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Annual Report

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GEST
GODDARD EARTH SCIENCES AND TECHNOLOGY CENTER

Goddard Earth Sciences and Technology Center (GEST)

Sixth Annual Report

10 May 2006

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INTRODUCTION

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INTRODUCTION

A Year of Change and A Year of Growth

It is daunting to assess the development of a research center that you have just joined. Over the summer of 2005, the Goddard Earth Sciences and Technology Center Director, Robert Curran, moved on to a position at the Climate Change Science Program Office in Washington. Bob has remained with UMBC as an employee and is serving in this role with CCSPO as an Intergovernmental Personnel Assignment. In July, 2005, I took over the role of Director of GEST and it has been a learning year for me. In trying to meet the entire GEST Faculty, I am continually impressed by the breadth of the research conducted by the Center and its fine researchers. My general response has been, "I didn't know we were doing that!" Unfortunately, this best kept secret is also not known by many of the faculty at UMBC and I have made a significant effort this year to make GEST research known more widely on the UMBC campus. At least five Departmental seminars have been given in Geography and Environmental Systems, Physics, Mechanical Engineering, and CUERE. It is just a start, but a significant one. Co-proposals on a number of research topics have occurred with GEST faculty and UMBC tenure-track faculty. While some are still in the review stage, a significant proposal was awarded to Robert Schiffer and Claire Welty as part of a NASA Applications cooperative agreement. Assaf Anyamba has co-proposed with Y. Sohn of GES and Susan Hoban's active group has broadened its reach into the Math, Computer Science and Electrical Engineering and Education Departments. This strengthening of the linkages between GEST and UMBC departments will be very important, especially in a year in which GEST will have its first UMBC Center Review. This peer review is mandatory for all UMBC Centers and we know that GEST will fare favorably in this assessment.

GEST's scientific achievements are documented in the few hundred pages of research topics below. But a review of this report only scrapes the surface of what GEST has become. The Center has become a model of how university and GSFC cooperation can work. It is being emulated in other center developments at GSFC and UMBC hopes to further demonstrate our expertise in how such Joint Centers can be successful, both for the University and for Goddard. While developments in Earth Sciences within NASA this year have posed some financial challenges, GEST has fared well, adding nearly 30 staff to its complement of researchers since January 2006. A new area of research has been included in the Center's activities, Heliophysics. This is a natural evolution of the thinking within NASA that the sun's energy drives our climate and our planet's response over geological time frames. Does the sun's energetics affect our planet on shorter scales, such as the last 1000 years? How important are short-term changes in the sun's output to decadal changes in climate? These open questions have encouraged the linkage of the traditional Earth Science disciplines with the solar system physical researchers in GSFC. While NASA is still adjusting how this linkage will be addressed, we have taken this area of research as an important one to GEST and have, this year, devoted a Goddard Visiting Fellow position, held by Raimund Muscheler, to enhancing the Sun-Climate Center led by Robert Cahalan and Doug Rabin. A new seminar series at GSFC has been investigating commonalities in research in this area at GSFC. In addition, we have formed a Heliophysics Group within GEST to enhance the collaborations between traditional Earth Science researchers and those who study the sun, heliosphere, and planetary interactions. Phillip Webb has become Group Leader in this area and has given a thoughtful vision for the group in a section below.

GEST Faculty continue to win awards at GSFC. A Laboratory for Atmospheres Outstanding Performance Award went to Oreste Reale; a Code 613.2, Scientific Leadership Award to Santiago Gassó; Best Public Summary to Ron Errico; Code 613.1 Science Support Awards to Jiundar Chern and Xiaowen Li; GMAO awards to Errico (scientific leadership award), Rolf Reichle, Julio Bachmeister, and Hiroo Hayashi; UARS Science Team award to Judit Pap; NASA Software of the Year Award to Sujay Kumar and Yudong Tian (along with PI's Houser and Peters-Lidard); a team award for Goddard Exceptional

Achievement to Alexander Smirnov, Oleg Dubovik and Tom Eck for AERONET; and a Certificate of Recognition to David Lary for the Autochem Software Package. I am sure that there are other external measures of recognition that I haven't listed here.

During 2005-6, two of our faculty, Richard Kelly and Lars-Peter Riishojgaard spent a great deal of their research time to developing concepts for new satellite missions. The Cold Lands Processes Experiment (CLPX) is designed to improve our ability to assess snow and ice coverage of the globe by combining passive microwave sensors at high spatial resolution with an L-Band Radar. While Kelly has moved to a faculty position at the University of Waterloo in Canada, Marco Tedesco continues to conduct studies in preparation for such a proposed ESSP mission. Further along is a concept development for the Molniya orbiter designed to measure polar clouds and winds and to contribute to improved forecast accuracies by filling in the sparse data available from the high Arctic region. The delay to ESSP proposing at NASA has encouraged Riishojgaard to seek external agency support for this mission and encouraging discussions have been held with the National Oceanographic and Atmospheric Administration.

Finally, singling out specific research topics is risky since so many excellent developments occurred this year. But let me highlight the Land Information System linkages to other global models done by Kumar, Jesse Meng, Chern, Kristi Arsenault, Joe Eastman, Jiarui Dong, Reichle and Matt Garcia, among many who work on and with this tool. These integrative efforts to combine a Systems approach to land/air/water modeling are likely to be the future of GSFC modeling research. Another particular strength area is in Assimilation and two groups are developing tools which should lead to chemical data assimilation in the near future. On the observational side, integration of multisensor suites of instruments (OMI, AURA, Aqua, CALIPSO, CLOUDSAT, Polder, MISR, TRMM) involves over half of GEST's research staff. It is an exciting time with the launch of the complete A-Train on April 28. I know that I will be joining GEST's faculty in contributing to our understanding of the Earth System by these combined measurements and modeling efforts.

It has been a privilege to join GEST this year and I hope for a stronger, growing 2007.

Raymond M. Hoff
Director

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EXECUTIVE SUMMARY

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Executive Summary

The Goddard Earth Sciences and Technology (GEST) Center had its cooperative agreement with NASA renewed for another 5 years to the year 2010. During the first year of this second term (its 6th year of existence), there has been renewed growth and change within its administrative staff and its research faculty. A new director has taken up his position to provide GEST with fresh leadership and forge new directions and relationships within the UMBC and NASA communities. Additional support staff has been hired to address the needs of expanded business services to our increasing faculty numbers. We have seen a turnover of about a third of our research personnel, with the departure of some scientists to academic faculty positions, the civil service, and other research organizations. GEST has welcomed into its ranks newly graduated Ph.Ds as well as experienced scientists from many countries world-wide, especially from Europe. We currently number about 110 in terms of research faculty and staff. Included amongst the recent arrivals are scientists in the newly formed Heliophysics research group. There remain a total of eight research groups within GEST, some under the guidance of new group leadership. The groups themselves have been reorganized to better represent the research themes of our diverse scientific interests.

All the scientific accomplishments have been through the combined research efforts of UMBC with its other consortium partners, Hampton University, Howard University, and Caelum Research Corporation. Northrop Grumman Corporation continues to provide advice and support through representation on the GEST Executive Board.

This Annual Report predominantly contains brief discussions of the research focus and results for the GEST faculty and staff. There are a total of 93 articles contributed by GEST faculty researchers and visiting fellows. Each report also lists the names of GSFC 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 year, there were 160 refereed scientific papers that were authored by GEST faculty and published in major journals. Another 46 papers were published in other literature, and a further 350 presentations and posters at numerous conferences and meetings during this same period. The impressive nature of our faculty's research accomplishments are shown in a number of ways. They have received in the order of 9 performance and peer awards from NASA for their distinguished work during the past year. The quality of their research is also measurable by the high success rate of proposals (107 funded out of 197, with 67 still pending a funding decision) submitted by our faculty to NASA, NSF, and other agencies in collaboration with their colleagues at GSFC and elsewhere.

This past year, the Goddard Visiting Fellows Program in the Earth-Sun Explorations Division saw only three international researchers participating in the program during the reporting period. A fourth arrived in January 2006 and will be in residence during the next few months as well. Seven others have been selected for this forthcoming year and the participating fellows are listed along with a summary of their proposed collaboration while at Goddard.

The Summer 2005 Educational Programs continued under GEST management with the following results. Ten graduates were matched with GSFC-based scientist mentors to work on specific Earth Sciences projects/problems/issues. GEST also hosted nine summer interns working with NASA scientist mentors on specific projects in the Earth Sciences. The GEST Graduate Fellowship program awarded one fellowship in the 2005/2006 timeframe.

As part of our cooperative research program with the Earth-Sun Explorations Division, GEST facilitates collaboration between scientists based at GSFC and in organizations outside the Center who must work for short periods at GSFC, at field research locations, or at external conference sites. Over 70 visitors

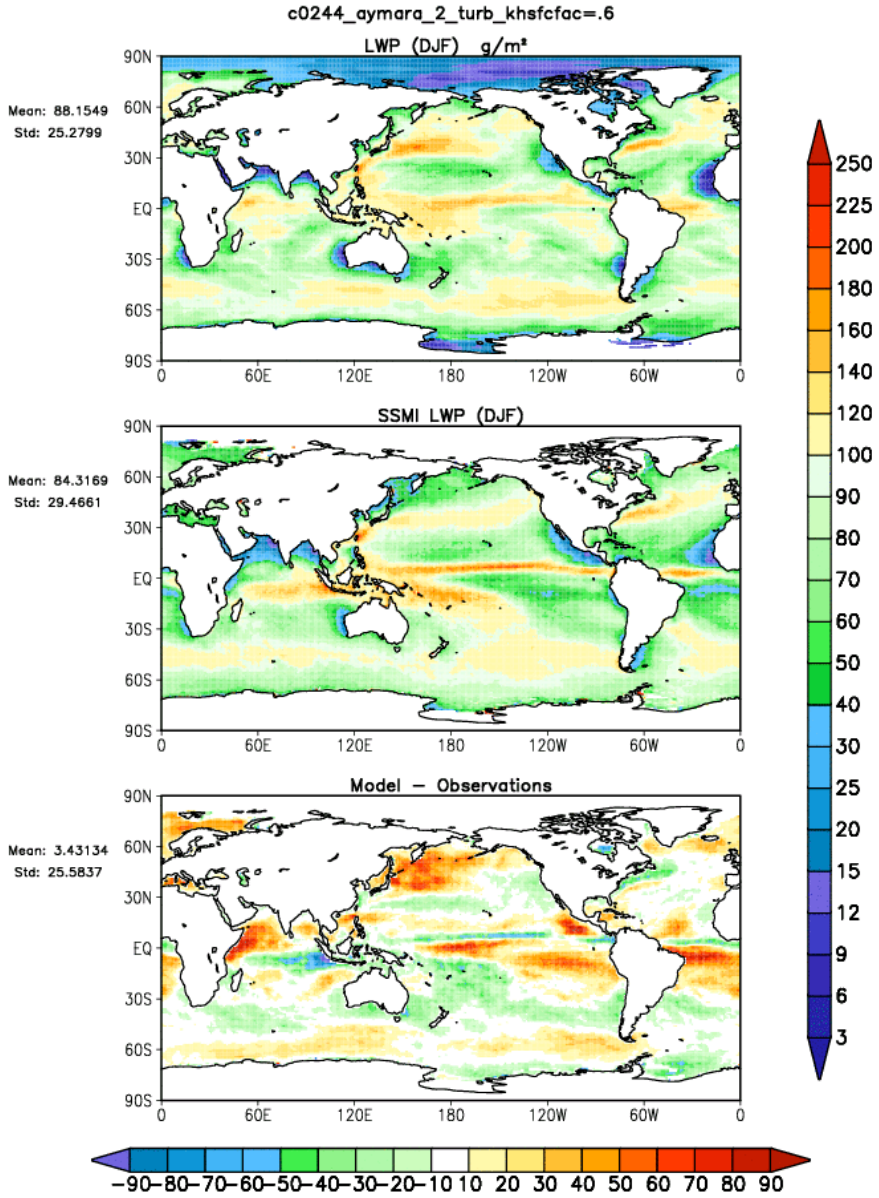
participated in this program from U.S. universities and institutions and international federal laboratories and universities during the reporting time frame. In this report you will find lists of U.S. and international scientists and their collaborating organizations that were assisted by the GEST administrative staff.

GEST continues to have as part of its organization the leadership of the International GEWEX Project Office (IGPO). This office provides management, service and coordination functions for more than 1000 scientists worldwide who are working on the water and energy cycle science and it supports the information and management needs of the World Climate Research Programme. Its efforts are reported in a separate section of this Annual Report.

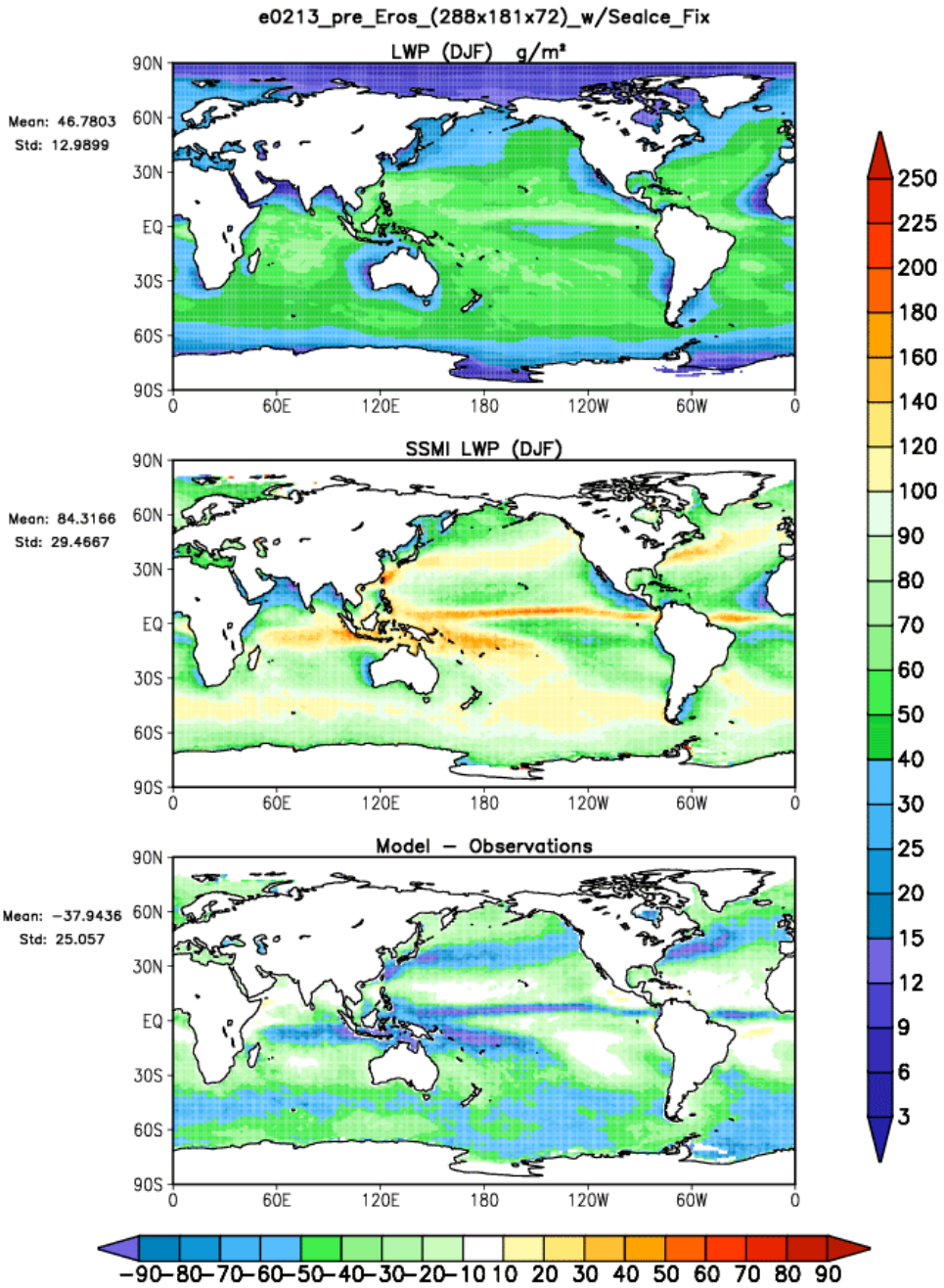
This report reveals the early manifestations of the reorganization of GEST has had very positive results. Some of these changes have been the result of recent changes within NASA itself, but also show planned new directions that are intended to strengthen the relationships with the UMBC community. As new challenges arise, it is very encouraging to see the multitude of activity and growth of GEST commencing once again.

Tom B. Low
Associate Director

Data Assimilation Research Group



The 3-panel figure above (and on the following page) compares two GEOS-5 climate model simulations of seasonal-mean, vertically-integrated cloud liquid water content, or "Liquid Water Path" (LWP), with microwave-based estimates of the same quantity from the Special Sensor Microwave/Imager (SSMI) satellite instrument. The top panels show the 3-month average GEOS-5 simulated LWP for December-1994 through January and February 1995 (DJF 94/95) in units of g m-2. (cont. on following page)



(cont. from preceding page) The middle panels show a multiseason SSMI climatology of LWP for DJF, while the bottom panels show the difference between GEOS-5 and SSMI. The two GEOS-5 simulations shown represent two versions of parameterized microphysics: an early version of the autumn 2005 ("Daedalus") release of GEOS-5 which had rapid freezing of freshly produced cloud particles (first page) and a later version with slower freezing (second page). Figures provided by Julio Bacmeister.

Data Assimilation Research Group

Data assimilation concerns the combining of different types of observations produced by different kinds of instruments with other prior information and constraints in order to produce an optimal estimate of the dynamical or chemical state of the atmosphere, ocean, or land. Satellite observations naturally are keys, since only they have the global coverage often required. Models are also keys, because they best extrapolate information from prior observations and estimates to the present time. They can also most accurately quantify physical relationships between what is actually observed (*e.g.*, a radiance) and what is to be analyzed (*e.g.*, a temperature). It is truly the combining of many useful observations, model described relationships and constraints that yields the least error prone estimates of the states of the earth system.

Sujay Kumar and Yudong Tian are members of the team that developed the Land Information System (LIS). This is a flexible, high-performance land surface modeling and data assimilation system. It has been adapted by many agencies and organizations to enhance prediction and research. During the past year, this effort received NASA's software of the year award. This software is also used in the task conducted by Jesse Meng, who has been examining results from the Global Land Data Assimilation System (GLDAS).

Several investigators examined assimilation for the oceans and atmosphere. In independent projects, Xin Lin and Ronald Errico examined issues related to the assimilation of observations from which precipitation and clouds could be inferred. Hiroo Hayashi worked on the assimilation of ozone-related observations in versions of the GMAO DAS. S. Daniel Jacob has been investigating the analysis of sea surface salinity using Aquarius measurements. Francesco Fedele and Errico have been examining the dynamical aspects of data assimilation using a quasi-geostrophic model that portrays many characteristics of the atmosphere. Errico has also been pioneering use of OSSEs to infer characteristics of data assimilation systems and has been collaborating on development of the GMAO adjoint modeling system.

Some members of the Data Assimilation Group are actively developing models used for assimilation and prediction. Julio Bacmeister has been examining, improving, and tuning convective and other parameterization schemes used in the GEOS-5 AGCM. Myong-In Lee has been carefully comparing how well diverse models and resolutions simulate the diurnal cycle of convection over North America, with the objective of understanding their behavior and improving their formulations. S. Daniel Jacob compared parameterizations of the ocean mixed-layer for the Hurricane Test Bed project. The predictability of inter-seasonal prediction has been examined by Yehui Chang in order to establish reasonable expectations for such predictions and to determine what factors require the most accurate simulation.

Most of these tasks have a strong developmental component. Many investigators within or outside NASA and GEST rely on the expertise of scientists within this group to develop the capabilities required to conduct their own research. Many of the scientific investigations performed in the summarized tasks are rather fundamental in nature, expanding our understanding of how the earth system and its models work. They will retain their applicability long after the specific tasks are completed.

Ronald Errico

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Task 971-00-002: **Parameterized Physics Development for GEOS-5, the Global Modeling and Assimilation Office (GMAO) Atmospheric General Circulation Model**

GEST Investigator: Julio T. Bacmeister

Collaborator: Max J. Suarez (GFSC), F. Robertson (MSFC), Siegfried Schubert (GSFC), Atanas Trayanov (SAIC), Baode Chen (SAIC), Myong-In Lee (GEST), Lawrence Takacs (SAIC), Caterina Tassone (SAIC)

Abstract

Work continued on parameterized physics for the GMAO atmospheric general circulation model, the GEOS-5 AGCM. This year's effort focused on three areas: (1) improved representation of cloud condensates; (2) reduction of top-of-atmosphere cloud radiative forcing (TOA-CRF) biases; and (3) control of simulated precipitation intensities and spin-up. The longer term goal of this work is to provide a state-of-the-art AGCM for GMAO data assimilation activity and seasonal forecasting activity. In order to meet these requirements the model must be capable of performing credible short-term weather-scale forecasts after initialization with analysis data, as well as providing accurate, free-running, long-term "climate mode" simulations. Physics development also requires analysis of errors and biases in existing systems. Analysis of the double ITCZ bias in existing AGCMs continued, along with a detailed analysis, in collaboration with M-I Lee, of the diurnal cycle of precipitation in AGCMs. Collaborative in-depth analysis of model physics quantities was initiated with F. Robertson of NASA/MSFC

Description of Research

The GMAO was established in 2003 to take over many of the tasks performed by the Data Assimilation Office (DAO) and NASA's Seasonal-to-Interannual Prediction Project (NSIPP). NSIPP's principal mission was to develop a fully-coupled atmosphere/land/ocean climate prediction system to study the impacts of satellite-based ocean and land-surface observations on climate predictability. The DAO's principal mission was to investigate and implement techniques for assimilating a variety of satellite atmospheric data, and to identify potential scientific and societal uses for these data. An important milestone for the GMAO is to develop a single atmospheric model capable supporting all of these missions. Improved parameterization of atmospheric moist processes will be critical to the success of this modeling effort.

Accomplishments during the Reporting Period

During the reporting period the GMAO modeling group released three versions (or "CVS tags") of the GEOS-5 AGCM: Boreas, Cerebus, and Daedalus. The alphabetical order of names reflects the development sequence. Each version differs from its predecessor primarily in the details of the physics parameterizations employed. Multi-year free-running climate simulations with each version were made. The Cerebus tag was also used in the MAP05 project to conduct quasi-operational forecasts during the 2005 hurricane season. The climate of the Boreas and Cerebus versions is similar, in that both exhibit substantial dry biases in the tropical lower troposphere, which was largely alleviated in the Daedalus tag through a major revision of boundary layer physics. However, all three current releases suffer from several similar biases, including: (1) a deficit in cloud liquid condensate amounts (in Daedalus this is coupled with what is likely an excess of ice condensate at middle levels in the troposphere); (2) an excess of shortwave cloud forcing in the tropics (despite deficient condensate paths); and (3) excessive global mean precipitation in climate mode. In addition the Cerebus and Daedalus tags suffer from opposite problems in precipitation initialization in forecasts, with Cerebus exhibiting a drastic precipitation spin-down or "shock" during the first time-steps of a forecast experiment, and Daedalus exhibiting a slower spin-up.

The first bias described above, and to some degree the second bias as well, were thought to be especially problematic given the longer term GMAO goal of assimilating satellite-retrieved cloud condensate data. A concerted effort was made to obtain reasonable cloud condensate simulations concurrently with reasonable, or at least acceptable, TOA-CRF simulations. This goal was largely obtained through a reformulation of the ice/liquid cloud production terms, and minor changes to the precipitation re-evaporation scheme in the model. In addition, estimates of convective cloud condensate were added, along with relationships between cloud fraction and turbulent diffusivities. The model currently produces a good simulation of cloud liquid water path—the only cloud condensate quantity for which global satellite verification data exists. TOA-CRF biases remain, however they are comparable to those in other major climate models, *e.g.*, NCAR CAM3 and GFDL AM2. These biases may be related to inadequate representations of cloud fraction in trade wind regions, which is a long-standing problem in AGCMs.

Initial precipitation behavior in forecasts with the GEOS-5 AGCM was found to be tied to the technique used to specify cloud base properties for convection. If convection is assumed to originate in the surface layer (lowest ~100 m of the atmosphere), a large precipitation shock results when the model is initialized with analysis data. The opposite problem occurs when convection is assumed to originate near the top of the planetary boundary layer. Precipitation is initially too low and gradually increases during the first few hours of the forecast. While not satisfactory from a physical standpoint this behavior should prove to be useful in "tuning" future versions of the model.

Objectives for the Coming Year

The performance GEOS-5 AGCM in both climate mode and forecast/assimilation mode will continue to be analyzed. The relationship between cloud fraction, cloud LWP and shortwave cloud forcing in the subtropics will be a particular focus of study. Techniques utilizing "parameterized dynamics" in the GEOS-5 SCM framework will be investigated in order to obtain a more effective test bed for physics parameterization development.

An effort will be made to collaborate more closely with Cloud modeling group at GSFC. This should lead to more rational assessment of convective parameterization details, such as specification of cloud base properties.

Work will also be performed on new gravity wave parameterizations for GEOS-5. Collaboration with NCAR and NRL modeling groups will be initiated.

Task 910-14-123: **Advancing Best Practices in Seasonal Climate Predictions**

GEST Investigator: Yehui Chang

Collaborator: Siegfried Schubert (PI, GSFC)

Abstract

This collaborative task seeks to advance the practices of seasonal climate prediction. The task's specific aims are to estimate the attributable causes for seasonal climate anomalies and assess their predictability on a near-real time basis through coordinated, multi-model GCM simulations; determine the upper limit of U.S. seasonal climate predictability for the recent climate record using SST-forced atmospheric GCM simulations of the post-1950 era; evaluate the extent to which this potential seasonal predictability is currently being realized in actual forecasts and hindcasts, and evaluate the skill of new generations of dynamical models and modeling systems; and appraise the prospects for U.S. seasonal forecast skill for the next decade based on a diagnosis of coupled dynamical models with a principal aim to reveal the sources for multi-year variations in skill.

Description of Research

The connections between atmospheric response and SSTs determine the potential predictability

and provide an estimate of the limit of seasonal forecast skill. The realization of the potential predictability depends on the skill of predictions of the boundary conditions. This research documents the potential predictability of U.S. seasonal surface temperature and precipitation, and to quantify what fraction of this could be realized. This analysis is done from the comparison of AGCM hindcasts with observed SSTs and forecast with predicted SSTs.

Accomplishments during the Reporting Period

The NSIPP coupled model forecasting system is used to examine the nature of the spring predictability barrier. The focus is on the predictability of subsurface variability, and how that evolves to limit predictability in the sea surface temperatures and ultimately the atmosphere. The skill of both persistence and coupled model hindcasts of the Nino3.4 index show a clear signature of a spring barrier in predictability. The work demonstrates that there is no spring persistence barrier for upper ocean heat content consistent with McPhaden [2003]. Lagged correlations show the anomalous warm water volume (WWV) leads Nino3.4 SST by 2-3 seasons. The results of this study agree with other ENSO forecast model studies indicating that accurate initialization of the equatorial upper ocean heat content reduces the spring prediction barrier for SST. The correlations show that the WWV leads Nino3.4 SST by 2-3 seasons. A boreal spring predictability barrier exists in SST. In contrast, WWV does not show a spring predictability barrier. In fact, February-March WWV anomalies have the greatest persistence. SST spring barrier and WWV persistence barrier, developed in the boreal winter, consistence with the observed. Initialization of the equatorial subsurface helps break through the spring barrier.

The spread and error ensemble forecasts for ENSO prediction for both CFS of NCEP and NSIPP forecast are studied. The work examines the performance of operational ensemble forecasts for ENSO prediction. It quantifies the SST ensemble spread and the spread compared to the RMS error of the forecasted SST anomalies. The task also studies the eastern, western tropical Pacific regions, Nino3, Nino3.4 and Nino4 indices, for all initial months and forecast lengths. The characteristic of the forecast error and the ensemble spread are important factors in the evaluation of the seasonal forecast system.

Objectives for the Coming Year

Research will continue to attempt to answer questions that are central to seasonal forecast efforts, having as their ultimate goal to determine the expected future skill improvements from a new generation of climate models. Activity will focus mainly around the following specific questions: (1) What are the attributable causes of seasonal climate variability? (2) Is the potential predictability of U.S. seasonal climate being realized, and what in particular is the role of air-sea interactions? The GEST investigator will also seek to advance the practices of seasonal climate prediction. The specific aims are to estimate the attributable causes for seasonal climate anomalies and assess their predictability and to determine the upper limit of U.S. seasonal climate predictability.

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

GEST Investigator: Ronald Errico

Collaborator: Ronald Gelaro (PI, GSFC), Ricardo Todling (SAIC), Runhua Yang (SSAI), Michiko Masutani (NCEP), Francesco Fedele (GEST), Martin Ehrendorfer (UIBK), Jean-Francois Mahfouf (EC), Peter Bauer (ECMWF)

Abstract

Ronald Errico has been applying his expertise to a number of facets of data assimilation problems encountered at the GMAO. These include development of adjoint-model techniques and software for identifying likely locations of data analysis errors, development of measures for ranking the importance of observation types and

monitoring the earth observing system, development of techniques for examining and imposing appropriate atmospheric dynamical balances, examination of OSSE results for estimating the character of analysis error, examination of the many issues peculiar to assimilation of precipitation, and development of an intermediate-complexity dynamical model for evaluation of proposed new data assimilation techniques. He also was the co-chief organizer of the International Workshop on the Assimilation of Satellite Cloud and Precipitation Observations in NWP Models held in May 2005.

Description of Research

Data assimilation is becoming an exacting science as ever more accurate analysis is demanded. This requires more sensitive measures of success and more informative techniques and tools to ferret out errors. As more investigators have begun tackling the problem, the number of claims of remarkable success has also dramatically increased, requiring independent verification. In support of these demands, Ronald Errico is directing the development and application of several innovative techniques for the examination and improvement of data assimilation systems. These include adjoint-model based tools for effective determination of sensitivities of analysis scores with respect to analysis fields, observations, and parameters, the use of OSSEs for characterizing analysis and background error statistics, normal-mode projection tools for measuring dynamical balances, and intermediate-complexity forecast models that sufficiently resemble the atmosphere but are more amenable to examination than NWP models.

Accomplishments during the Reporting Period

Progress in data assimilation requires reconsideration of the assimilation of observations affected by either clouds or precipitation. Their appropriate incorporation is much more problematic than the assimilation of data types already used. Issues of concern include the greater nonlinearity of observation and forward model operators, the non-normality and large variances of representativeness, retrieval, and model errors, the effects of both physical and dynamical imbalances, the requirement for new validation measures, the consideration of possibly fundamental predictability limits, etc. All these issues were reviewed by Errico and colleagues at an invitational international workshop that he organized in May 2005.

Examination of the NCEP OSSE datasets was extended to a high-resolution assimilation that included satellite radiance observations. The Kalman gain in the new data set is smaller compared with previous assimilations that used only conventional data and satellite wind data, due to the result that not only are analysis error variances approximately halved by the radiance data, but those of the background as well. Although the new assimilation is performed at T170 resolution, there is essentially no useful information in scales shorter than about T80. The vertical and horizontal length scales of analysis errors are similar to corresponding scales of errors in the background.

The presence of highly unrealistic vertical motions in upper atmospheric analysis has so far precluded implementation of a fully dynamically-consistent chemical-species assimilation scheme at the GMAO. The unrealism is due to imbalances created during the data assimilation of non-species observations, particularly in the troposphere. Two techniques for mitigating these imbalances have been developed, one based on nonlinear normal mode initialization and the other based on inclusion of a dynamical-noise penalty term in the FVGSI cost function. The former has been demonstrated to reduce most of the dynamical noise without degrading standard measures of analysis skill. The latter is still under development.

Development of the intermediate-complexity QG model has continued. Testing at T106L9 resolution revealed that the lack of a surface drag emulator yielded unrealistically large perturbation growth rates at that resolution. This in turn led to a reexamination of temporal variance in the model's climatology. Incorporation of surface drag and retuning has resulted in a climatology closer to the real

atmosphere at both high and medium resolution. Singular vectors have been produced using a Lanczos algorithm. Their characteristics are similar to ones produced for the GEOS4 model. Also, predictability experiments have been performed using analysis error estimates provided by the NCEP OSSEs, indicating the utility of the model for examining several data assimilation issues.

