertation examined the upper ocean heat budget variability due to oceanic mesoscale variability and its effect on the intensification of tropical cyclones. He served as a Postdoctoral Research Associate at the University of Miami, where he was involved in acquiring oceanographic data from the NOAA hurricane hunters using expendable probes and in the Eastern Pacific as part of the Eastern Pacific Investigation of Climate project. He was appointed as an Assistant Research Scientist in GEST in May 2002 based in the Oceans and Ice Branch at GSFC. As a member of Aquarius science team, Daniel conducts research on the effects of surface forcing and ocean mixing on sea surface salinity and leads observational and model experiments. He is also a member of the NASA Standards Process Groups and leads Technical Working Groups reviewing candidate standards on earth science data file formats and metadata.

Dr. Myeong-Jae Jeong received a B.S. degree in Astronomy and Atmospheric Sciences from Yonsei University in 1996, a M.S. degree in Atmospheric Sciences from Yonsei University in 1998, and a Ph.D. in Atmospheric and Oceanic Science from University of Maryland-College Park in 2005. He has been at Goddard since 2005 as a research associate, where he worked on the ground-based remote sensing and *in-situ* aerosol measurements utilizing NASA's two mobile laboratories: Surface-sensing Measurement for Atmospheric Radiative Transfer (SMART) and Chemical, Optical and Microphysical Measurements of In-situ Troposphere (COMMIT). His research experiences include development of aerosol retrieval algorithm based on satellite measurements, analyses of satellite-, ground-based, and air-borne *in-situ* measurements of aerosols and clouds, and radiative transfer simulations. He developed innovative techniques to infer the height and absorption of biomass-burning smoke aerosols, to classify the dominant types of aerosols, and to derive the optical properties of dust particles mixed with aerosols in the marine boundary layer. He participated in several field experiments to study the effects of aerosols, clouds, and surfaces on the climate of the earth. Dr. Jeong joined GEST as an assistant research scientist in November 2007. His current research interest includes refinement and development of satellite-based aerosol retrieval algorithms, synthesis of *in-situ* and remote-sensing aerosol measurements to derive value added information, and applications of satellite-based aerosol products to air quality and climate studies.

Dr. Juan Carlos Jusem received a Ph.D in Meteorology (1983) from the Florida State University (FSU), Tallahassee, FL, a MS in Meteorology from the same institution in 1979 and the title of Licenciado (equivalent to Batchelor) in Meteorology from the University of Buenos Aires, Argentina (1961). Both of his Theses are on effects of condensation on the structure of mountain waves, with a linear approach in the Master and a non-linear, numerical treatment in the Ph.D. Thesis. Before starting his graduated studies at FSU in 1976, he was successively GARP consultant, in charge of the Tropical Center of BDSP (1969-1972) and WMO Expert (1973-1975), teaching Dynamical and Tropical Meteorology at the University of San Jose, Costa Rica and acting as a Consultant at the Meteorological Service of El Salvador. In 1984, Dr. Jusem joined the General Modeling and Simulation Branch of the Laboratory of Atmospheres and cooperated in the elaboration of the first version of the gravity wave drag parameterization of the GLAS Model. He contributed in the task of diagnostics and interpretation of meteorological events that were important in testing and modifying model routines. He also monitored the model-inferred weekly precipitation by adapting quantitative precipitation analysis techniques. He also devoted a good deal of

time to study the impact of satellite observations on model forecasts. During the last year he was developing a technique to retrieve tropical cyclone tracks from model output datasets.

Dr. Hyokyung Kim received her Ph.D. in Atmospheric Sciences from Pukyong National University at Busan, Korea in 2004. Her Ph.D. thesis is on the retrieval of atmospheric hydrometeors using dual wavelength cloud radar. In 2004-2007, she had worked for the Korea National Institute of Meteorological Research about very short time forecasting of precipitation using the weather radars and development of weather forecast and analysis system. She joined GEST in February 2009 and is currently working on the test and development of algorithms to retrieve the microphysical properties of cloud and precipitation from space-borne radars. Her current research focuses on the simulation of radar data (at Ku and Ka band for GPM-Dual Frequency Radar) from cloud resolving model data, testing of the dual frequency radar algorithms from the simulated radar data and evaluation of its performance.

Dr. Kyu-Myong Kim received a Ph. D. in atmospheric sciences from Seoul National University, Korea, in 1996. His Ph. D. thesis is on the temporal and spatial structures of the seasonal and interannual variability of the tropical Pacific atmosphere and ocean based on in situ observation as well as ocean circulation model. In 1996, he came to Goddard Space Flight Center, as a National Research Council Resident Research Associates, where he worked on El Nino-Asian summer monsoon interaction and tropospheric biennial oscillation. Since then, he has been at Climate and Radiation Branch at NASA/GSFC as a USRA (Universities Space Research Association) Associate Scientist (1998-2000) and as a senior supporting scientist of Science Systems and Applications, Inc. (2000-2006). He joined GEST as an associate research scientist in January 2006. His research interest includes seasonal-to-interannual climate variability and predictability, climate modeling, and diagnostics. More recently, he has been worked on the effect of aerosol radiative forcing on the monsoon water cycle over various monsoon regions, particularly on the effect of aerosol induced elevated heating on the regional monsoon rainfall and circulation, by utilizing satellite and in situ observations as well as model simulation.

Dr. Alexander Klimas received B. S. and S.M. degrees from the Massachusetts Institute of Technology in 1962 and his Ph.D. from the same institute in 1966. He joined ARAP, Inc., Princeton, New Jersey in 1966 where he worked on the theory of plasma transport with particular attention to cosmic ray transport in turbulent magnetic fields. Dr. Klimas joined the Goddard Space Flight Center as a National Research Council Senior Resident Research Associate in 1973 where he continued his cosmic ray transport studies. He joined the staff at Goddard Space Flight Center in 1975. In the early 80's, Dr. Klimas's attention was drawn to the theory and simulation of electrostatic plasma phenomena. He studied the electron plasma phenomena of Earth's foreshock and the fundamentally nonlinear BGK type solitary wave modes associated with the late evolution of beams in collisionless plasmas. Later, Dr. Klimas turned to the methods of the emerging science of nonlinear dynamics to understand the nonlinear response of Earth's magnetosphere to varying conditions in the solar wind. This work evolved into studies of the non-equilibrium critical state of Earth's magnetotail and its relation to the system dynamics of turbulent reconnection in the tail. Most recently, Dr. Klimas has embarked on a simulation study of the details of the collisionless magnetic reconnection mechanism. Dr. Klimas has been a principal investigator on the ISEE Guest Investigator program, the NASA Space Physics Supporting Research and Technology Program, the Sun-Earth Connection Guest Investigator program, and the Goddard Space Flight Center Director's Discretionary Fund program. He is the recipient of the NASA Special Service Award.

Ms. Helen-Nicole Kostis is a research artist working at the intersection of art, science, and technology for the development of experimental artworks and visualization media. Her research interests include immersive environments, telematic performance art, interactive installations, scientific animations, data visualization techniques and design of visualization information. Born in 1976 in Chicago, she now lives and works in Maryland. She graduated from the University of Ioannina, Greece with a BS in Mathematics (1998) and she holds a Master's in Computer Science (2002) and a Master's in Fine Arts in Electronic

Visualization (2007) from the University of Illinois at Chicago. She currently holds a faculty position as a Research Associate at the University of Maryland, Baltimore County and the Scientific Visualization Studio, Goddard Space Flight Center, NASA, contributing to the production of scientific visualizations for Earth sciences using satellite data. She has exhibited nationally and internationally in numerous conferences and festivals: Version>03:Digital Arts Convergence at the Museum of Contemporary Art in Chicago (2003), Electronic Imaging Science and Technology, SPIE (2005), AG-Art performance "Loose Minds in a Box" (2005), WIRED Magazine NextFest (2005), SIGGRAPH Emerging Technologies Access Grid Art (2005), IGRID (2005), Super Computing Global (2005), FILE (2007), IEEE Virtual Reality (2007) and IEEE Vis (2007). She has also given courses and lectures in conferences including Symposium of Virtual Reality (2007) and the College Arts Association (2008). She is a member of College Arts Association (CAA) and an active volunteer of ACM SIGGRAPH: The Association for Computing Machinery Special Interest Group on Graphics and Interactive Techniques (2006-2008). She is the recipient of a collaborative Honorable Mention for 2007 Visualization Challenge from the National Science Foundation and Science Magazine and Individual Artist Award for Computer Arts (2008) from the Maryland State Arts Council.

Dr. Andriy Koval received a Ph.D. in physics (2006) from the Charles University, Prague, Czech Republic, and a MS in electronic systems (2001) and BS in electronics (2000) from the Sumy State University, Sumy, Ukraine. His Ph.D. thesis is on solar wind discontinuities and their interaction with the Earth's bow shock. In 2006-2009 he worked as a NASA Postdoctoral Program Fellow at the Heliospheric Physics Laboratory at the NASA Goddard Space Flight Center, where he worked on properties of interplanetary shocks and developed a new technique for the shock parameter determination from spacecraft measurements. In August 2009 he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County as an assistant research scientist. His main interest is in studying kinetic structures of solar wind discontinuities and in particularly interplanetary shocks, and he is developing a new technique to improve calibration of the Wind Magnetic Field Investigation (MFI) to produce high time resolution data product that will enable such studies.

Dr. Nickolay A. Krotkov received a Ph.D. in oceanography (physics and mathematics1990) from the P. P. Shirshov Institute of Oceanology Russian Academy of Sciences, and a MS (with honor) in Remote Sensing (1985) and a BS in physics (1983) from Moscow Institute of Physics and Technology, Russia. His Ph.D. thesis is on using polarization properties of scattered solar radiation in the oceanic remote sensing. He worked for 2 years at Russian Central Aerological Observatory on surface UV radiation modeling. Since 1993 he worked as a Post Doctoral Research Associate at USRA and UMCP and as research scientist at Raytheon on NASA Total Ozone Mapping Spectrometer mission to study volcanic clouds, surface and underwater ultraviolet radiation and aerosols. In 2000 he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a senior research scientist. His main research interests include radiative transfer modeling, ground-based and satellite UV remotes sensing of trace gases and aerosols. Since 2006 he is member of the Aura OMI science team responsible for SO_2 data. He has published over 60 refereed papers where the most recent ones are concentrated on satellite estimation of the surface ultraviolet irradiance, SO_2 and measuring of aerosol UV absorption properties.

Mr. Tom Kucsera joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a Research Analyst in January 2007. Mr. Kucsera has been at NASA Goddard for more than 25 years with much of this time in the Atmospheric Chemistry and Dynamics Branch. His M.S. in Meteorology was from the University of Maryland and B.S. in Atmospheric Science and Mathematics from SUNY Albany. He provides atmospheric modeling support, satellite data processing, data analysis, NASA mission campaign support and performs system administration on several computer architectures and platforms. Within his Branch at the NASA Goddard Space Flight

Center facility, Mr. Kucsera serves as Computer Administrator Group Leader, NASA Active Directory Administrator, and NASA Patchlink Administrator.

Dr. Michael Kurylo received a B.S. in chemistry from Boston College in 1966 and a Ph.D. in physical chemistry from the Catholic University of America in 1969. Following an NRC postdoctoral fellowship at the National Bureau of Standards, NBS (now the National Institute of Standards and Technology, NIST), he conducted research on elementary gas phase chemical reactions and subsequently led a laboratory research group in atmospheric kinetics and photochemistry until 2003. Dr. Kurylo was awarded the Department of Commerce Bronze and Silver medals in 1983 and 1991 respectively for his accomplishments in this area. In 1987, he began a detailed assignment at NASA Headquarters as manager of NASA's Upper Atmosphere Research Program where he developed, promoted, and implemented an extramural research program in stratospheric and upper tropospheric composition and directed its advanced planning at a national and international level. He served in this assignment through 2003 while still managing a laboratory research program at NIST. He transferred permanently to NASA in 2004. As a NASA program manager, Dr. Kurylo served as Program Scientist for numerous airborne science campaigns focused on stratospheric ozone depletion, chemistry-climate coupling, and satellite validation. He also served as Program Scientist for several satellite missions. For his NASA accomplishments, Dr. Kurylo was awarded two NASA Exceptional Service Medals and more than a dozen NASA Group Achievement Awards. His role in national and international scientific coordination has been acknowledged via the NASA Headquarters Cooperative External Achievement Award, the NOAA Environmental Hero Award, the Catholic University of America Alumni Achievement Award in the Field of Science, the US EPA Stratospheric Ozone Protection Award, and the 2008 Hillebrand Prize of the Chemical Society of Washington / American Chemical Society. Dr. Kurylo has served as a reviewer, contributing author, or lead author for every WMO/UNEP international ozone assessment over the past two decades. His efforts leading to the success of the Montreal Protocol have been acknowledged by his being named to the Montreal Protocol Who's Who listing. He chaired the WMO/UNEP Meeting of Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer in 1992, 2002, 2005, and 2008. He is an elected member of the International Ozone Commission and of the Scientific Steering Group of the SPARC Project of the World Climate Research Program, and co-chair of the international Steering Committee of the Network for the Detection of Atmospheric Composition Change. Following his retirement from NASA in January 2008, Dr. Kurylo joined GEST as a Senior Research Scientist where he is engaged in several national and international global change activities.

Dr. Leslie Lait received a B.A. in Physics and Mathematics from Union College in Lincoln, Nebraska in 1981, followed by a Ph.D. in Physics from Iowa State University in Ames, Iowa in 1987. His doctoral thesis described the first applications of M. Salby's asynoptic space-time Fourier transform analysis to real satellite measurements. After being graduated from Iowa State, Leslie spent two years as a National Research Council Fellow at NASA's Goddard Space Flight Center. Subsequently, he remained at Goddard, where his research has centered on applications of quasi-conservative coordinate analysis of non-coincident measurements of trace gases from satellite remote-sensing instruments and airborne in-situ instruments. He also provides support for NASA airborne field experiments. Dr. Lait joined GEST in March 2006, as Senior Research Scientist.

Dr. Daniel Laughlin received his Ph.D. in Education from American University in 2001. His area of focus was information technology in education and he conducted research in cognitive science experimenting with methods to explicitly teach critical and scientific thinking skills. Before joining the Goddard Earth Sciences and Technology Center in 2002, Dr. Laughlin taught for fourteen years at a number of institutions including American, Loyola and Villanova Universities. From 1997 to 2002, he taught pre-service and in-service teachers to use computers and the Internet in their own classroom. Dr. Laughlin is currently the NASA Learning Technologies Project Manager at Goddard Space Flight Center.

NLT supports the research and development of cutting-edge educational tools that combine NASA mission content with innovative technology and best teaching practices. The office has sponsored the development of tools that have been featured on the covers of science and technology magazines and have received international recognition for their contributions to learning. NLT is primarily focused on the research and development of educational immersive synthetic environments and leads the games research effort for NASA's Education Office. Dr. Laughlin's research interests include information technology management, cognitive science, educational technologies and the use of computer and video games as educational tools. He is co-author of the NASA eEducation Roadmap: Research Challenges in the Design of Persistent Immersive Synthetic Environments for Education & Training (2007).