Objectives for the Coming Year

Errico has three primary objectives for next year. The first is to demonstrate the utility of the almost completed adjoint modeling capability at the GMAO for error determination and observation monitoring. The second is to complete development of a dynamical noise suppression algorithm consistent with the FVGSI assimilation scheme. The third is to develop several data assimilation simulators, including a complete Kalman filter, for the QG model, and to use these to compare properties of various proposed reduced-rank and ensemble data assimilation schemes. Several manuscripts reporting on last year's research that are in various stages of preparation work must also be completed.

Grant 00000685: **Determination of the Effects of Non-modality on the Data Assimilation and Numerical Weather Prediction Problems**

GEST Investigator: Francesco Fedele

Collaborator: Ronald Errico (PI, GEST), Ronald Gelaro (GSFC), Runhua Yang (SSAI), Martin Ehrendorfer (UIBK)

Abstract

Using adjoint techniques and an intermediate numerical weather Quasi-Geostrophic (QG) model, certain properties of reduced-rank Kalman filter (RRKF) and Ensemble Kalman Filter (EnKF) schemes have been investigated. A preliminary timing study has been performed on a multi-processor computer to assess the feasibility of implementing the Kalman filter (KF) scheme for the QG model. Finally, the concept of the stochastic wave groups is investigated to explain the occurrence of extreme events in the general context of ocean and atmospheric dynamics.

Description of Research

The main goal is the development of a data assimilation system for the QG model based on the KF technique. Having such a data assimilation system built for the QG model will help in understanding certain properties of the KF algorithm in the context of a more realistic model that better represents the real atmosphere. Furthermore, the efficiency and accuracy of the different RRKF and EnKF data assimilation schemes can be assessed with an honest comparison against the reference KF solution. An analytical theory is being developed to explain extreme events by means of stochastic wave groups in the general context of ocean and atmospheric random waves.

Accomplishments during the Reporting Period

During this year Fedele became familiar with the QG model and its related Fortran coding. He also became acquainted with the data assimilation theory studying the properties of different algorithms such as the KF, RRKF and EnKF techniques.

To assess the feasibility of implementing the KF scheme in the context of the QG model, timing studies have been performed on a multi-processor computer. In particular, Fedele is interested in running the QG model with 10^4 degrees of freedom. Thus, in the KF algorithm, the challenges faced include the propagation of a covariance matrix of size $10^4 x 10^4$ and the inverse of a matrix of the same size during each assimilation cycling. Using a parallel machine consisting of 12 processors, Fedele found out that the computer time needed to assimilate a one-month period is roughly about 3-4 days. These preliminary studies clearly show the

feasibility of implementing the KF algorithm for the QG model.

The GEST investigator has also been working on understanding certain properties of the RRKF and EnKF assimilation schemes. As regard to these schemes, it is known that the initial error is only corrected in the sub-space of the growing forecast error consisting of the leading initial time singular vectors (SVs) computed over an assimilation time window. Moreover, due to non-modality mechanisms, the evolved leading singular vectors at the end of the time window have little projection onto the initial time leading singular vectors of the next assimilation time window. This implies that the error correction in to the sub-space of the initial time leading SVs may be insufficient since leading errors growing during the next cycle may not be corrected at all.

To get more insights into this problem, Fedele first considered successive time cycles I and II and examined the following question: what are the structures that at the beginning of the cycle I will strongly project onto the leading initial time singular vectors of the next cycle II? He found that these new structures, optimizing their projection onto subsequently growing SVs (initial SVs of cycle II), are very similar to the traditional initial time SVs for the cycle I. In fact, due to non-modality of the error growth, the large amplitude of the evolved SVs, at the end time of the cycle I, is sufficiently larger to compensate for the poor correlation with the successive initial time SVs for the cycle II. This work is being finalized and analyzed with a manuscript describing these results expected to be submitted by summer.

Fedele has been doing also some analytical work in the context of stochastic Gaussian and non-Gaussian processes to investigate the dynamics of both ocean and atmospheric processes during the occurrence of extreme events [Fedele, 2006a, 2006b]. He examined the following question: If an extreme event is recorded at certain time t_0, at a particular point $\mathbf{x}_0$ in space, what happened in the space-time neighborhood of $(t_0,\mathbf{x}_0)$?

It is found that with high probability the extreme event is due to the evolution of a well defined coherent structure (wave group) that as time evolves tends to contract forming an extreme wave and then it decays. The dynamics of the wave group resembles that of the singular vectors. Fedele is trying to find a relation between these two coherent structures that will allow understanding the stochastic nature of perturbation error growth and thus its predictability.

Objectives for the Coming Year

The main objective is to build the data assimilation system for the QG model on a parallel machine. Secondly, different reduced-rank assimilation schemes will be tested both in accuracy and performance through an honest comparison with the reference Kalman Filter solution. Finally, Fedele plans to explore new reduced-rank techniques based on the choice of new kind of singular vectors in order to improve data assimilation quality.

Task 910-19-135: **Studies of Ozone Distribution in the GMAO Satellite Ozone Data Assimilation System**

GEST Investigator: Hiroo Hayashi

Collaborator: Ivanka Stajner (PI, SAIC), Steven Pawson(GSFC)

Abstract

Since the first version of the online ozone data assimilation system (ozone DAS) showed beneficial results for studies on tropospheric and stratospheric ozone, it has been continuously developed and modified. As the GMAO meteorological fields have been operationally produced by the GEOS-4.0.3 data assimilation system, the online ozone DAS was reconstructed based on the GEOS-4.0.3 system. The new

version of online ozone DAS was used for long-term runs, experiments with the EOS-Aura data, etc. A new project for development of another online system to assimilate carbon monoxide data, in addition to ozone, has started.

Description of Research

Ozone is environmentally important because it protects us by absorbing harmful ultraviolet radiation in the stratosphere while acting as a strong oxidant to control other chemical constituents and providing a significant greenhouse effect in the troposphere. The main goal of this research is to provide better understanding of the stratospheric and tropospheric ozone distribution through the assimilation of satellite ozone measurements. For this purpose, online ozone DAS has been developed and used for many experiments. Future studies based on the online ozone DAS would lead to better understanding of the mechanisms to determine the ozone distribution in the real atmosphere.

Accomplishments during the Reporting Period

Although the first online ozone DAS had been developed on the GEOS-4.0.2 meteorological data assimilation system, the ozone assimilation and chemistry modules needed to be reconstructed for the next version of the GEOS system. Since the GMAO assimilated meteorological fields, which are necessary for ozone transport, have been operationally produced with the GEOS-4.0.3 system, a new ozone DAS base on the GEOS-4.0.3 was developed in order to perform experiments for long periods including recent years. The development of a new version of ozone DAS, which started in the last reporting period, was completed and the new ozone DAS has begun being used by the ozone group members, *e.g.*, experiments with the ozone data from OMI and MLS on board the EOS-Aura satellite.

Both versions have been tested with different parameters for the evaluation of the online ozone DAS. A couple of long term experiments were done to investigate interannual variability, differences between the ozone DAS versions, advantages over the offline ozone DAS, etc. This evaluation project has been continued since the previous reporting period and these results will be summarized by the ozone group leader. Some other experiments were made at the requests of researchers who were interested in products of the ozone DAS. Results from the experiments were provided not only for the ozone group members but also for projects out of GMAO (*i.e.*, research groups at Wisconsin University and at Naval Research Laboratory).

To evaluate the online ozone DAS, a large quantity of validation data from various sources since 1998 to the present time necessary. The global ozonesonde soundings were collected from the WOUDC and SHADOZ projects while the long-term satellite observations came from the HALOE, SAGE II and POAM III projects. These data were carefully qualified and processed in the same format for comparisons with the ozone distribution produced by the ozone DAS.

Objectives for the Coming Year

The development of another version of online ozone DAS has already started. In addition to ozone, the new system plans to include a carbon monoxide assimilation module. The planned system would be used to examine uncertainty of current carbon monoxide emission inventory as well as improvements over existing abilities.

Task 971-20-137: **Aquarius Sea Surface Salinity**

GEST Investigator: S. Daniel Jacob

Collaborator: David LeVine (Deputy PI, GSFC), Sirpa Hakkinen (GSFC), Nick Shay (University of Miami), George Halliwell (University of Miami)

Abstract

The primary focus of this task during the current reporting period has been on the development of a sea surface salinity forward model in relevance to the Aquarius Sea Surface Salinity (SSS) Mission. The forward model consists of an ocean general circulation model that simulates SSS and temperature and a microwave emissivity model that simulates the brightness temperatures at the Satellite. These simulated brightness temperatures will be used with auxiliary data to derive the algorithms for the retrieval of SSS from Aquarius measurements. Additionally, mixing parameterizations used in the ocean component of the coupled ocean atmospheric tropical cyclone intensity prediction system were shown to introduce significant variability in simulating the upper ocean heat content. As part of a NOAA sponsored Joint Hurricane Test bed project, multiple simulations were performed for state-of-the-art mixing parameterizations. Results from these simulations were evaluated in comparison with observations for three storms to identify more appropriate schemes for use in the coupled predictive models.

Description of Research

The upcoming NASA Earth System Science Pathfinder (ESSP) Aquarius mission 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 and galactic sources also affect Aquarius measurement. Therefore, a full forward model is needed for the retrieval of SSS. Upper ocean heat potential is an important factor in the rapid intensification of tropical cyclones. During storm passage, a large fraction of ocean cooling and reduction in heat potential is due to entrainment of cooler less turbulent water from below the oceanic mixed layer [Jacob *et al.*, 2000; Jacob and Shay, 2003]. Evaluation of oceanic mixing parameterizations in a hurricane-forced numerical ocean model in collaboration with scientists from the University of Miami is the focus of the NOAA Joint Hurricane Testbed.

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. Based on prior effort, a massively parallel version of the fully global hybrid coordinate ocean model coupled with an ice model (HYCOM) was implemented on the GSFC SC45 super cluster at two horizontal resolutions (2° and 0.72°) and ported to the Goddard SGI Altix super cluster during this period. The model initialized from the Levitus ocean climatology was integrated for 30 years to near dynamical equilibrium. Runoff for approximately 800 rivers in the domain was prescribed using a monthly climatology. Based on previous research (Jacob and Koblinsky 2006, in revision to be submitted to Journal of Physical Oceanography), the climatological Coupled Ocean-Atmospheric Data Set (COADS) is used during the spin-up phase followed by the National Centers for Environmental Prediction (NCEP) reanalysis fields for actual calendar days. The NCEP fields from the year 1948 to present are used to simulate the ocean circulation variability globally. In addition to providing surface salinity and temperatures over three complete three year cycles of Aquarius starting in the early 90s to the present, this period covers two regime shifts in the Pacific Ocean that are being investigated as part of a synergistic effort. A live access server (LAS) hosts relevant data sets used in simulations by the GEST investigator is

available at http://aquarius1.gsfc.nasa.gov:8080/las/servlets/dataset. SSS and temperature simulated by the global model are then interpolated on to a 0.1° horizontal resolution grid consistent with the land-sea mask used in the forward algorithm along with wind speeds, land temperatures and soil moisture from the NCEP reanalysis fields. These are input to the component where the brightness temperatures at the satellite are simulated.

The brightness temperature component of the forward model starts with the Aquarius orbit. Using the temperature, salinity, wind speed and soil moisture data, brightness temperatures are computed over the field of view using the emissivity algorithms for ocean, land and ice. The polarized brightness temperatures are then corrected for the rotation induced by the ionosphere and convoluted with the specified antenna pattern. The goal is to simulate the brightness temperatures over one three year period followed by two other independent three year periods. Effort on combining and optimizing the various pieces of the brightness temperature component is continuing with significant speed up being achieved in the surface module.

As part of a NOAA Joint Hurricane Testbed (JHT) funded project, a primitive equation ocean model configured with different entrainment mixing schemes and available high-resolution oceanic observations during the passage of three tropical cyclones are used to evaluate these schemes. Approximately 40 numerical experiments were performed and following recommendations were made to NCEP based on the results: (1) Ocean model initial conditions need to be validated on a regular basis for a better representation of the ocean as the oceanic thermal structure also significantly affects the observed cooling; (2) Past observations must be used with realistic forcing and initial conditions to further improve the statistical base of comparisons along with routine future observations to evaluate the ocean component on a post-hurricane season basis; and (3) The Mellor and Yamada [1972] scheme is the most appropriate scheme based on the comparison statistics followed by the GISS scheme [Canuto *et al.*, 2001]. Evaluation of these schemes requires ocean only simulations due to the other uncertainties that are introduced because of inaccurate forcing from the atmospheric component.

Objectives for the Coming Year

The major focus for the coming year will be on refining the Salinity forward model including all contributions to the brightness temperature at the L-Band Radiometer. Modeling of the SSS variability for different forcing data sets and its impact on oceanic thermohaline circulation also will be focused upon. Using simulated and *in-situ* data, SSS variability on different temporal and spatial scales is also being investigated. Regional circulation features and associated budgets in the Eastern Equatorial and North Pacific will be investigated using a combination of *in-situ*, remotely sensed and numerical model analyses.

Task 971-00-002: **Moist Physics Parameterization Studies for the NASA's Atmospheric General Circulation Models**

GEST Investigator: Myong-In Lee

Collaborator: Siegfried Schubert (GSFC), Max Suarez (GSFC), Isaac Held (GFDL), Arun Kumar (NCEP), In-Sik Kang (SNU)

Abstract

The simulations of the warm season diurnal cycle in the current AGCMs are investigated, which include the assessments of the impact from the model resolution increase and impact from the moist physics parameterization change. Although marginal improvements are obtained in some models in the higher resolution runs,

they are, in general, model-specific, and the simulated diurnal cycle is more influenced by the moist physics parameterization that is implemented differently among the models. A set of sensitivity experiments using the NASA/NSIPP AGCM showed that modifications of thermodynamic property of the sub-cloud layer and the relaxation time scale increase in the RAS convection scheme improve the diurnal cycle simulation, which highlights the importance of PBL and free-atmospheric processes in regulating diurnal convection. In this study, the model sensitivities to the deep convection scheme in the simulation of the tropical MJO are also investigated for the current AGCMs tested in the highly idealized aqua-planet condition.

Description of Research

Large uncertainties still lie in the moist physical parameterizations and their interactions with the grid-scale dynamics, which contribute to the major source of large diversities in the current climate simulation and future climate predictions by the current AGCMs. With a coordinated effort to understand and improve the moist process parameterized in the models, the investigator has carried out two relevant projects. One is on the warm season diurnal cycle simulation, for which the current AGCMs do poorly in simulating the diurnal cycle and consequently do poorly in simulating the mean warm season climate over much of the continental regions. The other is on the development of a simple framework for the model intercomparisons and the validation of moist physics parameterizations. One of the major applications of the framework is for the improvement in the tropical MJO simulation. Both projects benefit from the extensive intercomparisons of different AGCMs and many sensitivity experiments, which eventually aims to improve the moist physics parameterizations of the NASA's atmospheric general circulation models.

Accomplishments in the Reporting Period

The impact of horizontal resolution on the North American warm season diurnal cycle in three AGCMs (from NASA/GMAO, NOAA/NCEP, and NOAA/GFDL) was analyzed, with a particular focus on the diurnal cycle of precipitation. Ensembles of simulations were carried out for the warm season at typical climate model resolution of about 2° in latitude and longitude, and compared with additional ensembles of runs that differ only in the model resolution (about 1° and 1/2°). In validations with various *in-situ* and satellite observations, increased resolution was found to have mixed impacts on the diurnal cycle of precipitation (especially the phase). In the higher resolution runs, the models begin to resolve the nocturnal rainfall on the downstream side of Rocky Mountains and adjacent Plains. Similar improvements were found on the western slope of the Sierra Madre in the region of the North American monsoon. These improvements appear to be mostly the result of a better representation of the down-slope propagation characteristics of the convective signal initiated over the mountains. The improvements are, however, model specific with the NASA model showing the least sensitivity to resolution changes. The results further suggest that the models in general exhibit too strong coupling of the convection schemes to the surface, which results in weak sensitivity of the convection to large-scale dynamic forcing such as the nocturnal low-level jets [Lee *et al.*, 2006a]. A set of experiments with the NASA/NSIPP AGCM has been carried out to examine the sensitivity to the modification of convection scheme [Lee *et al.*, 2006b]. The results show that the simulation of diurnal convection is quite sensitive to the parameterized thermodynamic property of the sub-cloud layer and the relaxation time scale for the deep convection. The modified scheme tends to delay the phase of diurnal convection in most land regions, which is more close to the observed variation. However, some regions of nocturnal rainfall (*e.g.*, U.S. Great Plains) are still not adequately simulated, and this implies that the PBL and free atmospheric large-scale forcing plays a more important role than surface heat fluxes in initiating or inhibiting convection.

The characteristics of the simulated tropical sub-seasonal variability (15-90 days) in four AGCMs were compared in a simplified aqua-planet framework. The investigated models are the NASA/NSIPP, GFDL/AM2,

SNU/SNUGCM and NASA/GEOS5 AGCMs. The experiment uses the same configuration as the Aqua-Planet Experiment (APE) proposed by Neale and Hoskins [2001], but with a simple mixed-layer ocean of finite heat capacity at the lower boundary, which enables air-sea interaction processes. Although, as in the observation, the dominant tropical rainfall variability simulated by all the models consists of low-frequency eastward propagation signals, their amplitudes and speeds are quite different among the models. Two AGCMs (NSIPP and SNU) are characterized by small amplitude of sub-seasonal variances with fast propagation of convectively coupled equatorial waves, whereas the other two AGCMs (AM2 and GEOS5) are characterized by large amplitude of variances and much slower propagation of equatorial waves. Subsequent analysis and sensitivity experiments suggested that these differences are largely explained by the "Tokioka" modification in their Relaxed Arakawa-Schubert (RAS) convection scheme used in the latter models, which tends to suppress the parameterized convection and enhances the rainfall variability from grid-scale condensation process.

Objectives for the Coming Year

Warm season diurnal cycle simulation will be further investigated, mainly focusing on the response of diurnal convection to the PBL and free atmospheric large-scale forcing. A set of ensemble experiments in 0.5 degree horizontal resolution will be carried out with the newly developed GEOS5 AGCM. The model simulation will be validated particularly over the North American monsoon domain, where the special observations are now available from the NAME 2004 field campaign [Higgins *et al.*, 2006]. For the tropical sub-seasonal variability study, the vertical distribution of diabatic heating, clouds, and surface fluxes will be analyzed to examine the structure of propagating waves and the role of air-sea interaction and cloud-radiation feedback. The study will be also extended to the mid-latitude summertime and wintertime sub-seasonal variability simulated in the atmospheric and ocean-coupled climate models.

Task 910-14-124: **Rainfall and Cloud Assimilation/Interdisciplinary Science Research**

GEST Investigator: Xin Lin

Collaborators: Arthur Hou (PI, GSFC), Wei-Kuo Tao (GSFC), Williams Lau (GSFC), Peter Norris (GEST)

Abstract

A variational framework for assimilating satellite microwave rainfall retrievals has been developed, and its impact on the Goddard Earth Observing System (GEOS) Data Assimilation System (DAS) have been examined over the tropical oceans. This research is trying to apply the same methodology over both the Tropics and the extra-tropics where the atmospheric processes are dominated by different large-scale dynamics and moist physics, and over both the ocean and the land, where rainfall estimates from passive microwave radiometers are believed to be less accurate.

Description of Research

Global microwave rainfall retrievals from a 5-satellite constellation, including TMI from TRMM, SSM/I from DMSP F13, F14 and F15, and AMSR-E from EOS-AQUA, are assimilated into the NASA Goddard Earth Observing System (GEOS) Data Assimilation System (DAS) using a 1-D variational continuous assimilation (VCA) algorithm. The physical and dynamical impact of rainfall assimilation on GEOS analyses and forecasts is examined at various temporal and spatial scales.

Results show that rainfall assimilation renders the GEOS analysis physically and dynamically more consistent with the observed precipitation at the monthly-mean and 6-hour time scales. Over regions where the model precipitation tends to misbehave in distinctly different rainy regimes, the 1-D VCA algorithm, by compensating for errors in the model's moist

time-tendency in a 6-h analysis window, is able to bring the rainfall analysis closer to the observed. The radiation and cloud fields also tend to be in better agreement with independent satellite observations in the rainfall-assimilation run especially over regions where rainfall analyses indicate large improvements.

Accomplishments during the Reporting Period

A paper on the physical and dynamical impact of rainfall assimilation on the GEOS analyses and forecasts has been submitted to the *Monthly Weather Review*, published by the American Meteorological Society.

By collaborating with scientists from NASA GMAO, JPL, ECMWF, and NCEP, the researcher has analyzed a tremendous amount of cutting-edge satellite data to document the evolution of one of the most devastating tropical cyclone ever to hit the United States: Hurricane Katrina. The performance of the ECMWF and NASA global quarter-degree forecasts was evaluated against satellite observations, with a focus on precipitation and cloud. A paper on this research has been submitted to *EOS*, published by the American Geophysical Union.

The Global Precipitation Measurement (GPM) mission being planned for the beginning of the next decade is based on the concept of providing frequent global precipitation measurements using a space-borne precipitation radar as a calibrator of a constellation of passive microwave radiometers. GPM is designed to extend the successful Tropical Rainfall Measurement Mission (TRMM) in the tropics to higher latitudes, but with better temporal sampling and more accurate precipitation measurements. By simulating multiple satellite constellations in a high-resolution GCM and a global cloud model, Lin has been helping to optimize the GPM constellation, and provide guidance to the mission planning.

Objectives for the Coming Year

The objectives for FY 05-06 are to evaluate the impact on the NASA GEOS system after assimilating the heating profile data and to develop algorithms to assimilate satellite cloud data. Also, Lin hopes to start to develop preliminary methodologies to assimilate cloud data into cloud system models.

Another interesting topic the GEST investigator has been working on is to evaluate cloud and rainfall statistics generated by long-term 3-D cloud simulations forced by the NASA GEOS analysis. Lin is also collaborating with the Goddard Cloud Modeling Group to observationally evaluate the new Multi-Modeling Framework.

Task 974-03-070: **Global Land Data Assimilation System (GLDAS)**

GEST Investigator: Jesse Meng

Collaborator: Ken Mitchell (NOAA), Matt Rodell (GSFC), Christa Peters-Lidard (GSFC), Paul Houser (George Mason Univ.)

Abstract

To facilitate the technology transfer from scientific investigation in land surface processes to operational environmental prediction systems, the infrastructure of the Global Land Data Assimilation System (GLDAS) and the Land Information System (LIS) has been implemented on the NOAA/NCEP IBM supercomputers that serve the operational Global Forecast System (GFS, mid-range weather prediction) and Climate Forecast System (CFS, seasonal climate prediction). Two modes of GLDAS experiments are executed following the GFS and CFS configurations, respectively. The Noah land surface model (LSM), same as the land component in GFS and CFS, is executed in GLDAS to perform offline uncoupled land simulation with control and observed forcing options. The GFS mode of GLDAS extends from June 2005, the time of the most recent GFS upgrades, to near real time for updated global land condition monitoring. The CFS mode of GLDAS offers a 25 year land simulation (1980-2005) for global climate assessment. Simulation

results have been presented at various conferences.

Description of Research

Accurate assessment of land surface states—namely, soil moisture, soil temperature, vegetation, and snowpack—is critical in numerical environmental prediction systems because of their regulation of surface water and energy fluxes between the surface and atmosphere over a variety of spatial and temporal scales. GLDAS, developed jointly by NASA/GSFC and NOAA/NCEP, aims to perform high-quality global land simulation using state-of-art LSMs, enhanced surface and satellite observations, and advanced land data assimilation techniques. GLDAS can apply to a wide array of studies in the earth system biogeosciences and has the potential to improve the monitoring, assessment, and prediction of weather, climate, and the terrestrial energy, water, and carbon cycles.

Accomplishments during the Reporting Period

A notable application of GLDAS [Rodell *et al.*, 2004] is to provide enhanced land states and fluxes, via bias-reduced forcing and data assimilation, to numerical environmental prediction systems as the initial and boundary conditions. The GLDAS/LIS infrastructure has been implemented at NOAA/NCEP to perform offline uncoupled execution of the Noah LSM [Ek *et al.*, 2003], using various GLDAS execution options, for the development and execution of the NCEP operational Global Forecast System (GFS) and Climate Forecast System (CFS). It is concluded from the multi-institution (NCEP, GSFC, and several universities) North American Land Data Assimilation System (NLDAS, Mitchell *et al.*, 2004) that land states simulated by different LSMs may have large discrepancies, even though they reveal similar signals of climate variability. To initialize prediction systems with land states from the offline uncoupled LSM execution, such uncoupled execution must be physically consistent with the corresponding land component in the coupled prediction systems. In the software engineering point of view, it is also essential to have consistency in the computing platform, compiler, and libraries, between the offline LSM execution and the prediction systems. Therefore, GLDAS/LIS is implemented on the NCEP IBM supercomputer on which the operational GFS and CFS are executed, using the same compiler and libraries as used for GFS and CFS, and identical configuration as the land component in GFS and CFS, including the same grid specification, land-sea mask, terrain, soil and vegetation classes, and soil and vegetation parameters. The pilot NCEP/GLDAS experiment was configured to the experimental mode of GFS on the Gaussian horizontal grid of T62 (~1.875 degree resolution). Noah is executed, forced with the GFS companion Global Data Assimilation System (GDAS) and the optional observation based radiation and precipitation, for a period of twenty-six months from 01 November 2002 to 01 January 2005. Preliminary results shows that, with the observation based forcing, the GLDAS/Noah simulated surface fluxes are in better agreement with selected observations obtained from the Coordinated Extensive Observation Period (CEOP) [http://www.ceop.net/] reference sites as opposed to the corresponding prediction from the experimental coupled GFS/Noah [Meng *et al.*, 2005]. This pilot GLDAS experiment also participated in developing the most recent GFS upgrade deployed in June 2005 to provide land initial conditions when the previous land component of GFS (OSU LSM) [Pan and Mahrt, 1987] was replaced by Noah along with other major upgrades in the atmospheric physics and dynamics. At present, two modes of GLDAS experiments are continuing to be executed following the GFS and CFS configurations, respectively. The GFS mode of GLDAS (T382 Gaussian grid, ~0.3 degree resolution) starts from June 2005 to present, using GDAS and optional observed forcing, for updated global land condition monitoring. The CFS mode of GLDAS (T126 Gaussian grid, ~1.0 degree resolution) starts from January 1980 to September 2005, using NCEP Global Reanalysis 2 and optional observed forcing, for global climate assessment, also providing the land state ensembles for the development of the next generation CFS.

Objectives for the Coming Year

The following tasks are planned for the coming year: (1) Continuously extend current GLDAS executions and apply the results in a broad monitoring and assessment of weather, climate, and the terrestrial energy and water cycles; (2) Conduct initialization experiments of GFS and CFS with GLDAS land states to evaluate the impact of enhanced land conditions to the prediction; (3) Investigate the procedure to reproduce the land states and fluxes of the coupled GFS/Noah and CFS/Noah, using the uncouple GLDAS/Noah, for further sensitivity test and calibration of Noah; (4) Gather and evaluate additional global and regional precipitation datasets, and construct an integrated product of optimal precipitation forcing for the real time and retrospective GLDAS reruns; and (5) Gather and prepare the global snow analysis back to 1980, and investigate snow assimilation strategy to update the snowpack of the GLDAS executions.

Task 971-00-002: **Land Information System (LIS) Development and Applications**

GEST Investigator: Sujay Kumar

Collaborator: Christa Peters-Lidard (PI, GSFC)

Abstract

The Land Information System (LIS) is a high-resolution, high-performance land surface modeling and data assimilation system to support a wide range of land surface research activities and applications. The system has been demonstrated at high spatial resolutions (such as 1km) globally, with the use of scalable computing technologies. The flexible and interoperable design of LIS enables it to be used in a number of cross-cutting applications. Using advanced computational technologies and software tools, LIS has been coupled to other high resolution atmospheric models such as the Weather Research and Forecasting (WRF) and Goddard Cumulus Ensemble (GCE) models. Many operational and functional extensions for LIS have been proposed, ranging from flood forecasting to use in operational numerical weather prediction.

Description of Research

The land surface and atmosphere are coupled to each other over a variety of time scales through the exchanges of water, energy, and carbon. An accurate representation of land surface processes is critical for improving models of the boundary layer and land-atmosphere coupling at all spatial and temporal scales and over heterogeneous domains. Long term descriptions of land use and fluxes also enable accurate assessments of climate characteristics. In addition to the impact on climate modeling, land surface processes also affect the environment for growth of natural vegetation and provision of water resources. The goal of LIS is to provide a system capable modeling at high resolutions, enabling the ingestion of the vast array of high resolution observations from satellites and other environmental monitoring systems. The ability to operate at the same fine spatial scales of the atmospheric boundary layer and cloud models also helps in improving characterizations of the energy and water cycle.

Accomplishments during the Reporting Period

In the previous year, LIS software was awarded the NASA software of the year award. LIS was chosen from nominations from different NASA centers in the United States [http://icb.nasa.gov/nasaswy.html].

The coupled modeling system using LIS and WRF/GCE was used to perform simulations over a regional area in Oklahoma and results were evaluated against field observations. LIS is used as the land modeling component in the coupled system, enabling the use of an ensemble of land surface models, high resolution data, and data assimilation techniques. The impact of using realistic, high resolution land surface initial conditions on mesoscale processes such as convective initiation was demonstrated using the coupled system. The coupled system has been enhanced significantly and supports the use of multiple land surface models, and advanced

modeling options such as the usage of nested domains.

The coupled LIS-WRF system has been used to conduct several scientific evaluations. An investigation of the meteorological model's dependence on the radiation update frequency was conducted. The mesoscale processes were found to have a significant dependence on the choice of such model parameters.

LIS has also been used in scientific studies to evaluate the effectiveness of land surface heterogeneity representations in capturing subgrid scale variability. The studies have revealed the limitations of the heterogeneity representations especially over areas where pronounced heterogeneity exists. The representation of the land surface parameters were also found to significantly influence the feedback processes in the land-atmosphere system, affecting processes such as mesoscale convection.

The LIS tool has also been deployed to generate the level 4 products that combine the satellite observations and model predictions for soil moisture missions, using the capability of LIS to assimilate and constrain models with satellite observations.

A new paradigm using look-up-tables (LUTs) to represent parameterizations within numerical weather prediction and other atmospheric model was pursued through a NASA proposal call. Although this effort was not funded, a journal article describing the idea has been published.

LIS capabilities have been enhanced to replace the Air Force Weather Agency's operational land data assimilation system known as AGRMET. The LIS system has been enhanced to support the AGRMET radiation and precipitation processing schemes.

LIS has been employed to provide distributed modeling support for the Romanian destructive water abatement project. Algorithms for stream channel routing and distributed routing models were implemented in LIS as part of this effort.

Objectives for the Coming Year

In the coming year, Kumar plans to utilize the enhanced LIS-WRF system to perform a number of case studies over large domains to study the impact of high resolution land surface conditions on mesoscale processes. These studies will also focus on providing insights into the influence of land surface heterogeneity impacts. The GEST investigator plans to finish the benchmarking process for AFWA and continue the development of data assimilation algorithms into LIS. The data assimilation capability is expected to be utilized by a number of projects, including the effort to develop level 4 products, NASA energy and water cycle studies, etc. The AFWA has funded another effort to improve the precipitation processing and assimilation in LIS. This project will attempt at developing an improved precipitation processing and utilizing some existing precipitation climatological products.

Task 974-44-184: **Delivering the Award-Winning Land Information System**

GEST Investigator: Yudong Tian

Collaborator: Paul Houser (PI, GSFC), Christa Peters-Lidard (Co-PI, GSFC)

Abstract

Since 2002, the Land Information System (LIS) has been in development at GSFC. LIS is designed to be a leading-edge land surface modeling and data assimilation framework, to support broad land surface research and application activities. Development of the LIS was completed this year and was successfully delivered to its many customers. The final LIS has solid science modeling capability, technology innovation, interoperability and usability. LIS has enjoyed wide adoption by government, academic and commercial communities, and has been used to support

NASA missions. These accomplishments made LIS the co-winner of NASA's Software of the Year Award in 2005.

Description of Research

The Land Information System software [http://lis.gsfc.nasa.gov/] is a high performance land surface modeling and data assimilation system. It integrates parallel and distributed computing technologies with modern land surface modeling capabilities, and establishes a framework for easy interchange of other land surface models. The software includes an ensemble of land surface models and can be run regionally or globally on grids with horizontal resolutions ranging from 2.5 to 1km. The software may execute serially or in parallel on various high performance computing platforms. In addition, the software has well-defined, standard-conforming interfaces and data structures to interface and interoperate with other Earth System models. Developed with support from the Earth Science and Technology Office (ESTO), LIS has helped advance the Earth-Sun division's software engineering principles and practices, while promoting portability, interoperability and scalability.

Accomplishments during the Reporting Period

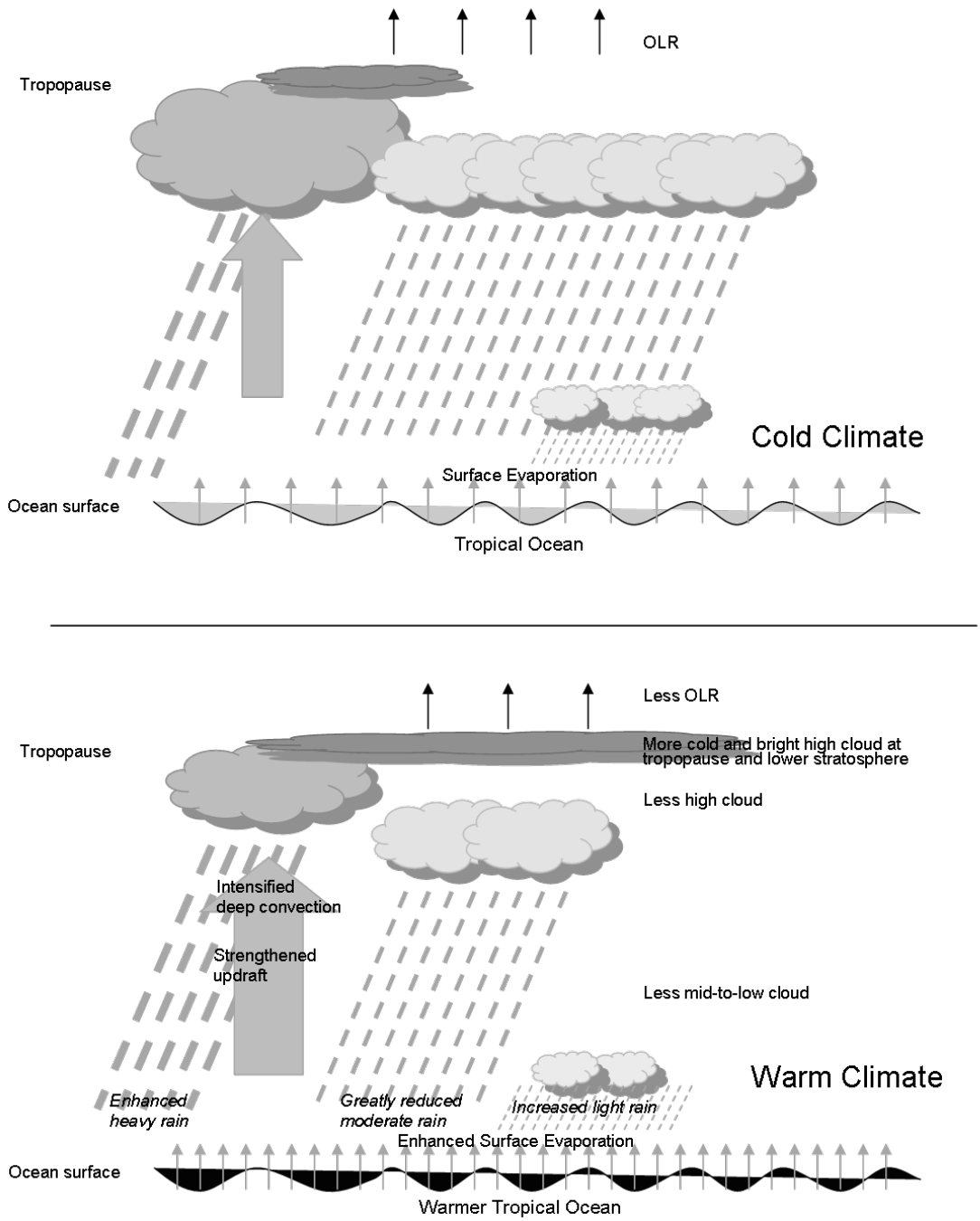
The LIS software met all the performance, portability, and interoperability requirements to enable near-real-time simulations at the full 1km resolution represented by EOS-era level 3 products, while generating 600 Gb per day of level 4 products. The LIS software includes a fault-tolerant job management system run on Linux clusters or other parallel systems, high-performance, high-availability parallel I/O based on the Graphical Analysis and Display System (GrADS)-Distributed Oceanographic Data System (DODS) servers with dynamic load-balancing and distributed data storage, and highly scalable data replication with peer-to-peer technology. The design, in addition to our compliance with the Earth System Modeling Framework (ESMF) is critical in making LIS a high performance Earth System modeling component with broader applications.

LIS is currently licensed to over 170 registered organizations—each consisting of multiple users—including 11 unique federal and state government partners and 45 universities/academic institutions, in addition to commercial and international interests from 19 unique foreign countries. A unique aspect of LIS is that the primary users include several federal agencies whose mission is to provide environmental forecasts that are in turn used by millions worldwide. NASA users include the science teams of the currently orbiting GRACE, TRMM, and Aqua/AMSR-E products. Other important NASA users include the Goddard Modeling and Assimilation Office (GMAO) and the Global Land Data Assimilation System (GLDAS). A key operational user is the joint NOAA/NASA National Land Data Assimilation System-Eta (NLDAS-E). Federal users and partners include NOAA's National Centers for Environmental Prediction, the Bureau of Reclamation, the U.S. Environmental Protection Agency, the Air Force Weather Agency (AFWA), and the U.S. Army Corps of Engineers/Engineering Research and Development Center (USACE). The LIS products are also used by two large international projects, namely the WMO's Coordinated Enhanced Observing Period (CEOP), and the WCRP's Global Energy and Water Cycle Experiment (GEWEX) Global Soil Wetness Project-2. Finally, LIS has been transferred to several commercial systems integrators, including Baron Advanced Meteorological Systems (BAMS) and Riverside Technologies, who specialize in weather and other environmental information services.

Objectives for the Coming Year

As LIS is now running in production mode, the GEST investigator will be focusing on science investigations using LIS as a powerful tool to help this research. Specifically, Tian wants to use LIS with the TRMM precipitation products to study the impact of these products on land surface hydrological simulations in the southeast U.S. This investigation will demonstrate how TRMM datasets help with flood/drought modeling, and will provide guidance to future precipitation measurement missions, such as GPM.

Global Modeling, Data Impact and Data Simulation Research Group



This schematic diagram illustrates the tropical ocean mean condition of the hydrological system in (a) a cool climate and (b) a warm climate, to reflect the contrast of tropical hydrologic climate before and after the effects of external climate forcings take place in state-of-the-art Coupled GCM (CGCM) simulations. When external climate radiative forcing increases, the change in precipitation is characterized by enhanced heavy rain and light rain, and greatly reduced moderate rain. The mean upward vertical velocity in the middle troposphere strengthens. Clouds significantly reduce in the upper troposphere, and greatly increase in the tropopause and lower stratosphere. The overall tropical convection has increased. This work has been published in International Journal of Climatology (Wang and Lau 2006), and will be included in the Intergovernmental Panel on Climate Change (IPCC), the Fourth Report (AR4). (Figure provided by Hailan Wang.)

Global Modeling, Data Impact and Data Simulation Research Group

The work performed by the members of the Global Modeling, Data Impact and Data Simulation Research Group (former GMAO-B) is focused on atmospheric, land, and oceanic data assimilation and modeling on a global scale, development of next generation global atmospheric models, data impact and simulation, and hurricane studies. The group consists of scientists supported by the Global Modeling and Assimilation Office (GMAO) and by the Goddard Laboratory for Atmospheres (GLA). The group reduced its size in 2004 and has undergone some further change during 2005: two of the five individuals supported by GMAO are now in other GEST groups (Xin Lin and Rolf Reichle), whereas four new scientists have become a part of the group: Juan Carlos Jusem, Sarith Mahanama, Lars Nerger and Hailan Wang. The scientists of the group, despite its relative small size, have produced 11 co-authored articles on peer-reviewed journals and had one proposal funded.

There is a wide variety of expertise that cannot be summarized but individually. Among the GMAO-funded scientists, Sarith Mahanama performs research on land surface modeling with emphasis on soil enthalpy memory and its impact on subseasonal to seasonal forecasting and precipitation variability. Lars Nerger is working on an ocean biogeochemical (OB) assimilation EOS model and has implemented a methodology based on the Kalman filter to assimilate SeaWiFS chlorophyll data into the NASA OB model. Peter Norris is involved in cloud assimilation studies, continuing the development of a cloud parameter estimation scheme to assimilate satellite inferred cloud data into the GMAO data assimilation system (GEOS5 DAS). He also collaborates in theoretical studies on a new cloud parametrization scheme. Lars Peter Riishojgaard leads the satellite data analysis group within the GMAO. The role of this group is to serve as a central resource within Goddard and the rest of NASA for atmospheric modeling and assimilation of satellite data in particular. He is also involved in the continued development of the scientific, technical and programmatic aspects of a new space mission, the Molniya Orbit Imager. Chaojiao Sun has been working primarily in ocean data assimilation in a global ocean circulation model. Her most important achievement is the evaluation and validation of the GMAO and GFDL data assimilation systems in experiments where identical forcings and observations were used. Important general questions related to ocean assimilation systems have been answered thanks to her work.

Among the scientists supported by the GLA, Kao-San Yeh, who is involved in global atmospheric modeling, has been developing a new integration method on a geodesic grid that is to become the dynamical core of the next-generation NASA finite-volume general circulation model (fvGCM). Hailan Wang works on two different tasks. One is the evaluation of the hydrological cycles in the Tropics, as a part of the US CLIVAR Climate Model Evaluation Project (CMEP). The second is the assessment of the impact of extratropical air-sea interaction on warm season precipitation anomalies predictability over the U.S. This second task is part of the NASA Seasonal to Interannual Prediction Project (NSIPP). Juan Carlos Jusem is a visiting senior research scientist who is working predominantly on the application of satellite surface wind data to improved ocean surface analyses and numerical weather predictions. He is also the Co-I of a recently funded proposal on Observing System Simulation Experiments, of which Oreste Reale is PI. Goal of this proposal is to assess the impact of existing observing systems and to simulate the impact of future ones. Beyond research on OSSE, Oreste Reale is involved primarily in synoptic and dynamic evaluations of the fvGCM, with emphasis on tropical cyclones.

All these efforts are meant to provide some practical applications to a large community of users, namely the entire GMAO, the Laboratory for Atmospheres, and (more generally) the entire NASA community involved with Earth and Sun Exploration sciences. All the scientists in the group are part of a complex, multitasking, multidisciplinary team effort that can be evaluated in its entirety only over several years of activity. In particular, designing and developing complex data assimilation code is extremely beneficial

for a broad community of users, but publications from this work often occur once every few years. In spite of the group's small size and of the demands of team work, the scientists generated 11 publications accepted or published in major peer-reviewed journals during the reporting period. It is expected that in the next year more of the obtained results, currently at the submission stage in several journals, will appear in the international scientific literature.

All scientists in this group have been demonstrated their motivation, their knowledge, their enthusiasm and their skill, steadily progressing towards carefully planned long-term research goals.

Oreste Reale

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

GEST Investigator: Juan Carlos Jusem

Collaborator: Robert Atlas (PI, NOAA), William Lau (GSFC)

Abstract

Several meteorological and oceanographic applications necessitate highly accurate observations of surface wind velocity. These are needed to run sea wave models; to get reliable estimates of fluxes of heat, momentum and water substance; and to construct surface climatologies. Additionally, surface winds constitute a necessary ingredient in the description of the weather and wave intensity at sea. Finally, surface wind data are useful to Numerical Weather Prediction (NWP) models by providing them both initial conditions and ground truths for forecast verification. The WINDSAT satellite, launched in December 2002, produced the surface wind data analyzed in this research. The period of analysis is January 2004.

Description of Research

The role of the GEST investigator in this task was to compare wind patterns extracted from WINDSAT and surface wind analyses produced by National Center for Environmental Prediction (NCEP). In the case of discrepancies, the researcher used cloud photos taken in the infrared by the Geostationary Operational Environmental Satellite (GOES) as another element of verification.

Accomplishments during the Reporting Period

It was possible to detect several discrepancies between WINDSAT windfield and the corresponding NCEP analysis. The most outstanding difference corresponds to 18 UTC / 6 January 2004 in the North Atlantic. WINDSAT captured a vortex pair near Greenland that was confirmed by GOES photos, but ignored by NCEP. This underlines the importance of using satellites in the early detection of storm systems. Another discrepancy, which took place earlier at 18 UTC / 2 Jan, was also observed in the North Atlantic and consisted of a well-defined cold front, detected by WINDSAT, corroborated by GOES, but absent in NCEP analysis. By the end of the reporting period, a proposal on Observing System Simulation Experiments (OSSE), which Oreste Reale of GEST is PI and Juan Carlos Jusem is Co-I, was funded, which will continue this investigation into surface wind discrepancies between reporting instruments.

Objectives for the Coming Year

The main objective will be to support OSSE. In particular, an important goal is the evaluation and utilization of the new one-year simulation by the ECMWF, currently in progress. The evaluation of the simulation (called “nature run”) will consist in establishing the level of likelihood of the different variables (temperature, wind, moisture, etc.), especially their respective range. The main utilization of the “nature run” is to identify advantages and/or deficiencies of the different prospective instruments whose impact on analysis and forecasts are to be studied, such as wind LIDARs.

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

Collaborator: Michele Rienecker (PI, GSFC), Randal Koster (GSFC), Max Suarez (GSFC)

Abstract

The GEST investigator explored soil enthalpy memory and its implications to subseasonal-to-seasonal forecast of AGCMs through two long-term AGCM experiments. The first was a standard AMIP-type ensemble experiment in which deep soil temperature continually interacted with the rest of the processes, while in the second experiment daily mean climatology of deep soil temperature from the first experiment was prescribed. The two experiments helped isolate the impact of persistence of ground heat (as its association with deep soil temperature) to the seasonal temperature and precipitation forecast skill of the AGCM. Removal of the variability deep soil temperature had produced a significant reduction in the persistence in surface temperature, as expected. The most interesting finding is the increased summer precipitation variability in the region of middle-north America. In a separate study, correction to the surface albedo parameterization scheme in the GEOS5 AGCM was implemented using the Moderate Resolution Imaging Spectroradiometer (MODIS) derived albedo products. Monthly scale parameters were computed to impose the MODIS albedo climatology while preserving the capability to capture the diurnal variation of surface albedo in the AGCM. Implementation of albedo-correction scale parameters showed an increase in surface temperature in North Africa, and a decrease in evapotranspiration in Amazon and Congo forests. Satellite surface temperature retrievals from the ISLSCP (global 3-hourly) for the period of 1986-1995 were processed and a global surface temperature assimilation experiment for the catchment LSM was set up as the third project. The final project was a water energy budget study in Sri Lanka focusing on predictability of inter-monsoon streamflow.

Description of Research

Proper understanding on the impact of land surface variability on seasonal prediction of precipitation and temperature of AGCMs should, in principle, increase the skill of AGCM's forecasting skill. As a member of the land modeling group of GMAO, the GEST investigator studies land-atmosphere interaction as influenced by land surface processes, and works to continually upgrade land surface parameters using the most recent satellite observations.

Accomplishments during the Reporting Period

During the AGCM study to assess the impact of subsurface temperature variability on meteorological variability, the investigator discovered anomalous atmospheric conditions that can lead to surface temperature anomalies, which in turn can lead to temperature anomalies deep in the soil. The deep soil temperature (and the associated ground heat content) has significant memory—the dissipation of a temperature anomaly may take weeks to months—and thus deep soil temperature may contribute to the low frequency variability of energy and water variables elsewhere in the system. The memory may even provide some skill to subseasonal and seasonal forecasts.

This study uses two long-term AGCM experiments to isolate the contribution of deep soil temperature variability to variability elsewhere in the climate system. The first experiment consists of a standard ensemble of AMIP-type simulations, simulations in which the deep soil temperature variable is allowed to interact with the rest of the system. In the second experiment, the coupling of the deep soil temperature to the rest of the climate system is disabled—at each grid cell, the local climatological seasonal cycle of deep soil temperature (as determined from the first

experiment) is prescribed. By comparing the variability of various atmospheric quantities as generated in the two experiments, we isolate the contribution of interactive deep soil temperature to that variability. The results show that interactive deep soil temperature contributes significantly to surface temperature variability. Interactive deep soil temperature, however, reduces the variability of the hydrological cycle (evaporation and precipitation), largely because it allows for a negative feedback between evaporation and temperature.

The second accomplishment is a new look at the assimilation of satellite retrievals of land surface temperature into a land surface model (ongoing collaboration with GEST colleague Rolf H. Reichle). Satellite retrievals of land surface temperature (LST, also referred to as "skin temperature") are available from a variety of polar orbiting and geostationary platforms. Assimilating such LST retrievals into a land surface model (that is either driven by observed meteorological forcing data or coupled to an atmospheric model) should improve estimates of land surface conditions. However, LST data from retrievals and models typically exhibit very different climatologies for a variety of reasons. For example, LST modeling is fraught with numerical stability problems, because the heat capacity associated with LST is very small. This requires land modelers to approximate the heat capacity as zero, or else be limited to a surface temperature prognostic variable that represents several centimeters of soil. LST retrievals from satellite, on the other hand, are strongly affected by the look-angle, a problem that is particularly acute with geostationary satellites. Moreover, satellites observe a radiometric temperature that is difficult to compare to the model's LST because the emissivity of the land surface is not well known. Finally, LST retrievals from different satellite platforms already exhibit different climatologies due to different sensor characteristics.

The assimilation of LST retrievals into a land surface model may thus benefit from a scaling approach whereby the LST retrievals from each sensor are scaled to the model's LST climatology before they are assimilated into the land model. After assimilation, the merged LST product may be scaled back into the climatology of the LST retrievals if the application calls for it. A simple and effective scaling method is to utilize a mapping between the cumulative distribution functions of the satellite and model data. Because of the strong seasonal and diurnal cycle of LST, scaling parameters must be derived separately for each 3-hour interval and for each month. Global, 3-hourly LST retrievals from the International Satellite Cloud Climatology Project (ISCCP) were processed for the period 1986 through 1995, and the experiment framework was set up for the assimilation into the NASA Catchment land surface model as it is driven with surface meteorological forcing data from the Global Soil Wetness Project 2 (GSWP-2).

The third accomplishment is related to surface albedo correction using MODIS Albedo products in the GMAO Land Surface Model. The catchment LSM (which is coupled to the GEOS-5 AGCM) uses a surface albedo parameterization scheme based on the Simple Biosphere (SiB) Model. The SiB parameterization scheme provides visible and near-infrared albedo, beam (black-sky) and diffuse (white-sky) albedo to the AGCM. Each spectral band is computed from weighted average of snow-free and snow albedo on land elements while snow-free albedo will be inserted directly into surface radiation calculations, with snow cover albedo (fraction of each catchment) is determined separately and combined in weighted mean at the land surface. Furthermore, the SiB parameterization scheme captures the diurnal variation of albedo using the zenith angle and vegetation parameters (LAI and Greenness fraction).

The MODIS albedo products have been made available for the period of 2000 through 2004 at a very high spatial resolution (global 1 min.), and a temporal time scale of approximately twice a month. Comparison between the MODIS and the AGCM albedo climatologies showed biases elsewhere around the world and that may affect the seasonal forecast of the AGCM. The climatology of the SiB albedo was computed by forcing the Catchment LSM offline for a 10-year

period for all the land-grid resolutions of the GEOS5 system (there are 5 different spatial resolutions varying from 4° to $1/4^o$) separately. The ratio between mean monthly MODIS and SiB albedos was constructed as the monthly scale factor for the albedo-correction. The method essentially imposes the MODIS climatology while preserving SiB formulation for the diurnal variation. These scale factors will be implemented in the GEOS5 modeling system, and an offline experiment with catchment LSM for a period of 10-years showed the albedo-correction yields a high surface temperature in north Africa and low evaporation in the Amazon and Congo forests and some regions around the world, compared to the SiB parameterization.

The fourth accomplishment is a study on water and energy budget in Sri Lanka, with emphasis on the predictability of Inter-monsoon Streamflow. Global water energy budget studies as well as long term soil moisture observation records have shown that the time scales of soil moisture anomaly dissipation is about 2-3 months. If soil moisture is predictable at seasonal time scales, the baseflow component of streamflow should, in principle, be predictable. This was being explored in this study.

Rainfall is low during inter-monsoon seasons in Sri Lanka and streamflow production in those seasons is mainly coming from the stored water in the soil moisture reservoir during the monsoon seasons. Proper understanding on streamflow production is important due to its socio-economic implications. Because of a dearth of long-term records of soil moisture observations for such analysis, researchers are forced to look for alternative methods. One such method used an accurate water and energy budget analysis to produce soil moisture estimates on the land surface. An atmospheric forcings data set was prepared for such analysis by merging a locally observed gridded (0.25°) precipitation data set with bias-corrected ERA-15 global reanalysis forcings data for the period 1979 through 1993. This data set was used to force the catchment LSM for the same period on 165-land elements (extracted from the highest resolution of the GEOS5 grid system) that comprises the study area of 65,160 km^2. Monthly streamflow observations from 10 measuring stations and surface temperature observations from 18 stations for the same period provided the platform for model evaluation. Model runoff and temperatures were in good agreement, and the results, in part, validated the model performance in the tropics. It also underscores the usefulness of global reanalysis forcings data on local hydrologic applications. The results indicated that the model soil moisture estimations are good enough for the predictability analysis. Autocorrelation of soil moisture was computed for the 4 seasons. It showed that the soil moisture memory is high (about 3 months) in all the seasons except for high rainfall season October - December. Site observations of soil moisture from 6 measuring stations (though some station data records do not fall inside the simulation period) were analyzed compared observed soil moisture dissipation time scales with that of the simulations. Both looked very similar. For the last part of this study, linear regression analysis will be performed to isolate the soil moisture and atmospheric contributions to the seasonal runoff predictability.

Objectives for the Coming Year

The GEST investigator will explore land-atmosphere coupling strength using the Single Column Model (SCM) through a series of experiments. The SCM is an offshoot of the GEOS5 AGCM that uses the same physics and software structure as the AGCM. Since the SCM is run on a single vertical column, using tower observations, the framework provides an ideal setting for computationally manageable sensitivity experiments at the land-atmosphere boundary.

Task 900-55-207: **Development of an Ocean Biogeochemical EOS Assimilation Model**

GEST Investigator: Lars Nerger

Collaborator: Watson Gregg (PI, GSFC)

Abstract

A simplified version of the SEIK filter with localized analysis, which is based on the Kalman filter algorithm, has been implemented with the NASA Ocean Biogeochemical Model (NOBM). The assimilation of the total chlorophyll data from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) under the constraint that the relative abundances of the Phytoplankton groups in the model remain unchanged, results in a significant improvement of the model-estimated chlorophyll compared to model simulations without assimilation. The assimilation provides an estimate of the complete surface chlorophyll field. Compared to independent *in-situ* data, the assimilation estimate shows in several regions smaller errors than the SeaWiFS data alone. Furthermore, the estimate of the annual primary production is strongly improved.

Description of Research

Satellite observations of ocean surface color provide nearly global information of the distribution of ocean surface chlorophyll. Due to the measurement of radiances in the visible part of the light spectrum, gaps in the observations result from clouds or polar nights. In addition, the satellite track results in regular data gaps. By assimilating ocean chlorophyll data into the global three-dimensional NOBM, which simulates physical, biogeochemical, and radiative processes, a complete chlorophyll field can be obtained together with other model field such as nutrients. In addition, derived variables like primary production can be produced. Furthermore, the combination of the observations with the NOBM has the potential to improve the understanding of the fundamental processes governing the distributions of biogeochemically important variables observed from space. Together, the performance of different assimilation systems can be studied.

Accomplishments during the Reporting Period

This task was initiated with the implementation of a simplified variant of the SEIK filter with localized analysis into the NOBM. The parallel data assimilation framework (PDAF) provides the filter algorithm [Nerger *et al.*, 2005]. The localized analysis [Nerger *et al.*, 2006] is obtained by the subsequent update of each single surface grid point of the model taking into account only observations within a specified distance from this grid point. While PDAF contains the full dynamic SEIK filter, a simplified variant of the algorithm is created by keeping the covariance matrix, which estimates the errors in the model state, constant. This avoids the requirement of an ensemble integration of model states, which strongly reduces the computational requirements of the assimilation process. The assimilation is configured such that only the surface chlorophyll field of the model is changed. Due to the fact that the model simulates four Phytoplankton groups (Diatoms, Chlorophytes, Cyanobacteria, and Coccolithophores) while only the total chlorophyll concentration is observed, the total chlorophyll concentration of the model state is computed as the sum of the Phytoplankton groups. In addition the assimilation update is performed under the constraint that the relative abundances of the Phytoplankton groups remain unchanged.

The assimilation system was applied to assimilate daily chlorophyll concentrations from SeaWiFS, which are interpolated to the model grid. The assimilation was performed over a period of seven years (1998-2004). The model error covariance matrix is initialized from a multi-year simulation of the NOBM without assimilation. The error estimates for the observations are assumed to be regionally varying. They are motivated by the varying deviations of SeaWiFS ocean chlorophyll data from independent *in-situ* observations of total

chlorophyll concentrations. Parameter studies have been performed to optimize the choice of observation errors and parameters like the influence distance of observations in the local SEIK analysis.

The assimilation provides complete estimates of the total ocean surface chlorophyll concentration as well as the fields simulated by NOBM (Phytoplankton groups, nutrients, etc.). The assimilation strongly improves the model estimated total chlorophyll concentration compared to the assimilated SeaWiFS data as well as compared to independent *in-situ* data. In addition, chlorophyll fields are provided which have a full coverage of the model domain in contrast to incomplete coverage of daily SeaWiFS data. Compared to *in-situ* data, the estimated chlorophyll concentration shows a smaller error in several regions of the global oceans than the daily SeaWiFS data. The NOBM also provides estimates of the primary production. While the free-run model overestimates the primary production, the assimilation reduces it to a value consistent with estimates from the Vertical Generalized Production Model (VGPM), which computes primary production from the SeaWiFS data only.

Objectives for the Coming Year

In the coming year, the assimilation system will be further developed. First, the investigator plans to update the lower layers of the model during the analysis of the SEIK filter. In addition, a multivariate analysis is planned, which also updates other model variables, like nutrients, during the analysis. To improve the error estimates of the model state, the implementation of the full SEIK filter with ensemble integration is planned. The performance of the full SEIK filter will be compared to that of the simplified filter.

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

GEST Investigator: Peter M. Norris

Collaborator: Arlindo da Silva (GSFC), Arthur Hou (GSFC)

Abstract

It is widely recognized that clouds play an essential role in moderating the climate. This recognition has prompted the continuing development of new cloud parameterizations for global climate models. What is currently needed is the ability to test these new parameterizations against different sources of observed and retrieved cloud information with global or large-scale coverage. Furthermore, at a time when many forms of ground-based and remotely-sensed data are being assimilated into global models—such as the NASA Global Modeling and Assimilation Office (GMAO) GEOS system—there are currently few mature efforts to directly assimilate cloud information into models. This is the background for this task within the GMAO to use retrieved cloud information to validate cloud properties within the GEOS model, to measure the capability of various new trial cloud parameterizations, and to assimilate cloud measurements directly into the data assimilation system. This work is largely funded by the Cloud-Radiation Modeling and Assimilation IDS, of which Dr. Arthur Hou is the PI.

Description of Research

Satellite cloud data assimilation work with Dr. Arlindo da Silva was written and submitted to the *Journal of the Atmospheric Sciences*. Work on incorporating the Cloud Parameter Estimation System into the new GEOS-5 DAS focused on developing an ESMF-compliant "Cloud Data Gridded Component" to provide various sources of satellite cloud data on the grid of the GEOS-5 model in a flexible way. Theoretical work was conducted on a new assumed-PDF statistical GCM cloud parameterization scheme (with GEST colleague Dr. Julio Bacmeister) that includes sub-gridscale variations in temperature, specific humidity, and condensed water content. Most existing statistical parameterizations only account for

moisture variability, while ignoring known and substantial subgrid-scale temperature variability. The new scheme should better capture the range of subgrid-scale variability present in MODIS and other high-resolution satellite cloud data, in preparation for assimilating this data. Instrument simulation experiments for a potential ESSP mission (SIRICE) to measure ice crystal mass and size using a sub-millimeter radiometer were conducted with Dr. David Starr, Dr. Steve Ackerman, Dr. Frank Evans, and Dr. Arlindo da Silva. These simulation experiments helped to quantify the sampling errors for a polar orbiting conical scanning radiometer by using the GMAO GEOS-5 GCM. As Co-I, assisted in the preparation of three NASA proposals on the theme of utilization of new satellite cloud data for validation and improvement of GEOS-5 cloud simulation and assimilation.

Accomplishments for the Reporting Period

Previous work involved developing a new cloud parameter estimation system (CPES), in collaboration with Dr. Arlindo da Silva, to assimilate ISCCP, SSM/I, and MODIS cloud data using a variational parameter estimation method. The CPES has shown positive impact not only on the modeled cloud properties (which were previously quite poor in the analysis) but also on the longwave and shortwave cloud forcing as independently validated against CERES top-of-atmosphere data. The first part of this work was submitted during the current reporting period [Norris & da Silva, "Assimilation of satellite cloud data into the GMAO Finite Volume Data Assimilation System using a parameter estimation method. Part I: Motivation and Algorithm Description," submitted to the Journal of the Atmospheric Sciences, January 2006]. A second paper with expanded analysis of the results is also close to being ready for submission.

Work on incorporating the CPES into the new GEOS-5 DAS has centered on developing an ESMF-compliant "Cloud Data Gridded Component." This software facilitates the extraction of various sources of cloud data onto the grid of the GEOS-5 model in a flexible way. Existing ISCCP-DX software has been incorporated into the new system. Existing MODIS and SSM/I software will be incorporated shortly. Using the Earth System Modeling Framework (ESMF) is consistent with GEOS-5 policy, and also allows the software to have future wider use within the satellite cloud data community.

In terms of GEOS-5 cloud parameterizations, the GEST investigator has been conducting research into higher-dimensional assumed-PDF statistical cloud parameterization schemes in collaboration with Dr. Julio Bacmeister. A new scheme under development includes sub-gridscale variations in temperature, specific humidity, and condensed water content. Most existing statistical parameterizations have the limitation of only accounting for total water content variability, while ignoring known and substantial subgrid-scale temperature variability. The motivation for this work is not only to improve cloud properties with the GEOS-5 GCM, but to also provide a parameterization that is capable of capturing the full range of subgrid-scale variability present in MODIS and other high-resolution satellite cloud data, in preparation for assimilating this data.

Initial work has included microphysical cloud droplet growth calculations performed in support of the parameterization design, and analytical derivations of the parameterization equations for a simple bounded PDF in total and liquid water content and temperature.

The researcher spent time preparing three ROSES proposals for which he was a Co-I with significant time: (a) *Assimilation of Cloud/Precipitation Information from CloudSat and A-Train in a Cloud-Resolving Model for Improving Global Forecast and Climate Systems,* PI: Dr. Arthur Hou (GSFC), a CloudSat and CALIPSO ROSES-2005 NRA; (b) *Improved clouds and radiation in GEOS-5 from global analysis, parameterization and assimilation of A-Train cloud retrievals*, PI: Dr. Lazaros Oreopoulos (JCET), a CloudSat and CALIPSO ROSES-2005 NRA, and (c) *Validation of Global Circulation Model Cloud Parameterization using GLAS Atmospheric Channel Measurements*, PI: Mr. Stephen Palm (SSAI), an ICEsat ROSES-2005 NRA. These proposals had a common theme of using new

types of satellite cloud data in conjunction with the GEOS-5 DAS and for improved cloud and radiation parameterization development.