Dr. Choon Ki Lee received a Ph. D. in Geophysics from Seoul National University, Korea, in 2006. His Ph. D. thesis is on the magnetotelluric study on the deep geoelectrical structure across the Korean Peninsula. Before joining GEST, he was a postdoctoral researcher in the Korea Ocean Research and Development Institute (KORDI) and the Korea Institute of Geoscience and Mineral Resources (KIGAM). In 2008, he came to Goddard Space Flight Center (GSFC) as a visiting research scientist, where he is working on the data processing of GRACE satellite gravity and the assimilation of satellite gravity data into ocean tidal model.

Ms. Katherine Lewis joined GEST as a Media Specialist in Interactive Science on June 16, 2008. She currently works as an interactive producer for Goddard's multimedia department, designing and developing Flash media for educational and informational purposes. As part of the web editing team, she also contributes to the regular maintenance and expediency of the Goddard and NASA websites. Working with Goddard’s TV and web video producers, she experiments with different interactive formats for disseminating science video content on the web. She received her B.S. in Media Arts and Design from James Madison University in 2003 and in the past has been an interactive media developer at the John F. Kennedy Center for Performing Arts.

Dr. Feng Li received a B.S. and a M.S. in atmospheric sciences from Nanjing University, China in 1993 and 1996, respectively, and his Ph.D. in atmospheric sciences from University of Illinois at Urbana-Champaign in 2005. His Ph.D. thesis studied gravity waves in the mesopause using lidar and airglow imager measurements. Dr. Li joined GEST in June 2007 after working at the Geophysical Fluid Dynamics Laboratory as a postdoctoral researcher for two years. Dr. Li’s research interests include gravity waves, middle atmosphere dynamics and chemistry, and coupled chemistry-climate modeling.

Dr. Xiaowen Li received her B.S. degree in atmospheric sciences from Beijing University, China. She received her M.S. from the Chinese Academy of Meteorological Sciences. Dr. Li finished her Ph.D. degree at the University of Chicago in 2002, studying cloud microphysics and radar meteorology. She joined GEST as a research associate in July 2002. Dr. Li pioneered the research on direct radiative effect of anthropogenic aerosols in regional climate change in her early career in China. She was also a member of China-Japan East Asia monsoon study project, and participated surface turbulence observation on Tibetan Plateau from 1994 to 1996. Her Ph.D. dissertation studied the evaporation in stratiform rain region using both 1-D and 2-D simulations. Dr. Li is currently involved in studying the impact of aerosols on cloud and precipitation systems using numerical models, and the improvement of both bulk type and bin spectra microphysical schemes in the Goddard Cloud Ensemble Model.

Dr. Qing Liang received a Ph.D. in Atmospheric Sciences (2006) from the University of Washington, Seattle and a BS in Atmospheric Sciences (1997) from Nanjing University, China. Her Ph.D. thesis is on the chemistry and variability of long-range transport of Asian pollution to North America. She worked for three years as a Postdoctoral Fellow at the NASA Goddard Space Flight Center under the NASA Postdoctoral fellowship program administrated by Oak Ridge Associated Universities, conducting research on stratospheric ozone chemistry. In 2009, she joined the Goddard Earth Sciences and

Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. Her main research interest is the atmospheric ozone chemistry and its interconnection with climate change and her goal is to support NASA's GEOS Chemistry Climate Modeling project with her experience on atmospheric ozone chemistry. Her publications include papers on long-range transport of Asian pollutions, global emission and transport of ozone depletion substances, e.g. CFCs and short-lived bromocarbons, and the impact of stratosphere-troposphere exchange on tropospheric ozone and NOx chemistry.

Dr. Liang Liao received the B.S. degree in Radio Physics and the M.S degree in Space Physics from Wuhan University, Wuhan, China, in 1982 and 1985, respectively, and the Ph.D. degree in Meteorology from the University of Utah, Salt Lake City, in 1993. His research interests include the radio wave propagation, electric field scattering, and atmospheric radar and radiometer remote sensing on clouds and precipitation. Currently, he is an Associate Research Scientist at the Goddard Earth Sciences and Technology Center/UMBC.

Dr. Xin Lin received a B.S. in meteorology from Peking University in 1990, and M.S. and Ph.D. degrees in atmospheric science from Colorado State University in 1992 and 1997, respectively. His Ph.D. research focused on meso- and large-scale observational studies in both the tropics and midlatitudes. He worked as a postdoctoral researcher and then as a research associate at Colorado State University between 1997 and 2001. Dr. Lin joined GEST in 2001, and has been working in NASA Global Modeling and Assimilation Office on rainfall and cloud assimilations. His interest includes atmospheric convection, cloud parameterization, and remote sensing.

Dr. Alexander S. Lipatov is a Senior Research Scientist at GEST. Dr. Lipatov received a MS (1969) in gas dynamics and thermodynamics, a Candidate of Sciences (PhD) (1972) in plasma physics from Moscow Institute of Physics and Technology (Dept. of Aerophysics and Applied Mathematics), a Doctor of Sciences in theoretical and mathematical physics, from Institute for Space Research (IKI), Russian Academy of Sciences (1988), and a title "Professor of Space Physics" from the Russian Ministry for Higher Education (1995). He occupied the following professional positions. Institute for Space Research, Russian Academy of Sciences: 1972-1984 Research Scientist; 1984-1991 Senior Scientist; 1991-1996 Lead Scientist/Professor. Dialogue Science, A.A. Dorodnitsyn Computing Center (Institute) Russian Academy of Sciences: 1997-present time Lead Scientist/Professor. Moscow Institute of Physics and Technology, Department of Problems of Physics and Energetics: 1973-1990 Assistant Professor; 1990-1992 Associate Professor; 1990-1993 Deputy Head of Basic Chair (Sub-faculty) "Space Physics" (including "Space Physics", "Astrophysics" and "Computational Physics" basic specialties); 1993-present time Professor. He is a member (1975), and he was a member of the Council, a Chairman of commission for working with young scientists (1982-1988) of the Central House of Scientists, Russian Academy of Sciences. He also worked as long term visiting professor (1992-2006): East-West Space Science Center, Space and Plasma Physics Group, Univ. of MD at College Park; Max-Planck Institut fuer Extraterrestrische Physik, Berlin, Germany; Bartol Research Institute, University of Delaware; Max-Planck Institut fuer Aeronomie/Institut fuer Sonnensystemforschung, Germany; Institut fuer Theoretische Physik, Technische Universitat Carolo-Wilhelmina Braunschweig, Germany; Department of Atmospheric, Oceanic and Space Sciences, University of Michigan; Department of Physics, University of Alberta, Edmonton, Canada. Dr. Lipatov research interest includes the development of the advanced computational models (hybrid and the Complex Particle Kinetic concepts), the hybrid/Boltzmann simulation of the global interaction of the plasma flow with the moons, comets, the planets and heliosphere with weak own magnetic field and a strong ionosphere, as well as, the collisionless shocks and magnetic field reconnection in the plasma systems with reversed magnetic field configuration. Dr. Lipatov joined GEST in January 2007, as Goddard Senior Visiting Research Fellow.

Dr. Alexei I. Lyapustin received an MS/BS in physics from Moscow State University in 1987, and Ph.D. in Aerospace Remote Sensing from Space Research Institute, Moscow, Russia in 1991. Before joining GEST in February 2002, Dr. Lyapustin was a Research Fellow for two years in the Universities Space Research Association (USRA) and assistant research scientist in JCET UMBC. Dr. Lyapustin actively works in 1D and 3D radiative transfer in planetary atmospheres. His current research interests are focused on retrievals of atmospheric aerosol and surface bidirectional reflectance from MODIS and future NPOESS VIIRS sensors using the time series analysis. His group has developed the AERONET-based surface reflectance validation network (ASRVN) – an operational system producing surface BRF and albedo from MODIS and MISR instruments at AERONET locations for global validation analysis and science applications. Alexei is a current science team member of MODIS and NPP Science Teams, of GOES-R Algorithm Working Group, an associate member of the VIIRS Operational Algorithm Team (VOAT), and a member of GeoCape Mission Formulation Team.

Dr. Sarith Mahanama received a B.Sc.Eng from the University of Peradeniya, Sri Lanka in 1993, and a Ph.D. in water and environmental engineering in 2000 from the University of Hong Kong where his major research interest was water balance studies at the land-atmosphere boundary and predicting river discharges in large scale river basins using large scale meteorological forcings. In 2000 he joined Universities Space Research Association to work at the NSIPP. Later in 2000, he joined GEST/UMBC where he is still employed, to continue at the GMAO. His main research interest is studying the role of the land surface on seasonal forecasting of AGCMs.

Dr. Jianping Mao received a MS (1992) and a Ph.D. (1995) in Meteorology from the University of Maryland at College Park, MD. His Ph.D. thesis is on climate signal analysis in the global surface air temperature climate records. He worked for two years as a Postdoctoral Research Associate in the same university where he expanded his work on atmospheric radiation and remote sensing. After that he participated in the development of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) ranging from system configurations to data retrieval algorithms. He started his research on CO_2 remote sensing in 2001. In 2009, he joined the Goddard Earth Sciences and Technology Center as a member of research faculty. His main research interest is in the mission concepts, feasibility and sensitivity studies and performance analysis for new measurements about Earth and other planets. His current goal is to support NASA's carbon missions with his experience in atmospheric radiation, remote sensing and climate change studies.

Dr. Toshihisa Matsui received a Ph.D. in Atmospheric Science (2006) from Colorado State University, M.S in Earth & Environmental Resource Management (2002) from University of South Carolina, and a BS in Civil Engineering (1999) from Kobe University in Japan. In 2007, he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. His current research topics include development of multi-sensor satellite simulator in order to i) improve microphysics scheme in cloud-resolving models, ii) support development of radiance-based data assimilation system in the mesoscale modeling systems, and iii) facilitate remote-sensing algorithm development by providing a priori simulation database.

Dr. Will McCarty received a B.S. in Meteorology from Valparaiso University in 2003 and a M.S. and Ph. D. in Atmospheric Science from the University of Alabama in Huntsville in 2005 and 2008, respectively, where he was a recipient of the NASA Earth and Space Science Fellowship. His research was in the assimilation of thermal infrared hyperspectral measurements into a pseudo-operational mesoscale modeling system and the assessment of single field-of-view cloud contamination in these measurements. He continued his work at UAH as a research associate until January 2009, when he joined UMBC/GEST as an assistant research scientist. As a member of GEST, he has been affiliated with the Global Modeling and Assimilation Office under the sponsorship of Dr. Ron Gelaro.

Dr. Jan Merka received a Ph.D. in Plasma Physics (2000) from the Charles University, Prague, Czech Republic, and a MS in Astrophysics (1996) from the same university. His Ph.D. thesis is on the properties of the high-altitude magnetospheric cusp regions. In 2001, he was awarded the National Research Council Research Associateship Award and worked for three years as Resident Research Associate at the Laboratory for Extraterrestrial Physics at NASA Goddard Space Flight Center where he studied solar wind interaction with the Earth magnetosphere. From 2004 to 2006 he worked as Senior Research Scientist for the L-3 Communications Government Services, Inc., in the Laboratory for Solar and Space Physics at NASA/GSFC. In March 2006, he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as an Associate Research Scientist. His main research interests are the formation and properties of magnetospheric boundaries, application of data assimilation methods in space physics, and distributed data systems. He is the Principal Investigator of the Virtual Magnetospheric Observatory development at NASA/GSFC. His publications include papers on magnetospheric cusps, bow shock models, and solar wind data assimilation.

Dr. Priscilla N. Mohammed received a Ph.D. in Electrical Engineering (2005) and a Master's Degree in Electrical Engineering (2001) both from the Georgia Institute of Technology, Atlanta GA, and a BS in Electrical Engineering (1999) from the Florida Institute of Technology, Melbourne, FL. As a Ph.D. student, Priscilla performed microwave measurements of gaseous phosphine and ammonia under simulated conditions for the outer planets and used these measurements to develop a radio occultation simulator to predict absorption and excess Doppler due to Saturn's atmosphere. Much of this work was in support of the Cassini mission to Saturn. Based on these laboratory results, the Cassini Project Science Group made the decision to extend the Ka-band (32 GHz) operation throughout the mission tour. The predicted attenuation profiles for the Cassini radio occultation maneuver of May 2005, earned her an invitation by the Cassini Radio Science Team to present a paper on their behalf at the 37th Annual Meeting of the Division for Planetary Sciences in Cambridge, England. In 2006 she joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of their research faculty. Since joining GEST she has done research and published in the field of radio frequency interference mitigation in microwave radiometers. She is currently the Level 1B science algorithm team lead for the SMAP (Soil Moisture Active and Passive) mission which encompasses space flight application of her research.

Dr. Gyula I. Molnar received an M.S. in physics (1973) and a Ph.D. in geography/meteorology (1976) from the Roland Eötvös University of Budapest, Hungary. He was civil servant for the Hungarian Meteorological Service until 1982, while in 1976-77 he won a British Council Scholarship at the Department of Atmospheric Physics, Oxford University, Oxford, England to work on multispectral satellite retrievals of atmospheric parameters. He came to the U.S. in 1982 (NCAR, Boulder, CO) to work on developing a satellite imagery-based cloud retrieval schemes. He has joined AER, Inc. in Cambridge, MA in 1983 and worked on projects related to the evaluation of potential climate changes due to man's activities. In 1994, he started to work for the GOES Project at NASA/GSFC for improving cloud retrievals, and later to assess cloud/water vapor/climate interactions for the areas viewable from geostationary satellites. He has also developed a novel satellite-based sea surface temperature retrieval scheme. More recently, he was working in the AERI Project at UMBC to develop CO, CO_2, and CH_4 retrievals for an upward-looking infrared spectrometer. Most recently, he has been working for the AIRS-Project with Dr. Susskind at NASA/GODDARD. He has published nearly 30 refereed papers so far in satellite remote sensing/sounding, as well as in global climate change related topics.

Dr. Andrea Molod worked in the GMSB/DAO/GMAO from 1985-2003, participating in the development of the physical parameterizations in the atmospheric GCM with special focus on convection, turbulence, and land surface parameterizations. She received her Ph.D. in Atmospheric Dynamics from the department of Earth and Planetary Sciences at Johns Hopkins University in 2003, doing research involving GCM simulation of turbulence over heterogeneous terrain. During her post-doctoral research

appointment at MIT's department of Earth, Atmospheric and Planetary Sciences, Dr. Molod developed a new flexible technique for the interactions between different elements of a GCM, and continues her work on land-atmosphere interactions. She rejoined the GMAO in December of 2007, and is focusing her model development efforts on improving the simulation of turbulent and moist processes.