Objectives for the Coming Year

The analytical work for the new cloud parameterization with the first candidate sub-gridscale moisture and temperature PDF will be completed shortly. This new cloud parameterization will be tested in GEOS-5. The influence of non-phase change processes (*e.g.*, turbulence) on the PDF will be investigated with Dr. Julio Bacmeister. The parameterization will be extended to a PDF having skewed variability in both temperature and moisture. The existing cloud parameter estimation system will be implemented in GEOS-5 in an ESMF-compliant manner, and driven using ISCCP and MODIS Level-II cloud data constraining the new PDF parameterization. Part II of CPES write-up will be submitted to JAS. Extensions of the SIRICE simulation experiments will be performed with the new cloud parameterization. Connection of the new PDF cloud parameterization with statistical radiative transfer work by Dr. Lazaros Oreopoulos of JCET will be implemented in GEOS-5.

Task 910-08-99: **Synoptic-Dynamic Evaluation and Improvement of the NASA Finite Volume General Circulation Model**

GEST Investigator: Oreste Reale

Collaborator: Robert Atlas (PI, NOAA), William Lau (GSFC)

Abstract

This task was originally focused on the synoptic and dynamic evaluation of various aspects of the finite volume general circulation model developed at GSFC. The research was performed within the `Data Impact and Modeling Team' in the Laboratory for Atmospheres at the NASA Goddard Space Flight Center, originally led by Dr. Robert Atlas. The main goal under this task was to investigate and improve the representation of high-impact weather systems in the finite-volume General Circulation Model (fvGCM), with emphasis on tropical cyclones. Dr. Reale was also leading the science evaluation of the so-called NASA Project Hurricane, to assess the performance of the second version of the model during the past hurricane season. The research performed under this task has produced co-authorship on three peer-reviewed articles and the 2005 NASA Laboratory for Atmospheres Outstanding Performance Award.

After the departure of Dr. Atlas, the main collaborator of the present task became Dr. Lau. The goal of this task now includes a more general assessment of tropical cyclogenetic processes within the Atlantic, impact of Saharan air and Saharan dust over cyclogenesis, and, more generally, the African Monsoon.

At the end of the reporting period, the GEST investigator had also become the PI of an awarded grant on the Observing System Simulation Experiments (OSSE). This will represent a separate task in the forthcoming years.

Description of Research

The main goal of this task is to evaluate the potential of the fvGCM in simulating weather events at spatial and temporal scales near the limits imposed by model resolution, or events that generally represent a challenge from the modeling and data assimilation perspectives, particularly tropical cyclones. The research also explores the impact of different data types (*e.g.*, satellite-derived wind and rainfall data etc.) and model improvements in particular synoptic situations.

Accomplishments during the Reporting Period

During 2004, a member of the Data Impact and Modeling Team (Bo-Wen Shen, SAIC) brought the fvGCM to the resolution of a quarter of a degree. It had been the main achievement of this

particular task at that time, to find, demonstrate and quantify the impact of the increased resolution, with particular emphasis on the Atlantic hurricane season. This effort produced an article [Atlas *et al.*, 2005] in which the investigator was the second author, in collaboration with 8 other scientists from NASA and NOAA Geophysical Fluid Dynamics Laboratory (GFDL).

During 2005, as a part of a major collaborative effort involving the Global Modeling Assimilation Office (GMAO), the Scientific Integration and Visualizaiton Office (SIVO), the Laboratory for Atmospheres, NCCS and NAS, the quarter-of-a-degree fvGCM was put into an operational mode by providing real-time forecasts to the Florida State University (FSU). At FSU the so-called Super-Ensemble, a powerful predictive tool that encompasses several forecasts from different models is operationally used to aid the National Hurricane Center in their operational forecasting. Two versions of the fvGCM (GEOS4 and GEOS5) characterized by the same dynamical core but by different physics, were run four times a day and their forecasts were sent to FSU during the entire 2005 hurricane season. This was the core activity of the so-called NASA Project Hurricane, which was funded under the MAP 05 umbrella. The main effort of this particular task was to lead the science evaluation of the NASA Project Hurricane, providing a model assessment and evaluation. During this task, the PI investigated the behavior of GEOS4 and GEOS5 under different situations and for different cases of hurricanes. Two articles are in preparation.

As a part of this task, the PI also contributed to the analysis of a further, experimental increase in resolution in the NASA fvGCM (up to one eight of a degree), which led to a co-authorship in an article published early in 2006 [Shen *et al.*, 2006], the first such article demonstrating the capability of a GCM to resolve mesoscale vortices.

Beyond the previously described research, this particular task was also generally devoted to analyzing the performance of the fvGCM and/or the impact of new data with respect to extreme events. Another article aiming to investigate the impact of QuikSCAT data on hurricane simulation, has been published [Atlas *et al.*, 2005] in the *Journal of Photogrammetry and Remote Sensing*.

Finally, during the year, the Proposal 'Observing System Simulation Experiments' was funded, and Dr. Oreste Reale, as a PI, is now supporting and leading part of the team originally called Data Impact and Modeling.

Objectives for the Coming Year

The main goal of this task is continuing in the Goddard Laboratory for Atmospheres to evaluate the potential of the fvGCM in simulating weather events at spatial and temporal scales near the limits imposed by model resolution. Emphasis will now be put on the African Monsoon, the African Easterly Jet and on the development of African waves into tropical cyclones.

The research exploring the impact of different data types, (*e.g.*, satellite-derived wind data, rainfall data, etc.) and to simulate new instruments will instead become the focus of the newly funded proposal on OSSE, which will require the PI to lead part of the former Data Impact and Modeling team. This is going to be a separate task.

Alongside these two main goals, research will be conducted to investigate any new fundamental aspects pertaining to synoptic and dynamic meteorology that might arise during the evaluation of the fvGCM with particular emphasis on hurricanes.

Task 910-01-010: **Leadership of the GMAO Satellite Data Group**

GEST Investigator: Lars Peter Riishojgaard

Collaborator: Michele Rienecker (PI, GSFC)

Abstract

The main activity of this task is to lead the research and development efforts taking place in the satellite data group of the Global Modeling and Assimilation Office (GMAO). The office serves as a central resource within GSFC and the agency for atmospheric modeling and assimilation of satellite data in particular. The satellite data group now consists of about ten individuals, pending uncertainties in the overall situation of the NASA's budget for earth science. The role of this group within the GMAO is to ensure that current and future satellite data—both from research and operational satellites—be assimilated as efficiently as possible, and when necessary to initiate new experimental activities or develop new methodologies to ensure that this overall goal is met.

Another important activity led by the investigator is the continued development of the scientific, technical and programmatic aspects of a new space mission, the Molniya Orbit Imager. This mission was originally targeted for a future Announcement of Opportunity of NASA's Earth System Science Pathfinder (ESSP) program, but given the abovementioned uncertainties of the NASA science budget, alternative avenues remain under exploration. The mission concept has its roots in the investigator's work pioneered in the DAO since 2001 on assimilation of the MODIS winds.

The investigator is also the NASA Deputy Director of the NASA/NOAA/DoD Joint Center for Satellite Data Assimilation. The responsibility is to—in collaboration with the JCSDA Director—define the strategic goals of the center, to ensure the coordination between the JCSDA and relevant activities in the GMAO, and to manage the resources allocated to the center by NASA Headquarters.

Accomplishments in the Reporting Period

Work in the satellite data group falls into five main categories: (i) data ingest, including preparation of operational data streams and research data sets, file conversion, and quality control; (ii) supervising the routine assimilation of satellite data and troubleshooting; (iii) conducting data impact experiments to verify and where possible improve the impact of satellite data on GMAO systems; (iv) devise new methodologies appropriate for satellite data; and (v) test candidate new satellite data in GMAO systems.

In the previous year, most of the emphasis had been on areas (i) and (ii). The reason was that the GMAO was in the process of transitioning to a next generation system GEOS-5 based on the Grid-point Statistical Interpolation (GSI) developed jointly by the GMAO and NOAA/NCEP. With test versions of this system now available, increased emphasis is now being placed on areas (iii) through (v). Much of the effort has been devoted to preparing GEOS-5 for the Modern Era Retrospective-analysis for Research and Applications (MERRA) project, a 25+ year reanalysis of the entire satellite record of atmospheric observations. Part of the challenge of this project is that for certain historical satellite measurements this will be the first time they are evaluated and analyzed using modern data assimilation tools.

Work on assimilating MODIS winds is ongoing. Currently, the effort is centered on clarifying the incremental impact of having these data available in real time. Due to inherent limitations of the data acquisition pattern and ground segment for a polar orbiting system, real-time wind delivery is not possible, but the question remains important for the design of future missions.

In 2004, the investigator proposed to launch a meteorological imager in a Molniya orbit in order to demonstrate the capabilities of this orbit to provide high repeat rate cloud and water vapor images. Work on the mission proposal continued throughout 2005 concerning the technical, scientific and programmatic aspects. A baseline ESSP mission architecture was established through a series of design studies, industry solicitations and following evaluations. The concept passed the Technical Management Review at Goddard in July 2005 with excellent grade for maturity. Alternative scenarios have been developed under which NOAA and/or a European partner would play more important roles, including financial. Given the current dire outlook for ESSP funding, the focus is now increasingly on the development of the mission according to one of these collaborative scenarios.

The Joint Center for Satellite Data Assimilation (JCSDA) continues to develop, and a substantial amount of time was spent on reviewing and managing the grants awarded by the JCSDA through its Announcement of Opportunity (AO). The investigator also took the initiative to explore the possibility of developing a national Observing System Simulation Experiment (OSSE) capability for satellite observations under the auspices of the Joint Center. A NASA proposal led by the investigator is pending. Three other members of the JCSDA executive are co-investigators and the overall effort has received the endorsement of the GOES-R program and the NPOESS IPO.

Objectives for the Coming Year

The key tasks for the satellite data group in the GMAO in 2006 will be to provide support for two high-profile GMAO activities: MERRA, and MAP06. The latter is a series of intensive high-resoluton forecast studies with the GEOS-5 system to be carried out during the 2006 hurricane season.

Concerning the Molniya Orbit Imager, the goal is to further broaden the support for the mission in the science and operational communities and to explore ways of funding this mission outside the ESSP program.

Task 971-00-002: **GMAO Ocean Data Assimilation System**

GEST Investigator: Chaojiao Sun

Collaborator: Michele Rienecker (PI, GSFC), Tony Rosati (GFDL), Ichiro Fukumori (JPL), Michael Ghil (UCLA/Ecole Normale Supérieure), Dmitri Kondrashove (UCLA)

Abstract

This task focuses on research in global ocean data assimilation at GMAO. The major achievement is the evaluation and validation of GMAO and GFDL ocean data assimilation systems that performed experiments using identical forcing and observations. Extensive and diverse observational data sets were used. Some general questions related to different ocean assimilation systems were answered. Salinity treatment has been found to be important to both correct model bias in salinity and provide a more realistic current structure. The results were written up and submitted to the journal *Monthly Weather Review*.

Description of Research

One of the goals of this research is to develop a clear understanding of the ocean data assimilation systems (ODAS) at GMAO and their impact on the coupled forecasts, which uses the ocean states derived from assimilation as initial conditions for the coupled model. The evaluation and validation of the ODAS is

through comparison of the analyses with independent observations, such as sea surface height from satellites (TOPEX/JASON), temperature and velocity from TAO moorings and various scientific cruises, as well as salinity data from various sources, especially the recently deployed Argo arrays that consist of thousands of floats which profile the ocean to about 2000 m depth. Another goal is to improve the ODAS using different techniques and making use of the knowledge gained from the validations. The GEST investigator is also working on the coupled data assimilation problem, specifically, to do parameter estimation using extended Kalman filter in an intermediate coupled ocean-atmosphere model.

Accomplishments during the Reporting Period

The major accomplishment during this reporting period is in the ocean data assimilation research: a manuscript has been submitted to a major journal [Sun *et al.*, 2006] detailing this research. The GMAO and GFDL ocean data assimilation systems (ODAS) are two major systems in the ocean assimilation community. These well-exercised ODAS of optimal interpolation and 3D-VAR, are used in intercomparison experiments as part of the CEDP Consortium for Ocean Data Assimilation Consortium for Seasonal-to-Interannual Prediction (ODASI). In these experiments, identical observations (temperature only) and forcings are used by all assimilation systems. The GMAO ODAS updates salinity either through model T-S relationship or assimilating synthetic salinity profiles derived from Levitus climatology. This research addresses some of the most basic questions with regards to evaluation of different systems: How do different assimilation procedures impact the analyses, including those fields that are not directly assimilated (due to lack of observations) such as salinity and currents? Do temporal and spatial variability from different systems exhibit different behavior? What is their impact on the seasonal forecast skill (especially on ENSO prediction)? The problem of treating salinity while assimilating temperature observations has been widely investigated in this work.

Extensive and diverse data sets are utilized in evaluating and validating analyses, including TAO mooring data, TAO service cruise data collected over the years, and data from a cruise during the Tropical Instability Wave Experiment in 1991. The results show that both GMAO and GFDL analyses capture the main variability of temperature, current and salinity, but differences exist for different schemes. The treatment of salinity has impacts on salinity and current structures. Schemes that adjust salinity based on climatology while assimilating temperature are able to correct model salinity bias successfully, and produce better currents. Newly available Argo temperature and salinity data are now assimilated, and work is under way to investigate the impact of salinity observations on ocean analysis and evaluate model forecast error covariances between temperature and salinity.

A peer-reviewed paper was published in the journal *Remote Sensing of the Environment* [Foster *et al.*, 2005] with the GEST investigator as the second author. This paper complements an earlier paper on snow data assimilation [Sun *et al.*, 2004] and focuses on the modeling of observation errors of satellite passive microwave observations of snow mass.

Objectives for the coming year

A major goal is to make a significant contribution in improving the GMAO ocean data assimilation system. The main objectives are to (i) derive and evaluate model forecast error covariances from MOM4 and Poseidon V5; (ii) lead the effort in the GMAO for the ECCO-GODAE project; (iii) evaluate the GMAO coupled seasonal forecast performance and investigate the impact of ocean assimilation which provides the initial condition for the ocean state; (iv) develop methods for parameter estimation in an intermediate coupled model; (v) continue to develop diagnostic tools to evaluate ocean data assimilation systems.

Task 913-43-182: **U.S. CLIVAR Climate Model Evaluation Project (CMEP): Hydrological Cycles in the Tropics**

Task 913-12-117: **NASA Seasonal-to-Interannual Prediction Project (NSIPP): Effects of Extratropical Air-Sea Interaction on Predictability of Warm Season Precipitation Anomalies over the United States**

GEST Investigator: Hailan Wang

Collaborator: William K.-M. Lau (GSFC)

Abstract

The CMEP project studies and evaluates the late nineteenth- through twentieth-century climate simulations by state-of-the-art coupled General Circulation Models (GCMs). Work performed under this task includes investigation of atmospheric hydrological cycle in the tropics, the long-term Sahel drought from the 1970s to the 1990s, and East Asian winter monsoon, in the coupled model simulations.

The NSIPP project studies the maintenance mechanism of extratropical air-sea interaction in boreal summer. By coupling a Mixed Layer Ocean model (MLO) of variable depth to the NASA NSIPP 1 AGCM over global oceanic domain, the simulation shows that the extratropical atmosphere-ocean system is well self-sustained during boreal summer.

Description of Research

The Climate Model Evaluation Project (CMEP) supports the diagnostic analyses leading to the evaluation of coupled climate model simulations of the late nineteenth- through twentieth-century. The objective is to increase community-wide diagnostic research into the quality of model simulations, leading to more robust evaluations of model predictions and a better quantification of uncertainty in projections of future climate. The results of this research are anticipated to aid in understanding and assessing the uncertainty of the future climate change projections for the Inter-governmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4) at global and regional scales.

The NSIPP project investigates the mechanisms and the roles of extratropical air-sea interaction on the predictability of U.S. summertime precipitation anomalies using observations and NASA NSIPP models. The research effort includes climate diagnosis of various physical and dynamical fields in observations as well as simulations of coupled and un-coupled GCM experiments.

Accomplishments during the Reporting Period

Supported by the CMEP, the GEST investigator engaged in three major research efforts that significantly contribute to the IPCC AR4: (1) Atmospheric hydrological cycle in the tropics. In this study, the tropical hydrological cycle in the late nineteenth- through twentieth-century simulated by sixteen AR4 coupled GCMs have been comprehensively analyzed, and compared with available observations. When driven by the sum of historical external forcings corresponding to the twentieth century, all the coupled models consistently simulate the observed warming trend in the twentieth century. However, significant diversity is seen among the coupled models in simulating the trends and variability of cloudiness and precipitation in the tropics. Clouds still remain the major source of uncertainty. (2) Sahel drought. This study investigates the physical mechanisms of the long-term Sahel drought from the 1970s to the 1990s. The relationships between the Sahel drought and variations in the surrounding oceanic boundary conditions as well as the strength of local land-atmosphere interaction in the model simulations have been explored. Three sufficient conditions for a long-term Sahel drought have been found: (i) During the Sahel drought period, the Indian Ocean's SST had a clear increasing trend but its oscillation was out of phase with the variation of

the Sahel precipitation. (ii) The Sahel precipitation oscillated in the same phase with the Atlantic SST index. (iii) The land-atmosphere interaction was enhanced due to increased evaporation and reduced soil moisture. (3) East Asian winter monsoon. This study examines the climatology and trend of the East Asian winter monsoon, particularly occurrence and intensity of cold surges, over 1960-1999 in twelve IPCC AR4 coupled GCM simulations.

In the NASA NSIPP project, we focus our investigation on the maintenance of extratropical air-sea interaction in boreal summer. A MLO model of variable depth is coupled to the NSIPP Atmospheric GCM over global oceanic domain. Since oceanic horizontal and vertical transport processes are absent in the MLO, the output of the model simulations can be used to investigate the maintenance of dominant coupled modes in extratropics that are independent of ENSO. The coupled model simulated relationship between various physical and dynamical fields in the Northern Hemisphere (NH) extratropics in boreal summer shows good agreement with available observations. Local processes dominate the simulated summertime extratropical air-sea interaction. The interannual variations of NH extratropical SST, the overlying atmospheric circulation, and those of the local storm track, cloudiness, large-scale precipitation and incident solar short-wave radiation, in the coupled model simulation, are strongly coupled to one another, so that the whole atmosphere-ocean system is well self-sustained.

Objectives for the Coming Year

Work in the coming year will continue to investigate the impact of global warming on regional phenomenon, including tropical warm rain processes and East Asian winter monsoon, in IPCC AR4 coupled climate model simulations. Another major research effort will be on investigating the climate transitions in the 1970s.

Task 910-14-125: **Development of a Next-Generation Finite-Volume Dynamical Core on Geodesic Grids**

GEST Investigator: Kao-San Yeh

Collaborator: Robert Atlas (PI, NOAA)

Abstract

Derived, tested and optimized the third-order formulation of the Streamline Subgrid Integration (SSI) method for numerical transport on icosahedral geodesic grids. Extended the transport algorithms to shallow-water dynamics as well as the 2D idealized atmospheric dynamics. Revised the manuscript on the SSI second-order transport schemes. Participated in the forecasting of hurricanes with the high-resolution NASA finite-volume General Circulation Model (fvGCM).

Description of Research

The goal of this project is to develop a next-generation dynamical core of the fvGCM model with the finite-volume method on icosahedral geodesic grids. This potential dynamical core is intended for future application in the NASA finite-volume General Circulation Model (fvGCM) as a major component for global high-resolution modeling. While the quasi-uniform distribution of icosahedral geodesic grids provides a solid foundation for achieving great parallel efficiency for the enormous amount of computation required by global high-resolution modeling, the major effort is to overcome the scientific difficulty of developing sufficiently accurate numerical algorithms with desired physical properties, such as local conservation and monotonicity for both weather and climate applications.

Accomplishments during the Reporting Period

The GEST investigator derived, tested and optimized the third-order formulation of the SSI method for numerical transport on icosahedral geodesic grids with the higher order of accuracy

that is needed for simulating small-scale atmospheric phenomena. He also extended the transport algorithms for icosahedral geodesic grids to shallow-water dynamics as the 2D idealized test before constructing the 3D hydrostatic atmospheric dynamics.

A manuscript on the SSI second-order transport schemes was revised. Yeh participated in the forecasting of hurricanes with the high-resolution NASA fvGCM, and assisted in the writing of a paper that was submitted to the *Journal of Geophysical Research Letters*.

Objectives for the Coming Year

The GEST investigator will design and test the formulation for 3D hydrostatic atmospheric dynamics on icosahedral geodesic grids.

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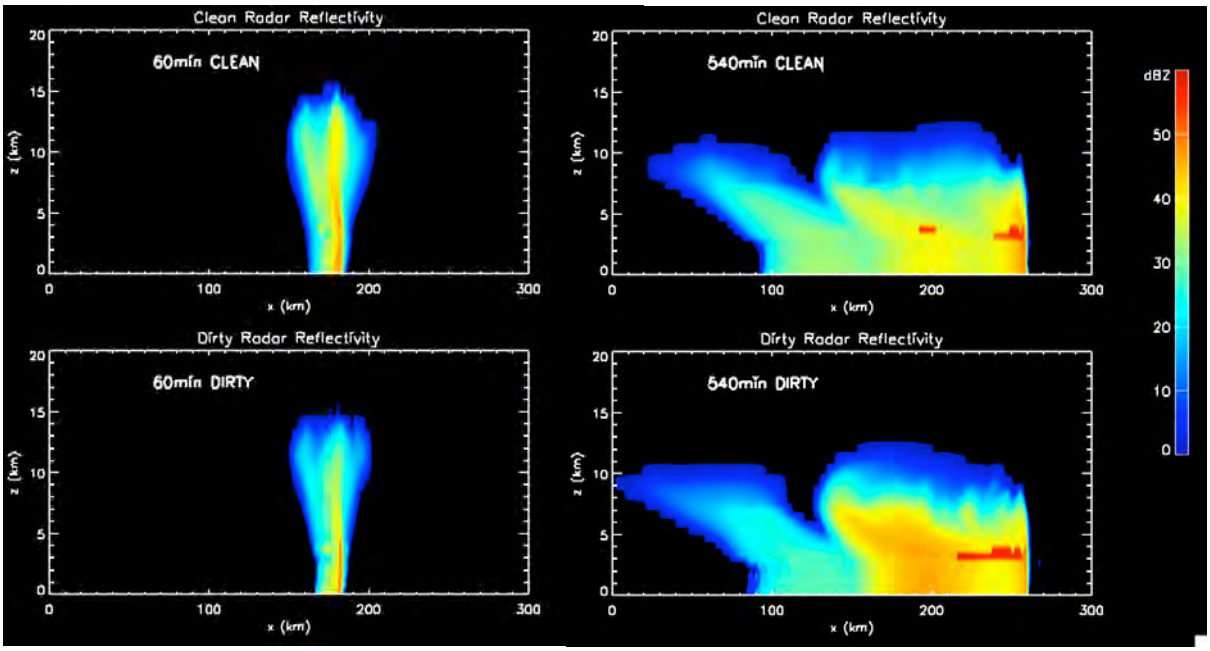
Cloud Modeling and Analysis Research Group



Influences of environmental pollution on rain formation in a mid-latitude squall line, simulated by the Goddard Cumulus Ensemble Model with a state-of-the-art spectral bin microphysical scheme. The rain is suppressed in a polluted/dirty environment at the initial stage (lower left panel compared with clean environment in upper left panel). After the squall system grows into its mature stage (right column), rain suppression continues to occur in the polluted environment (lower right panel) at the leading edge (right edge) of the rain system. In the mean time, it also enhances the stratiform rain and produces wider anvil clouds. (Figure courtesy of Xiaowen Li.)

Cloud Modeling and Analysis Research Group

The Cloud Modeling and Cloud Analysis Research Groups were combined this year and became the largest science group in GEST. The group seeks to understand the physical process of different cloud systems and their interaction with climate changes. The research is conducted through modeling and observations with studies ranging from cloud dynamics, microphysics, atmospheric radiation transfer, and to the remote sensing of aerosol, cloud and precipitation.

Using cloud modeling to understand the interaction between a cloud system and its environment continues to be one of the major research elements within the group. Progress continues to be made on the improvement/development of the Goddard Cumulus Ensemble (GCE) model (a cloud-resolving model) (X. Zeng), as well as on the performance of numerical simulations to better understand the physical processes of the tropical and mid-latitude convection (C.-L. Shie and X. Zeng). Results obtained from these long-term GCE simulations of convective systems over tropical and mid-latitude environments have genuinely characterized a quasi-linear relationship between the atmospheric temperature and water vapor distributions, as well as generally demonstrated an agreement with observations from the targeted episodes. A new promising modeling approach, the Goddard Multi-scale Modeling Framework (MMF), was developed by implementing a 2-D GCE into the finite-volume General Circulation Model (fvGCM) (J.-D. Chern). It was found that the MMF outperformed the fvGCM in simulating the geographical distribution of precipitation and cloud amount. An improved explicit bin microphysical scheme was implemented into GCE to better understand the interaction between aerosol and cloud, and precipitation (X. Li). This improved microphysical scheme produced more realistic distribution of the cooling due to melting, as well as the structure of stratiform rain. Another study utilized a GCE simulation dataset and collocated satellite observations to identify the similarities and discrepancies between the modeled and satellite retrieved rain and cloud properties, as well as to provide the basic matrix for improvement of model's physics and the satellite retrieval algorithm (Y. Zhou).

Several scientists in the group conducted observational and numerical studies to understand the interaction between the cloud system (occurring in a hurricane, tropical cyclone, or convective system) and its large-scale environment. One study examines the seasonal and interannual-to-decadal climate variability using global precipitation, a first step to answer whether there is a corresponding acceleration of water cycle given a relatively confident belief of global warming in the past decades (G. Gu). There are growing concerns regarding whether the increased tropical cyclone activity is a result of global warming. A numerical study suggested that the change in cloud dynamics caused by global warming might affect hurricane intensity (L. Wu). The upcoming Global Precipitation Measurement Mission (GPM) leads to an increased interest in the middle latitude weather system. A numerical simulation of extratropical cyclone has been conducted (M. Han).

Non-precipitating clouds, such as cirrus, has been well known to play an important role in the global energy balance. However, the mechanisms determining its maintenance and dissipation are not well understood. A numerical simulation has thus been undertaken to study cirrus cloud for the subtropics and mid-latitudes (R.-F. Lin). Aerosol amount is an important parameter in studying the effects of aerosol on cloud properties. In a study using a 3-D radiative transfer, it is found that the aerosol optical depth is difficult to retrieve in clear regions of fair-weather cumulus because clouds enhance the reflected sunlight substantially (G. Wen).

Another major research element in the Cloud Modeling and Analysis Research Group is to study clouds, precipitation, and aerosols via remote sensing. Progress continue to be made in developing methods to better estimate precipitation using satellite, airborne, and ground-based radar and radiometers. Precipitation estimation from satellite passive microwave radiometer observations is improved by using a database of precipitation profiles derived from observation, such database traditionally being from

physical models (M. Grecu). Airborne Doppler radars continue to be used for field experiment and developing new methods for estimate precipitations. Last year, the radars were deployed to Costa Rica twice in supporting NASA's TCSP and CR-AVE experiment (L. Li, L. Belcher). The observations from X-band and W-band radar have been used to estimate drop size distribution, vertical motion and attenuation in stratiform rain (L. Tian). Using sea surface return as a possible calibration target for 94 GHz radar has been examined (L. Li). The Doppler radar data from TCSP has been processed (L. Belcher). A new X-band radar flying on an Unmanned Aerial Vehicle (UAV) are under development for observing hurricanes (L. Li). There are several efforts underway to support the ground validation of TRMM/GPM including evaluating the performance of the NASA polarimetric ground-based radar (J. J. Wang) and validation of satellite radar measurements with that of ground (L. Liao). Also, varieties of topics associated with microwave radar application for the retrieval of microphysical properties of hydrometeors have been studied (L. Liao). An investigation on radar pulse averaging to achieve more accurate reflectivity measurement has been conducted (K.-S. Kuo).

Lidar and sun photometer are used to retrieve aerosol microphysical parameters. One study showed that multi-wavelength lidar technique is able to provide comprehensive information about aerosol microphysical parameters (Veselovskii). A new MPLNET (Micro-Pulse Lidar World-wide Network) site has been established to provide better coverage of long term observations of aerosol and cloud properties around the globe (Berkoff). New approaches to determine cloud height with infrared imaging radiometers, as well as to understand ocean reflectance using lidar, are being developed (Lancaster).

This brief summary and the detailed reports that follow demonstrate that the GEST Cloud Modeling and Analysis Research Group is active in a variety of relevant research topics of interest to the global climate change and hydrological science communities. This research has been well advertised through journal publications, conference participation, and seminar presentations.

Lin Tian and Chung-Lin Shie

Task 912-19-131: **Processing and Analysis of Radar and Ancillary Data in Support of NASA's High-Altitude ER-2 Doppler Radar (EDOP) and Cloud Radar System (CRS)**

GEST Investigator: Larry R. Belcher

Collaborator: Gerald Heymsfield (PI, GSFC), Lihua Li (GEST), Lin Tian (GEST)

Abstract

The EDOP and CRS radars were deployed to San Jose, Costa Rica during July 2005 to support the NASA Tropical Cloud Systems and Processes (TCSP) field program. The CRS radar was also deployed to San Jose, Costa Rica during January 2006 to support the NASA Aura Validation Experiment (CR-AVE). These two deployments required travel and participation in each field program, maintenance of networking and computing equipment, processing, quality control, and archival of the radar data collected during these field experiments. The archival and analysis of satellite data is also being conducted to augment the EDOP and CRS observations during TCSP.

Description of Research

A primary goal of the NASA Convection and Moisture Experiment (CAMEX) and more specifically, the Tropical Cloud Systems and Processes (TCSP) field program, is to better understand meso-scale conditions leading to the development, intensification, and decay of tropical cloud systems (*i.e.*, tropical storms and hurricanes). To address this goal, EDOP and CRS were deployed on board the NASA High Altitude ER-2 aircraft (based in San Jose, Costa Rica) during July 2005 to sample cloud systems in the eastern Pacific and Caribbean oceans. One objective of this research is to process, conduct quality-control techniques, and analyze the EDOP and CRS data collected during the TCSP campaign, each data set providing a high-resolution view of tropical cloud systems. Ancillary data (*e.g.*, geo-stationary and orbital satellites, aircraft flight level data) are also incorporated to provide additional information about cloud structure and evolution of tropical systems.

Accomplishments during the Reporting Period

The EDOP and CRS radars were deployed to the TCSP mission in Costa Rica in July 2005. This deployment required the development and maintenance of networking and computing equipment for use during the field campaign and travel to the field experiment. Processing, quality control, and archival of the radar data was conducted following the field campaign to enable analysis of cloud systems as viewed by airborne radar. More recently, the CRS was deployed to San Jose, Costa Rica for CR-AVE field program. Similar to the TCSP deployment, the CR-AVE campaign also required travel to the experiment and additional IT and data processing efforts. A "first-run" processing of each of these data sets has been completed and delivered. While the priority of this work is to gain a better understanding of the structure and dynamics of cloud systems, the EDOP and CRS radars only provide "snapshots" of storms flown by the ER-2. The inclusion of ancillary data (*e.g.*, satellite, sounding, *in-situ*) is required to help provide a better understanding of the large-scale structure and evolution of the cloud systems observed. The incorporation of additional instruments and their associated data sets has required research to better understand the observations and limitations of a given data source and software development for visualization and analysis. This effort includes visualization and analysis of geo-stationary satellite data (*e.g.*, GOES-12) and high-resolution radiometer data from the AVHRR and AMSU-B deployed on the NOAA polar orbiting satellites, the TMI on the TRMM satellite, and SSM/I on the DMSP satellites, and finally AMSR-E on the AQUA satellite.

Objectives for the Coming Year

While the initial processing of EDOP and CRS data from TCSP and CR-AVE has been completed, analyses of these data have

uncovered minor problems (*e.g.*, offset and folded Doppler velocities). As solutions to these problems become available, further efforts will be required to re-process the data and update the data archive. Ongoing analysis of ancillary data (*e.g.*, satellite) and inclusion of additional *in-situ* aircraft observations will aid in accurately describing interesting case studies from TCSP, such as the investigation of the evolution of hurricane Emily on 16-18 July 2005. Participation in upcoming field campaigns (and associated IT and processing efforts) is also anticipated in 2006.

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

GEST Investigator: Timothy Berkoff

Collaborator: Sandra Valencia (SSAI), Judd Welton (PI, GSFC), James Cambell (SSAI), James Spinhirne (GSFC), Brent Holben (GSFC), Si-Chee Tsay (GSFC)

Abstract

Instrumentation management and technical oversight was provided to ensure the successful deployment and operational performance of lidar systems in NASA GSFC's Micro-Pulse Lidar NETwork (MPLNET). This included continued efforts to support commercial activities specifically tailored for MPLNET. In addition to continuing support of existing MPLNET sites, instrument coordination and implementation of lidar deployments for new sites and field campaigns has continued and increased participation in MPLNET to the highest levels in the history of NASA GSFC.

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. Each site in the network uses an elastic-scattering lidar co-located with a sunphotometer 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 assure 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 commercialization efforts.

Accomplishments during the Reporting Period

New MPLNET sites were established at Seoul National University's Gosan station in Korea, NOAA's Trinidad Head station in California, Meteorological Research Institute's Anmyeon station in Korea, and Spain Institute of Aerospace Technology's Tenerife station. MPLNET instrumentation support was provided for two successful field campaigns: one as part of the East Asian Study of Tropospheric Aerosols–International Regional Experiment (EAST-AIRE) campaign operating a MPL near Beijing and the Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment (BASE-ASIA). Refurbishment, repair, and recalibration of lidars also occurred for systems already part of MPLNET, including a system owned by the Scripps Research Institute anticipated to be deployed to the Maldives in 2006, a lidar that was redeployed to the CERES Ocean Validation Experiment (COVE) platform located at the Chesapeake lighthouse platform, and on-site repair of a system located at the Admundsen-Scott South Pole Station. Technical support was provided to ongoing MPLNET sites located at Syowa station in the Antarctic, National Central University in Taiwan, and the MPL operating at NASA GSFC. Currently there are 10 sites continuously operating in MPLNET, expanding the network to its largest levels since the inception of the project.

Throughout the reporting period, oversight of MPL commercialization activities was provided. This is the first full year that a NASA MPL licensed vendor has been selling the new "Type

4B" version of the instrument which permits research groups to purchase a lidar fully compatible with MPLNET operational requirements. Systems purchased by network partners were evaluated for alignment quality, performance, and calibration prior to deployment at MPLNET sites. Technical feedback was provided to correct deficiencies observed in commercial units and improve instrument operational performance. To further extend future laser source availability for MPLNET lidars, an alternate vendor was identified to provide a version of an existing model laser modified to meet MPLNET requirements. As a result, this new-style laser system was successfully retrofitted into an existing MPL for redeployment to an MPLNET partner for site operational measurements. The first field results of this new MPL laser configuration are expected in the next reporting period.

In addition to instrument development, site operational issues were also investigated. Measurements obtained during this reporting period indicated thermally induced window-lensing and air-path scintillation effects can significantly impact the MPL overlap calibration properties under certain environmental conditions. A preliminary study was conducted to document the degree of sensitivity of induced lensing effects by recording thermal window images for different thermal load cases. Data were analyzed for thermal gradient properties and coupled with a MPL overlap model to predict the expected error for different conditions. From this information, improvements in the window mount design and calibration procedures were developed to reduce bias errors in the MPL overlap calibration. The window improvements have been validated for cold-load thermal cases, and evaluation of hot-load cases are expected in summer 2006. Information on the improved design configuration was provided to the NASA commercial vendor, and is now offered as a product for research groups to utilize at network sites.

Objectives for the coming year

The main objectives for the upcoming year are to enable further expansion of MPLNET by continuing to provide management of instrumentation matters for the network, and investigation of key technology and calibration improvements. In addition, satellite calibration-validation studies are planned, and development of new tools are anticipated to more directly integrate MPLNET data products with time-coincident satellite observations.

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

GEST Investigator: Jiun-Dar Chern

Collaborator: Wei-Kuo Tao (PI, GSFC), Christa Peters-Lidard (GSFC), Xin Lin (GEST)

Abstract

The foremost challenge in parameterizing convective clouds and cloud systems in large-scale models is the proper representation of the many coupled, dynamical and physical processes that interact over a wide range of scales, from microphysical to synoptic and planetary. This makes the comprehension and representation of convective clouds and cloud systems one of the most complex scientific problems in earth science. To break the cloud parameterization deadlock in global models, a new modeling approach, the Multi-scale Modeling Framework (MMF) or superparameterization, was developed. The ideal is to use the cloud-resolving model (CRM) in each column of a global model to explicitly represent small-scale and mesoscale cloud processes and interactions among them. The framework is very promising but also very expensive computationally. The PI has successfully developed a Goddard MMF based on the finite-volume General Circulation Model (fvGCM) and the Goddard Cumulus Ensemble Model (GCE), Two yearly MMF control experiments and four seasonal sensitivity studies

have been carried out to explore the capabilities and limitations of the system. The model results have been analyzed and evaluated against satellite observations, simulations from the fvGCM, and the ECMWF reanalysis. It is found that the MMF has a great potential to reduce some of the common systematic biases found in climate models. The MMF can also provide global simulations of the cloud statistics that can be compared with new and emerging satellite platforms such as the Tropical Rainfall Measuring Mission (TRMM), Global Precipitation Measurement (GPM), the Moderate Resolution Imaging Spectroradiometer (MODIS), and the CloudSat.

Description of Research

Current and future NASA satellite programs can provide cloud, precipitation, aerosol and other data at very fine spatial and temporal scales. Such programs require a MMF that couples a global general circulation model (GCM) with a CRM in order to use these satellite data to improve the understanding of the physical processes that are responsible for the variation in global and regional climate and hydrological systems. The use of a GCM will enable global coverage, and the use of a CRM will allow for better and more sophisticated representation of physical processes. At GSFC, a MMF based on the two-dimensional GCE and the fvGCM has been developed. The main objectives are (1) to use NASA satellite data and field campaign observations for validating and improving the MMF; (2) to compare the MMF results with results from conventional GCMs and other MMFs; (3) to produce and provide multi-dimensional cloud datasets (*i.e.*, a cloud data library) to the global modeling community to help improve the representation of moist processes in climate models and to improve our understanding of cloud and radiation processes. The MMF also has a great potential to substantially reduce systematic errors in forecast models and to improve long-range forecasts and climate prediction capabilities.

Accomplishments During the Reporting Period

The GSFC MMF has been developed based on the fvGCM global model and the 2D GCE cloud-resolving model. It includes the fvGCM running at 2.5^{o} x 2° horizontal resolution with 32 vertical layers from the surface up to 0.4 hPa and a two-dimensional GCE at each fvGCM grid column using 64 x 28 grid points with 4 km horizontal resolution and cyclic lateral boundaries. Globally, there are a total of 13,104 GCEs running at the same time. The time step for the 2D GCE is 10 seconds, and the fvGCM-GCE coupling frequency is one hour (*i.e.*, the fvGCM physical time step). At each fvGCM column, the global model provides the mean atmospheric conditions and the large-scale temperature and moisture advection forcings to the GCE and the cloud model feedbacks the tendencies of thermodynamic variables and cloud statistics. The MMF has been successfully applied and its performance tested for two different climate scenarios, El Nino (1998) and La Nina (1999), using observed sea surface temperatures (SSTs). Initial conditions came from a GEOS 4 analysis at 0000 UTC 1 November 1997 and 1998. A similar run with the same initial conditions and SSTs was performed using the fvGCM. The simulated results have been compared with ECMWF reanalysis and satellite observations (TRMM, ISCCP, NVAP, Terra, Aqua, Aura MLS). It is found that the MMF is superior to the fvGCM in simulating the geographical distribution of precipitation and cloud amount. The inter-tropical convergence zone (ITCZ), the south Pacific convergence zone (SPCZ), the south Atlantic convergence zone (SACZ), and extra-tropical storm tracks are well reproduced by the MMF. The shift in tropical precipitation to the central Pacific in January 1998 during the El Nino is also well simulated. Hovmoller diagrams from simulated daily tropical precipitation rate indicate that the MMF produces a vigorous Madden-Julian oscillation (MJO) in contrast to the fvGCM run where the MJO is virtually nonexistent. The simulated hourly dataset has been used to study the diurnal variability in precipitation frequency and intensity. The results show that the MMF is superior to the fvGCM in reproducing the correct timing of the frequency maximum in late afternoon (1400-1600 LST) over land and in early morning (0500-0700 LST) over ocean.

Despite some promising preliminary results from the MMF, the current MMF has potential weaknesses and uncertainties such as (1) the use of cyclic lateral boundary conditions in the CRM, (2) CRMs in neighboring GCM grid boxes can communicate only through the GCM, (3) use of coarse vertical and horizontal grid sizes in the CRM, (4) the absence of land surface and terrain effects in the CRMs, (5) the two-dimensionality of the CRMs, (6) the use of simple, bulk microphysics and parameterizations for radiation and sub-grid-scale turbulent processes in the CRM, and (7) thermodynamic feedback/interaction only between the CRM and GCM. To explore some of these limitations, the GEST investigator has carried out four seasonal sensitivity studies to examine the impacts of hydrometeor transport, momentum nudging and cloud microphysics on the performance of the MMF. In addition, a newly revised bulk 3ICE microphysics scheme with special improvements on the ice/graupel process and saturation technique has been implemented to the MMF. The scheme removes the unrealistic presence of high-density ice (*i.e.*, graupel or hail) and excessive snow amount in the stratiform region. The 1998 and 1999 cases are being rerun on the Columbia computer at NASA/AMES, a supercomputer with thousands of processors, with this revised microphysics scheme. Chern has also prepared the initial conditions and SST boundary conditions for the MMF control simulations for year 2000-2005.

The MMF requires a substantial amount of computing resources, two to three orders more expensive than current climate models. Only supercomputers such as the Columbia computer are able to achieve results in a timely fashion. The MMF currently uses the same multi-level parallel hybrid MPI/OpenMP design and communication module as the fvGCM for parallel computing. The fvGCM uses OpenMP in the vertical and one-dimensional MPI horizontal domain decomposition in the latitude direction. The hybrid parallel computing design has achieved computational efficiency, scalability, and portability for fvGCM runs with high resolution such as 1/8 degree. For the low-resolution (2° x 2.5^o) MMF application, however, the maximum number of processors is currently limited to 32 due to only one-dimensional MPI horizontal domain decomposition and the OpenMP does not work well with the embedded GCE. To improve the performance and scalability, two-dimensional horizontal domain decomposition is needed for the MMF. The MMF team has collaborated with Henry Jin at NASA/Ames on improving the scalability of the MMF. A new version of MMF will be ready in April 2006 that will have the MPI in latitudinal direction and the OpenMP in longitudinal direction for using at least 256 CPUs on Columbia.

Chern received the NASA/GSFC Mesoscale Atmospheric Processes Branch Exceptional Science Support Award on Dec. 19, 2005.

Objectives for the Coming Year

The GEST investigator will carry out six additional yearly (2000-2005) MMF control experiments to assess the performance of the model and compare the results with NASA satellite observations to improve the capability of the system. Chern also plans to develop a new coupled fvGCM-3D MPI GCE-LIS modeling system by the end of 2006 to study the effects of land surface-atmosphere interaction on cloud and precipitation systems. He will work with H. Jin at NASA/AMES to study the parallelization strategy and improve the performance of this system. The goal is to have MPI in both fvGCM and 3D GCE for using at least 2048 CPUs on the Columbia computer. An asynchronous IO module will be used to improve the model performance and to monitor the system when it is running.

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

GEST Investigator: Mircea Grecu

Collaborator: Robert F. Adler (PI, GSFC)

Abstract

Precipitation estimation from satellite passive microwave radiometer observations is a problem that does not have a unique solution that is insensitive to errors in the input data. Traditionally, to make this problem well-posed, *a priori* information derived from physical models or independent, high quality observations is incorporated into the solution. In the present study, a database of precipitation profiles and associated brightness temperatures is constructed to serve as *a priori* information in a passive microwave radiometer algorithm. The precipitation profiles are derived from a TRMM combined radar-radiometer algorithm, and the brightness temperatures are the TRMM TMI observed brightness temperatures. Since the observed brightness temperatures are consistent with those derived from a radiative transfer model embedded in the combined algorithm, the precipitation-brightness temperature database is considered to be physically consistent.

Description of Research

The database examined here is derived from the analysis of a month-long record of TRMM data that yields more than a million profiles of precipitation and associated brightness temperatures. These profiles are clustered into a tractable number of classes based on the local sea surface temperature, a radiometer-based estimate of the echo top height (the height beyond which the reflectivity drops below 17 dBZ), and brightness temperature principal components. For each class, the mean precipitation profile, brightness temperature principal components, and probability of occurrence are determined. The precipitation-brightness temperature database supports a radiometer-only algorithm that incorporates a Bayesian estimation methodology. In the Bayesian framework, precipitation estimates are weighted averages of the mean precipitation values corresponding to the classes in the database, the weights being determined according to the similarity between the observed brightness temperature principal components and the brightness temperature principal components of the classes. Because the classes are stratified by the sea surface temperature and the echo top height estimator, the number of classes that are considered for a retrieval is significantly smaller than the total number of classes, making the algorithm computationally efficient.

Accomplishments during the Reporting Period

The radiometer-only algorithm is applied to TMI observations, and precipitation estimates are compared to combined PR/TMI reference estimates. The TMI-only algorithm supported by the empirically-derived database produces estimates that are more consistent with the reference values than precipitation estimates from the version 6 TRMM facility TMI algorithm. Cloud resolving model simulations are used to assign a latent heating profile to each precipitation profile in the empirically-derived database, making it possible to estimate latent heating using the radiometer-only algorithm. Although the evaluation of latent heating estimates in this study is preliminary, since realistic conditional probability distribution functions are attached to latent heating structures in the algorithm's database, a generally positive impact on latent heating estimation from passive microwave observations is expected.

Objectives for the Coming Year

The investigator will focus on the large-scale application of the newly derived approach to TRMM data. Although the new, empirical databases lead to much-reduced biases in radiometer-based precipitation estimates on a global basis, regional biases up to 20% in monthly-means are still noted. In addition, field

campaign data indicate uncertainties in the prescription of ice-phase and mixed-phase precipitation single-scattering properties that contribute to additional errors in radiometer estimates. Therefore, the objectives for the coming year are to improve the combined radar/radiometer estimates of precipitation and latent heating vertical profiles and create more representative supporting databases using these profiles for radiometer-only remote sensing applications. These objectives will be achieved by (a) improving the physics assumptions in the estimation method itself and by (b) analyzing the statistical distributions of estimated precipitation/latent heating profiles over the globe.

Task 971-21-145: **TRMM Project Science**

GEST Investigator: Guojun Gu

Collaborator: Robert F. Adler (GSFC)

Abstract

Interannual-to-decadal climate variability in the global hydrological (water) cycle is an essential part of the global climate change. This kind of variability includes variations related to ENSO, NAO, and volcanic eruption, and possibly longer-term change/trend. How to quantify and correctly estimate these variations is a critical, very first step to answer whether there is a corresponding acceleration of water cycle given a relatively confident belief of global warming in the past decades. This is the primary objective in this study. Also the investigator further examines the confidence on achieving any possible answer on this question at this moment.

Description of Research

Global and large regional rainfall variations and possible long-term changes are examined using the 26-year (1979-2004) Global Precipitation Climatology Project (GPCP) monthly dataset. This task's emphasis is to discriminate among variations due to ENSO, volcanic events, and possible long-term climate changes in the tropics. Linear regression methods are applied to extract the relations between rainfall anomalies and two large-scale environmental anomaly indices in the tropics, *i.e.*, Nino3.4 and volcanic index. Statistical tests are used to examine the results, particularly the estimated long-term rainfall changes/linear trends.

Accomplishments during the Reporting Period

Although the global linear change of precipitation in the data set is near zero during the time period, an increase in tropical rainfall is noted, with a weaker decrease over northern hemisphere middle latitudes. Focusing on the tropics (25°S-25°N), the data set indicates an upward trend (0.06 mm day^{-1}/decade) and a downward trend (-0.02 mm day^{-1}/decade) over tropical ocean and land, respectively. This corresponds to an about 4.9% increase (ocean) and 1.6% decrease (land) during the entire 26-year time period. Techniques are applied to isolate and quantify variations due to ENSO and two major volcanic eruptions (El Chichón, March 1982; Pinatubo, June 1991) in order to examine longer time-scale changes. The ENSO events generally do not impact the tropical total rainfall, but, of course, induce significant anomalies with opposite signs over tropical land and ocean. The impact of the two volcanic eruptions is estimated to be about a 5% reduction in tropical rainfall over both land and ocean. A modified data set (with ENSO and volcano effects removed) retains the same approximate linear change slopes, but with reduced variance, thereby increasing the confidence levels associated with the long-term rainfall changes in the tropics [Gu *et al.,* 2006, submitted to *J. of Climate*].

Rainfall variability on seasonal and interannual-to-interdecadal time scales in the tropical Atlantic is quantified using the GPCP monthly rainfall dataset [Gu and Adler, 2006]. The ITCZ measured by monthly rainfall between 15°W-37.5^{o}W attains its peak as moving to the northernmost latitude (8°N-10°N) during July-September in which the most total rainfall is

observed in the tropical Atlantic basin (17.5°S-22.5°N, 15°W-37.5°W); the ITCZ becomes weakest during January-February with the least total rainfall observed as it moves to the south. In contrast, rainfall variability on interannual to interdecadal time scales shows a quite different seasonal preference. The most intense interannual variability occurs during March-May when the ITCZ tends to be near the equator and becomes weaker. The relationships between rainfall anomalies in the tropical Atlantic and three distinct sea surface temperature (SST) modes are further explored on interannual to interdecadal time scales. The ITCZ strength and total rainfall amount in the tropical Atlantic basin are significantly modulated by the Pacific El Niño and the Atlantic equatorial mode (or Atlantic Niño) particularly during boreal spring and summer; whereas the impact of the Atlantic interhemispheric mode is considerably weaker. Regarding the anomalous latitudes of the ITCZ, the influence could come from both local, *i.e.*, the Atlantic interhemispheric and equatorial modes, and remote forcings, *i.e.*, El Niño; however, a direct impact of El Niño on the latitudes of the ITCZ can only be found during April-July, not in winter and early spring in which the largest SST anomalies are usually observed in the equatorial Pacific.

Objectives for the Coming Year

The first objective will be to further investigate regional responses to ENSO, NAO, and volcanic eruptions. Secondly, Gu plans to examine the regional long-term rainfall changes in various tropical regions. Finally, the coupled processes in the tropical Atlantic basin and West African region will be explored by means of the recently-archived, high-quality TRMM products.

Task 00000768: **Numerical Simulations of Extratropical Cyclones with Applications to TRMM and GPM**

GEST Investigator: Mei Han

Collaborator: Scott Braun (PI, GSFC), Jian-Wen Bao (NOAA/ETL), William Olson (JCET), P. Ola. G. Persson (CIRES, NOAA/ETL)

Abstract

As the future GPM mission leads to increasing interest in precipitation systems in higher latitudes, TRMM data in the middle latitudes are applied to analyze the distribution of precipitation associated with extratropical cyclones. TRMM observed an intense NCFR over the eastern Pacific Ocean offshore of California. The TMI brightness temperature suggests that, compared to the southern end of the rainband, more precipitation ice was present in the northern portion of the NCFR. A high-resolution numerical simulation with MM5 showed that a larger amount of graupel was present in that region. The model diagnosis suggests that an advancing upper-level front played a key role in determining the structure.

Description of Research

The Global Precipitation Measurement (GPM) mission will lead to an increased focus on midlatitude weather system so that improving rain rate retrievals at higher latitudes will become important. Although designed to monitor and study precipitation throughout the tropics, TRMM has coverage in the higher latitudes (up to ~38° N and ~38° S). TRMM PR and TMI observations are used to examine mid-latitude frontal rainbands associated with extratropical cyclones in the eastern Pacific Ocean. Numerical simulation using MM5 was conducted, and the dynamics and thermodynamics of frontal rainband have been examined.

Accomplishments during the Reporting Period

Research efforts have focused on a case study of a mid-latitude frontal rainband system observed by TRMM with a special focus on the distribution of the precipitation. TRMM observed an intense narrow cold frontal rainband (NCFR) associated with an extratropical cyclone over the eastern Pacific Ocean offshore of California. It revealed a long frontal variation of

the precipitation distribution of the NCFR. The TMI polarization corrected brightness temperature suggests that, compared to the southern end of the rainband, more precipitation ice was present in the northern portion of the NCFR. A simulation with the fifth-generation Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) Mesoscale Model (MM5) has been conducted. This high-resolution numerical simulation captured the precipitation distribution of the frontal rainband observed by TRMM. It confirmed that a large amount of precipitation ice, *i.e.*, graupel, occurred in the northern portion of the NCFR.

The numerical model diagnosis showed the dynamical and thermodynamical structures of the frontal rainband and the accompanying cyclone. Analysis suggests that an advancing upper-level front played a key role in determining the structure. The potential vorticity advection associated with the upper-level front induced stronger quasigeostrophic upward motion along the northern portion of the NCFR than its southern end. This intense upward motion led to deeper updrafts, enhanced condensation and greater production of ice particles in that region. The upper-level front was associated with a "treble clef" shape of high potential vorticity, which is a common character of cyclone occlusion. The research findings have been reported in 11th Conference on Mesoscale Processes and 2005 PMM Science Team Meeting. A peer-review publication is in preparation, which is planed to be submitted in early FY 06-07.

Objectives for the Coming Year

Future research will compare the TRMM data and simulation output to aircraft observations of the front to study the finer-scale variations of the precipitation structure, including both the variations in the leading narrow convective line as well as variations in the trailing stratiform rain. Furthermore, relationships between observed and simulated microwave brightness temperatures and surface rainfall will be explored.

Task 912-23-147: **Global Precipitation Mission Physical Radiative Transfer Model**

GEST Investigator: Kwo-Sen Kuo

Collaborator: Eric Smith (GSFC)

Abstract

The Global Precipitation Measurement (GPM) mission will consist of a core satellite and several constellation satellites. The core satellite will be equipped with a dual-wavelength rain radar and a microwave radiometer while the constellation satellites will have only radiometers onboard. This is an ambitious mission aimed to further our understanding of the global water cycle.

In this reporting period, Kuo took another look at the number of pulses needed in a robust radar reflectivity measurement under the more realistic, non-Poisson assumption for drop number distributions. To facilitate non-liquid phase precipitation retrievals, he created a prototype system to generate realistic particles for single-scattering property calculations by the DDSCAT program.

Description of Research

The theoretical basis of radar pulse averaging was established some fifty years ago based on the assumption that the drop number distribution in the pulse volumes being averaged follows the Poisson distribution. Mounting evidence reveals that this is not the case. The GEST researcher is investigating the required average pulse count needed to achieve the desired confidence with more realistic drop number distributions.

Although the capability of calculating single-scattering properties for arbitrarily shaped particles is inherent in the Discrete Dipole Approximation (DDA) and an excellent public domain program based on DDA, DDSCAT, has

been available for years, only the single-scattering properties of relatively simple shapes have been obtained. The reason lies in the fact that it is not trivial to generate complicated and realistic shapes to serve as input to DDSCAT. Kuo has constructed a prototype system to ease the generation of realistically shaped particles and to archive the results necessary.

Accomplishments during the Reporting Period

Kuo began investigating the required pulse count needed to obtain a reliable radar reflectivity measurement under a more realistic assumption of the drop number distribution in the pulse volumes whose signals are being averaged. The theoretical basis of pulse averaging was previously established by Marshall and Hitschfeld [1953] based on the assumption that the total numbers of drops in the pulse volumes follow a Poisson distribution. More recent studies indicate that the drop number distribution may be far from Poisson. Preliminary results show that, depending on the variability, 35% to 90% more pulses may be needed on average to achieve the same confidence as in the Poisson case. More detailed analyses are being carried out. There are indications that if the echo signal from each pulse is saved one may estimate the required pulse count for average based on the variability in these echoes.

Supervising the work of graduate student Hezekiah Carty (University of Maryland, College Park), Kuo has led the investigation of atmospheric remote sensing involving non-spherical particles presents a difficult challenge in all electromagnetic spectra employed for the purpose, including visible, infrared, and microwave. The Discrete Dipole Approximation has been established as an accurate and versatile method for obtaining the single-scattering properties of irregularly shaped particles. A program, DDSCAT, based on DDA was made public by its authors [Draine and Flatau, 2003] for this use a number of years ago. However, the generation of irregularly shaped objects to be fed to DDSCAT as input is a non-trivial and tedious task. Kuo and Carty have constructed a prototype system based on free, public-domain software to conveniently and interactively generate complicated shapes and to archive the shape and/or DDSCAT computation results in a database. The generation of irregularly shaped object is done interactively using Wings3D [http://www.wings3d.com], a subdivision modeler used to generate characters or objects for animation. The object is then saved in an object file with an ".obj" extension. A Perl script in turn reads the file, analyzes the object, fills with dipoles in the interior of the object, and generates the input file for DDSCAT. The object, and/or the DDSCAT simulation results, are then catalogued and saved in a SQL database. The database software used is also free and public domain; SQLite [http://www.sqlite.org] is currently being used, but the researchers are porting the code to the popular MySQL [http://www.mysql.com].

Objectives for the Coming Year

Kuo plans to finish and publish the pulse averaging study. The shape-generation system and DDSCAT calculations will be applied to some realistic precipitation particles, and a comparison of the single-scattering properties obtained with realistic shapes to those obtained with parameterized Mie calculations will be performed.

Task 912-01-012: **Development of Advanced Electro-Optic Instrumentation and Technologies for Earth and Climate Monitoring**

GEST Investigator: Redgie S. Lancaster

Collaborator: James D. Spinhirne (GSFC), Kathrine F. Manizade (SSAI)

Abstract
Developing advanced electro-optical instrumentation for satellite remote sensing is critical to understanding the processes that govern possible changes in the Earth climate. Among the complement of instruments used in satellite remote sensing are infrared imaging radiometers and lidar systems. Infrared radiometers have been an important part of Earth remote sensing since the inception of the space program whereas the introduction of lidar into space is relatively recent and is exemplified by the launch of the Geoscience Laser Altimeter System (GLAS) aboard the Ice, Cloud and land Elevation Satellite (ICESat) in 2003. Advances in infrared imaging and lidar technologies have consistently enabled Earth science missions to assume increasingly challenging measurements goals.

Description of Research
Clouds represent an important feedback mechanism in establishing the energy budget of the Earth, as they both reflect incoming sunlight and trap outgoing thermal radiation. This balance between cooling and warming is governed, in part, by the height, thickness and radiative properties of clouds. Further, cloud inputs represent possibly the greatest uncertainty in model predictions of future climate, and current predictions of global climate change remain uncertain as to whether the atmospheric response to anthropogenic forcing is to grow warmer or cooler. To improve both the accuracy and utility of global climate models experimental constraints on cloud properties are required.

Oceans represent a potentially valuable target for calibrating the measurements of space borne lidar systems. When used in this manner approximately two-thirds of the Earth's surface becomes a calibration source thereby reducing the need for specialized experiments that require the convergence of logistical and environmental conditions. However, the reflective properties of the ocean surface must be accurately predicted from limited environmental data that are readily available on a global basis. The objective of this work is to assess the capability of current ocean reflectance models based upon wind speed.

Accomplishments during the Reporting Period
A novel method of stereo cloud height determination was developed using multi-spectral thermal imagery acquired during the Infrared Spectral Imaging Radiometer experiment aboard the space shuttle that exploits the linear relationship between cloud brightness temperature and cloud top height. The temperature information is used to segment the imagery into cloud layers upon which a two-dimensional correlation algorithm operates to yield a measure of parallax. This measure of parallax provides estimates of cloud height, which are compared with coincident lidar measurements. It was found that this algorithm provides estimates of cloud-top height with sub-pixel resolution of approximately ±0.40 km on a single-pixel basis for clouds in the observed altitude range of 0.5 to 10 km.

To test the current understanding of ocean reflectance, Lancaster compared surface pulse returns measured with the 1064 nm altimetry channel of the Geoscience Laser Altimeter System (GLAS) on the Ice, Cloud and land Elevation Satellite (ICESat) with the predictions of near-IR reflectance from current ocean models. Measurements of wind speed retrieved from the SeaWinds database of the QuikSCAT satellite provide the model input. Research found that, while ocean models do not provide a full description of the nadir lidar observations, this calibration technique yields a precision that exceeds that accomplished using White Sands as

a target and does not require the coordination that accompanies specialized calibration experiments.

Objectives for the Coming Year

The GEST investigator plans to secure funding so that he can adapt the Compact Visible and Infrared Radiometer for inclusion on an aircraft. Additionally, stereo algorithm development is planned that will integrate LandSat imagery into the ISIR imagery in order to remove the background scene and provide more complete information on multiple cloud layers. This is being done to continually advance the mission concept of a satellite payload to measure cloud heights and winds in the infrared. Depending upon funding the GLAS lidar work will be directed toward a more comprehensive study of ocean reflectance that integrates measurements made using the NOAA network of ocean buoys. This may also be expanded to identify and retrieve ocean reflectance measurements in the visible relating to ocean health using GLAS data.

Task 912-19-131: **Doppler Radar Development, Field Deployment and Data Analysis for Atmospheric Research**

GEST Investigator: Lihua Li

Collaborator: Gerald Heymsfield (PI, GSFC), Larry Belcher (GEST), Lin Tian (GEST)

Abstract

This research activity concerns development of new instruments including the NASA GSFC funded X-band UAV Radar (URAD) and the NASA Instrument Incubator Program (IIP) funded High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP). The investigator field-deployed the NASA GSFC ER-2 Doppler Radar (EDOP) and Cloud Radar System (CRS) in San Jose, Costa Rica during the summer of 2005 in support of the NASA Tropical Cloud System and Processes (TCSP) program. A CRS test flight on a NASA WB57 was performed, and then the researcher proceeded with a field experiment in San Jose, Costa Rica during the winter of 2005/2006 in support of the NASA Costa Rica Aura Validation Experiment (CR-AVE), radar data processing and analysis. Additional acvitity included collaboration with scientists from GSFC and other research institutes on data analysis, interpretation and journal articles. Finally, Li supervised summer students, engineers (GSFC Code 555), a technician and a GEST scientist in efforts to fulfill instrument development or scientific research tasks.

Description of Research

Tropical storms play a significant role in the global climate system and pose one of the largest natural threats to coastal areas and maritime interests. Many aspects of the chemical, dynamical, physical processes and interaction with clouds in the tropical upper troposphere and in the layer surrounding the tropical tropopause are not well understood. Microwave and millimeter Doppler radars have proven their effectiveness in measuring the structure of cloud and tropical storm systems, and in tracking the position and intensity of these weather related events. Radar measurements provide important information for scientists to better understand air-sea transfer under very strong wind forcing and physical processes of tropical storms to improve storm forecasting. Knowledge of precipitation and convective processes, as elements impacting on the resultant latent heating of the tropical disturbances and their structure, is also an exceeding important ingredient in modeling of storm intensity and movement.

Accomplishments during the Reporting Period

The GEST investigator was author or co-author of three papers published by peer-reviewed journals and three conference papers; submitted four research proposals, including a multi-million dollar NASA IIP project; led a group of engineer and technician in the development of the X-band UAV Radar and the NASA IIP HIWRAP for tropical storm research; and field

deployed radar in support of two important NASA experiments, TCSP and CR-AVE.

As the leading author, Li's effort contributed to the publication of a journal paper on using CRS measurement for study of ocean surface backscatter. The ocean surface has been widely used as a calibration target for airborne and spaceborne microwave sensors. However, at millimeter-wave frequencies, the ocean surface backscattering mechanism is still not well understood due to the lack of experimental measurements. The unprecedented results enhance our knowledge about the ocean surface scattering mechanism at 94 GHz and provide a valuable reference to develop a real time calibration algorithm for airborne millimeter-wave cloud radars and for the ongoing NASA CloudSat mission, which will utilize a 94 GHz spaceborne cloud radar for global ice cloud measurements.