Ms. Laura Spector Motel is a media specialist at the Goddard Space Flight Center. In 2004, she received a B.A. from Franklin & Marshall College in Lancaster, PA and in 2005 earned an M.A. from American University in Journalism and Public Affairs, with a concentration in Broadcasting. Ms. Motel also has a news production background from WUSA-TV9, WGAL-TV8, and BBC World News in Washington D.C. She joined GEST in April 2007, and has since been working on breaking news and media production, as well as media outreach for GSFC.

Mr. Thomas Narock received a MS in Applied Physics from the Johns Hopkins University and a BS in Astronomy from the University of Maryland, College Park. He is currently working on a Ph.D. in Information Systems from the University of Maryland, Baltimore County. In 2006 he joined the Goddard Earth Science and Technology Center at the University of Maryland, Baltimore County. His primary research areas focus on data search and retrieval and applications of artificial intelligence to space physics data.

Dr. Peter M. Norris received a BS and MS from the University of Auckland, New Zealand, in 1986 and 1989, and a Ph.D. in Oceanography in 1996 from Scripps Institution of Oceanography (SIO), University of California, San Diego, where his major research interest was numerical modeling of the stratocumulus-topped marine boundary layer. He continued this research in 1996 as a Research Oceanographer in the Marine Meteorology Research Group at SIO, and then in 1997-1998 took up a New Zealand Science and Technology Postdoctoral Fellowship at the National Institute for Water and Atmospheric Research in New Zealand, where he worked on marine boundary-layer modeling. In 1999 he joined the GSFC Center for Excellence in Space Data and Information Science (CESDIS) as a Staff Scientist working on cloud parameterization behavior in a high-resolution global belt version of NCEP's Eta model. In 2000 he joined UMBC/GEST as an Assistant Research Scientist, working at the NASA Data Assimilation Office (DAO), now the Global Modeling and Assimilation Office (GMAO), on cloud modeling and assimilation. He has also participated in numerous atmospheric field experiments, including the FIRE Cirrus II, Kansas, 1991, FIRE ASTEX, Azores, 1992, and TOGA-COARE, Solomon Islands, 1993, taking roles in data collection, aircraft flight direction, and data analysis.

Dr. Mark A. Olsen received a B.S. in physics from the University of Northern Iowa in 1993 and a Ph.D. in physics from Iowa State University in 2000. His doctoral research examined near-tropopause dynamics and structure of baroclinic systems in total column ozone data and mesoscale model analyses. From 2000 to 2002, he held a National Research Council postdoctoral fellowship at GSFC where his work concentrated on midlatitude stratosphere-troposphere exchange of ozone and mass. Dr. Olsen became a research associate at GEST in December 2002 and later appointed assistant research scientist in December 2004. Dr. Olsen's research interests include upper-troposphere/lower-stratosphere structure and dynamics, cross-tropopause transport, and climate change.

Dr. Lesley Ott received a BS in Physical Sciences in 2000 and a PhD in Atmospheric and Oceanic Sciences in 2006 from the University of Maryland, College Park. Her doctoral dissertation focused on improving the understanding of convective transport, lightning NO production, and ozone photochemistry in thunderstorms using high-resolution computational models. After leaving the University of Maryland, Dr. Ott spent two years in the Global Modeling and Assimilation Office at Goddard as a NASA Postdoctoral Fellow before joining the Goddard Earth Sciences Technology Center at the University of Maryland, Baltimore County in 2008. Since coming to Goddard, her research has focused on understanding the processes that control atmospheric trace gas distributions.

Dr. Xiaohua Pan became a research associate at GEST/UMBC in Nov 2009. She obtained her B.S. and M.S. degree both in meteorology from the Nanjing Institute of Meteorology (1999) and National Academy of Meteorology Science (2002), respectively. Then she received her PhD degree in Climate Dynamics at George Mason University in May 2009 under Dr. J. Shukla. She studied "the impact of mean climate on the simulation and prediction of ENSO" as her PhD dissertation. Her interests include: the interaction of air quality with climate; the impact of biomass burning on climate; the assessment and development of earth system model; climate warming; climate variability with various time scales ranging from intraseasonal to decadal, such as MJO, ENSO, and NAO; weather and climate prediction and predictability.

Dr. Lynn Parnell received a PhD in Mechanical Engineering (1974) and a BS (1967) from New Mexico State University, Las Cruces, NM, and a MS in Biological and Agricultural Engineering (1969) from North Carolina State University, Raleigh, NC. His PhD dissertation is on the vibration of beams with attached mass. After a tour of duty in the U.S. Army leading an engineering team conducting systems analysis of the tactical fire control system, TACFIRE, he led and directed research in the hydromechanics of Naval systems at the Space and Naval Warfare Systems Center (SSC Pacific) and its predecessor laboratory organizations for 20 years. During that time his research focus was on theoretical, experimental and computational aspects of ship hull design, undersea vehicle propulsion, combustion, drag reduction technologies and missile airframe design and analysis. Dr. Parnell then served for 15 years as program director and coordinator for HPC at SSC Pacific. He was the laboratory's leading expert and national representative on HPC technology and directed its HPC Center whose primary focus was on advanced parallel computational methods for command, control, communications, computing, intelligence, surveillance and reconnaissance. He was responsible for acquisition, operation and management of the Center's HPC systems – scalable parallel supercomputing servers and clusters at multiple classification levels – in support of the full breadth of science and engineering disciplines at the laboratory. He served for many years as a member and leader of research and fellowship award panels for SSC Pacific and the Department of Defense HPC Modernization Program.

Dr. Erricos Pavlis received his Dipl. Ing. from the Nat. Tech. Univ. of Athens, Greece in 1975, and his PhD in Geodetic Science from The Ohio State Univ., Columbus, Ohio. Dr. Pavlis is currently a Research Associate Professor, Physics, at the Univ. of Maryland, Baltimore County, doing research for NASA. He participated in the LAGEOS, LAGEOS 2, the Crustal Dynamics and WEGENER Projects, the TOPEX/POSEIDON and JASON Missions, and the development of EGM96. Currently science team member of GRACE and OST missions, and a co-PI of the LARES mission, Science Coordinator for the GGOS Bureau for Networks and Communications, member of the GGOS Steering Committee, the IERS Directing Board, the ILRS's Governing Board, the Central Bureau and ILRS Coordinator for Analysis and Modeling, chairman of the ILRS Refraction Study group, member of IAG's Subcommission 3.3, and associate editor for the journal of Celestial Mechanics and Dynamical Astronomy.

Dr. Antti A Pulkkinen is currently Associate Research Scientist in the University of Maryland, Baltimore County, Goddard Earth Sciences and Technology Center operated at NASA Goddard Space Flight Center. Dr. Pulkkinen received his PhD in theoretical physics from the University of Helsinki, Finland in 2003. Subsequently he joined the nonlinear dynamics group at NASA Goddard Space Flight Center to carry out his postdoctoral research during years 2004-2006. Dr. Pulkkinen's PhD and postdoctoral research involved studies on both ground effects of space weather and complex nonlinear dynamics of the magnetosphere-ionosphere system. He has been both leading and participating numerous space weather-related projects where scientists have been in close collaboration with industrial partners. In most of these projects, Dr. Pulkkinen's work has involved general geomagnetic induction modeling and modeling of space weather effects on pipelines and power transmission systems. Recently he has been working on utilizing the established modeling capabilities in semi-operational nowcasting and forecasting of space weather. Dr. Pulkkinen is the main or co-author of about 50 peer-reviewed scientific articles.

Dr. Cynthia Randles received a S.B. in Earth, Atmospheric, and Planetary Sciences from the Massachusetts Institute of Technology (MIT) in 2000, an M.A. in Atmospheric and Oceanic Sciences in 2004 from Princeton University, and a Ph. D., also in Atmospheric and Oceanic Sciences, from Princeton University in September, 2007. As a graduate student at Princeton, she was advised by V. Ramaswamy of the Princeton Atmospheric and Oceanic Sciences (AOS) Program and the NOAA Geophysical Fluid Dynamics Laboratory (GFDL). Her research focused on the climate impacts of carbonaceous aerosols using a suite of numerical models ranging from an aerosol microphysics model to GFDL's general circulation model (GCM). During her tenure at Princeton from 2001 to 2007, Dr. Randles was funded through the Department of Energy (DOE) Global Change Education Program (GCEP) Graduate Research Environmental Fellowship (GREF). For the 2006-2007 academic year, Dr. Randles was awarded the prestigious Marvin L. Wesley Distinguished GREF Fellow Award for her graduate work in climate science. In 2008, She received a one-year Goddard Visiting Fellowship from the Goddard Earth Sciences and Technology Center (GEST) at the University of Maryland, Baltimore County to work with Dr. Peter Colarco in the NASA Goddard Atmospheric Chemistry and Dynamics Branch (Code 613.3). During her time as a fellow, she worked to implement and examine the semi-direct aerosol effect in the NASA GEOS-5 general circulation model. In 2009, Dr. Randles was awarded a NASA Postdoctoral Fellowship (NPP) to continue her work examining aerosol-climate interactions in GEOS-5. Since August 2009, Dr. Randles has been an Assistant Research Scientist at UMBC GEST. She is currently working to improve the representation of aerosol optical properties in GEOS-5 while continuing to investigate aerosol-climate interactions.

Dr. Oreste Reale received his Laurea in geophysical engineering from the University of Trieste, Italy, in 1990. From 1990 to 1992 Dr. Reale worked on applied geophysics at the University of Trieste. From 1992 to 1996 he was a graduate student at the University of Maryland, College Park, where he received his M.S. in meteorology in 1994, and his Ph.D. in meteorology in 1996. Upon completing his doctorate, from 1996 to 1999 Dr. Reale worked in Italy, contributing to the development of a meteo-hydrological operational center (CMIRL, Genoa, Italy). From his activity in Italy he resulted being co-advisor on three theses on synoptic meteorology at the University of Trieste and one thesis in hydrology at the University of Genoa. From 1999 to 2001 Dr. Reale worked in the Center for Ocean-Land-Atmosphere Studies, Institute for Global Environment and Society (COLA-IGES), Maryland, on the impact of land-surface evaporation variability and on the dynamics of Mediterranean floods. He joined GEST in July 2001 as an Associate Research Scientist, working on the synoptic and dynamic meteorology of extreme events, such as tropical cyclones, and on their sensitivity to model improvements and data types. In 2005 Dr. Reale became PI of 3-year funded NASA proposal on Observing System Simulation Experiments, in 2006 became co-I of a funded NASA proposal on the African Monsoon and in 2009 became co-I of a funded NASA proposal on long term characteristics of tropical cyclones.

Dr. Christian Retscher received his Ph.D. in Physics (2004) and M.Sc. in Physics (2000) from University of Graz, Austria. His thesis is on stratospheric ozone and temperature sounding by the Envisat/GOMOS stellar occultation sensor. Besides his academic career his was a developer and trainer in the IT business (Linux, Databases, Programming). In the years 2005 – 2007 he worked at European Space Agency (ESA), Frascati, Italy, where he was involved in Grid Computing activities in Earth observation with emphasis on atmospheric science. In Sep 2007 he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, where he works on applications and services for satellite data and is involved in validation activities.

Dr. Lars Peter Riishojgaard received an M.Sc. in geophysics from the University of Copenhagen in 1989 and a Ph.D. in geophysics from the same institution in 1992. His permanent affiliation from 1989 through

1995 was with the research department of the Danish Meteorological Institute in Copenhagen. Part of his thesis work in general circulation modeling with special emphasis on processes relevant for stratospheric ozone was carried out at the Centre National de Recherches Meteorologiques in Toulouse. He took up a visiting scientist position there from 1993-1994, a period during which he pioneered the application of variational assimilation methods to the problem of driving dynamical flow fields from tracer observations. Late in 1995 he came to the Data Assimilation Office (DAO) at NASA Goddard as a USRA visiting fellow. He designed and led the development of a three-dimensional ozone assimilation system, in parallel with carrying out research in the area of state-dependent covariance modeling. In June 1999 he took up a staff position at EUMETSAT in Darmstadt with user requirements for future space-based observing systems as the main responsibility. In August 2000 he returned to the DAO to lead the development of its analysis system, and with the formation of the GMAO in 2003 he became the lead of its satellite data group. He became the NASA Deputy Director of the newly created Joint Center for Satellite Data Assimilation in 2002 and became the second director of the Center in 2007. In 2004 he launched the initiative for a new space mission, the Molniya Orbit Imager, the purpose of which is to demonstrate the high temporal resolution imaging capabilities of this orbit for the high-latitude regions. He has since played leading roles in a number of different space mission proposals and is the Co-Chair of the US Working Group on Space-Based Wind Lidars. He is the Chair of the Open Program Area Group on the Integrated Observing System under WMO's Commission for Basic Systems. Dr. Riishojgaard has been with UMBC since February 1997 and with GEST since September 2000.

Dr. Menelaos Sarantos received his B.S. in Physics from the University of Patras, Greece, in 1997, and his M. S. and Ph.D. in Physics and Astronomy from Rice University, Houston, TX, in 2000 and 2005, respectively. Previously a Research Associate at the University of Maryland, College Park (2005-2007), and a NASA Postodoctoral Fellow (2007-2009) at Goddard Space Flight Center, he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as an Assistant Research Scientist this year. His research details the interaction of the solar wind with planetary objects such as Mercury and the Moon. Dr. Sarantos is presently a Co-Investigator of the DREAM (Dynamic Response of the Environment At the Moon) Team, a node of the newly established NASA Lunar Science Institute. He is also a Co-Investigator of the ESA-JAXA-NASA Bepi Colombo mission to Mercury. During the past year he served as the organizer of the GSFC Heliophysics Science Division Seminar.

Dr. Robert A. Schiffer is a Senior Research Scientist at the Goddard Earth Science and Technology Center (GEST) at the University of Maryland, Baltimore County (UMBC). He retired from NASA in 2002 after 39 years of service to NASA, including 11 years as a research scientist/engineer at the Jet Propulsion Laboratory at the California Institute of Technology, and 28 years at NASA Headquarters, where he served as Deputy Director of the Research Division in the Office of Earth Science. Over a period of 18 years Dr. Schiffer was seconded (part-time) to the World Meteorological Organization (WMO) Secretariat in Geneva, Switzerland, where he served as Director of the Radiation Projects Office for the World Climate Research Programme (WCRP). He subsequently served as interim Director of the International Project office for the WCRP Global Water and Energy Cycle Experiment (GEWEX), located in Silver Spring, Maryland. For over 10 years Dr. Schiffer chaired the U.S. Global Change Research Program (USGCRP) - Interagency Committee on Observations and Monitoring, and co-chaired the Interagency Committee on the Global Water Cycle. He also served as Executive Director of the U.S. Secretariat for International Global Observing Systems Programs, and co-chair of the US/USSR bilateral working group on climate modeling. Dr. Schiffer earned his M.S. and Ph.D. degrees (Atmospheric Sciences) from the University of California at Los Angeles, and B.Aero.E and M.Aero.E degrees (Aeronautical Engineering) from the Polytechnic Institute of New York University, He was licensed as a Professional Engineer in New Jersey and in California in 1965. While at NASA, he was awarded the Distinguished Service Medal, NASA's highest award, and two Medals for Outstanding Leadership, for his contributions to interagency and international climate research and global environmental observations. He is a Fellow of the American Meteorological Society, and currently serves as a consultant to NASA and

the WMO on global change scientific planning, and is the Principal Investigator for the NASA grant to UMBC covering operation of the International GEWEX project Office.