During the past year, Li worked closely with scientists from University of Wyoming, National Centers for Atmospheric Research (NCAR), University of Colorado and NASA GSFC on data analysis and the retrieval of cloud microphysical properties using radar, lidar and radiometer measurements obtained from the NASA CRYSTAL-FACE field campaign. Effort on this task has made significant contribution to radar calibration, data analysis and interpretation in the collaborative research studies, which led the publication of two peer-reviewed journal papers and a number of conference presentations.

In new instrument development, task effort has been contributed to the development of a low-cost, miniaturized, light-weight, X-band radar (9.3 GHz) for flying on a UAV. During the Atlantic hurricane season, waves frequently come off the African continent and about one-tenth of these develop into hurricanes that eventually may threaten the coastal U.S. Key measurements as to whether or not a wave develops into a tropical storm are the ocean surface winds and sea surface temperatures. Current satellite precipitation and wind sensors (TRMM, QuickScat, AMSR, etc.) have resolutions that are too large and revisit times that are too infrequent to study this problem. Aircraft sensors with higher spatial resolutions and frequent sampling are desired. Unfortunately, tropical storm genesis frequently occurs in the 5000 km region between the outer Caribbean Islands and Africa. The Global Hawk is the only current UAV and aircraft that is capable of flying in this region for an extended period (24-48 hours) and with a large payload (2000 pounds). Instruments for this promising UAV are required and it will be necessary to miniaturize and reduce costs of current aircraft radars and radiometers. Currently, the radar antenna drive has been fabricated and the radar transceiver is under integration.

Similar to the X-band URAD, the NASA IIP project HIWRAP is also designed for tropical storm research, but HIWRAP is a more sophisticated conical scanning Doppler radar system. The scientific goal of HIWRAP is to obtain the 3D wind field from tropical storm and 2D surface wind by measuring the Doppler velocity, as well as storm intensity by measuring radar reflectivity. It will take advantage of the cutting edge solid state power transmitter, using advanced pulse compression technique and low power consumption Field Programmable Gate Array (FPGA) digital receiver to reduce the size, weight and power consumption to boost up the Technique Readiness Level (TRL) in subsystem and system level and serves as prototype instrument for possible future space operation. HIWRAP operates at Ku- and Ka-band frequencies (near NASA GPM radar band) and transmits and receives four beams at two different incident angles simultaneously. The development of HIWRAP poses a number of technique challenges including design and fabrication of a compact, dual-band, dual looking angle scanning antenna; a compact, low power consumption multi-frequency radar transceiver for high altitude operation; a high altitude, power efficient real time digital receiver and processor. As a project Co-PI and leading research engineer of this project group, Li has contributed substantially in HIWRAP project development, deeply involved in the project science study, radar system design and implementation.

Field observation is essential to obtain the highly demanded research data. The NASA TCSP aims at gaining understanding of tropical cyclone genesis and improved understanding of the global ice water and water vapor fields in the upper troposphere and their relation to global radiative fields, and improved understanding of the dynamical and radiative processes that produce these clouds. NASA TCSP deployed two Doppler radars on an ER-2 high altitude aircraft, including CRS and EDOP. As the principle engineer, the GEST investigator installed the radar, checked the test flights and participated in the field campaign. Due to the harsh environment, both EDOP and CRS had hardware problems during the experiment. Task work ensured the radar collected important data. Months after TCSP, CRS was installed on a NASA WB57 in support the NASA CR-AVE program. The payload environment of WB57 is significantly different from ER-2. A number of mechanical and electrical modifications had to be made in order to fly CRS on the WB57. During the experiment, cold temperatures in the playload area and strong vibration caused the misalignment of antenna and electrical problems in the radar. Due to Li's efforts, CRS still collected data throughout the field campaign. Valuable experience was also gained for future flights on WB57.

Objectives for the Coming Year

The GEST investigator will be developing the UAV X-band radar/radiometer instrument. As the leading system engineer, Li will oversee the design, fabrication and test of the new instrument, including the radar RF front end, data system, and possible integration on the aircraft and test flight. As the project engineer of the NASA GSFC group for HIWRAP, Li will be responsible for the radar system design and radar transceiver fabrication. Finally, the CRS and EDOP will be deployed in the field. The ongoing NASA field observation program, Tropical Composition, Cloud and Climate Coupling (TC4), will deploy a suite of airborne remote and *in-situ* sensor at Guam in the winter of 2006/2007 for tropical cloud and storm system study.

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

GEST Investigator: Xiaowen Li

Collaborator: Wei-Kuo Tao (PI, GSFC)

Abstract

A cloud-resolving model, the Goddard Cumulus Ensemble (GCE) model with an explicit bin microphysical scheme (from HUCM), has been used to study the impact of increasing aerosol concentration on cloud structures, their radiation properties and precipitation systems. Simulations for different cases at multiple locations revealed the complexity of the aerosol-cloud-precipitation interactions. The next step is to find the observational evidence for the simulation-based theories. In order to do that, the detailed particle size distributions simulated by the GCE model were used as inputs for a radiative transfer model to synthesize various radiative properties (*e.g.*, brightness temperature, radar reflectivity) that could be potentially observed from the satellite. The synthesized radiative properties can also be applied to the research of improving and validating various satellite retrieval algorithms such as those for TRMM and the future GMP mission.

Description of Research

Aerosols pose the greatest uncertainty to the future climate according to ICCP reports, due to the complexity of both their chemical components and physical characteristics, and their short life spans in the atmosphere. Progess has been made in the quantification of the direct effect of anthropogenic aerosols—*i.e.*, the radiative forcing of the aerosol itself—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 observation and by simulation.

The biggest uncertainty is the aerosol feedbacks on surface rainfall, which not only involves the cloud microphysics, but also depends on the complicated microphysics/dynamics feedback. Comparison of the cloud systems simulated by different microphysical schemes by the investigator has started to reveal some important links between the cloud microphysics and dynamics, and the possibility of observing the indirect effect from the space.

Accomplishments during the Reporting Period

The investigator has continued testing and improving the GCE bin spectral microphysical model during the reporting period. An explicit raindrop collisional breakup scheme has been included into the bin spectral model. The inclusion of the collisional breakup reduces the mean raindrop size which is biased to the large sizes in the previous comparison with both the surface and airborne observations. The rain evaporation at the lower levels also increases as a result of more surface raindrop area for the same rainfall rate. The dynamical impact of including the raindrop breakup scheme, however, has been shown to be small in all three previously simulated cases (a midlatitude summer time MCS, and tropical MCS, and a sea breeze deep convection).

Another improvement of the GCE model is the additional of new melting model which solves the equation of the fraction of the water within a melting ice particle explicitly, instead of the instantaneous melting used previously in the model. The improved melting scheme produces more realistic distribution of cooling due to melting, especially in the stratiform rain region where the melting process is an important heat sink. It also improves the structure of the stratiform rain simulated in the PRE-STORM MCS case. A one-dimensional steady state model using the explicit melting scheme has compared well with the airborne dual frequency Doppler radar observation during the CRYSTAL-FACE field experiment.

The spectral bin microphysical scheme has also been implemented in a 2-D GCE version with cyclic boundary conditions. This type of model setting enables the investigator to perform long-term model integration using the observed large-scale forcing. It is especially important for understanding the lifecycle of aerosols and the feedbacks of the rain processes on an aerosol's lifetime. Preliminary results for a convection event over an 8-day period in South China Sea (SCSMEX case) show very good agreement with the bulk simulations. The same cyclic boundary condition code has been recently used to simulate a winter cyclonic storm over Japan Sea. The simulated snowfall structure agrees reasonably with the observations.

One application of the cloud-resolving model simulation is to study the pollutant and water vapor transport due to deep convection. The GCE model output has been used to drive a tracer program. The results show that increasing the aerosol concentration over the continental MCS may reduce the vertical transport of near surface pollutants into the upper troposphere. Another major application of the cloud-resolving model simulations is to use the detailed cloud profile, and the unique particle size distribution simulated by the spectral bin microphysical scheme, to synthesize the radiative property of the clouds that can be observed by various passive and active instruments. The investigator has identified several variables from satellite observation that could be sensitive to the aerosol-cloud-precipitation interactions. This study also shows promising results in helping the algorithm development for the high-frequency GPM satellite channels.

Objectives for the Coming Year

After showing the complicated responses of different precipitation systems to the increase of the aerosol and cloud CCN concentrations, a major task that follows is to find the cloud microphysics/dynamics interaction mechanisms that are responsible for these different sensitivities, including how these mechanisms could affect the earth hydrology cycle and energy balance. Long-term simulation with the full aerosol life cycle will be simulated to address these broader issues. The bin spectral model will also be implemented into the 3-D framework and MPI version of the GCE model to allow for faster and more realistic cloud system studies.

Task 975-32-159: **Application of Air/Space-Borne Radar to Atmospheric Remote Sensing**

GEST Investigator: Liang Liao

Collaborator: Robert Meneghini (PI, GSFC)

Abstract
Research is conducted on a variety of topics associated with microwave radar applications for the retrieval of microphysical properties of hydrometeors. Based on the simulations of air/space-borne radar signatures in snow, mixed-phased hydrometeors and rain, the investigator constructed various radar algorithms in deriving the characteristic parameters of particle size distribution. An assessment of uncertainties or errors of the radar algorithms is carried out by use of the radar measurements during field campaigns in which a more complete set of data are available. While the focus is on the dual-wavelength radar techniques for the GPM radar in estimating snow and rainfall rates, the research also exploits the methods that combine with the measurements of polarimetric and dual-Doppler radars. To validate the estimates from radar and other satellite sensors, a framework is founded for an accurate registration of multi-sensor data taken at different platforms (air/space- and ground-based measurements).

Description of Research
Research under this task includes: (1) Simulations of dual-wavelength radar profiles in stratiform rain; (2) Assessment of the radar techniques to retrieve the microphysical properties of hydrometeors; (3) Validation of radar measurements and its algorithms for estimates of rain rate using the data taken from the instruments mounted on different platforms; (4) Application of Mirror Image algorithms for TRMM PR measurements to check some of the standard products of TRMM PR; and (5) Study of the effective dielectric constant of mixed-phase particle.

Accomplishments during the Reporting Period
Validation of precipitation measurements and estimates from satellite active and passive sensors is essential for the success of the TRMM and GPM missions. One of the critical steps in validation is to accurately resample data from space-borne and ground-based instruments to a common grid. Because of differences in the scattering geometries of space-borne and ground-based observations, accurate registration of data is a challenging problem. This problem is further complicated if there are offsets in time among the measurements. As a result, one or more of the data sets may require translation, rotation, or scaling to ensure reliable comparisons among them. In this study, Liao designed a prototype for data coordinate transformation system (DCTS) that can be used to accurately register the data acquired by multiple sensors from space- and ground-based platforms. The instantaneous and statistical comparisons of the PR and WSR products have been made through 8-year TRMM measurements for the validation of the PR measurements and its estimates. The analysis of results indicates that the reflectivity fields derived from the PR data after attenuation correction agree well with those obtained from the WSR-88D. Comparisons of rain rates also yield good agreement with the conditional mean rain rate from the PR and WSR-88D. Furthermore, the agreement improves in the comparison of area-averaged rain rates.

Airborne radar has shown promise in accurately inferring microphysical properties of snow and rain if the measurements are made at more than one wavelength. Recent field experiments, such as AMSR-Wakasa Bay Field Experiment and CRYSTAL-FACE, offer excellent opportunities to examine radar techniques for the retrieval of characteristic parameters of hydrometeors. A dual-wavelength radar technique that relates the ratio of radar reflectivities at 2 wavelengths (defined as the differential frequency ratio, or DFR) to the median volume diameter of hydrometeors has been extensively studied recently because of its relevance to the proposed spaceborne radar operating at Ku (~14 GHz) and

Ka (~35 GHz) bands aboard the Global Precipitation Measurement Mission (GPM) satellite. It has been shown from several studies that the median volume diameter of snow can be reasonably well derived from dual-wavelength measurements and that the estimates are nearly independent of the snow density. Estimates of the snow number concentration, however, are sensitive to the snow density. This leads to uncertainties in the retrieval of the number concentration unless the snow density is known. To validate dual-wavelength radar algorithms, measurements in snow from the APR-2 dual-wavelength (Ku and Ka band) and ACR (W-band, 94 GHz) radars aboard the NASA P3 aircraft during AMSR-Wakasa Bay Field Experiment has be used to check the consistency of the results using the radar measurements from several different frequency pairs.

A dual-wavelength algorithm that uses measurements of radar reflectivity factors at 10 and 94 GHz has been analyzed for the retrieval of snow and rain, based on the measurements of EDOP (10 GHz) and CRS (94 GHz) radars that were flown on the NASA ER-2 aircraft during CRYSTAL-FACE experiment. With the Doppler capabilities of EDOP and CRS radars, the measured mean Doppler velocities at the two wavelengths can be used to aid in validation of the dual-wavelength algorithm. Among the most useful quantities of the dual-wavelength Doppler velocities is the differential Doppler velocity (DDV) that is not affected by air motion and depends primarily on the median volume diameter. The DFR has several advantages in deriving snow parameters: it has a much larger dynamic range than the DDV; it is sensitive to the median volume diameter of hydrometeors; and the attenuation at X-band in dry snow is generally negligible. Although attenuation effects are more substantial at W band, forward-going attenuation correction methods should be effective in reducing the errors. In contrast to the limitations of the DDV in snow, the DDV in rain tends to be relatively large, and thus it can be used to estimate the particle size parameters. One of the great advantages of using DDV to derive particle size information in rain is that the method is immune to the problem of rain attenuation that can be very severe at high frequencies, such as W band. In contrast, accurate attenuation compensation is critical in using the DFR to estimate particle size parameters of rain. In this study, the consistency of the particle parameters derived from the DFR and DDV in rain has been checked. This provides insight into the relative accuracies of the two approaches and provides information on the retrieval accuracies in using DFR measurements from spaceborne radars.

Objectives for the Coming Year

The GEST investigator will continue research on a variety of topics associated with airborne and spaceborne weather radar analysis generally and the TRMM Precipitation Radar (PR) and GPM Dual-Wavelength Precipitation Radar specifically. The work includes 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 a dual-wavelength Doppler airborne weather radar, and the validation of the TRMM standard products using ground-based measurements.

Task 912-02-036: **Physics of Cirrus Clouds and Their Role in Global Climate**

GEST Investigator: Ruei-Fong Lin

Collaborator: David O'C. Starr (PI, GSFC)

Abstract

Cirrus plays an important role in the global energy balance. However, its formation, evolution, and especially the mechanisms determining its maintenance/dissipation, are not well understood. This task studies two types of cirriform clouds in 2005: (1) a subtropical cirrus anvil observed on July 23, 2002 during the NASA CRYSTAL-FACE campaign and (2) mid-latitude cirrus clouds observed by the

Raman Lidar and the millimeter-wavelength cloud radar in the ARM SGP site. In both studies, numerical cloud models are utilized. The quality of the simulations is monitored by the observational data. The ice mass budget of the cloud is analyzed. The results may provide useful insight into the design of a cirrus parameterization scheme in general circulation models (GCMs).

Description of Research

On 23 July 2002, a line of land-based convective storms developed between Lake Okeechobee and the Florida east coast as a result of complex interactions between lake and sea breeze fronts and outflow boundaries. The cirrus anvil that was produced by these storms extended south-southwesterly across southern Florida and was extensively measured by the arrays of aircrafts in the NASA-sponsored Cirrus Regional Study of Tropical Anvils and Cirrus Layer - Florida Area Cirrus Experiment (CRYTAL-FACE) campaign. The GEST investigator used the Fifth-Generation NCAR/Penn State Mesoscale Model to simulate a full life cycle of an anvil observed on 23 July 2002 in the CRYSTAL-FACE campaign and to verify model simulations with ground-base observations as well as *in-situ* measurements. The first objective was to examine whether the simulation was a reasonable one. The second objective was to identify the cloud scale processes and circulations that contribute to its maintenance and those responsible for the disorganization and eventual break-up of the observed anvil.

Two cirrus episodes have been selected from the bountiful dataset of mid-latitude cirrus observed by the ARM SGP site. Both are cirrus with a visible optical depth less than 4. Furthermore, from the satellite images, both have considerable area coverage and appear to be rather uniform; namely, a condition that the horizontal advection of hydrometeors may be of secondary importance for the local cloud property tendency. Lin used a 1-D model [Lin *et al.*, 2005] with explicit bin microphysics coupled with the SGP forcing data [Zhang and Lin, 1997] to simulate the observed cirrus. The objective is to understand the high ice supersaturation observed by the Raman lidar [Comstock *et al.*, 2004] and ice nucleation processes.

Accomplishments in the Reporting Period

Cirrus anvil is formed by ice particles and moist air carried by the cirrus outflow and detrained ice particles and moisture from the convection in the upper troposphere. Mesoscale ascent in the middle-to-upper troposphere downwind of the convection further enhances ice particle growth as ice particles sediment. The ice mass budget of a simulated cirrus anvil after the cessation of the convection is analyzed from the CRYSTAL-FACE campaign. In order to gain insight into the cirrus parameterization scheme, the ice mass equation is integrated over an area with a size comparable to a typical GCM grid size. This simple procedure easily separates the contribution terms into two scales: those may be resolved by a GCM and those could not be resolved.

The unresolved processes are of comparable magnitude to their associated resolved terms, except for the production term. Furthermore, it is important to account for the difference between the cloud fraction and the area fraction of snow particles in order to obtain an accurate estimate of the vertical ice mass fluxes, especially for the mid-tropospheric section of a deep anvil.

Model output derived brightness temperature in the infrared window region (10.2-11.2 micron) was compared with the GOES-8 Channel 4 brightness temperature. This particular simulation, despite capturing the main convection events successfully, produces a cirrus anvil that is too broad in area coverage and that has a much greater optical depth. Furthermore, the simulated anvil dissipates much more slowly compared with the observed, implying a weak dissipating mechanism in the mesoscale model that may require modification.

Preliminary modeling results from mid-latitude cirrus observed by the ARM SGP site are promising. The 1D model captures the overall evolution of the observed cirrus, when the model is initialized using the Raman lidar humidity profile. In contrast, the large-scale humidity profile is too dry to produce comparable clouds.

Objectives for the Coming Year

A manuscript detailing the CRYSTAL-FACE July 23, 2002 case study is in preparation and will be submitted to a refereed journal within this year. It is expected that phase one of the mid-latitude cirrus study will be accomplished within this year, too. The second phase of this project may involve ingesting turbulent wind data obtained from the millimeter cloud radar into the 1D model.

There are two new projects for the coming year. Lin will modify the 1D model to simulate methane clouds on Titan. She will also implement his cirrus bin microphysical module into the Goddard Cumulus Ensemble Model.

Task 912-10-109: **Various Numerical Applications on Tropical and Mid-Latitude Convective Systems using a Cloud-Resolving Model**

GEST Investigator: Chung-Lin Shie

Collaborator: Wei-Kuo Tao (PI, GSFC), Arthur Hou (PI, GSFC), William Olson (JCET), Xiping Zeng (GEST), Xin Lin (GEST), Yaping Zhou (GEST)

Abstract

Research tasks performed during this past reporting year consist of two major studies. One focused on quasi-equilibrium thermodynamic or climate states in global regions and over oceans, respectively, using numerical results obtained from the Goddard Cumulus Ensemble (GCE) model or the Goddard Earth Observing System Version-3 (GEOS-3) global re-analysis monthly products, along with observations. The second study involved extensive 3-D cloud system simulations using a newly developed 3-D GCE/MPI (Message Passing Interface) model. In the first study, the distribution of domain-averaged temperature (T) and water vapor (Q) fields were examined for the three tropical oceans (*i.e.*, the Pacific, Atlantic and Indian Oceans), as well as Tropics, mid- and high-latitudes. The second study aimed to simulate various marine and continental cloud systems using the GCE model (a cloud resolving model) driven by either observed or GEOS-3 large-scale forcing fields, as well as to investigate the associated impact of large-scale forcing on various modeled quantities such as hydrometeors and precipitation.

Description of Research

The primary objective of this research, which involves series of numerical simulations using the GCE model, aims to better understand the role cloud systems have played on the water and energy cycle in climate systems by examining interactions between clouds and the large-scale environmental components such as large-scale T and Q forcing. As the chosen CRM for a NASA Interdisciplinary Science (IDS) Project, GCE has recently been successfully upgraded into an MPI version with which great improvement has been achieved in computational efficiency, scalability, and portability [Juang *et al.*, 2005]. By basically using the large-scale temperature and moisture advective forcing, as well as the temperature, water vapor and wind fields obtained from either field campaign observations or the GEOS-3 reanalysis data from different geographic locations, the 3-D GCE/MPI model was proposed to simulate various marine and continental cloud systems to understand and elaborate on the physical processes associated with the tropical and extra-tropical energy and hydrological cycle. This long-term task of performing extensive model simulations also aims to produce massive simulated cloud data—"Cloud Library" in compensating the scarcity of real field campaign data in both time and space (location).

Accomplishments during the Reporting Period

In earlier studies on the tropical quasi-equilibrium states of temperature (T) and moisture (Q) based on the GCE modeled simulations, the various external large-scale meteorological conditions were found to be critical in determining the equilibrium states. Examining this finding required investigation of the slope of the Q-T relations, which turns out to be linear in the Tropics. As a continuation of the

aforementioned studies, the investigation of the domain-averaged Q-T relationship was extended from the Tropics to the Pacific, Atlantic and Indian Oceans, as well as mid-, high latitudes using the GEOS-3 global reanalysis monthly products [Shie *et al.*, 2006a]. Similar to the Tropics, a positively correlated Q-T distribution was found over the entire oceanic region. This oceanic regime fell within the lower bound of the tropical regime. The extra-tropical climate equilibriums became more complex, but insight on modeling sensitivity could be obtained by linear stepwise regression of the integrated T and Q. A globally curvilinear Q-T distribution, similar to the famous Clausius-Clapeyron curve (*i.e.*, saturated water vapor pressure versus temperature), was thus found in this study. Accordingly, Q increased faster with T over oceans than over the Tropics. A positive correlation was also found between T and sea surface temperature (SST); however, for one degree of increase in T, SST is found increased with 1.1 degrees for a warmer ocean, which is slightly less than an increase of 1.25 degrees for a colder ocean. It seemingly indicates that more/less heat is needed for an open ocean to maintain an air mass above it with a same degree of temperature raise during a colder/warmer season (or in a colder/warmer region). Q and SST were also found to be positively correlated in a manner that quantitatively resembles an earlier result in a previous study (performed by other scientists). Relative humidity (RH) exhibits similar behaviors for oceanic and tropical regions. RH increases with increasing SST and T over oceans, while it increases with increasing T in the Tropics. RH, however, decreases with increasing temperature in extra-tropics. It is suspected that the tropical and oceanic regions may possess a moister local boundary layer than the extra-tropics so that a faster moisture increase than saturated moisture increase is favored for the former regions.

To simulate various marine and continental cloud systems using the GCE model, one of the major tasks is to simulate the targeted cloud systems at different geographic locations[Shie *et al.*, 2005, 2006b]. The 2-D and 3-D GCE simulated results using the respective field campaign observations and GEOS-3 data generally show good qualitative agreement, yet with some quantitative discrepancy. For example, in one simulated episode, the modeled water vapor with the GEOS-3 forcing is found to carry a drier bias than that with the sounding forcing, which is consistent to the relatively drier GEOS3 moisture forcing. The modeled rainfall results are also found consistently corresponding to a properly correlated large-scale T and Q forcing not only temporally but also quantitatively. Accordingly, the simulated surface rainfall using sounding/GEOS-3 forcing is almost perfectly in phase with the respective forcing correlation quantity. The rainfall amounts are also found varied proportionally with values of the corresponding forcing correlation. A handful of collaborative studies—*i.e.*, Lin *et al.* [2006], Olson *et al.* [2006], Tao *et al.* [2006], Zeng *et al.* [2005, 2006a,b], and Zhou *et al.* [2006]—are also performed related to this IDS project.

The GEST investigator also has collaborations with Columbia University, NOAA, and Osaka Prefecture University in Japan, as well as Chinese Academy of Sciences in China. These collaborations led to his being co-author in a handful of publications [Gao *et al.*, 2006; Juang *et al.*, 2005; Perez *et al.*, 2004; Shige *et al.*, 2005, 2006].

Objectives for the Coming Year

Next year's research tasks will carry on most of the ongoing projects that were detailed above, particularly focusing on a project based on the simulation of the various marine and continental cloud systems. In such a project, a 3-D GCE/MPI model will be continually and intensively utilized to explore its simulation territory unto the extra-tropical region, or even globally.

Task 912-02-027: **Analysis of Dual-wavelength Doppler Radar Measurements; Retrieval of Precipitation, Vertical Air Velocity, and Rain and Water Vapor Attenuation of Stratiform Rain**

GEST Investigator: Lin Tian

Collaborator: Gerald Heymsfield (PI, GSFC), Lihua Li (GEST), Ramesh Srivastava (Univ. of Chicago)

Abstract

Airborne Doppler radar observations at 94 and 10 GHz during the CRYSTAL-FACE field experiment are analyzed for estimating rainfall rate and other physical charsteristics of stratiform rain. Using differences of return power as well as Doppler velocity measured at the two frequencies, it is possible to estimate the raindrop size distributions, vertical air velocity, and water vapor attenuation that are nearly proportional to the water vapor content. The method is applied to the observations near Key West, Florida. The magnitudes and vertical variation of the averaged velocity are remarkably similar to what has been reported in the literature for area-averaged vertical velocity in extensive stratiform rain. The averaged profile of raindrop size distribution has shown evidence of drop breakup below the melting band and evaporation in the lower levels in the region of downdrafts. The potential ability to retrieve raindrop size distribution, vertical air velocity, and water vapor distribution as functions of the height is exciting because it offers the possibility of direct calculation of profiles of evaporation and, therefore, latent heating and cooling in the atmosphere using microphysical principles.

Precipitation retrieval in the mixed phased cloud, such as convective cloud with strong updraft and startiform cloud associated with a warm front is a challenging task. In this type of cloud, the ice and supercooled water often co-exists which makes the interpretation of the reflectivity observation difficult. Another research project has been conducted to characterize the properties of snow and melting layer of the stratiform rain with a melting layer model.

Description of Research

Precipitation monitoring from satellites such as the Tropical Rain Measuring Mission (TRMM) is important for flood hazard and weather prediction and climate change studies. Rain has been very difficult to measure accurately over a wide range of intensities because there is generally insufficient information about rain properties. 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. In addition, at 35 GHz, cloud and water vapor attenuation become significant. This research effort focus on using 94 GHz and 10 GHz airborne Doppler radar observations to advance our understanding of the microphysical and dynamics of the stratiform rain and to improve the remote sensing of rain and snow from satellite.

Accomplishments during the Reporting Period

Investigators developed a technique for retrieving raindrop size distribution (RSD), vertical air velocity, and attenuation by precipitation and water vapor in light stratiform rain using observations by airborne, nadir looking dual-wavelength (X-band, $3.2\ cm$ and W-band, $3.2\ mm$). In this technique, for a given shape parameter of RSD, the median drop diameter of the RSD and the vertical air velocity are retrieved using only the mean Doppler velocities at the two wavelengths. The intercept of the RSD is estimated from the observed reflectivity at the longer wavelength assuming no attenuation at that wavelength. The attenuation of the shorter wavelength radiation by precipitation and water vapor are retrieved

using the observed reflectivity at the shorter wavelength.

The techniques are applied to a light stratifom rain near Florida. Through analysis of the Doppler velocity at longer wavelength and retrieved water vapor attenuation, Tian found that the RSD in the light stratiform rain is closer to exponential. Retrieved raindrop size distribution shows evidence of drop breakup below the melting band and evaporation in the lower levels in the region of downdrafts. The magnitudes and vertical variation of the velocity are remarkably similar to what has been reported in the literature for area-averaged vertical velocity in extensive stratiform rain measured by the VAD method. The potential ability to retrieve the parameters of the RSD, the vertical air velocity, and the water vapor distribution as functions of the height is exciting because it offers the possibility of direct calculation of profiles of evaporation and, therefore, latent cooling in the atmosphere using microphysical principles.

Uncertainty of the water vapor distribution is attributed to a large error in the estimate of rainfall rate when the melting band attenuation at 10 GHz is considered. The investigator has worked with other scientists to develop an algorithm that uses reflectivity measured by multi-frequency radar to estimate water vapor attenuation.

Analysis of the reflectivity and Doppler velocities at X and W- band in the snow and melting band has been conducted. Unlike rain, this study is more complex because the radar measurements are affected by particle size distribution as well as their density and shape. Two studies have been conducted in this research: (1) compare the observation and modeled profile of reflectivity and Doppler velocity; (2) searching for the relationship between DSD in rain and in snow.

The investigator has provided the support for NASA's TCSP field experiments, including checking data quality in the field, data calibration and processing, and updating the computer software.

Objectives for the Coming Year

The GEST investigator will continue the research in snow and melting layer. She will be using radar and simultaneously aircraft microphysical measurements to study mixed-phased cloud. Tian will continue to analyze the CRYSTAL and new field observations, concentrating on using X and W-band reflectivity and Doppler velocity to estimate the DSD in snow and melting band, and cloud and water vapor attenuation. Finally, she will be providing support for upcoming field experiments.

Task 912-31-157: **Comparison of Aerosol Microphysical Parameters Retrieved from Multi-Wavelength Lidar and Sun Photometer**

GEST Investigator: Igor Veselovskii

Collaborator: David N.Whiteman (GSFC)

Abstract

Multiwavelength lidars are a promising tool for profiling tropospheric aerosol microphysical parameters. The results of theoretical and experimental studies demonstrate that a simplified multi-wavelength Raman lidar that is based on a frequency-tripled Nd:YAG laser allows estimation of the particle size distribution and complex refractive index. To study this technique further the lidar derived parameters are compared with column-integrated aerosol properties provided by the robotic sun photometer that is used in the network called AERONET. Results obtained with a multi-wavelength Raman lidar developed at NASA/GSFC will be presented. This lidar is used to quantify three aerosol backscattering and two extinction coefficients. Aerosol

microphysical parameters are retrieved from these optical data by using inversion with regularization. Vertical profiles of volume concentration, effective radius and complex refractive index are compared with column-integrated values measured by sun photometer. The results demonstrate that the lidar-derived values are in good agreement with the more established sun photometer results. Comparison of particles size distribution shows that the lidar reproduces the fine mode well, but has difficulty retrieving the coarse mode with similar accuracy. Future work planned with this system will be described.

Description of Research

Lidar profiling of tropospheric aerosols is a rapidly developing research field. Numerous theoretical and experimental studies performed during the last decade have demonstrated that the multi-wavelength lidar technique is able to provide comprehensive information about aerosol microphysical parameters. The results thus established demonstrate that the key to successful retrieval of aerosol parameters is the joint use of aerosol backscattering and extinction coefficients, which dictates the use of Raman or high spectral resolution lidars. Another important finding is that a simplified multi-wavelength Raman lidar that is based on a frequency-tripled Nd:YAG laser allows estimation of the particle size distribution (PSD) and complex refractive index .

To study this technique further the lidar-derived parameters can be compared with similar results from other instruments. One of the recognized instruments for retrieval of column-integrated aerosol properties is the robotic sun photometer that is used in the network called AERONET. The comparison of lidar and sun photometer data has been performed in several publications. In these studies the comparisons were limited mainly to aerosol optical density, Angstrom parameter and lidar ratios. The only comparison of particle microphysical parameters derived from both instruments was reported in recent publication of Muller *et al.* [2005]. That comparison demonstrates reasonable agreement between lidar and sun photometer. Still, to prove the potential of multi-wavelength lidar technique, additional comparisons and detailed analysis of obtained data are needed.

The GEST investigator reported the results of lidar measurements in the summer of 2005 at Greenbelt, MD. The ultimate goal in this task is the use of sun photometer data as a constraint in mulit-wavelength lidar inversion algorithm, so the comparisons presented constitute a first step toward this goal.

Accomplishments during the Reporting Period

The experiments were performed with a multi-wavelength Raman lidar developed at NASA/GSFC. The lidar is based on a tripled Nd:YAG laser with 50 Hz repetition rate. The output powers at 355, 532 and 1064 nm are 20, 7.5 and 14 W respectively. The backscattered light is collected by a 40-cm aperture Schmidt-Cassegrain telescope with operational field of view of 0.35 mrad. The telescope is connected through an optical fiber to a receiving module that includes an off-axis parabolic mirror for collimation. The spectral components of the collimated signal are separated by dichroic mirrors and interference filters and detected using photomultiplier tubes or APDs (Hamamatsu R1924 PMTs, H7422P-40 module (607 nm), Licel IR enhanced Si APD in analog mode (1064 nm). In the current configuration of the system, it is able to detect three elastic backscatters and two nitrogen Raman signals at 387 and 607 nm. The detection system also has provisions to measurement both vapor and liquid water although those data are not analyzed here. Recording of both Raman and backscatter signals allows independent calculation of the particle backscattering β and extinction α coefficients. Previous studies demonstrate that quantifying these three aerosol backscattering β and two extinction α coefficients is sufficient for estimation of aerosol microphysical parameters.

The measurements were performed during July-August 2005. This season in the vicinity of Washington, DC is frequently characterized by hazy conditions and provides excellent opportunity for comparison with a sun photometer. The majority of aerosols are concentrated inside planetary boundary layer (PBL). Particles are close to spherical and their

parameters don't vary strongly through PBL. In particle size distribution (PSD), fine mode is dominating, which is also convenient, because retrieval of coarse mode from the multi-wavelength lidar measurements is more difficult at the present time.

For comparison with the sun photometer it is desirable to perform the measurements starting from the lowest altitude as possible. To accomplish this, Veselovskii performed the measurements with the lidar system operating at 18 degrees above the horizon. No special correction for overlap function was made, so backscattering and extinction coefficients were calculated starting from 0.75 km altitude. Measurements were performed in nighttime (about 9 pm of local time) to detect Raman signals at sufficient height. This was two hours later than last sun photometer measurement.

The vertical profiles of backscattering and extinction coefficients measured were used as input to retrieve aerosol microphysical parameters through inversion with regularization. With his algorithm, he retrieved effective radius (r_{eff}), particle number (N_t), surface (S_t), volume (V_t) densities, and also real m_R and imaginary m_I part of refractive index. As shown previously, the results of the retrieval depend on the type of kernels used. The optimal results are attained when retrieval is performed with both number and volume kernels and the average of obtained values is taken.

The comparison of aerosol parameters retrieved from lidar and sun photometer on 2 August, 2005 is shown in the table below. The lidar provides trustworthy estimation of fine mode parameters such as effective radius, concentration and complex refractive index. At the present, the lidar technique has difficulty in retrieving the coarse mode with sufficient accuracy. Improvements in the coarse mode retrieval require input optical data of lower absolute errors.

Parameter		Lidar	Sun photometer
Effective radius (fine) r_{eff}, μm		0.14±0.1	0.149
Volume C_v (fine), $\mu m^3/cm^2$		55±10	75
Refractive index	m_R	1.42±0.05	1.39
	m_I	0.005±0.0025	0.0042

Grant CV526574: **The Evaluation and Application of Ground-Based Radar in TRMM/GPM GV Program**

GEST Investigator: Jian-Jian Wang

Collaborator: Robert Adler (GSFC), Ali Tokay (JCET), Lawrence Carey (Texas A&M University), John Gerlach (GSFC)

Abstract
The NASA Polarimetric Radar (NPOL) is NASA's only portable polarimetric precipitation research radar. This S-band dual-polarimetric (H and V) radar can provide all polarimetric products including reflectivity (Zh), radial velocity (Vr), differential reflectivity (Zdr), and differential propagation phase (Ψdp). Polarimetric radar inferred microphysical (*e.g.*, hydrometeor type, amount, and size) and rainfall properties are crucial for an accurate estimation of rainfall amount and can play an important role in the ground validation program of TRMM and future GPM when comparing the satellite measurements to the NPOL observations. The main effort is to evaluate the performance of this advanced radar, and provide suggestions for the future improvement of this polarimetric weather radar. In addition, the evaluation and usage of the dataset collected by several NOAA NEXRADs, covering the greater Wallops Island area, might prove of interest as a candidate for a coastal ground validation site for GPM.

Description of Research

The central research in this task is to test the NPOL polarimetric performance relative to that of established polarimetric radars (*e.g.*, CSU-CHILL, NCAR SPOL, and BMRC CPOL) with different hardware installed to improve the operation, and to analyze the available NEXRAD data that covers the greater Wallops Island area and to make the intercomparison between them and other ground-based radars at Wallops (*e.g.*, SPANDA, TOGA). To do this, we have set a rain gauge and distrometer network within 150 km radius to NPOL radar, which is currently located at Oyster, Virginia. Key technical and scientific issues have been developed and studied include (a) the standardized procedure and methodology to process and analyze the polarimetric radar and NEXRAD data; (b) the rain rate in different precipitation systems; (c) the hydrometeor types and amount in precipitation systems; and (d) the comparison of rain rates derived from polarimetric radar and NEXRAD with the observations by rain gauges and distrometer.

Accomplishments during the Reporting Period

Previous efforts found that the new developed NPOL radar has three major problems including (a) the NPOL radar suffered a serious reflectivity attenuation problem when the antenna was wet, (b) the polarimetric radar data are very noisy comparing to other developed research radar, and (c) there are severe back lobe signals when the echo is strong. In summer 2005, the back plane of NPOL radar was modified by adding a 1/4 " mesh screen and everything was repainted and recoated. The effort is to remove the back lobe problem, and to reduce the effects of wet antenna. It may further improve the echoes from V channel and therefore reduce the noisiness of the polarimetric radar data. In order to evaluate the performance of NPOL radar after the installation of the mesh screen, we have collected several cases during the period of July to September 2005. Detailed case studies are performed to examine the NPOL data quality and compare NPOL results to the results from other radars.

Starting with the estimation of differential reflectivity (Zdr) bias by examining the histogram of Zdr in anvil echo, data were chosen that was characterized by low-to-moderate reflectivity (15-25 dBZ) at high elevation angle (≥15 deg) well above the bright band (> 6.0 km) at moderate ranges (10≤Range≤60 km). Research found that Zdr had a positive bias of +0.5-1.0 dB. Next, the NPOL reflectivity data was compared with Wakefield NEXRAD (KAKQ) radar and S-band SPANDAR radar, which are 102 km southwest and 82 km northeast to the NPOL, respectively. The correlation between SPANDAR, NEXRAD and NPOL was very good (> 0.9). The match of reflectivity data among all three radars we examined is reasonably good. This gives us confidence that the NPOL reflectivity data are very reliable.

It is found that the back lobe issue is fixed by the new installed mesh screen. The wet antenna issue is improved, from 8-12 dBZ off before the installation to 3-6 dBZ off after that. However, the problem is not totally solved, especially in the strong convective systems. To compare NPOL with other established polarimetric radars, samples representing drizzle were taken, which should be characterized approximately by specific differential phase, Kdp ≈ 0° km^{-1}, Zdr ≈ 0 dB, and correlation coefficient, $\rho_{HV} \approx 0.99$. The results demonstrate that polarimetric data quality for the NPOL radar has little improvement comparing to that before the installation of mesh screen. It is not yet up to the standards of other established research polarimetric radars in the international community. For example, the random measurement error in the measured differential phase (Ψ_{dp}) is about 8° compared to more typical values of 1.4° to 2.5° for the other radars. An upper-end empirical estimate of the standard error in Zdr is 0.9 dB compared to about 0.3-0.4 dB for the other radars. These NPOL measurement errors above are consistent with depressed values of the NPOL correlation coefficient (ρ_{HV}) in the “drizzle” data.

In summary, the task findings are: (a) The NPOL reflectivity and radial velocity data are good. The polarimetric data can be used to categorize the hydrometeor types in the

convective system; (b) The NPOL polarimetric data are too noisy for conducting quantitative rain rate estimation; and (c) The FLAPS design for the NPOL antenna may not provide high quality polarimetric data that a traditional antenna is capable of. A replacement of the antenna is necessary to make NPOL a high quality research radar.

Objectives for the Coming Year

The GEST investigator will focus his effort on the evaluation of the ground-based radar data collected in the greater Wallop Island region including the NASA NPOL radar and NEXRAD at Wakefield, VA, Sterling, VA, and Dover, DE. The combined Dover, Sterling and Wakefield radars will be employed to generate the storm rain totals where the storms will be selected based on characteristics of the storm and satellite overpass. SPANDAR radar has wide area of overlap with operational radars and will be used for cross-calibration. Along with archived weather charts, the disdrometers and collocated vertically pointing radars will to serve to determine the characteristics of the storms. Considering that microwave sensor based precipitation estimates differ over the oceans, land, and coasts, the greater Wallops Island area within three operational radar coverages provides a unique opportunity to evaluate all three algorithms. He will process the rain gauge and distrometer data collected during the same period of radar operation. Then, the total rainfall derived from all three instruments will be analyzed and compared. This comparison will provide further information about the performance of the network.

Task 913-00-000: **Atmospheric Solar Radiative Transfer**

GEST Investigator: Guoyong Wen

Collaborator: Robert F. Cahalan (GSFC), Alexander Marshak (GSFC), Lazaros Oreopoulos (JCET), Tamas Varnai (JCET), Juan Fontenla (LASP, Univ. of Colorado), Thomas Woods (LASP, Univ. of Colorado)

Abstract

The first research area focuses on quantifying of the 3D radiative effects of clouds on the aerosol retrieval. This study is conducted on fair-weather cumulus in biomass burning region in Brazil. With a combination of EOS observations and 3D radiative transfer modeling efforts, Wen has quantified 3D radiative effects of clouds on the reflected sunlight in clear patches in a realistic cumulus cloud field, and associated errors in ambient aerosol retrievals. Clouds are found to be effective to enhance reflected sunlight in clear patches in cumulus cloud fields. The enhancement is wavelength dependent. The additional reflected sunlight could be translated to more aerosol amount in 1D retrieval, leading to a wrong relation between the cloud properties and aerosol amounts. Thus 3D cloud-aerosol radiative interaction is crucial in understanding the indirect effects of aerosols on climate. The second research focus area is on the variations of the solar energy. Results from analyses of spectral solar irradiance (SSI) from SIM (Spectral Irradiance Monitor) on the SORCE (Solar Radiation and Climate Experiment) satellite show that SSI at different wavelengths does not vary uniformly with time as assumed before. Long term monitoring the variations of spectral and total solar irradiance is important in climate research.

Description of Research

Aerosol amount is an important parameter in studying the effects of aerosol on cloud properties. However, it is difficult to retrieve aerosol optical depth in clear region of fair-weather cumulus because clouds enhance the reflected sunlight substantially. The 3D scattering of sunlight from clouds is the primary diffuse radiation source in the clear regions embedded in cloud fields. The additional diffuse radiation reflected to space could be translated into more aerosols in 1D retrieval, leading to a wrong relation between the cloud properties and

aerosol amounts. This research targets the quantification of 3D radiative effects on radiation fields and aerosol retrievals.

Another research task area is the effort to advance 3-dimensional radiative transfer modeling capabilities. This project is called International Intercomparison of 3D Radiations Codes (I3RC) supported by NASA and DoE's ARM program. The goal of this project is to compare results from state-of-the-art 3D radiative transfer techniques on a variety of input cloud fields with a wide degree of complexity. The investigator actively participates in I3RC activities and is assisting in the construction of cases from EOS observations as well as observations from ARM for the third phase of I3RC.

Solar radiation is the major driving energy source for atmospheric and oceanic circulations, and climate. Understanding this input energy is crucial for understanding the physical, chemical, and biological processes of the Earth-atmosphere system. The objective of this part of the research is to study the characteristics of solar irradiance variations, and the effects of atmosphere on solar spectral irradiance transfer. With satellite, ground-based solar radiation measurements, and atmosphere profile from soundings, we have a new approach to examine the clear sky radiative transfer. The results from the studies of radiative transfer in turn can improve the remote sensing of aerosol.

Accomplishments During the Reporting Period

The 3D cloud effects on reflected sunlight and retrieval of aerosols embedded in cumulus cloud fields are quantitatively determined. This research was carried out using 3D Monte Carlo simulation of solar radiative transfer in cumulus cloud fields of ASTER images. The cloud optical depth field from MODIS is used in the simulation. A paper summarizing the results has been published in a refereed journal [Wen *et al.*, 2006]. Further research has been carried out to understand physical mechanisms of 3D cloud-aerosol radiative interaction. A paper about the new findings is in preparation.

The 3-dimensional structure also has significant impacts on cloud droplet retrieval. The investigator worked with colleagues to quantify this effect. A paper describing the results is in press in a refereed journal [Marshak *et al.*, 2006].

This past reporting period has been busy for the task group. The investigator together with colleagues actively participated in collecting and analyzing satellite images from MODIS, ASTER and MISR. The investigator's effort was significant in the success of the third I3RC workshop.

The spectral solar irradiance from SIM was analyzed. The results show that the spectral solar irradiance as a function of wavelength does not vary uniformly in time. The UV spectral irradiance is found weakly correlated with visible and near-IR spectral irradiance. The UV spectral irradiance is primarily from the chromosphere, while the visible and near-IR spectral are from the photosphere. The empirical orthogonal function (EOF) analysis is applied to the time series of spectral solar irradiance. A special feature was identified in the EOFs. The results were presented in the SORCE meeting.

The investigator is the leading scientist of aerosol and surface properties in the I3RC project supported by NASA and DoE's ARM Program. The project was carried out smoothly in Phases I and II through the efforts of all scientists on the project. A co-authered paper that summaries the major results bas been published in a peer reviewed journal [Cahalan *et al.*, 2005].

Objectives for the Coming Year

The main objective for the coming year is to investigate the detailed physical mechanisms of 3D cloud-aerosol radative interaction and its impacts on retrieval of aerosol and cloud properties in complex atmospheric conditions. To accomplish this, the investigator will use a variety of satellite and ground radiometer measurements. A 3D radiative transfer model will be used to interpret the observations. 3D retrieval of aerosol and cloud properties is anticipated. One objective is to look at MODIS,

ASTER, and MISR images in the Amazon or other regions in the world. With different spatial resolutions and angular capability, some interesting results are expected for cloud and aerosol studies. Based on their research findings the task team will work to correct 3D cloud effects on aerosols retrievals. Wen will also continue to investigate the solar spectral irradiance observations from SIM on SORCE satellite. Since the launch of the SORCE in January 2003, there have been three years of SIM data available, allowing for searching of some signatures of variations of solar spectral irradiance.

Task 912-18-129: **Study of Tropical Cyclone Activities**

GEST Investigator: Liguang Wu

Collaborator: Scott Braun (PI, GSFC)

Abstract

The investigator has been working at the Mesoscale Atmospheric Processes Branch of GSFC since 2002, mainly advancing our understanding of tropical cyclone activities. Research activities include: (1) tropical cyclogenesis through numerical simulation; (2) potential impacts of global warming on the tropical cyclone activity; (3) hurricane rapid intensification under the environmental influence such as environmental horizontal wind shear; and (4) assessing the climate impact of the Three Gorges Dam using NASA satellite data. Preliminary findings include the destructive effect of Saharan dust air on tropical cyclone formation and intensification, the relationship between the increasing intense hurricanes and shifts in the prevailing hurricane tracks over the past three decades, the possible mechanism for hurricane rapid intensification, and the potential effect of the Three Gorges Dam on regional climate.

Description of Research

Hurricanes, as a key component of the global climate system, can be significantly affected by the global climate change, and, in turn, introduce feedbacks on the global climate system. Therefore, it is necessary to understand the mechanisms involved in the formation and intensity change of tropical cyclones and their interaction with large-scale circulation. During the past year, the research focus has been placed on investigating the physical mechanisms involved in tropical cyclogenesis including the effect of Saharan Air Layer (SAL) through analysis of Aqua/AIRS data products and numerical simulation, identifying the possible impact of global warming on tropical cyclone activities in the western North Pacific, eastern North Pacific, and North Atlantic basins, and understanding how the environmentally-induced inner-eye asymmetries contribute to hurricane rapid intensification.

Accomplishments during the Reporting Period

The hurricane season of 2005 was the busiest on record and Hurricane Katrina (2005) is believed to be the costliest hurricane in U.S. history. There are growing concerns regarding whether this increased tropical cyclone activity is a result of global warming, as suggested by Emanuel [2005] and Webster *et al.* [2005], or just a natural oscillation [Goldenberg *et al.*, 2001]. Since the tropical sea surface temperature (SST) warming also leads to the response of atmospheric circulation, which is not solely determined by the local SST warming, this study suggests that it is better to take the tropical cyclone activities in the North Atlantic (NA), western North Pacific (WNP) and eastern North Pacific (ENP) basins as a whole when searching for the influence of the global-scale SST warming on tropical cyclone intensity. Over the past 30 years, as the tropical SST increased by about 0.5 °C, the linear trends indicate 6%, 16% and 15% increases in the overall average intensity and lifetime and the annual frequency. The analysis shows that the increased annual destructiveness of tropical cyclones reported by Emanuel [2005] resulted mainly from the increases in the average lifetime and annual frequency in the NA basin and from the

increases in the average intensity and lifetime in the WNP basin, while the annual destructiveness in the ENP basin generally decreased over the past 30 years. The changes in the proportion of intense tropical cyclones reported by Webster *et al.* [2005] were due mainly to the fact that increasing tropical cyclones took the tracks that favor for the development of intense tropical cyclones in the NA and WNP basins over the past 30 years. The dynamic influence associated with the tropical SST warming can lead to the impact of global warming on tropical cyclone intensity that may be very different from our current assessments, which were mainly based on the thermodynamic theory of tropical cyclone intensity.

Using the retrieved temperature and humidity profiles from the AIRS instrument suite on the NASA Aqua satellite, the Saharan Air Layer (SAL) and its influence on the formation of Hurricane Isabel (2003) are simulated numerically with the MM5 model. The warmth and dryness of the SAL (the thermodynamic effect) is assimilated by use of the nudging technique, which enables the model thermodynamic state to be relaxed to the profiles of the AIRS retrieved data for the regions without cloud contamination. By incorporating the AIRS data, MM5 better simulates the large-scale flow patterns and the activity of Hurricane Isabel in terms of the timing and location of formation and the subsequent track. The temperature and humidity profiles of the AIRS retrieved data products are useful for investigating the influence of the SAL on tropical cyclones. By comparing with an experiment without nudging of the AIRS data, it is shown that the SAL may have delayed the formation of Hurricane Isabel and inhibited the development of another tropical disturbance to the east. This case study confirms the argument by Dunion and Velden [2004] that the SAL can suppress Atlantic tropical cyclone activity by increasing the vertical wind shear, reducing the mean relative humidity, and stabilizing the environment at lower levels.

Analyses of the NASA TRMM rainfall rate and MODIS land surface temperature indicate that the precipitation in the mountainous area north of the Yangtze River increased after the water level rose to 135 m due to the induced anomalous downward motion of the air in the vicinity of the waterway coupled with the upward motion of the air in the mountainous area during the daytime. This study suggests that the TGD construction altered the regional climate pattern (~ 100 km) rather than the local scale (~10 km) as projected in previous assessments.

It is found that the large-scale environmental flow with given meridional shear affects tropical cyclone intensity through changing asymmetric and symmetric structures in the tropical cyclone inner core region. For a weak vortex embedded in the zonal flows with low-level cyclonic and upper-level anticyclonic shears, the environmental forcing continuously excites radially propagating inner core asymmetries in the inner core. The axisymmetrization of these inner core asymmetries, as coupled with moist and boundary processes in a conditionally unstable atmosphere, provides a trigger for the eyewall contraction, making inner convection dominant and leading to rapid intensification.

Objectives for FY 05-06

In the next year, the investigator will continue his efforts on understanding tropical cyclone activities. Most of his research work will focus on the formation of tropical cyclones and the environmental controls on tropical cyclone activity.

Task 912-29-152: **Evaluating Clouds in Long-Term Cloud-Resolving Model Simulations**

GEST Investigator: Xiping Zeng

Collaborator: Wei-Kuo Tao (PI, GSFC), Joanne Simpson (GSFC)

Abstract

Cloud-resolving models, in contrast to numerical weather prediction models, choose fine spatial resolution so that they represent clouds explicitly, avoiding cumulus parameterization. A question is whether current cloud-resolving models can work as well as expected in long-term simulations. Thus, it is interesting to evaluate long-term cloud-resolving model simulations with observational data. Two 20-day continental cases in the middle latitude are simulated with a three-dimensional (3D) cloud-resolving model (CRM) in contrast to the Atmospheric Radiation Measurement (ARM) data. All numerical experiments, as compared with observations, give reasonable simulations of surface rainfall but overprediction of cloud residues in the upper troposphere. As planned, the overprediction of cloud residues will be explored.

Description of Research

Clouds play a central role in weather and climate change. They are associated with cloud microphysics, radiation and circulations, and connect the processes together. Due to the scale difference of cloud microphysics, cloud and large-scale circulation, numerical simulation plays an important role in studying the nonlinear relations of clouds to other processes. Thus, 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 satisfying, especially in the Tropics.

Cloud-resolving models use fine spatial resolution. They can simulate clouds explicitly and represent the microphysical physics of clouds with parameterization properly. 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 in contrast to the Atmospheric Radiation Measurement (ARM) observational data.

Accomplishments During the Reporting Period

Many factors affect the simulations of precipitation and clouds in cloud-resolving models, such as dimensionality and land surface. The GCE model was used to simulate two 20-day continental cases in the middle latitude. All numerical experiments, as compared with observations, give reasonable simulations of surface rainfall but over predict cloud residues in the upper troposphere. The sensitivity of cloud properties to dimensionality is studied to isolate the origin of the overprediction of cloud residues. Owing to different buoyancy damping in two- and three-dimensional models, surface precipitation fluctuates rapidly with time and the air near the tropopause is dehumidified spuriously in the two-dimensional model.

Surface fluxes from a land surface model are compared with those from observations. Using the two kinds of surface flux data, the sensitivity of clouds to surface fluxes is studied, showing that the surface fluxes from the land surface model play an interesting role in the proper simulation of cloud fraction in the lower troposphere, which is understandable. Since the land surface model was driven with 1 km-resolution data, their fine resolution may lead to better area-averaged fluxes than that from "sparse" observational stations, although the fluxes from the land surface model are not as accurate as the ARM fluxes at a point. However, the conclusions are still open on the comparison of the two kinds of surface flux data.

Objectives for the Coming Year

In the coming year, the first objective is to study the sensitivity of cloud residues to various factors such as cloud microphysics and land surface. Secondly, the GEST investigator plans to explore a way to model the bias or overprediction of cloud residues in the upper troposphere.

Task 913-12-117: **Cloud-Radiation-Precipitation Modeling and Assimilation for Improving Weather Prediction and Climate Modeling**

GEST Investigator: Yaping Zhou

Collaborator: Arthur Hou (PI, GSFC), Ming-Dah Chou (GSFC), Leo J. Donner (GFDL), William Lau (GSFC), Shian-Jian (GSFC), Philip Rasch (NCAR), Yogesh Sud (GSFC), Wei-Kuo Tao (GSFC)

Abstract

High resolution, multi-satellite, multi-senor observations of cloud and precipitation from TRMM, CERES and MODIS instruments provide an opportunity to evaluate the cloud, radiation and precipitation parameterizations in climate models as well as simulations from cloud resolving models in great detail. A series of numerical simulations have been generated using the 3D Goddard Cumulus Ensemble (GCE) model by another GEST investigator, Chung-Lin Shie, for targeted cloud systems at different geographic locations (tropics and subtropics; marine and continental). This study utilized these GCE simulation datasets and collocated satellite observations for statistical comparison of rain and cloud properties. The goal is to identify the similarities and discrepancies between the model results and satellite retrievals, as well as to provide the basic matrix for improvement of the model's physics and the satellite retrieval algorithm.

Description of Research

The treatment of cloud-radiation and convective processes represents a major source of uncertainty in global models. Systematic errors in cloud and precipitation parameterization can prevent data assimilation systems from making effective use of observations. They also introduce fundamental uncertainties in modeling the global water and energy cycle, thus limiting our ability to predict climate change. This study aims to use observations of cloud, radiation and precipitation processes and cloud resolving model simulations to evaluate and improve physical parameterizations of global system performance. The cloud resolving model (CRM) will serve as a bridge between observations and physical parameterizations due to its capability of explicitly simulating the cloud and precipitation in great detail. To reach the goal, the cloud resolving model itself has to be vigorously tested against observations for various dynamical environments and cloud/rain types.

Accomplishments during the Reporting Period

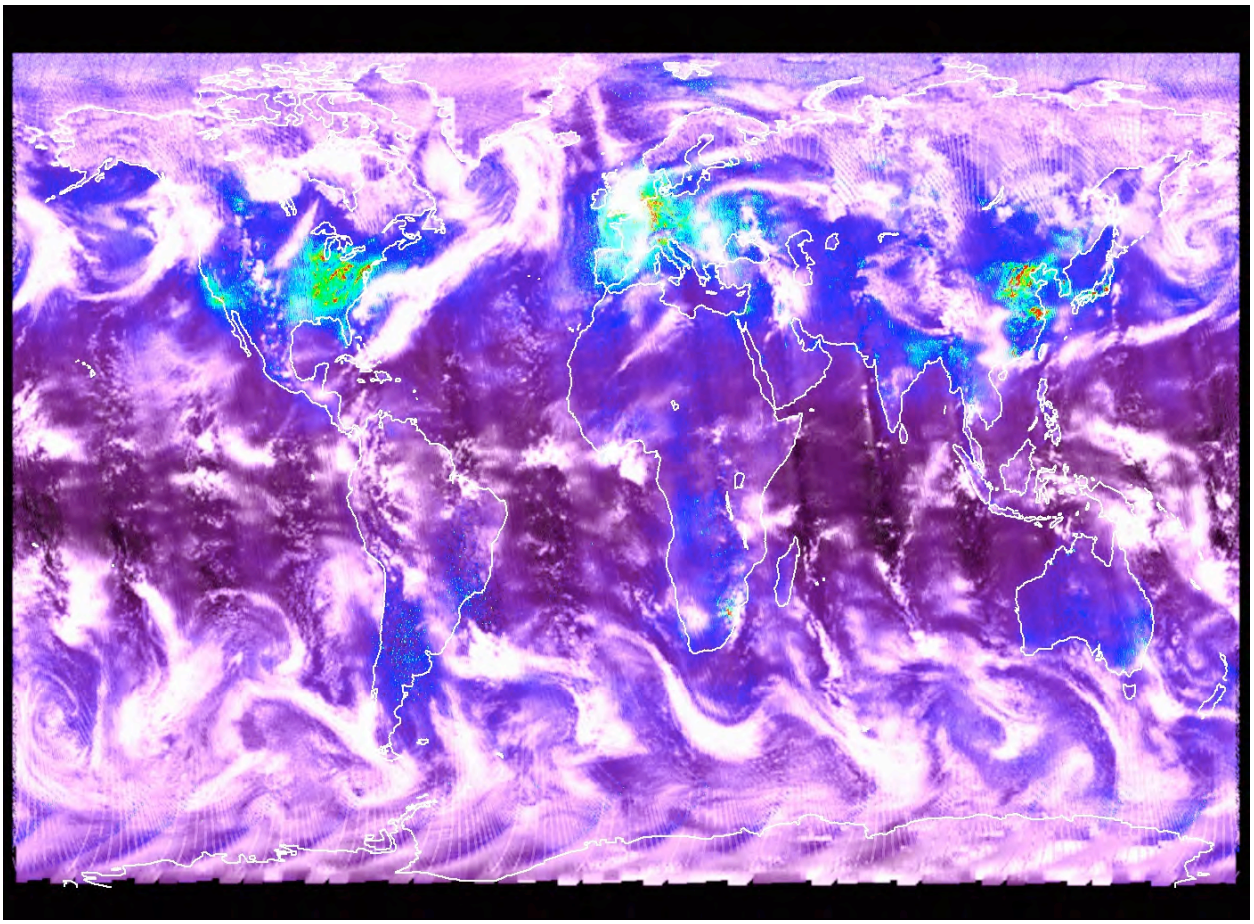
Statistical evaluation of the cloud resolving model using high resolution satellite observations is a new approach and many interesting results were found and several papers are being prepared to document these findings. In Zhou *et al.* [2006], GCE simulations during the SCSMEX experiment are compared with TRMM TMI and PR rainfall measurements and CERES single scanner footprint (SSF) radiation and cloud retrievals. It is found that GCE is capable of simulating major convective system development and reproducing the total surface rainfall amount as compared with rainfall estimated from sounding. Further examination of the rainfall spectrum finds that GCE produces more heavy rains and many dripping light rain than PR or TMI observations. GCE also appears to produce heavier vertical hydrometer profiles of rain, graupel when compared with TMI retrievals and PR radar reflectivity. The intense rain cells are also consistent with the CERES cloud and radiation measurements. The model produces similar amount of high cloud but less total cloud amount so that domain averaged OLR from the model is higher than the observation. Results from other field

experiments indicate different problems. For example, GCE produces the right amount of total cloud fraction but a very small amount of low cloud compared with MODIS observations during CRYSTAL-FACE. Model sensitivity tests are being performed to diagnose and address the possible causes for discrepancy.

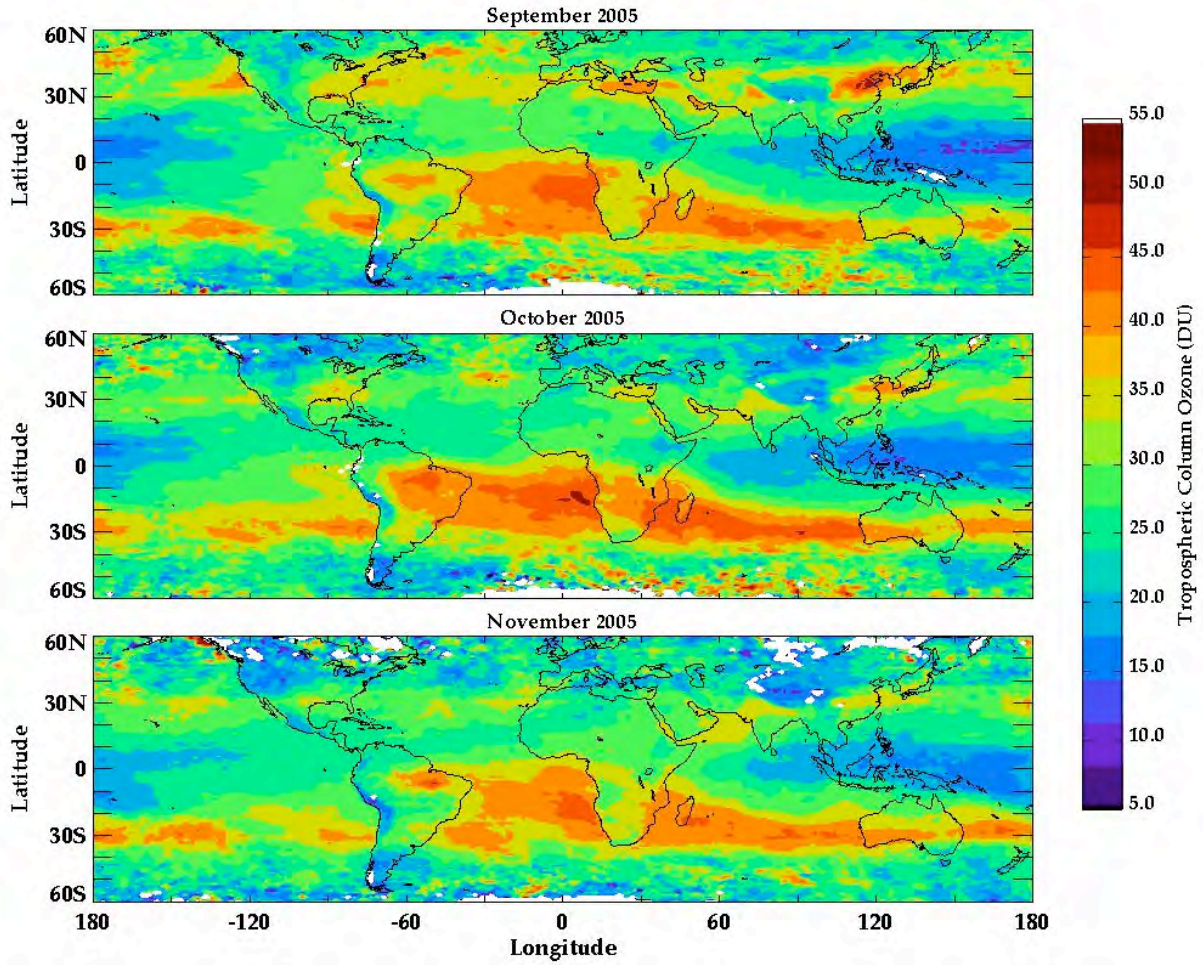
Objectives for the Coming Year

The main focus will be to address the findings from this year's analysis: How to improve the GCE representation of cloud, rain spectrum? The satellite-to-GCE comparison will be expanded to different cloud systems. Other factors, such as aerosol and cloud microphysics will be considered in the analysis as well.