Dr. Henry B. Selkirk received his Ph. D. in Meteorology in 1986 from the Massachusetts Institute of Technology (MIT), Cambridge, MA and a BA in 1977 from The Evergreen State College in Olympia, WA. His Ph.D. thesis was an observational study of the Madden-Julian oscillation. Before arriving at GEST in December 2008, Dr. Selkirk had been working in the Earth Sciences Division at NASA Ames Research Center on topics related to tropical climate, weather and wave dynamics, atmospheric trace constituents, aerosols and transport processes, and stratosphere-troposphere exchange processes. He has participated in some 20 research aircraft missions since 1987 providing flight planning and meteorological support. In 2004 he organized with Costa Rican collaborators the first of what became five Ticosonde high-frequency radiosonde campaigns in Costa Rica, extending these observations in 2005 to what is now an ongoing program of CFH and ECC ozonesonde measurements. This continuing work remains a joint enterprise with Dr. Holger Vömel of the Deutscher Wetterdienst, Dra. Jessica Valverde of the Universidad Nacional and with the Instituto Meteorlógico Nacional of Costa Rica. These observations provide a unique and important source of accurate water vapor measurements in the TTL for satellite validation and climate modeling.

Dr. Joe Sexton is a geospatial ecologist who uses remotely sensed datasets to study ecosystem dynamics in space and time. Joe earned a B.S. in Wildlife Ecology and Conservation with a minor in Zoology at the University of Florida (1999), an M.S. in Forest Ecology at Utah State University (2003), and a Ph.D. in Ecology at Duke University (2009). His research focuses on the dynamics of forested landscapes, with special attention to the services these ecosystems provide to humans.

Dr. Jainn J. Shi received his B.S. degree (1982) in Atmospheric Sciences from National Taiwan University, Taiwan. He received his M.S. and Ph.D. in Atmospheric Sciences from the North Carolina State University, Raleigh, North Carolina. Dr. Shi completed his Ph.D. degree in 1993, studying real case numerical simulations of hurricanes with a three-dimensional tropical cyclone model. He worked on-site at Naval Research Laboratory (NRL) between 1992 and 2004. During this period, his research activities included numerical studies on the dynamic structure of tropical cyclones, derive algorithms to retrieve, validate and utilize a wide range of geo-environmental satellite images, including Special Sensor Microwave/Imager (SSMI). Research activities were also concentrated on developing high resolution (< 1 km) land surface and urban canopy model for COAMPS. Dr. Shi has been working on-site at NASA/GSFC since 2004. Current research areas include: 1) implementing Goddard's microphysics and radiation schemes into the Weather Research and Forecast (WRF) model; 2) investigating the precipitation processes associated with various mesoscale convective systems, tropical cyclones, and hurricanes using mesoscale models; 3) identifying statistical characteristic of clouds, convective updrafts and downdrafts; and 4) studying cloud-radiation interactions and their impact on diurnal variation of precipitation. Dr. Shi joined GEST in 2008.

Dr. Chung-Lin Shie, originally from Taiwan, R.O.C., received a B.S. in atmospheric sciences from National Taiwan University, then a M.S. in meteorology from Pennsylvania State University, and a Ph.D. in meteorology from Florida State University. He started working at NASA/GSFC as a research scientist since February 1993, affiliated first with SSAI (as Research Meteorologist till February 1997, then Senior Research Meteorologist till March 2001), and then Associate Research Scientist with UMBC/GEST (since April 2001) ever since. During his early career (from February 1993 to March 1997), he mainly worked on the development and improvement of an EOF (Empirical Orthogonal Functions) model for surface humidity retrieval over the global oceans using the SSM/I precipitable water data. He later helped producing a global (2x2.5 grid) daily air-sea surface flux product (GSSTF1) for a 7.5-year period (from July 1987 to December 1994), which was archived and distributed by the Goddard DISC. Since April 1997, he joined a research project involving numerical simulations using the GCE model, and scientific

analysis to study radiative-convective systems and their interactions with large-scale environment. He has recently further extended the scope of his multi-tasking research works. His current research works also involve research projects such as EOS, NEWS, and NAMMA. He recently won a MEaSUREs funded proposal to resume the air-sea flux production that he had helped establishing during 1993-1997. In 2006, he won a "Meritorious Service Award" from COAA for his genuine performance serving as one of the COAA Board Directors during 2003-2004. He also won the "Annual Outstanding Performance Award" of Mesoscale Atmospheric Processes Branch, NASA/GSFC in both 2000 and 2004, as well as won an "Outstanding Mentoring Award" from UMBC/GEST in 2003. During his association with SSAI for 1993-2000, he had won Annual Performance Awards eight years in a row.

Dr. Ja Soon Shim received a B.S. degree from Seoul National University, Seoul, Korea in Physics Education in 1987, and her M.S. and Ph.D. degrees in the field of Particle Physics from the same university in 1987 and 1993, respectively. She received her second Ph.D. degree in Space Physics from Utah State University in 2009. In September 2009, she joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a visiting research associate.

Dr. Christopher A. Shuman joined the Goddard Earth Science and Technology Center, on May 30, 2007 Associate Research Scientist. He is currently working with Dr. David J. Harding, Planetary Geodynamics Branch, NASA Goddard Space Flight Center, Greenbelt MD on enhanced laser altimetry concepts for cryospheric science. From 2001-2007, he was a Physical Scientist with the Cryospheric Sciences Branch, and the Deputy Project Scientist for the ICESat Mission (2001-2005), as well as an Adjunct Research Faculty, ESSIC, University of Maryland, College Park. From 1999-2001 he was an Assistant Research Scientist, Earth System Science Interdisciplinary Center, University of Maryland, College Park. From 1996-1998, he was a Visiting Research Fellow with the Universities Space Research Association at NASA Goddard Space Flight Center's Oceans and Ice Branch working with Dr. Robert A. Bindschadler. From 1994-1996, he was a National Research Council, Resident Research Associate at NASA Goddard Space Flight Center's Oceans and Ice Branch, Greenbelt, MD working with Dr. Robert A. Bindschadler. From 1992-1994, he was a Research Associate at the Earth System Science Center and Department of Geosciences of The Pennsylvania State University, working with Dr. Richard B. Alley. Dr. Shuman received his Ph.D. in Geosciences in 1992 and his M.S. in Geology in 1987 from The Pennsylvania State University, and his B.S. in Geology in 1982 from Moravian College. Dr. Shuman has authored or co-authored research papers on laser altimetry and its combination with other remote sensing data to define subglacial lakes in Antarctica, on the accuracy of early ICESat-1 data, on composite temperature records derived from AWS passive microwave data from SMMR and SSM/I and IR data from AVHRR, as well as correlating those records through stratigraphic correlation with stable isotope ratio profiles in shallow snow layers. He has worked extensively in Greenland (7 deployments) and Antarctica (7 deployments including Fall 2009 Operation Ice Bridge flights from Punta Arenas, Chile) and began his cryospheric career helping to date the GISP2 ice core. He is currently the longest serving (surviving?) member of PoDAG (http://nsidc.org/daac/podag.html) and is also on the Executive Committee of the Cryospheric Focus Group of AGU http://www.agu.org/focus_group/cryosphere/membership.html#exec).

Dr. Kumar Hemant Singh received a Ph.D. in Geophysics (2003) from the Freie University , Berlin, Germany, and a MTech in Applied Geophysics (1999) from University of Roorkee (Now IIT Roorkee), Roorkee, India, and a BSc in Physics (1996) from the University of Delhi, Delhi,. His Ph.D. thesis is on the Modelling and Interpretation of Global Lithospheric Magnetic Anomalies. He worked for 2 year as a Postdoctoral Researcher at the Geo FroschungsZentrum, Potsdam, Germany where he continued and expanded his work on modeling and interpretation of ocean magnetic anomalies. In 2006 he joined the University of Leeds, Leeds, UK as a lecturer. His main research interest was the world digital magnetic anomaly map. He then moved to Goddard in 2007, as a NASA postdoctoral fellow and worked on lunar magnetic anomaly maps. Since, 209, he works as Associate research scientist with University of Maryland Baltimore County and at GSFC on non-tidal ocean induced magnetic anomalies. His

publications include papers on satellite magnetic data modeling and interpretation, world magnetic anomaly maps and ocean magnetic anomalies.

Dr. Radina Soebiyanto received her B.S. (2002) and Ph.D. (2008) degrees in Systems and Control Engineering, and her M.E.M. (Masters of Engineering and Management, 2003) degree from Case Western Reserve University in Cleveland, Ohio. During her Ph.D. thesis, Dr. Soebiyanto developed a large-scale mathematical model of molecular interactions involved in cancer, and subsequently introduced a multilevel, hierarchical systems approach that can be used to guide the selection of biological experiments for the discovery of soft molecular targets. She worked as a mathematical modeler at Immunetrics (Pittsburgh, Pennsylvania), before joining GEST as a Research Associate in August 2008. Her current research is on using remotely-sensed environmental and climatic data in empirical and theoretical models to predict and facilitate the control of infectious disease transmission including vector-borne diseases. She is also studying the environmental signature on seasonal disease outbreaks.

Dr. In-Sun Song received a Ph.D. (2005) and a MS (1999) in Atmospheric Sciences and a BS (1997) in Astronomy and Atmospheric Sciences from Yonsei University, Seoul, South Korea. His Ph.D. thesis is on the generation mechanisms of convectively forced internal gravity waves and the relationship between the mechanisms and the vertical propagation condition of atmospheric gravity waves. He worked for two years as a Postdoctoral Research Associate at Laboratory for Atmospheric Dynamics in Yonsei University. During this period, he concentrated on the development of ray-based gravity wave parameterization. He joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a research faculty in 2007. His research interest includes generation mechanisms of gravity waves and the development of gravity wave parameterization for use in large-scale models.

Dr. Fabien Stalport is a geologist and geochemist (master of Earth and Universe Sciences), and is also specialized in chemistry of the atmospheric pollution and physic of the environment (master of chemistry of the atmospheric pollution and physic of the environment). His masters, his PhD and his first year of post doc were mainly focused on the development of laboratory experiments to predict the evolution of the organic matter in the martian environment and to study the biological signature of inorganic materials produced by the living organisms and called biominerals. His experiments are scientific data for the future SAM instrument (Sample Analysis at Mars) onboard the rover of the MSL 2011 mission (Mars Science Laboratory). In 2009, he joined the scientific team of Paul Mahaffy (Code 699, NASA/Goddard Space Flight Center). Paul Mahaffy is the principal investigator of the SAM instrument. Fabien Stalport is on charge to test the derivatization part of the instrument SAM, especially the Pyr-GC-MS, in order to optimize and interpret the expected *in situ* results. He also continues his works about the evolution of the organic matter in the martian environment and the biominerals.

Mr. Stephen D. Steenrod received a B.S. with a dual major of Atmospheric Science and Mathematics from the State University of New York at Albany in 1981 and a M.S. in Meteorology from the University of Wisconsin - Madison in 1983. His graduate work investigated the diurnal variation of oceanic convection. He then came to Goddard Space Flight Center in the Oceans and Ice Branch, working on a model of the wind-driven ocean circulation. After a few years he moved to the Atmospheric Chemistry and Dynamics Branch, where he continues to work. In this branch he has worked mainly with the analysis and coding of the 3D Chemical Transport Model. For the last few years he has been working on the Global Modeling Initiative (GMI), which is part of the NASA Modeling Analysis and Prediction (MAP) program. GMI investigations support the development and integration of a state-of-the-art modular 3-D chemistry and transport model (CTM) that includes full chemistry for both the troposphere and stratosphere. The GMI model is involved in the assessment of anthropogenic impacts, such as those from aircraft, future changes in atmospheric composition, and the role of long-range transport of pollution. The GMI model serves as a testbed for different meteorological fields, emissions, microphysical mechanisms,

chemical mechanisms, deposition schemes, and other processes determining atmospheric composition, both gas-phase and aerosol.

Dr. Susan Strahan received a BS in chemistry from Stanford University in 1980 and a Ph.D. in chemistry from the University of California, Berkeley in 1986. As an NRC postdoc at NASA Ames Research Center, her research involved making stratospheric trace gas measurements with an airborne spectrometer on the NASA ER-2. As a visiting scientist at the NOAA Geophysical Fluid Dynamics Lab (GFDL) from 1990-2, she continued the analysis of those measurements, using the results to evaluate the polar transport in the GFDL 'SKYHI' model. Since 1992 she has been at the NASA Goddard Space Flight Center, presently working in the Atmospheric Chemistry and Dynamics Branch. Her research involves analysis of trace gas measurements from aircraft and satellite platforms. The observational analyses are used to develop diagnostics that evaluate the credibility of atmospheric models. She is the Project Manager for the Global Modeling Initiative. She contributes to the evaluation of the NASA GMI chemistry and transport models and chemistry-climate models.

Mr. David Stroud is currently the Multimedia/Education Technology Senior Producer at GEST. He received a B.S. in Film Production from Temple University in 1982 and an M.F.A. in Photography/Digital Media from The University of Delaware in 1994. For the first 12 years of his professional life, Mr. Stroud successfully ran his own business freelancing in the commercial production of film, television and video. He gained credits on projects such as Hollywood motion pictures, music videos, commercials, industrial films, and network news. After graduating with his MFA, he was an Assistant Professor of Digital Media and Photography at various colleges and universities, first as an adjunct then as a tenure-tracked Assistant Professor of Art/Imaging Technologies. While at Harford Community College, he developed a new degree program in Visual Communications. Between 1993 and 2000 he worked as a fine-artist. This work was personal research that supported his work in academia as an Artist/Educator. The research included developing a portfolio, showing the work and conducting lectures. Regional galleries and museums have critically acclaimed his work, and his work has been included in the collections of private individuals. In 2001 Mr. Stroud joined a team of education and outreach specialists within the Earth Science Directorate at NASA's GSFC. The team focused on utilizing emerging media technologies, to develop and disseminate engaging and relevant Educational and Public Affairs Outreach materials. His primary contribution to the team is to bring his considerable media production experience to every aspect of the budgeting, design, development, administration and execution of a wide range of projects that include web applications, interactive multimedia kiosks and CD-ROMs, live interactive web-casts, software design and development, and video programs. In 2006, Mr. Stroud joined GEST to continue his work developing New Media applications for science communication and to conduct research and development of emerging technologies for the support of NASA Science Missions, Science Outreach and Science Education.