Atmospheric Chemistry and Dynamics Research Group



Total column amounts of NO_2 as seen by OMI on April 15 2005. The polluted regions in the eastern United States, Europe and the Far East are clearly visible. White areas represent clouds. (Provided by Eric Bucsela.)



Recent measurements of tropospheric column ozone (in Dobson Units) derived from Aura OMI and MLS satellite instrument measurements. Shown are maps for September-November 2005. (Figures provided by Jerry Ziemke and Sushil Chandra.)

Atmospheric Chemistry and Dynamics Research Group

The composition of the atmosphere—its gases and particles—plays a critical role in connecting human welfare with global and regional environmental changes since the atmosphere links all of the principal components of the Earth system. The Atmospheric Composition chapter of the Strategic Plan for the U. S. Climate Change Science Program identifies the following questions for research [http://www.climatescience.gov/Library/stratplan2003/final/default.htm]:

> Question 3.1: What are the climate-relevant chemical, microphysical, and optical properties, and spatial and temporal distributions, of human-caused and naturally occurring aerosols?
>
> Question 3.2: What are the atmospheric sources and sinks of the greenhouse gases other than CO2 and the implications for the Earth's energy balance?
>
> Question 3.3: What are the effects of regional pollution on the global atmosphere and the effects of global climate and chemical change on regional air quality and atmospheric chemical inputs to ecosystems?
>
> Question 3.4: What are the characteristics of the recovery of the stratospheric ozone layer in response to declining abundances of ozone-depleting gases and increasing abundances of greenhouse gases?
>
> Question 3.5: What are the couplings and feedback mechanisms among climate change, air pollution, and ozone layer depletion, and their relationship to the health of humans and ecosystems?

Research by members of the Atmospheric Chemistry and Dynamics Research Group directly contributes to answering these questions.

In 2005, Robert Curran became a member of GEST's Atmospheric Chemistry and Dynamics Research Group. He was previously the Director of GEST from its inception in 2000 until July 2005. Subsequently he joined the staff of the U. S. Climate Change Science Program Office, while maintaining his relationship as research faculty with UMBC. In this capacity he is editor of the annual publication, "Our Changing Planet" (http://www.usgcrp.gov/usgcrp/Library/ocp2006/ocp2006.pdf) and serves as liaison to the interagency working group on Atmospheric Composition. This working group is composed of the federal agency program managers responsible for implementing research programs related to Atmospheric Composition. The working group also oversees the development of integrated science and implementation plans relevant to Atmospheric Composition and Climate Change. Simply put, the Atmospheric Composition working group is a forum in which the relevant federal agencies sponsoring research in atmospheric composition (gaseous and particulate) and its interaction with climate change meet to coordinate joint projects, report highlights of program research and develop future research plans.

Modeling studies and comparisons with measurements

One of the major goals of the atmospheric modeling at NASA/GSFC and GEST is to study atmospheric radiative, dynamical, and chemical interactions in a unified modeling framework. This unified modeling approach would help to assess the impacts of natural and anthropogenic perturbations on the global and regional atmospheric chemical composition as well as the mutual interactions of global air quality and the climate system. Several coordinated efforts are currently underway. Several 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 Global Modeling Initiative (GMI) team at Goddard (including GEST investigators Susan Strahan and Bryan Duncan) finished the development of a new CTM that has a combined chemical mechanism for both the troposphere and stratosphere (the 'Combo Model'). New diagnostics of transport near the tropopause have been developed from recently acquired aircraft trace gas data sets and are being used to evaluate the new model. The tropospheric and stratospheric versions of the GMI CTMs have participated in international model intercomparisons examining future emissions scenarios.

Bryan Duncan has applied the COMBO CTM to help evaluate and understand data collected by several instruments onboard NASA's AURA satellite. Duncan and M. Schoeberl (NASA GSFC) used the model to interpret the characteristics of the the stratospheric 'tape recorder' in carbon monoxide (CO) (a seasonal oscillation in tropical lower stratospheric CO), in the Microwave Limb Sounder (MLS) data on AURA satellite, which are linked to seasonal biomass burning. The CO tape recorder was well reproduced by the GMI COMBO CTM. Duncan, with Jerry Ziemke and Sushil Chandra, also of GEST, compared the seasonal and zonal characteristics of the model's tropospheric column ozone (TCO) with ozone measurements from the Ozone Monitoring Instrument (OMI) and MLS instruments. They are currently working to interpret the observed stratospheric column ozone (SCO) with the aid of the model's SCO.

Thomas Diehl extended the Goddard Chemistry Aerosol Radiation and Transport model (GOCART) to investigate the influence of aerosols on air quality and climate radiative forcing. GOCART is a global scale model and is driven by assimilated meteorological data from the GEOS-4 DAS. It can simulate the major atmospheric aerosols, including sulfate, dust, black carbon, organic carbon and sea-salt, from both natural and anthropogenic sources. Reseach areas included global impact of western African aerosols, and the influence of the long-range transport of aerosols on regional air quality over the United States.

Huisheng Bian used a unified CTM system (UCTM) model to simulate atmospheric CO_2 and CO fields and compared results with various measurements from surface, aircraft, and satellite. Based on this study, she and co-authors explored the impact of convective transport on atmospheric tracer distributions and revealed the intricate nature of simulating the Earth system, where balances between different processes (in their study case uncertainties in convective transports and emissions) can obscure the physical nature of relationships within the system. She also implemented a new model which coupled UCTM with Goddard Global Modeling and Assimilation Office (GMAO) GEOS-4 assimilationsystem (fvGCM) to forecast CO/CO_2 fields for mission planning support and evaluated GMI aerosol simulations (GMI-UMich) against measurements and GOCART CTM model simulation.

Many outstanding atmospheric chemistry and climate questions require knowledge of the transport of air and chemical interactions at levels from the stratosphere to the surface. Mark Olsen has investigated stratosphere-troposphere exchange (STE) and its relationship to climate change. He has shown that sea surface temperatures can play a major role in determining the amount of annual STE. A model study illustrates that observed trends in sea surface temperature result in an increasing amount of STE. He has also shown that any trend of STE in the atmosphere could be detected from ground-based measurements of hydrogen chloride (HCl). The influence of the Antarctic ozone hole on atmospheric structure and dynamics has also been investigated.

Gary A. Morris combined results from the GSFC trajectory model with data from ozonesondes to derive ozone loss rates in the lower stratosphere for the Stratospheric Aerosol and Gas Experiment (SAGE) III Ozone Loss and Validation Experiment (SOLVE, January – March 2000) and for Airborne Arctic Stratospheric Expedition (AASE)-2 (January – March 1992) in an approach similar to the Match technique [Rex, 1993]. The study suggests an alternate approach to Match using trajectory mapping that more accurately reflects the true uncertainties associated with Match and reduces the dependence upon

filters that may bias the results in the original Match approach, in which ~95% of matched data are rejected.

Santiago Gassó compared *in-situ* and retrieved aerosol fine mode fraction (FMF) during the ACE-Asia field campaign. The comparison suggested that retrieved FMF from remote sensing could be used to discriminate between fine and coarse mode dominated aerosols. He also upgraded the pollution sources within the Navy Aerosol forecast model (NAAPS) and compared with ground measurements of sulfate mass and AERONET optical depths. In a separate study using MODIS true color images and aerosol optical thickness he revealed dust activity in the Patagonia region and estimated mass fluxes advecting into the South Atlantic Ocean. He also started a critical analysis of the NPOESS Preparatory Project aerosol algorithm.

New satellite climate data sets

Jerry Ziemke and Sushil Chandra continued to maintain and develop the NASA satellite-derived data sets of tropospheric column ozone (TCO) and stratospheric column ozone (SCO) for 1979-present. From TOMS and SBUV measurements they developed a new comprehensive ozone data product covering low-to-high latitudes for 1979-present: (1) tropospheric ozone, (2) upper stratospheric ozone, and (3) lower stratospheric ozone. They also used ozone measurements from the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) instruments onboard the Aura satellite to derive global distributions of both tropospheric column ozone (TCO, see the color figure on the reverse of this section's title page) and stratospheric (SCO). This research has led to substantial new understanding of the dynamics and sources/sinks of global tropospheric and stratospheric ozone by combining both measurements and photochemical transport models.

An algorithm to infer troposheric and stratospheric column nitrogen dioxide (NO_2) distribution from the AURA OMI instrument has been developed by Eric Bucsela for the Ozone Monitoring Instrument (OMI) on NASA AURA satellite. He analyzed large amounts of NO_2 data and compared them to aircraft *in-situ* NO_2 measurements from several AURA validation flight campaigns: INTEX-A (summer 2004), PAVE (January and February 2005), and INTEX-B (Spring 2006). The ground-based validation efforts like DANDELIONS in the Netherlands, and Brewer direct sun NO_2 measurements at GSFC were also analyzed. Validation results were used to improve OMI NO_2 algorithm.

Mark Wenig is currently developing the OMI NO_2 level 2 to level 3 data processing algorithm, which creates global maps of NO_2 vertical column densities, and works on techniques to analyze these image sequences to determine the processes, which govern the underlying dynamics. For the generation of the level 3 gridded data product optimal weights for averaging all OMI pixels lying on the same grid cell are calculated based on an error analysis of the NO_2 vertical column densities. For the estimation of dynamical parameters the structure tensor technique is used which allows the direct estimation of NO_2 life times, source strengths and sinks from NO_2 image sequences.

Nickolay Krotkov has developed an algorithm to infer tropospheric and stratospheric sulfur dioxide (SO_2) distribution for OMI. The AURA OMI SO_2 volcanic data set will continue the TOMS SO_2 record, which covers a quarter-century [http://toms.umbc.edu], but the improved sensitivity and smaller footprint of OMI will extend the range of detection to smaller eruptions and older clouds, and to degassing volcanoes. Thus, the diffuse boundaries of volcanic clouds can be imaged better and the clouds can be tracked longer. More significantly, the improved sensitivity now permits daily global measurement of passive volcanic degassing of SO_2 and of heavy anthropogenic SO_2 pollution to provide new information on the relative importance of these sources for climate studies.

Satellite Data Assimilation

New earth observation platforms require data validation. Data assimilation is ideally suited to assist in this as it provides objectives metrics of agreement between observations and numerical models. David Lary has been involved in two areas of research. The first area is the use of probability distribution functions and multi-constituent chemical data assimilation, with particular emphasis on EOS Aura validation. The second area is the use of neural networks to parameterize and accelerate various aspects of atmospheric chemical simulation.

Clark Weaver continued development of an assimilation system for atmospheric aerosols and studied the impact of aerosols on the remote determination of atmospheric temperature and moisture profiles. The assimilation system utilizes radiances in the visible and near infrared as measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the Earth Observing System (EOS) satellite platforms. Satellite measured radiances are used to identify atmospheric aerosols over dark oceanic and land surfaces. His second study addresses the radiative impact of aerosols on the infrared radiances used in determining atmospheric temperature and moisture profiles. Radiances used in the second study are from the TIROS Operational Vertical Sounder (TOVS) High-resolution Infrared Radiation (HIRS) instruments on the NOAA operational satellites.

Nickolay A. Krotkov

Task 916-39-176: **Improvement and Application of Multiple Chemical Transport Models (CTMs) in Atmospheric Chemistry Study and Mission Support**

GEST Investigator: Huisheng Bian

Collaborator: Randy Kawa (GSFC), Mian Chin (GSFC)

Abstract

Three Chemistry and Transport Models (CTMs) are being developed and/or improved in Goddard's Atmospheric Chemistry and Dynamics Branch (code 916) for a range of scientific objectives. All three models share common features to provide global chemical and aerosol perspective to aid in interpreting surface, aircraft and satellite observations and comparisons. However, each model is specifically designed to pursue its particular purpose. Unified CTM (UCTM) can be used easily to explore new and innovative ideas to fill identified scientific gaps. It has been used to characterize the impact on CO_2 atmospheric distribution due to convective cloud transport. It has also been used to examine the influence of biomass burning emission on CO simulation by comparing simulated CO using different biomass burning inventories and evaluated these CO distributions with measurements. The CTM coupled with Goddard Global Modeling and Assimilation Office (GMAO) GEOS-4 system (fvGCM) forecasts aerosol and CO/CO_2 fields for mission planning support. For example, 5-day daily aerosol and CO/CO_2 forecast by fvGCM has been provided to direct the NASA Aura Validation Experiment (CR-AVE) field measurement and assist post-campaign analysis. The Global Modeling Initiative (GMI) serves as a comprehensive test bed that can be used for the assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry. GMI aerosol simulations (GMI-UMich) have been evaluated against measurements and GOCART simulation. The strength and weakness of GMI-UMich simulation have been identified for future improvement.

Description of Research

All models and simulations are designed for specific purposes although they may have many similarities and some of the uncertainties may be inherent in all models. In addition, models also range from simple, user-friendly models to complex models requiring expert users and support staff. No model is suitable for all purposes. Conversely, only select models are appropriate for supporting specific analyses. As examples, UCTM is designed in such a way that each physical and chemistry module can be upgraded easily through an interface. UCTM focuses on studying tracers that are not involved in complex chemical process. Its concise and flexible features make it a good test bed for exploring new and innovative algorithm. fvGCM calculates tracer distribution on-line in a global circulation model. This feature enables it to provide real time interaction between meteorological fields and a tracer's dynamical and chemical processes. Therefore, fvGCM is a powerful tool to support field campaigns. GMI is designed to maintain a state-of-the-art modular 3-D chemistry and transport model that can be used for assessment of various complex atmospheric chemical processes. Compared with UCTM, GMI is more comprehensive and sophisticated and it requires more expensive calculation and technical support. Our efforts in these models' development and improvement are expected to provide powerful and suitable tools for scientific research which focuses on chemical/dynamical processes in the Earth's atmosphere while emphasizing the support of mission (AURA) and mission planning activities (AVE and CR-AVE).

Accomplishments During the Reporting Period

The GEST investigator has been engaged in the development, improvement and application of all three models in the reporting period, including the direct contributions described below. First, two approximations to convective transport (Conv1 and Conv2) have been implemented in UCTM to explore the impact on

calculated atmospheric CO_2 distributions. Conv1 approximates the convective transport by using the bulk convective mass fluxes to redistribute trace gases. The alternate approximation, Conv2, partitions fluxes into updraft and downdraft, as well as into entrainment and detrainment, and has potential to yield a more realistic simulation of vertical redistribution through deep convection. The discrepancies arising from the different approaches are the largest in the NH middle latitudes in the summer season, which is about a 30% of the CO_2 seasonality for that area. This indicates the crucial importance of quantifying the transport error in CO_2 simulations. Our study also shows that introducing supplemental emissions constrained by the framework of IPCC2001 to account for possible land use change can offset the overestimated CO_2 driven by Conv2 and residual terrestrial CO_2 sink. This result highlights the intricate nature of simulating the Earth system, where balances between different processes (in this case uncertainties in convective transports and emissions) can obscure the physical nature of relationships within the system.

Second, the global CO for the year 2000-2001 is simulated with our current 'best' knowledge in CO simulation (standard case). A series of sensitivity experiments—each with a particular variation of an input dataset, a parameterization, or a scheme—is conducted for the year 2000 to explore the sensitivities of global and regional atmospheric CO response to uncertainties in several important model processes such as emission, chemistry, and transport. A comparison is performed for the sensitivity experiments between the standard simulation and the measurements from satellite MOPITT instrument, surface and airborne CMDL network, and field campaigns TRACE-P and ACE-Asia. For example, the evaluation of the three *a priori* and two *a posteriori* biomass burning emissions indicates that the *a posteriori* emissions improve CO simulation generally; however, further investigations are needed for some regional anomalies, such as extremely high CO over Central America. The simulated CO fields also demonstrate that the systematic bias induced by different methodologies and data origins is more significant for biomass burning emission than its interannual variation between 2000 and 2001 on global scale.

Third, CO productions from oxidation of biogenic NMHC and atmospheric CH_4 are implemented into fvGCM to overcome the previous failure in the comparison between CO simulation and AVE aircraft measurement. Furthermore, CO_2 simulation has been implemented in fvGCM based on the experiences obtained from UCTM. The forecast provided by fvGCM for CO, CO_2, as well as aerosol contributed from the working group, has been used in learning proposed flight conditions in the CR-AVE field campaign and therefore enhance the ability to characterize validation opportunities and satisfy validation priorities. In the UT/LS, CO and aerosol are key validation objectives. The post-campaign analyses by comparison of model simulations with Aura and aircraft measurements help explain mission data in terms of constituent gradients and temporal changes caused by chemical and transport processes in the troposphere and stratosphere.

Fourth, work in implementing GOCART-like aerosol simulation into GMI is being performed so that it can be compared to the current GMI-UMich aerosol simulation within a single GMI model framework. The goal is to improve the aerosol simulation by exploring the multiple choices and then integrating an optimized science and technical solution. As a first step, global aerosol mass and optical thickness (AOT) simulated by two aerosol CTMs (GOCART and GMI-UMich) are evaluated and the strength and shortcoming of the model approaches are investigated. These two offline CTM models are driven by the same meteorological fields (NASA GEOS-4), use the same dynamic transport algorithm, and have the same spatial resolution. However, they differ partially in aerosol optical properties, emission, dry/wet deposition, and chemistry. The simulated aerosol masses are evaluated with data from surface measurements (*e.g.*, IMPROVE network) and field campaigns (*e.g.*, ACE-Asia and TRACE-P). AOT are calculated using modeled aerosol mass but external mixed for GOCART and partially internal mixed for GMI-Mich. These AOT are

evaluated using satellite observations from MODIS and MISR and ground measurements from AERONET. The research demonstrates that there are significant differences in simulated aerosol mass and AOT by the two approaches and therefore further investigation and improvement for aerosol simulation is necessary.

Objectives for the Coming Year

In the coming year, CO field simulated by UCTM will be further analyzed to clarify the discrepancies of vertical profile arising from its comparison with MOPITT satellite data over Asia region. This scientific application of the UCTM will assist the evaluation of vertical sensitivity and precision of retrieved satellite data. These scientific findings will be delivered to the public. The investigator will continuously provide global chemical and aerosol perspective to aid in interpreting aircraft and satellite observations and comparisons in post-mission analysis toward the scientific and validation goals of CR-AVE. Further investigation will be also performed to quantitatively evaluate the features and/or parameterizations which induce the differences by comparing processes and optical properties between GOCART and GMI-UMich. What was learned from this study will direct the implementation of GOCART-like aerosol simulation into the GMI framework in order to span a wide spectrum of possible science and technical solutions.

Task 916-13-121: **Climate and Trace Species**

GEST Investigator: Eric Bucsela

Collaborator: James Gleason (GSFC), Edward Celarier (SGT), Mark Wenig (GEST), Kenneth Pickering (GSFC), P.K. Bhartia (GSFC), Ernest Hilsenrath (JCET), Ellen Brinksma (KNMI), Pepijn Veefkind (KNMI)

Abstract

This reporting year saw analysis of large amounts of data from the Ozone Monitoring Instrument (OMI) on NASA AURA satellite and improvements in the retrieval algorithm. A paper describing the development of the OMI NO_2 algorithm has been formally accepted in the journal *IEEE/TGRS*. Furthermore, studies to validate the NO_2 data from OMI were conducted and analyzed. The aircraft validation campaigns included INTEX-A, whose data were collected in the summer of 2004, PAVE in January and February 2005, and the ongoing INTEX-B campaign in the spring of 2006. The ground-based validation efforts, like DANDELIONS in the Netherlands and Brewer measurements from GSFC, were also conducted. Results from these campaigns were discussed at the AURA validation meeting in Greenbelt, Maryland in September 2005 and later that year at the annual meeting of the American Geophysical Union in San Francisco. Results from the study of some of these validation data were considered in making improvements to the OMI algorithm. The data from OMI were prepared and submitted for provisional release in 2005.

Description of Research

The principal objective of the past year's research was to support trace-gas-retrieval for the EOS AURA mission. Work focused on NO_2 retrievals from OMI, and on ground- and aircraft-based validation programs. The goal was to better understand results from the instrument, deployed on the EOS AURA satellite in July 2004, and to prepare the data for provisional release. Measurements made during validation experiments were intended both to verify NO_2 amounts from OMI and to use profile data to improve the retrieval algorithm. An additional goal was to address OMI calibration issues and to look towards a public release of the data in FY 2006-2007.

Accomplishments During the Reporting Period

During year 2005-2006, the OMI NO_2 data were provisionally released, and work during this period included refinement of the algorithm used

to extract NO_2 from the OMI spectra, as well as examination and analysis of data returned by OMI. A significant effort was also spent in looking at validation data in conjunction with the satellite measurements. All work is being carried out at NASA as part of a joint venture with KNMI in the Netherlands, and the details are described below. Significant milestones for the year included acceptance of the algorithm paper, the provisional data release, and analysis and presentation of the first validation results at meetings in Greenbelt, MD and San Francisco, CA.

The OMI data were provisionally released in Fall 2005. The purpose of this release was primarily to give members of the scientific community a chance to evaluate the OMI NO_2 product and compare it with results from a number of validation campaigns. Several changes were made in the algorithm in preparation for the provisional release. The first involved implementation of an improved set of *a priori* NO_2 profiles used for computing the tropospheric AMF. The new profiles generally resulted in somewhat larger AMFs and hence smaller retrieved tropospheric NO_2 amounts. The investigator also explored a number of methods for reducing the cross-track bias in the OMI detector. This bias affects the spectral fit and manifests itself as "striping" along the orbital track when NO_2 column amounts are displayed on a map. The algorithm now uses all data in the tropics and mid-latitudes from a given day to compute a striping correction for that day. Further improvement in the algorithm is possible if only three orbits at a time are used to calculate the correction, or if only data based on the same solar irradiance spectrum are used. Such methods are planned for use in upcoming generations of the algorithm.

An additional (and more significant) change made in the algorithm prior to the data's provisional release had to do with the way in which the tropospheric and total NO_2 column is reported. Based on the assumed *a priori* NO_2 profiles shapes from the Harvard GEOS-CHEM model and the measured initial NO_2 vertical columns above cloud tops, the amount of NO_2 present below the clouds had been estimated. Early results from OMI showed that this method produced very large estimates of NO_2 columns in cloudy regions. In polluted areas of the world, these amounts were often greater than the NO_2 columns actually observed in the clear spaces between the clouds. Based on the likelihood that the *a priori* profiles were not well known and that errors in the profiles might account for some of these discrepancies, it was decided to report only the observed NO_2 visible from OMI, *i.e.*, the NO_2 above the clear terrain and/or clouds, if present. The result was smaller reported NO_2 columns in most cloudy regions.

Several additional tests were performed with the OMI NO_2 algorithm. Most of these were conducted using actual OMI data rather than simulated data, which had been used during the pre-launch phase of algorithm testing. Investigations of retrievals in clear and cloudy regions revealed that in mid-northern latitudes, the initial vertical column density tended to be higher in clear than in cloudy areas. This is consistent with the notion that clouds tend to mask NO_2 in the polluted areas in mid-northern latitudes. However, in the tropics, cloudy areas had higher NO_2 columns than clear regions, consistent with NO_2 production above convective clouds and the enhancement in visibility of any free tropospheric NO_2 above bright cloud surfaces. Since the algorithm uses both clear and cloudy areas to compute the stratospheric NO_2 background, several tests were performed to reduce the effect of tropospheric bias—either above clear or cloudy areas—on the stratospheric field estimate in the operational algorithm.

Since the deployment of OMI, numerous validation campaigns have been conducted to measure atmospheric trace constituents like NO_2 from the ground and from aircraft. The GEST researcher examined results from several of these campaigns and explored the possibility of modifying the algorithm based on those findings. Composite NO_2 profile shapes over land and ocean areas were obtained in the summer of 2004 during INTEX-A, and the following winter during the PAVE campaign. These showed relatively different amounts of NO_2 in the boundary layer and free troposphere

than those estimated by the GEOS-CHEM model, which is used in the algorithm for AMF calculation. Use of the measured profiles in the OMI algorithm would yield different NO_2 amounts, and these differences were discussed at the OMI validation meeting and the AGU meeting in Fall 2005. In the latter meeting, the GEST investigator also presented results from the DANDELIONS validation effort in the Netherlands and discussed implications for the OMI algorithm. Additional validation measurements were made from GSFC using the Brewer instrument. These tended to show tropospheric NO_2 amounts some 20-30% higher than those measured by OMI. The first results of analysis from the INTEX-B campaign also tend to show somewhat more NO_2 than measured by OMI. Further analysis of data from both these campaigns continues.

Objectives for the Coming Year:
Work during fiscal year 2006-7 will involve continued characterization of the OMI instrument, refinement of the algorithm, and analysis of the data. Further progress should be made in understanding anomalies in the detector. Some of these anomalies have already provided clues about variations in instrument sensitivity across the satellite track. Results from the further analysis will be fed back to those involved in OMI calibration to develop improved versions of the Operational Parameter File (OPF) used to process OMI spectral data. The GSFC algorithm, which converts the slant columns to vertical columns, will also be improved, with particular focus on *a priori* NO_2 profiles, clouds, and aerosols, and their effects on the tropospheric air mass factor. Radiative transfer calculations of air mass factors will also be re-examined. Further measurements and analysis relating to OMI validation efforts will also be conducted. The OMI NO_2 data will be publically released in the coming year. Additional studies will be undertaken as funding permits.

UMBC 00001762: **U. S. Climate Change Science Program Office (CCSPO) Staff Through a NASA Supported Intergovernmental Personnel Act (IPA) Appointment**

GEST Investigator: Robert J. Curran

Collaborator: Jack Kaye (NASA HQ), Peter Schultz (Acting Director, CCSPO)

Abstract and Description of Work
Robert Curran was the Director of GEST from its inception in 2000 until July 2005. Subsequently he continued his affiliation with UMBC and GEST through a NASA-provided, Intergovernmental Personnel Act position in the U. S. Climate Change Science Program Office. The U.S. Climate Change Science Program (CCSP) is a collaborative interagency program designed to improve the government wide management of climate science, integrating the U.S. Global Change Research Program (USGCRP) with the U. S. Climate Change Research Initiative. 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 mandated 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 it provides an overview of recent and near-term expenditures 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. Curran serves as lead editor for *Our Changing Planet*.

In addition to his editor responsibilities, Curran serves as liaison to the interagency working group on Atmospheric Composition. This working group is composed of the federal agency program managers having the

responsibility to implement research programs related to Atmospheric Composition. The working group also oversees the development of integrated science and implementation plans relevant to Atmospheric Composition and Climate Change. Simply put, the Atmospheric Composition working group is a forum in which the relevant federal agencies sponsoring research in atmospheric composition (gaseous and particulate) and its interaction with climate change meet to plan their reporting of results and plans.

Accomplishments During the Reporting Period

The fiscal year 2006 edition of *Our Changing Planet* was published and distributed in November 2005. Initial development and editing of the draft was performed before Curran joined CCSPO. However, final edit and the lengthy process of review by the agencies involved in CCSP was Curran's responsibility. Distribution of this document to the relevant Congressional committees, subcommittees and members of both houses was Curran's responsibility. The final version of this document is available on the web [http://www.usgcrp.gov/usgcrp/Library/ocp2006/ocp2006.pdf].

Objectives for the Coming Year

Development of *Our Changing Planet* for FY 2007 began in November 2005. The objectives for the current year are to keep the development of this document on schedule for publication and distribution in mid-summer 2006. This will depend upon the timely and favorable review by all agencies of the federal government. A second goal for 2006 is to continue work with the Atmospheric Composition working group in developing the Synthesis and Assessment product 2.3 entitled, "Aerosol properties and their impacts on climate." This is one of 21 Synthesis and Assessment products to be produced by CCSP.

Task 916-62-216/ Grant 00001238: **Three-Dimensional Modeling of Atmospheric Chemistry and Aerosol Processes**

GEST Investigator: Thomas L. Diehl

Collaborator: Mian Chin (PI, GSFC), Peter Colarco (GSFC), Bryan Duncan (GEST), Huisheng Bian (GEST), Tom Kucsera (SSAI), Alexander Smirnov (GEST), Yogesh Sud (GSFC)

Abstract

The capability to use meteorological fields from version 4 of the GEOS DAS (GEOS-4) was implemented in the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model, which is a prerequisite for a simulation of the period 1980 to 2000. This required major changes in several parameterizations and a comprehensive evaluation of the new model version. The researchers also evaluated another set of meteorological fields derived from forecasts. Other research foci included the application of the GOCART model to assess the global impact of western African aerosols, and to study the influence of the long-range transport of aerosols on regional air quality over the United States. Diehl continued his participation in the Aerocom project, conducting a study on the aerosol indirect effect.

Description of Research

The goal of this task is to develop and extend GOCART, and 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 major accomplishment during the reporting period was the implementation of the capability to use meteorological fields from the GEOS-4 DAS in GOCART. A number of modules had to be completely replaced or modified to be consistent with the GEOS-4 fields, including convective and large-scale scavenging, boundary layer mixing, dry deposition and others. The burden for dust and sea salt is significantly higher in the GEOS-4 based results (as compared to GEOS-3 results), which is due to a higher sedimentation lifetime and a decrease in the large scale precipitation in GEOS-4. The lifetime due to dry deposition is shorter, since the resolution in the PBL is lower in GEOS-4. The total aerosol optical thickness (aot) at 550nm derived from the GEOS-4 results shows better agreement with MODIS data, except over the oceans at low latitudes, where sea salt values are too high.

The GEST investigator also performed GOCART simulations with GEOS-4 meteorological fields from assimilation and from a 12-18 hour forecast. The results show noticeable differences in aerosol distributions, with forecasted aerosols higher in the tropics but lower in the extra tropics. This is mainly due to the differences in the convection and precipitation in the meteorological data sets. It is also observed that the aot derived from the forecast-based results for April 2001 agrees slightly better with AERONET data than the results from the assimilation-based runs.

GOCART and satellite data were used to quantify the aerosol sources and distributions to support AMMA, analyze AMMA data and assess the global impact of western African aerosols. Diehl first validated GOCART's capability to reproduce the seasonal variations of aerosol emission, composition, and distributions over western Africa, using data from MODIS, AERONET as well as aircraft data (EOP). For 2001, the researchers found that 20-50% of sulfate aerosols over western Africa originate from the anthropogenic sources over Europe. It seems that there are serious air quality problems over western Africa with most areas exceeding 100 $\mu g/m^3$ for PM10 and 50 $\mu g/m^3$ for PM2.5. It is more severe in the dry season than in the monsoon season. Dust and biomass burning aerosols from western Africa are transported over long distances, mostly to the tropical Americas and to Europe.

Another research activity focused on the implications for regional air quality from the intercontinental transport of aerosols. Researchers were particularly interested in the contribution of both regional anthropogenic emission and long-range transport to the PM2.5 concentration over the United States and in the seasonal variation of the background PM2.5. Some of the results for 2001 showed that 60% of the surface PM2.5 over the western US is of natural origin, while 60% of PM2.5 over the eastern US is due to domestic anthropogenic sources. 60% of surface fine mode dust over the southwestern US is due to the local deserts, while in other regions Asia and Africa contribute significantly (50% and 25-30% respectively). The background PM2.5 has large seasonal variations, with the highest values in April through June.

Diehl continued to participate in the Aerocom initiative, which he had previously provided with results from GOCART model runs for an analysis of the diversities of aerosol burden and aot within 20 aerosol models. The results of this study have been published in [Kinne *et