Dr. Timothy J. Stubbs is an Assistant Research Scientist at GEST whose interests cover the fields of planetary science and heliophysics. He received both his PhD in Space Physics (2002) and MSci in Physics (1998) from Imperial College, London. His PhD work concerned ion injection and transport in the high-latitude magnetosphere. In 2002 he began his National Research Council Resident Research Associateship at NASA/GSFC, during which he studied magnetospheric and auroral processes using spacecraft observations, and began his research on surface charging and dust transport in the lunar environment. He has been a member of the UMBC/GEST research faculty since 2005 and continues to work at NASA/GSFC on modeling and understanding the dynamic interaction of the space environment with the Moon, and other airless bodies in the Solar System. He often advises on various aspects of the lunar environment and the implications for science and exploration activities on the Moon. Dr Stubbs is a Participating Scientist on the Lunar Reconnaissance Orbiter (LRO) mission, and is affiliated with the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument team. He is also a member of

the NASA Lunar Science Institute's Dynamic Response of the Environment At the Moon (DREAM) team.

Dr. Aleksandre Taktakishvili is currently Associate Research Scientist in the University of Maryland, Baltimore County, Goddard Earth Sciences and Technology Center operated at NASA Goddard Space Flight Center. Dr. A. Taktakishvili received his PhD in theoretical physics from the Institute of Space Research, Moscow, Russia, in 1984 and his Doctor of Sciences Degree in 2001 in Abastumani Observatory (Georgia, former USSR). He worked in Abastumani Observatory for a number of years and then in Space Research Institute. In 2005 he joined the Community Coordinated Modeling Center at Space Weather Laboratory of NASA/GSFC to carry out his research in space weather modeling. Dr. Taktakishvili has been working on space weather models available at the CCMC and most recently on solar and heliosphere models. Dr. Taktakishvili's dissertations and research involved studies of the charged particle dynamics in Earth's magnetosphere, solar-terrestrial interactions and physics of space plasma. Dr. Taktakishvili has participated in numerous space weather-related projects. He worked in close collaboration with observers and model developers. He is the main or co-author of more than 40 peer-reviewed scientific articles.

Dr. Qian Tan received a Ph.D. in Atmospheric Chemistry (2004) from the Georgia Institute of Technology, Atlanta, Georgia, and a BS in Atmospheric Dynamics (1996) from the Nanjing University of Nanjing, China. In graduate school, she used a coupled regional climate-chemistry model to study the budget and fate of anthropogenic pollutants in East Asia. She worked as a Postdoctoral Research Associate at Department of Earth, Atmospheric, and Planetary Science at MIT where she expanded her work to global scale and focused on an important greenhouse gas, methane. In 2007 she joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. Her main research interest is to combine her experience in both global and regional scale modeling and study the impacts of long range transport on fate of pollutants and regional air qualities.

Dr. Zhining Tao attained his BS and MS degrees in Environmental Chemistry from Nanjing University and Nankai University, respectively. After one and half years' tenure with a provincial EPA in China, he moved to the U.S. and obtained his Ph.D. in Environmental Science from the University of Illinois at Urbana-Champaign (UIUC) in 2003. Prior to joining GEST of UMBC in 2009, Dr. Tao has worked at the Illinois State Water Survey of UIUC for over 5 years, first as an assistant professional scientist and then as an atmospheric scientist. There he led and co-led multiple projects funded by USEPA and USDOE among the ones sponsored by states of Illinois and Minnesota. His major takings included air pollutant emissions measurement and modeling, regional modeling of air quality and its feedback from climate change, modeling of invasive species, and atmospheric modeling support for geological carbon sequestration. At GEST, Dr. Tao will continue his research in atmospheric chemistry and regional modeling.

Dr. Inge Loes ten Kate obtained her MS in aerospace engineering from Delft University of Technology, in the Netherlands, in 1999, where she graduated with a thesis on the design of an aerocapture manoeuvre around Mars. During her studies she did an internship at Arianespace working on Ariane 4 and 5 flight data analysis. After her graduation she worked at the National Aerospace Laboratory NLR, the Netherlands, on signal validation of GalileoSat, the European satellite navigation system. A change in working area led to her PhD in 2006 in Astronomy / Planetary Sciences, with a thesis entitled "Organics on Mars – Laboratory studies of organic material under simulated martian conditions". Since September 2006 she works for GEST at Goddard Space Flight Center.

Dr. Lin Tian received a Ph.D in atmospheric science from the University of Chicago in 1995 where her major research interest was radar meteorology and cloud microphysics. In 1997 she joined University

Space Research Association and worked at NASA Goddard Space Flight Center. In October 2000, she joined the Goddard Earth Science and Technology Center. In the past three years, she conducted research in the areas related to the remote measurement of precipitation and understanding of storm structures and microphysical characteristics of precipitation using observations from the ER-2 airborne Doppler radar. She has analyzed EDOP Doppler radar data in support of TRMM to improve rainfall rate estimate. She also studied microphysics of storms such as raindrop size distribution and melting ice particles using EDOP and ground based polarimetric radar data. Other than her scientific research, she has gained tremendous experience in EDOP data collection, processing and software developing. She participated three TRMM field campaigns and CRYSTAL-FACE experiment, and processed all EDOP and CRS data for archiving and distribution.

Dr. Stephen Ungar: Although originally trained as an astrophysicist, Dr. Ungar has gained considerable experience in remote sensing of the earth's surface throughout his career. He was Director of the Earth Resources Program at NASA's Goddard Institute for Space Studies (GISS) from the program's inception in 1971 until its components were transferred to GSFC in 1982 as part of the refocusing of the GISS mission to Climate Research. During his tenure at GISS, he participated in the Large Area Crop Inventory Experiment (LACIE) and the AgRISTARS project. He was a member of the working group that helped define the spectral, spatial and radiometric characteristics for the first Landsat Thematic Mapper (TM) sensor. In subsequent years, Dr. Ungar has been heavily involved in major NASA remote sensing field programs, including the First ISLSCP Field Experiment (FIFE) and the Boreal Ecosystem-Atmosphere Study (BOREAS). He was selected as one of nine American PIs to participate in the Soviet-sponsored FIFE follow-on experiment (KUREX) conducted at the Kursk Biospheric Sciences Preserve in the former Soviet Union. He has participated on both the MODIS Characterization Support Team (MCST) and the MODIS Science Data Support Team (SDST). Dr. Ungar served as the Earth-Observing 1 (EO-1) Mission Scientist from the mission’s inception in 1996 until his retirement from NASA in April 2008. He also served as the Project Scientist for NASA’s Morning Constellation, consisting of the Landsat-7, EO-1, SAC-C, and Terra satellites flying in formation. He participates in many international venues and served as Chair of the Committee on Earth Observing Satellites (CEOS) Working Group on Calibration and Validation (WGCV). He was an official delegate to the 2007 GEO Earth Summit in Cape Town, South Africa, and he currently serves as Task Leader for the GEO Task on Data Quality Assurance across the 9 GEO Societal Benefit Areas. Dr. Ungar received the NASA Medal for Exceptional Achievement on December 4, 2002 in recognition of his role in advocating and maintaining high scientific standards resulting in data far surpassing the expectations of the user community for the EO-1 technology demonstration mission.

Dr. Yury Vikhliaev received his masters degree in applied math and physics from the Moscow Institute of Physics and Technology in 1996, with specialization in geophysical fluid dynamics and oceanography. From 1996 to 1999 he was a research assistant in the Geological Institution of Russian Academy of Science, where he worked on reconstruction of history of sedimentary basins and participated in creation of geo-information database of tectonic maps of the Pre-Kaspian Sedimentary Basin. From 1997 to 1999 he was employed at SOVGEOINFO as an operational technician and participated in creation of geo-information database of topographic maps of Russia. He received his Ph.D. degree in Climate Dynamics from George Mason University, Fairfax Virginia, USA in January 2006. His Ph.D. research was focused on understanding the decadal climate variability in the Pacific Basin and analysis of low frequency dynamical modes in numerical climate models using the breeding technique. Upon graduation, Dr. Vikhliaev received a position of research scientist at the Center for Ocean-Land-Atmosphere Studies, Calverton, Virginia. His work was focused on understanding climate noise and climate predictability using coupled general circulation model simulations. Dr. Vikhliaev joined the GEST/GMAO in November 2006 to work on a new coupled general circulation model that will is used for climate studies, data assimilation and climate forecasts.

Dr. Hailan Wang received her M.S. (1997) and Ph.D. (2000) in Atmospheric Sciences from the University of Illinois at Urbana-Champaign, Urbana, IL, and a B.S. (1994) in Marine Meteorology from the Ocean University of China, China. Her Ph.D. thesis is on understanding the maintenance mechanism of climatological stationary waves in NCEP/NCAR Reanalysis and the GFDL AGCM simulations. She then spent two years at the GFDL and Princeton University as a postdoctoral visiting scientist during 2000-2002. Dr. Wang joined the Goddard Earth Sciences and Technology Center at the University of Maryland at Baltimore County in December 2002. Her main research interest is on climate variability and predictability on timescales ranging from seasonal to long-term trends.

Dr. Jian-Jian Wang received his Ph.D. degree in Meteorology from the University of Hawaii in 1995. He also holds a M.S. degree in Meteorology (1990) and a B.S. degree in Meteorology (1987) from Peking University, China. Dr. Wang specializes in tropical meteorology, satellite and radar meteorology. His research and publications have focused on the structure and evolution of mesoscale precipitation systems and the interaction between the systems with different scales in the tropics. During the last ten years, he has worked extensively with a broad spectrum of instrumentation including conventional and dual-Doppler radars, TRMM satellite, as well as aircraft and sounding data. His observational studies have focused on the syntheses of physical processes revealed by different data sources from mesoscale field experiments (e.g. Hawaiian Rainband Project, SCSMEX). Dr. Wang joined JCET at the University of Maryland Baltimore County in 1999 as an Assistant Research Scientist. He became an Associate Research Scientist in GEST/UMBC in 2005. Between 1997 and 1999, he was a postdoctoral Research Associate with the University of Illinois and NCAR; during that period, his research led to a better understanding of the thermal and dynamic effects of local topography on large-scale airflow. In 1995, Dr. Wang's proposal was awarded by UCAR for a two-year postdoctoral fellowship working on NCEP's regional spectral model (RSM) to improve numerical forecasts in the Pacific Region. He was also a Research Assistant at the University of Hawaii (1990-1995) and Peking University (1987-1990).

Dr. Yongli Wang graduated from University of California, Los Angeles in August 2003 with his Ph.D. degree in Planetary and Space Physics. During his graduate study, under the direction of Professor Christopher T. Russell and Dr. Joachim Raeder, Dr. Wang made an extensive study in interplanetary shocks, Io mass loading, magnetosphere-ionosphere coupling, magnetotail dynamics, geomagnetic substorms, and global magnetohydrodynamic (MHD) simulations. In his thesis, the Plasma Depletion Layer (PDL), he used multi-spacecraft observations and global MHD simulations and made a systematic study of PDL mechanism, dynamics, and dependence on various solar wind conditions. After his graduation, he joined Space Science and Applications group at Los Alamos National Laboratory as a Postdoc Research Associate in September 2003, where he worked with Dr. Richard C. Elphic and Dr. Joachim Birn on large-scale multi-spacecraft statistics of Flux Transfer Events (FTEs) using Cluster observations and magnetotail bubble dynamics using Birn magnetotail model. Dr. Wang joined SP Systems, Inc. in January 2006 as a Senior Scientist and was stationed at NASA/GSFC working with Dr. Guan Le and Dr. James A. Slavin on Space Technology 5 (ST-5) spacecraft data calibration, as well as Field-Aligned Current (FAC) and Flux Transfer Event (FTE) statistics. In November 2006, Dr. Wang joined UMBC/GEST as an assistant research scientist to continue his ongoing work and new investigations using NASA THEMIS mission data and space weather simulations. Dr. Wang's research interest and expertise include: solar-terrestrial relationships, plasmas physics in space, solar wind-magnetosphere-ionosphere-thermosphere coupling, large-scale modeling of magnetosphere, magnetosheath and magnetopause physics, FTEs, FACs, magnetotail dynamics, interplanetary shocks, Io Mass loading in Jupiter's magnetosphere, computational fluid dynamics, numerical methods and advanced simulation techniques (including adaptive mesh refinements), high performance computing, and multiple satellite observational study. Dr. Wang has authored and co-authored 32 scientific papers in peer-reviewed journals and has made 75 presentations in national and international scientific meetings. He has served as a reviewer for Advances in Space Research, Annales Geophysicae, Geophysical Research Letters, Journal of Atmosphere and Solar-Terrestrial Physics, and Journal of Geophysical Research. He

has also served as a proposal reviewer for NASA Geospace Sciences Program, NASA Living With a Star Program, NSF Geospace Environment Modeling Program, has been served in the panel of NSF Cyber-Enabled Discovery and Innovation Program.

Dr. Yujie Wang received a BS and an MS in physics from Tsinghua University, Beijing, China in 1994 and 1998 respectively, and Ph.D. in geography from Boston University, Boston, MA in 2002. In July of 2002, Dr. Wang joined GEST center of UMBC. During his Ph.D. study, Dr. Wang's research was mostly focused on the prototyping and validation of radiative transfer based EOS MODIS LAI/FPAR algorithm. Since 2004, he has been developing the AERONET-based surface reflectance validation network (ASRVN) designed for global validation of land surface reflectance products from space-borne instruments and sensor calibration support. At present, he is developing a new generic aerosol retrieval and atmospheric correction algorithm, MAIAC, for the EOS MISR, MODIS and future NPOESS VIIRS instrument.

Dr. Clark Weaver's first scientific initiation was at Ohio State University at the Byrd Polar Research Institute. His Masters Thesis topic was the fractionation of isotopic oxygen in snow over Antarctica. He received his Ph.D. in Atmospheric Science from Colorado State University in 1987. His dissertation was on the mechanism for marine stratocumulus break up. Next, he joined the research group at the Graduate School of Oceanography at University of Rhode Island and studied the transport of mineral dust to ocean drilling sites using paleoclimate models. He joined the Atmospheric Chemistry and Dynamics Branch at NASA Goddard in 1991 and has worked there ever since. His current interests include: stratospheric transport, data assimilation and remote sensing.

Mr. Scott Weissinger joined GEST as an Assistant Research Scholar on September 14, 2009. He received his B.A. in Film from Cornell University in 2003 and his M.F.A. in Science and Natural History Filmmaking from Montana State University in 2009. While at MSU, he received a fellowship from the Montana Space Grant Consortium and produced videos in collaboration with the MSU Solar Physics group. At Goddard, Scott is the Heliophysics and Astrophysics video producer, working with missions such as SDO, Fermi, and Swift.

Mr. Ernie Wright has been using computer graphics to visualize scientific data for two decades. His early work included isosurface cloud visualization for the Defense Nuclear Agency Weapon Effects Directorate and terrain visualization for the Central Intelligence Agency Office of Imagery Analysis. More recently, he was a LightWave 3D senior programmer, leading LightWave's third-party developer community as the host of its Internet mailing list and the author of the LightWave Server Development Kit. His interests include amateur astronomy and the history and philosophy of science; a short paper about his open-source software for visualizing the star catalog in Ptolemy's Almagest appeared in the May 2007 *Journal for the History of Astronomy*. He has a B.S. in computer and information science with a minor in communication from University of Maryland University College. He currently works as a programmer/animator in Goddard's Scientific Visualization Studio.

Dr. Kai Yang received a B.S. in physics from Sun Yat-Sen University (China) in 1984 and a Ph.D. in physics from Kansas State University in 1991. Dr. Yang has extensive experience in satellite remote sensing, covering data analysis, science algorithm development, and its operational implementation for multi-spectral (MODIS, TOMS) and hyper-spectral (OMI, GOME, AIRS) instruments. In 1994 Dr. Yang came to NASA Goddard Space Flight Center and performed radiative transfer modeling for MODIS science algorithm development and developed the MODIS level 2 gridded products. In 2001 Dr. Yang joined the OMI science support team, developed and implemented the current operational OMI total ozone and sulfur dioxide (SO_2) retrieval algorithms for NASA and their automatic quality assessment (QA) schemes. Dr. Yang developed an advanced combo algorithm, named the iterative spectral fitting (ISF) technique, for simultaneous retrieval for ozone and SO_2 from backscattered ultraviolet (BUV)

measurements and introduced an alternative UV aerosol index for enhanced aerosol detection. Recently Dr. Yang discovered that the altitude of an absorber plume can be directly determined from hyper-spectral BUV radiance, and demonstrated this finding for the first time by extending the ISF technique to estimate the height of a volcanic SO_2 plume. His primarily research interests are remote sensing of trace gases and aerosols, and the study of their effects on atmospheric chemistry and climate.

Dr. Weidong Yang received his Ph.D in physics from Michigan Technological University in 2004. He received his BS and MS in physics majoring in optics and laser physics in 1988 and 1991, respectively. His research work has been in optical sensing and signal processing focused on the development of novel techniques and physics in atmospheric sciences, astrophysics/astronomy and remote sensing. Prior to joining UMBC/GEST as an assistant research scientist, he worked as postdoctoral researcher in Physics department and Electrical & Computer Engineering department of Michigan Technological University.

Dr. Yuekui Yang received his Ph.D. from the Unversity of Illinois at Urbana-Champaign in Atmospheric Sciences in 2007 and a MS (1990) and BS (1987) in Atmospheric Sciences from the Science and Engineering University of the Army, China. His research involves the application of the solar background from spaceborne lidar instruments, the effect of atmosphere multi-scattering on lidar altimetry, satellite cloud detection, cloud structure and its impact on climate modeling etc. Dr. Yang has extensive experience in working with spaceborne and airborne remote sensing instruments, including GLAS, MISR, CALIOP, MODIS, ASTER, AVHRR, GMS, GOES, MAS, and MASTER. During his stay at University of Illinois, he was responsible for the development, implementation and validation of the Radiometric Camera-by-camera Cloud Mask over land for the MISR mission. He also studied the impacts of 3-D radiative effects on satellite cloud detection and their consequences on cloud fraction and aerosol optical depth retrieval. Dr. Yang had 10 years of pre-doctoral working experience, holding positions from a researcher in atmospheric sciences, a meteorological radar software engineer, to a software project manager. Dr. Yang joined GEST in March 2007.

Dr. Teppei Yasunari received his Ph.D. from Hokkaido University, Japan, in Earth System Science in 2008, his M.S. from Hokkaido University, Japan, in Geoscience in 2005, and his B.S. from Hirosaki University, Japan in 2003 in Earth Science. He has been carrying out dust particle analysis in Alaskan ice cores, model simulation and meteorological data analyses for Asian dust, and stratospheric material transports from Asia to Alaska (related to the stratosphere-to-troposphere transport, STE), field observations for ice core drilling, snow pit works, and meteorological and aerosol measurements in his PhD study. He mainly works with Dr. William K-M Lau, Dr. Randal Koster, Dr. Yogesh Sud, Dr. Kyu-Myong Kim, Dr. Mian Chin, and Dr. Qian Tan at NASA/GSFC. His work here is to estimate how much dust and black carbon impact on Himalayan glacier meltings by using snow-albedo feedback model, satellite data, and field observation data.

Dr. Hongbin Yu received his Ph.D. in Atmospheric Chemistry (2000) from the Georgia Institute of Technology, Atlanta, GA, and a MS (1992) and a BS (1989) both in Atmospheric Physics from the Nanjing University in China. He was the faculty member at the Department of Atmospheric Sciences of the Nanjing University from 1992 to 1996, where he taught and conducted research on air pollution and atmospheric boundary layer. Dr. Yu worked at Georgia Tech as a postdoctoral fellow from August 2000 through December 2002, and as a research scientist from January 2003 to October 2004. Dr. Yu then joined Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County. His current research task is to assess the measurement-based estimates of the aerosol climate forcing and aerosol intercontinental transport. Dr. Yu's publications cover topics of global aerosol assimilation and direct radiative forcing, intercontinental transport of aerosol, aerosol-cloud interactions, impacts of aerosols on ecosystems, land-atmosphere interactions, and atmospheric dynamics, tropospheric ozone and nitrogen chemistry, and air pollution and boundary layer meteorology.

Dr. Boris Yurchak received a M.S. in Electronics, from Kharkov Institute of Radioelectronics, USSR in 1969, and a Ph.D. in geophysics (physics and mathematics) in 1980 from the Institute of Experimental Meteorology, Goskomhidromet (USSR Weather Service), Obninsk. His major research interest was radar methodology applications to cloud and precipitation measurements and atmospheric diffusion. From 1969 to 1996, Dr.Yurchak served as a research scientist, senior research scientist at the Institute of Experimental Meteorology, developing radar methodology for atmospheric research. In period from 1988 to 1992 he served as a co-director of the Joint Soviet-Vietnamese Center on Tropical Meteorology in Hanoi, Vietnam. From 1996 to 2001 he served as a senior research scientist and branch head at the Russia Federal Environmental Emergency Response Center, Obninsk, Russia, where he developed remote system for detecting clouds of chemical and radioactive pollutants at emergency situation. Also he used remote sensing capabilities for study of environment contamination. In July 2002 Dr. Yurchak joined Caelum Research Corporation and started working on the NASA's Earth Science & Public Health Program. In June 2003 he joined UMBC where continued working on the program. Since 2006 he is working on the NASA's Cryospheric Sciences Program. Dr. Yurchak has been with GEST since July 2002. His current research interests include remote sensing applications for cold regions and radar backscatter from spatially extended geophysical targets.

Dr. Xiping Zeng received his B.S. and M.S. degrees in atmospheric physics from Nanjing Institute of Meteorology. He then taught courses and conducted research of clouds in this institute from 1987 to 1995. From 1995 he began his Ph.D. studies in Physics Department of New Mexico Tech with his focus on the ensemble simulation of tropical convection and its interaction with large-scale vertical circulation. After receiving his degree, he continued his work as Postdoc Research Physicist there for a while, and then he joined GEST center as Research Associate. Now Dr. Zeng is cooperating with the scientists in GSFC and universities, evaluating precipitation and clouds in long-term cloud-resolving model simulations with observational data.

Dr. Qingyuan Zhang received a Ph.D. in Natural Resource and Environmental Study (2006) from the University of New Hampshire (UNH), Durham, NH, a MS in Applied Mathematics (1996) from TsingHua University, and a BS in Mathematics (1994) from the ShanDong University, China. His Ph.D. thesis is on estimation of fraction of absorbed PAR by chlorophyll using daily MODIS data and the development of a vegetation photosynthesis model. In 2006 he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a Goddard Visiting Fellow. His main research interests are carbon cycle modeling, estimation of fAPAR by chlorophyll ($FAPAR_{chl}$), phenology, light use efficiency at chlorophyll level (LUE_{chl}) and the seasonal-to-interannual variation of the canopy. His goal is to support NASA's EO-1 mission, NASA's HyspIRI mission, Light Use Effiency (LUE), Carbon Cycle Projects and Water/Energy Cycle Projects. His publications include papers on estimation of $fAPAR_{chl}$, LUE_{chl}, phenology, and on vegetation photosynthesis model and land use.

Dr. Yan Zhang received a Ph.D. in Atmospheric Sciences from Georgia Institute of Technology in 2008 and a BS in Atmospheric Sciences from the Nanjing Institute of Meteorology in 1998. Her Ph.D. thesis studied impact of biomass burning aerosol on land-atmosphere interactions and monsoon circulation over Amazonia. Dr. Zhang joined GEST in September 2009 after working at Jackson of geosciences in University of Texas Austin as a postdoctoral researcher for one year. In Austin she used CoudSat, AIRS, and MLS data to investigate water and pollution transport over the tropics. Dr. Zhang's research interests include using both regional climate model and satellite data to study aerosol impacts on energy and hydrology cycles.

Dr. Zhibo Zhang received a Ph.D. in Atmospheric Sciences (2008) and a MS (2004) from the Texas A&M University and a BS in Meteorology (1998) from the Nanjing University, China. His Ph.D. thesis is on the satellite-based remote sensing of ice clouds. In January 2009, he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, where he works with

the MODIS cloud science team leaded by Dr. Steven Platnick on the development of infrared cloud property retrieval algorithm.

Dr. Yaping Zhou received a Ph.D. in Physical Oceanography and a M.S. in Computer Science from Stony Brook University in 1999. After graduation, she worked at NASA Langley Research Center and National Environment Prediction Center for brief periods before she came to Goddard. In 2004, she joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. Dr. Zhou has worked on various research topics from radiative transfer modeling to onboard data compression and climate diagnostics. Her current interests include using long-term satellite observations of cloud and precipitation for detecting trends in tropical hydrological cycles and changes in precipitation characteristics. She also uses short-term high-resolution TRMM data for evaluating global and cloud resolving model performance.

Dr. Jerry Ziemke came to NASA Goddard in 1994 as an NRC research fellow specializing in atmospheric composition and dynamics. He received a Ph.D. in Physics (1990) from Iowa State University, an M.A. in Mathematics (1986) from Minnesota State University, an M.S. in Physics from the University of Minnesota Minneapolis (1984), and a B.S. in Physics and Mathematics (1981) from Minnesota State University. He has more than 50 refereed publications with about half of them as first author. Since coming to Goddard he has collaborated with scientists both at Goddard and elsewhere on a large range of topics, but primarily relating to studies on atmospheric ozone. Since 1996 his main focus has been satellite retrieval of tropospheric ozone, and since 2005 he has been the Principal Investigator on the American OMI Science Team for the retrieval of tropospheric ozone. Dr. Ziemke became an associate research scientist within UMBC GEST in March 2002.

Dr. Viktor Zubko received a Ph.D. in Physics (1984) from the Ukrainian National Academy of Sciences, Kyiv, Ukraine, and a M.S. in Astrophysics (1979) from Taras Shevchenko State University, Kyiv, Ukraine. His Ph.D. thesis is on the theoretical modeling of solid and liquid carbon particles in the atmospheres of late-type stars. He worked for 10 years at the Main Astronomical Observatory of the Ukrainian Academy of Sciences, Kyiv, Ukraine as a research scientist on modeling physical and chemical properties of circumstellar and interstellar dust particles. From 1994 to 1997, he worked at the Nicolas Copernicus University, Toruń, Poland as a research scientist on solving inverse problems in modeling interstellar extinction. From 1997 to 1999, he was a Visiting Scientist at the Department of Physics, Technion–Israel Institute of Technology, Haifa, Israel, where he developed his PRT code and used it for modeling cosmic dust. From 2000 to 2001, he was a Research Scholar with the Department of Physics and Astronomy, University of Kentucky, Lexington, where he modeled dust and water line emission from circumstellar shells of late-type stars. From 2001 to 2004, he was a Research Scientist at the NASA Goddard Space Flight Center (GSFC), Greenbelt, Maryland, and worked on modeling of cosmic dust and atmospheric aerosols. From 2004 to 2006, he worked as a Senior Scientific Analyst at Nortel Government Solutions, Inc., Lanham, Maryland, where he developed science algorithms and software for data processing of hyperspectral imaging satellite observations. From 2006 to 2009, he worked as a Principal Support Scientist at Wyle Information Systems Group/Goddard Earth Sciences Data and Information Services Center, NASA GSFC, Greenbelt, Maryland, where he was responsible for development of algorithms and software for data fusion of various geophysical parameters. In 2009 he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. His research interests include theory and modeling of atmospheric aerosols and cosmic dust, polarized radiative transfer in atmospheric and space systems, light scattering by small particles, remote sensing of aerosols, numerical inversion techniques for ill-posed problems, principal component analysis, and scientific programming His publications include papers on theory and modeling of cosmic dust grains and atmospheric aerosols.

Faculty and Staff

Faculty	Title
Abuhassan, Nader	Associate Research Engineer
Anyamba, Assaf	Associate Research Scientist
Arsenault, Kristi	Research Associate
Beck, Jefferson	Research Associate
Bell, Benita	Visiting Assistant Research Scientist
Benna, Mehdi	Assistant Research Scientist
Benson, Craig	Research Associate
Berkoff, Tim	Assistant Research Engineer
Bian, Huisheng	Assistant Research Scientist
Bindschadler, Robert	Senior Research Scientist
Boardsen, Scott	Associate Research Scientist
Burger, Matthew	Associate Research Scientist
Celarier, Ed	Associate Research Scientist
Chandra, Sushil	Senior Research Scientist
Chang, Yehui	Associate Research Scientist
Chern, Jiun Dar	Associate Research Scientist
Chu, D. Allen	Associate Research Scientist
Colarco, Amelia	Research Associate
Cook, Laurie	Instructional Designer
Curran, Robert	Senior Research Scientist
de Matthaeis, Paolo	Research Associate
Delaney, Marcianna	Assistant Research Scientist
Diehl, Thomas	Assistant Research Scientist
Dinnat, Emmanuel	Assistant Research Scientist

Faculty	Title
Eck, Thomas	Assistant Research Scientist
Errico, Ronald	Senior Research Scientist
Fitzgibbons, Ryan	Research Associate
Follette-Cook, Melanie	Assistant Research Scientist
Gassó, Santiago	Assistant Research Scientist
Gatebe, Charles	Associate Research Scientist
Gautam, Ritesh	Research Associate
Georgieva, Elena	Associate Research Scientist
Grecu, Mircea	Assistant Research Scientist
Guenther, Bruce	Senior Research Scientist
Han, Mei	Research Associate
Han, Shin-Chan	Assistant Research Scientist
Harris, Brooke	Assistant Research Scholar
Hoban, Susan	Senior Research Scientist
Hoffman, Matthew	Research Associate
Huang, Jingfeng	Assistant Research Scientist
Hwang, Kyoung-Joo	Assistant Research Scientist
Imber, Suzanne	Research Associate
Jacob, S. Daniel	Assistant Research Scientist
Jeong, Myeong-Jae	Assistant Research Scientist
Jusem, Juan Carlos	Visiting Senior Research Scientist
Kim, Hyokyung	Visiting Assistant Research Scientist
Kim, Kyu-Myong	Associate Research Scientist
Klimas, Alexander	Senior Research Scientist
Koratkar, Anuradha	Associate Research Scientist (Leave of Absence)

Faculty	Title
Korkin, Sergey	Research Associate
Kostis, Helen-Nicole	Research Associate
Koval, Andriy	Assistant Research Scientist
Kowalewski, Matthew	Assistant Research Engineer
Krotkov, Nickolay	Senior Research Scientist
Kuo, Kwo-Sen	Scientist, Caelum Research Corporation
Kurylo, Michael	Senior Research Scientist
Kuzmicz-Cieslak, Magda	Faculty Research Associate
Lait, Leslie Robert	Senior Research Scientist
Laughlin, Daniel	Assistant Research Scientist
Lawford, Richard	Senior Research Scientist
Lee, Choon-Ki	Visiting Research Associate
Li, Feng	Assistant Research Scientist
Li, Xiaowen	Assistant Research Scientist
Liang, Qing	Assistant Research Scientist
Liao, Liang	Associate Research Scientist
Lin, Xin	Associate Research Scientist
Lipatov, Alexander	Senior Research Scientist
Lyapustin, Alexei	Assistant Research Scientist
Mahanama, Sarith	Assistant Research Scientist
Mao, Jianping	Associate Research Scientist
Matsui, Toshihisa	Assistant Research Scientist
McCarty, Will	Assistant Research Scientist
Merka, Jan	Associate Research Scientist
Mohammed, Priscilla	Research Associate

Faculty	Title
Molnar, Gyula	Assistant Research Scientist
Molod, Andrea	Associate Research Scientist
Norris, Peter	Assistant Research Scientist
Olsen, Mark	Assistant Research Scientist
Ott, Lesley	Research Scientist
Pan, Xiaohua	Research Associate
Parnell, Lynn	Senior Research Scientist
Pavlis, Erricos	Research Associate Scientist
Peng, Jinzheng	Research Associate
Pulkkinen, Antti	Assistant Research Scientist
Randles, Cynthia	Research Associate
Reale, Oreste	Associate Research Scientist
Retscher, Christian	Assistant Research Scientist
Riishojgaard, Lars-Peter	Senior Research Scientist, Director JCSDA
Samsonov, Andrey	Assistant Research Scientist
Sarantos, Menelaos	Assistant Research Scientist
Schiffer, Robert	Senior Research Scientist
Selkirk, Henry	Associate Research Scientist
Sexton, Joseph	Research Associate
Shi, Roger	Associate Research Scientist
Shie, Chung-Lin	Associate Research Scientist
Shim, Ja Soon	Visiting Research Associate
Shoemaker, Jennifer	Earth Science Video Producer
Shuman, Christopher	Associate Research Scientist
Singh, Kumar	Associate Research Scientist

Faculty	Title
Soebiyanto, Radina	Research Associate
Song, In-Sun	Assistant Research Scientist
Stalport, Fabien	Research Associate
Stoyanova, Silvia	Faculty Research Assistant
Strahan, Susan	Senior Research Scientist
Stroud, David	Assistant Research Scientist
Stubbs, Timothy	Assistant Research Scientist
Studinger, Michael	Associate Research Scientist
Sun, DeZheng	GVF – Associate Research Scientist
Taktakishvili, Aleksandre	Associate Research Scientist
Tan, Qian	Assistant Research Scientist
Tao, Zhining	Associate Research Scientist
ten Kate, Inge	Visiting Assistant Research Scientist
Tian, Lin	Associate Research Scientist
Toure, Ally	Visiting Research Associate
Ungar, Steven	Senior Research Scientist
Unninayar, Sushel	Senior Research Scientist
van Oevelen, Peter	Associate Research Scientist, GEWEX Director
Veselovskii, Igor	Associate Research Scientist
Vikhliaev, Yuri	Research Associate
Wang, Chien	Goddard Visiting Fellow
Wang, Hailan	Assistant Research Scientist
Wang, Jian-Jian	Assistant Research Scientist
Wang, Yongli	Assistant Research Scientist
Wang, Yujie	Assistant Research Scientist

Faculty	Title
Weaver, Clark	Associate Research Scientist
Wen, Guoyong	Assistant Research Scientist
Wiessinger, Scott	Assistant Research Scholar
Williams, Michelle	Media Specialist
Yang, Kai	Assistant Research Scientist
Yang, Weidong	Assistant Research Scientist
Yang, Yuekui	Research Associate
Yasunari, Teppei	Visiting Research Associate
Yokoyama, Tatsuhiro	Visiting Assistant Research Scientist
Yu, Hongbin	Associate Research Scientist
Yurchak, Boris	Senior Research Scientist
Zeng, Xiping	Assistant Research Scientist
Zhang, Qingyuan	Research Associate
Zhang, Yan	Research Associate
Zhang, Zhibo	Research Associate
Zhao, Yunhe	Scientist, Caelum Research Corporation
Zhou, Yaping	Assistant Research Scientist
Ziemke, Jerry	Associate Research Scientist
Zubko, Viktor	Associate Research Scientist

Associate Staff	Title
Belvedere, Deborah	Water & Energy Cycle Focus Area Liaison
Franz, Heather	Research Analyst
Garner, Robert	Media Specialist
Lewis, Katherine	Media Specialist

Faculty	Title
Martin, Adam	Media Specialist
Motel, Laura	Media Specialist
Narock, Thomas	Research Analyst
Kucsera, Tom	Research Analyst
Schindler, Trent	Media Specialist
Steenrod, Stephen	Research Analyst
Wright, Ernie	Media Specialist

Administrative Staff	Title
Casasanto, Valerie	Program Coordinator
Dawson, Mary	Business Specialist
Eichenlaub, Danita	Acting Director
Hoff, Raymond	Executive Director
Houghton, Amy	Communications Specialist
Hyman, Camilla	Accountant I
Manalansan, Cathy	Administrative Assistant II
Nguyen, Katie	Business Specialist
Stivers, Derek	Business Specialist
Von Gunten, Nina	Administrative Assistant I
Young, Margo	Business Specialist

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Acronyms and Abbreviations

Acronym/Abbreviation	Expansion/Definition
ACAM	Airborne Compact Atmospheric Mapper
ACE	Aerosol-Cloud-Ecosystem
AER	Atmospheric and Environmental Research, Inc.
AEROCOM	Aerosol Model Intercomparison
AERONET	Aerosol Robotic Network
AFES	Atmospheric General Circulation Model for the Earth Simulator
AFWA	Air Force Weather Agency
AGCM	Atmospheric General Circulation Model
AGRMET	Agricultural Meteorological Model
AGU	American Geophysical Union
AHE	Aerosol Humidification Effect
AI	Aerosol Index
AIE	Aerosol Indirect Effect
AIM	Aeronomy of Ice in the Mesosphere
AIRS	Atmospheric Infrared Sounder
AITT	Airborne Instrument Technology Transition
AMIP	Atmospheric Model Inter-comparison Project
AMMA	African Monsoon Multidisciplinary Analysis Project
AMO	Atlantic Multi-decadal Oscillation
AMS	American Meteorological Society
AMSR-E	Advanced Microwave Scanning Radiometer for the Earth Observing System
AMSU	Atmospheric Microwave Sounding Unit
AOD	Aerosol Optical Depth
AOGS	Asia Oceania Geosciences Society
AOP	Apparent Optical Properties
AOS	Atmospheric and Oceanic Sciences Program
AOT	Aerosol Optical Thickness
API	Application Programming Interface
AQRS	Air Quality Research Subcommittee
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
ARM	Atmospheric Radiation Measurements
ARMS	Army Remote Moisture System
ARS	Agricultural Research Service
ASCAT	Advanced Scatterometer
ASD	Airborne Saharan Dust
A-SRVN	AERONET-based Surface Reflectance Validation Network
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTEX	Atlantic Stratocumulus Transition Experiment
ATM	Airborne Topographic Mapper
AURA	NASA EOS satellite on polar sun synchronous afternoon orbit
AVDC	Aura Validation Data Center
AVHRR	Advanced Very High Resolution Radiometer
AVP	Aerial Vehicles Program
AWD	African Wave Disturbance
AWOS	Automated Weather Observation Stations

Acronym/Abbreviation	Expansion/Definition
AWS	Automatic Weather Stations
BDC	Brewer-Dobson Circulation
BRD	Bidirectional Reflectance Distribution Function
BRF	Bidirectional Reflectance Factors
BSRN	Baseline Surface Radiation Network
BUV	Backscattered ultraviolet
C3VP	Canadian CloudSat/CALIPSO Validation Project
CACGP	Commission on Atmospheric Chemistry and Global Pollution
CALIOP	Cloud and Aerosol LIdar with Orthogonal Polarization (CALIPSO lidar)
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAPS	Cassini Plasma Spectrometer
CAR	Cloud Absorption Radiometer
CARE	Centre for Atmospheric Research Experiments
CARMA	University of Colorado/NASA Community Aerosol and Radiation Model for Atmospheres
CCM	Chemistry-Climate Model
CCMC	Community Coordinated Modeling Center
CCMVal	Chemistry Climate Model Validation
CCRI	U.S. Climate Change Research Initiative
CCSP	U.S. Climate Change Science Program
CCSRNIES	Center for Climate System Research and National Institute for Environmental Studies
CDA	CASSINI Cosmic Dust Analyzer
CENR	Committee on the Environment and Natural Resources
CEOP	Coordinated Energy and Water Cycle Observations Project
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth's Radiant Energy System
CESDIS	Center for Excellence in Space Data and Information Science
CFAD	Cumulative frequency by altitude diagrams
CGCM	Coupled General Circulation Model
CGMS	WMO Coordination Group for Meteorological Satellites
CIRES	Cooperative Inst. for Research in Environmental Sciences, Univ. of CO
CLAMS	Chesapeake Lighthouse and Aircraft Measurements for Satellites
CLASIC	Cloud and Land Surface Interaction Campaign
CLIVAR	Climate Variability and Predictability
CLM	Community Land Model
CLOLR	Clear-Sky Outgoing Longwave Radiation
CMAQ	Community Multi-scale Air Quality
CMAVE	Center for Medical, Agricultural & Veterinary Entomology
CME	Coronal Mass Ejection
CMORPH	Climate Prediction Center Morphing Technique
CMOS	Canadian Meteorological and Oceanography Society
CMWG	Cloud Modeling Working Group
COAA	Chinese American Oceanic and Atmospheric Association
COARE	Coupled Ocean-Atmosphere Response Experiment
COD	Cloud Optical Depth
Co-I	Co-Investigator
COLA	Center for Ocean-Land-Atmosphere Studies
COMMIT	Chemical, Optical and Microphysical Measurements of In-situ Troposphere

Acronym/Abbreviation	Expansion/Definition
CONAE	Comision Nacional De Actividades Espaciales (Argeninean National Space Agency)
COOP	Cooperative Observer Program
CORA	Colorado Research Associates
COSPAR	Committee on Space Research (International Council for Science)
COSPEC	Correlation Spectrometer
COVE	CERES Ocean Validation Experiment
CPC	Climate Prediction Center
CPES	Cloud Parameter Estimation System
CRaTER	Cosmic Ray Telescope for the Effects of Radiation
CRAVE	Costa Rica Aura Validation Experiment
CRM	Cloud Resolving Model
CRS	Cloud Radar System
CRTM	Community Radiative Transfer Model
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment
CSU	Colorado State University
CTM	Chemical Transport Model
CW	Continuous Wave
CZL	Coronal and Zodiacal Light
DAAC	Distributed Active Archive Center
DAO	Data Assimilation Office
DAS	Data Assimilation System
DC	Direct Current
DEM	Digital Elevation Model
DISC	Data Information Service Center
DoD	United States Department of Defense
DoE	United States Department of Energy
DORIS	Doppler Orbitography and Radio-positioning Integrated on Satellite
DPR	Dual Frequency Precipitation Radar
DREAM	Dynamic Response of the Environment At the Moon
DRI	Drought Research Initiative
DROPPS	Distribution and Role of Particles in the Polar Summer Mesosphere
DSD	Drop Size Distribution
DU	Dobson Unit
EC	Environment Canada
ECMWF	European Centre for Medium-Range Weather Forecasting
ECU	East Carolina University
EDOP	ER-2 Doppler Radar (ER-2)
EDR	Environmental Data Record
EGU	European Geosciences Union
EHP	Elevated Heat Pump
EL	Equilibrium Line
ENA	Energetic Neutral Atoms
ENCAM	Enceladus' Atmospheric Model
ENCAM-3D	Enceladus' Atmosphere Model (3D version)
EnKF	Ensemble Kalman Filter
ENSO	El Niño Southern Oscillation
ENVISAT	ESA Environmental satellite
EOF	Empirical Orthogonal Functions

Acronym/Abbreviation	Expansion/Definition
EOS	Earth Observing System
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ER	Electron Reflectometer
ERA40	ECMWF 40 Year Re-analysis
ERS-2	ESA Earth Research Satellite (2)
ESA	European Space Agency
ESD	Electrostatic Discharge
ESMF	Earth System Modeling Framework
ESRL	Earth System Research Laboratory
ESSIC	Earth System Science Interdisciplinary Center
ESSP	Earth System Science Partnership
ESTEC	European Space Research and Technology Centre
ET	Evapotranspiration
EUV	Extreme Ultra-Violet
EVDC	Envisat Validation Data Center
FAA	Federal Aviation Administration
FAC	Field-Aligned Current
FAO	United Nations Food and Agriculture Organization
FAS	Foreign Agricultural Service
FAST	Fast Auroral SnapshoT explorer
FEWSNET	Famine Earl Warning Systems Network
FIPS	MESSENGER Fast Imaging plasma Spectrometer
FIRE	First ISCCP Regional Experiment
FL	Firn Line
FOV	Field Of View
FSU	Florida State University
FTE	Flux Transfer Event
FUV	Far Ultraviolet Imager
fvGCM	finite volume General Circulation Model
GARP	Global Atmospheric Research Program.
GCE	Goddard Cumulus Ensemble
GCEP	Global Change Education Program
GCM	Global Climate Model
GCM	General Circulation Model
GEBA	Global Energy Balance Archive
GEIS	Global Emerging Infections Surveillance and Response System
GEM	Geospace Environment Modeling
GEO	Group on Earth Observations
GEOS DAS	Goddard Earth Observing System Data Assimilation System
GEOS	Goddard Earth Observing System
GEOS-3	Goddard Earth Observing System, Version 3
GEOS-4	Goddard Earth Observing System Model, version 4
GEOS-5	Goddard Earth Observing System Model, version 5
GEOS-CCM	Goddard Earth Observing System – Chemistry Climate Model
GEOSS	Global Earth Observation System of System of Systems
GES	NASA's GSFC Earth Sciences
GEST	Goddard Earth Sciences & Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory

Acronym/Abbreviation	Expansion/Definition
GFED	Global Fire Emission Dataset
GHP	GEWEX Hydrometeorology Panel
GIC	Geomagnetically Induced Current
GIMMS	Global Inventory Modeling and Mapping Studies
GISP2	Greenland Ice Core Project 2
GLA	Goddard Laboratory for Atmospheres
GLACE-2	2nd phase of the Global Land-Atmosphere Coupling Experiment
GLAS	Geoscience Laser Altimeter System
GloPac	Global Hawk Pacific Mission
GLS	Global Land Survey
GMAO	Global Modeling and Assimilation Office
GMI	Global Modeling Initiative
GMPP	GEWEX Modeling and Predication Panel
GMS	Geostationary Meteorological Satellite
GMU	George Mason University
GOCART	Goddard Global Ozone Chemistry Aerosol Radiation and Transport
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by the Occultation of Stars
GPCP	Global Precipitation Climatology Project
GPLLJ	Great Plains Low Level Jet
GPM	Global Precipitation Measurement (Mission)
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GrIS	Greenland Ice Sheet
GRP	GEWEX Radiation Panel
GRUMP	Global Rural-Urban Mapping Project
GSFC	Goddard Space Flight Center
GSI	Grid Point Statistical Interpolation
GSSTF	Goddard Satellite-based Surface Turbulent Fluxes
GSSTF2	Goddard Satellite-based Surface Turbulent Fluxes, Version 2
GW	Global Warming
GWP	Gravity Wave Parameterization
GWSP	Global Water System Project
HAP	Hydrologic Applications Project
HIRDLS	High Resolution Dynamic Limb Sounder
HSRL	High Spectral Resolution Lidar
HST	Hubble Space Telescope
I3RC	International 3D Radiation Code
IAHS	International Association of Hydrological Sciences
IAMAS	International Association of Meteorology and Atmospheric Sciences
IASI	Infrared Atmospheric Sounding Interferometer
ICESat	Ice, Cloud, and Land Elevation Satellite
ICESS	Institute for Computational Earth Systems Science
ICSU	International Council of Scientific Unions
IDL	Interactive Data Language
IDS	Interdisciplinary Science in the NASA Earth Science Enterprise
IDS	International DORIS Service
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency

Acronym/Abbreviation	Expansion/Definition
IGAC	International Global Atmospheric Chemistry
IGARSS	International Geoscience and Remote Sensing Symposium
IGBP	International Geosphere-Biosphere Programme
IGOS	Integrated Global Observing Strategy
IGOS-P	Integrated Global Observing Strategy – Partners
IGPO	International GEWEX Project Office
IGWCO	Integrated Global Water Cycle Observations
IIP	NASA's Instrument Incubator Program
iLEAPS	International Land Ecosystem-Atmospheric Processes Study
IMAGE	Imager for Magnetopause - to - Aurora Global Exploration
IMF	interplanetary magnetic field
IMPACT	Integrated Microphysics and Chemistry on Trajectories
IMPROVE	Interagency Monitoring for Protected Visual Environments
INMS	Ions and Neutrals Mass Spectrometer
INR	Interference to Noise Ratio
INSPIRE	Interactive NASA Space Physics Ionospheric Radio Experiments
INTEX	Intercontinental Chemical Transport Experiment
INTEX-B	Intercontinental Transport Experiment B
INTEX-NA	Intercontinental Transport Experiment – North America
IO3C	International Ozone Commission
IOC	International Oceanographic Commission
IOOS DMAC	Integrated Ocean Observing System Data Management and Communications
IPA	Intergovernmental Personnel Act
IPCC	Intergovernmental Panel on Climate Change
IRAD	NASA/GSFC's Internal Research And Development
IRI	International Research Institute for Climate and Society
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climatology Project
ISIS	International Satellites for Ionospheric Studies
ISMWG	International Soil Moisture Working Group
IT	Information Technology
IT	Ionosphere-Thermosphere
ITC	International Institute for Geo-Information and Earth Observations
ITRF	International Terrestrial Reference Frame
JAXA	Japan Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology
JCSDA	Joint Center for Satellite Data Assimilation
JPL	Jet Propulsion Laboratory
JPS	Joint Planning Staff (for WCRP)
JSC	WMO/ICSU/IOC Joint Scientific Committee (for WCRP)
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Dutch Meteorological Institute)
KWAJEX	The Kwajalein Experiment
LADEE	Lunar Atmosphere and Dust Environment Explorer
LADTAG	Lunar Airborne Dust Toxicity Advisory Group
LAMP	Lyman Alpha Mapping Project
LASCO	Large Angle Spectrometric Coronagraph
LASER	Lunar Advanced Science and Exploration Research

Acronym/Abbreviation	Expansion/Definition
LASP	The Laboratory of Atmospheric and Space Physics
LDCM	Landsat Data Continuity Mission
LDEO	Lamont-Doherty Earth Observatory
LEAM	Lunar Ejecta and Meteorites
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LHG	Lunar Horizon Glow
LIDAR	Laser Imaging Detection and Ranging
LIS	Land Information System
LISR	L-Band Interference Suppressing Radiometer
LITE	Lidar In-Space Technology Experiment
LIMA	Landsat Image Mosaic of Antartica
LOLA	Lunar Orbiting Laser Altimeter
LP	Lunar Prospector
LRO	Lunar Reconnaissance Orbiter
LSM	Land Surface Model(ing)
LST	Land Surface Temperature
LXO	Lunar X-ray Observatory
MAG	MESSENGER Magnetometer
MAIAC	Multi-Angle Implementation of Atmospheric Correction
MAP	Modeling, Analysis and Prediction
MAS	MODIS Airborne Simulator
MASTER	MODIS/ASTER Airborne Simulator
MATLAB	Matrix Laboratory (Mathworks software)
MCST	MODIS Characterization Support Team
MEASURES	Making Earth System data records for Use in Research Environments
MERRA	Modern Era Reanalysis for Research and Applications
MESS-3D	Mercury's Environment Simulator (3D version)
MESSENGER	MErcury Surface, Space Environment, GEochemistry, and Ranging
METEOSAT	Meteorological Satellite
MetOp	Meteorological Operational Satellite (European AVHRR equivalent)
MHD	Magnetohydrodynamics
MISR	Multi-angle Imaging SpectroRadiometer
MIT	Massachusetts Institute of Technology
MJO	Madden-Julian Oscillation
MLS	Microwave Limb Sounder
MM5	The 5th generation of Penn. State Univ. - NCAR Mesoscale Model
MMF	Multi-Scale Modeling Framework
MMS	The Magnetospheric Multi-Scale mission
MODIS	Moderate Resolution Imaging Spectro-Radiometer
MODTRAN	Moderate Resolution Atmospheric Transmission
MOM	Modular Ocean Model
MPE	Multi-sensor Precipitation Estimate
MPI	Message Passing Interface
MPLNET	Micro-pulse Lidar Network
MSG	Meteosat Second Generation
MSL	Mars Science Laboratory
MSU	Microwave Sounding Units
NACP	North American Carbon Program
NAMMA	NASA African Monsoon Multidisciplinary Analysis
NAS	NASA Advanced Supercomputing

Acronym/Abbreviation	Expansion/Definition
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCCS	NASA Center for Computational Science
NCEP	National Centers for Environmental Prediction
NCFR	Narrow cold front rain band
NDACC	Network for the Detection of Atmospheric Composition Change
NDVI	Normalized Difference Vegetation Index
NEESPI	Northern Eurasian Earth Science Partnership Initiative
NESC	NASA Engineering and Safety Center
NESDIS	National Environmental Satellite, Data, and Information Service
NEWS	NASA Energy and Water Cycle Study
NGIMS	Neutral Gas and Ion Mass Spectrometer
NIA	National Institute of Aerospace
NIP	New Investigators Program
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NRA	NASA Research Announcement
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NRCS	Natural Resources Conservation Services
NRL	Naval Research Laboratory
NRT	Near-Real Time satellite data (usually within 3 hours of acquisition)
nSD	Normalized Snow Depth
NSF	National Science Foundation
NSIPP	NASA's Seasonal-to-Interannual Prediction Project
NSIT	NEWS Science Integration Team
NSO	National Solar Observatory
NWP	Numerical Weather Prediction
NWS	National Weather Service
OCO	Orbiting Carbon Observatory
ODS	Ozone Depleting Substance
O-F	Observation-minus-forecast
OGCM	Ocean General Circulation Model
OLR	Outgoing longwave radiation
OMI	Ozone Monitoring Instrument
OMIDAPS	OMI Data Processing System
OML	Ocean Mixed Layer
OMNO2	Aura Ozone Monitoring Instrument Product for NO2
OMPS	Ozone Mapping and Profiling Suite
OSSE	Observing System Simulation Experiments
PAL	Passive Active L-band
PALS	Passive Active L-band Sensor
PARCA	Program for Arctic/Antarctic Climate Assessment
PAVE	Polar AURA Validation Experiment
PBL	Planetary Boundary Layer
PDE	Partial Differential Equation
PDO	Pacific Decadal Oscillation
PDF	Probability density function

Acronym/Abbreviation	Expansion/Definition
PEACE	The Plasma Electron and Current Experiment
PERSIANN	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks
PI	Principal Investigator
PIC	Particle-in-cell
PID	Particle Impact Detector
PMW	Passive microwave
PNNL	Pacific Northwest National Laboratory
POAM	Polar Ozone and Aerosol Measurement
PoDAG	Polar DAAC Advisory Group
PPPL	Princeton Plasma Physics Laboratory
PR	Precipitation Radar
PRD	Precision Range Determination
Pre-AVE	Pre-Aura Validation Experiment
PSC	Polar stratospheric cloud
PSD	Particle size distribution
PSS	Precision Subsampling System
QA	Quality Assurance
QBO	Quasibiennial oscillation
QC	Quality Control
QMS	Quadrupole Mass Spectrometer
QPE	Quantitative Precipitation Estimate
QSCAT	QuikScat: Polar Orbiting Satellite carrying a scatterometer
RETRO	Reanalysis of the Tropospheric chemical composition over past 40 years
RFI	Radio Frequency Interference
ROSES	Research Opportunities in Space and Earth Sciences
RPI	Radio Plasma Imager
RRS	Rotational Raman Scattering
RSS	Remote Sensing Systems
RTM	Radiative Transfer Model
SAC	Science Advisory Committee
SAFARI-2000	Southern African Regional Science Initiative 2000
SAG	Scientific Advisory Group
SAIC	Science Application International Corporation
SAL	Saharan Air Layer
SAM	Sample Analysis at Mars
SAM	Southern Annulalr Mode
SAMSIM	SAM Instrument Simulator
SAO	Semiannual Oscillation
SAR	Synthetic Aperture Radar
SBUV	Solar Backscatter Ultraviolet
SCA	Snow cover area
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SCSMEX	South China Sea Monsoon Experiment
SDO	Solar Dynamics Observatory
SDSU	Satellite Data Simulation Unit
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEM	Solar EUV Monitor
SIDE	Suprathermal Ion Detector Experiment

Acronym/Abbreviation	Expansion/Definition
SIM	Solar Irradiance Monitor
SIMPL	Swath Imaging Multi-Polarization Photon-Counting Lidar
SIO	Scripps Institution of Oceanography
SIR	Shuttle Imaging Radar
SIVO	Software Integration and Visualization Office
SLP	Sea Level Pressure
SMAP	Soil Moisture Active-Passive
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMMR	Scanning Multichannel Microwave Radiometer
SMOS	Soil Moisture and Ocean Salinity
SOC	Stratospheric Ozone Column
SOHO	Solar and Heliophysical Observatory
SOP-3	Special Observing Period of the NAMMA campaign
SORCE	Solar Radiation and Climate Experiment
SoS	Science on Sphere
SOS	Successive Orders of Scattering
SPARC	Stratospheric Processes and their role in Climate
SPASE	Space Physics Archive Search and Extract
SPASEQL	SPASE Query Language
SPG	Standards Process Group
SSA	Single Scattering Albedo
SSAI	Science Systems and Applications, Inc.
SSAV	Space Science Analysis and Visualization
SSC	Scientific Steering Committee
SSM/I	Special Sensor Microwave / Imager
SSS	Sea surface salinity
SST	Sea surface temperature
SSW	Stratospheric Sudden Warmings
ST5	Space Technology 5
STC	Science and Technology Corporation
STE	Stratosphere-troposphere exchange
STS	Supercooled ternary solution
SuperDARN	Super Dual Auroral Radar Network
SVS	Scientific Visualization Studio
SWE	Snow water equivalent
SWMF	Space Weather Modeling Framework
T3EF	TRMM Triple-sensor Three-step Evaluation Framework
TC	Tropical Cyclone
TC4	Tropical Composition, Cloud and Climate Coupling
TCSP	Tropical Cloud Systems and Processes
TES	Tropospheric Emission Spectrometer
TF HTAP	Task Force on Hemispheric Transport of Air Pollution
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIM	Total Irradiance Monitor
TMI	TRMM Microwave Imager
TMPA	TRMM Multi-Sensor Precipitation Analysis
TOA	Top of the Atmosphere
TOC	Tropospheric Ozone Column
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer

Acronym/Abbreviation	Expansion/Definition
TRMM	Tropical Rainfall Measuring Mission
TSVO	TRMM Satellite Validation Office
TTL	Tropical Tropopause Layer
UARS	Upper Atmospheric Research Satellite
UC	University of California
UCLA	University of California at Los Angeles
UIC	User Interface Committee (Group on Earth Observations)
ULF	Ultra-Low Frequency
UMBC	University of Maryland, Baltimore County
UMCES	University of Maryland Center for Environmental Studies
UMCP	University of Maryland, College Park
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
USAID	United States Agency for International Development
USAMRUK	United States Army Medical Research Unit (Kenya)
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USGCRP	United States Global Change Research Program
USGS	U.S. Geological Survey
USRA	Universities Space Research Association
UTC	Universal Time Coordinate
UTLS	Upper Troposphere- Lower Stratosphere atmospheric region
UV	Ultraviolet
UV-MFRSR	UV Multifilter Rotating Shadowband Radiometer
UVS	Ultraviolet/Visible Spectrometer
VAPoR	Volatile Analysis of Polar Regolith
VHO	Virtual Heliospheric Observatory
VIIRS	Visible/Infrared Imaging Radiometer Suite
VIRS	Visible and Infrared Sensor
VIS	Visible Imaging System
VLIDORT	Vector LInearized Discrete Ordinate Radiative Transfer
VMO	Virtual Magnetospheric Observatory
VO	Virtual Observatory
WAC	Wide Angle Camera
WACMOS	Water Cycle Multimission Observation Strategy (ESA Programme)
WAM	West African Monsoon
WAVES	Water Vapor Validation Experiments
WCFR	Wide Cold Frontal Rainband
WCRP	World Climate Research Programme
WHO	World Health Organization
WINDII	Wind Imaging Interferometer
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting model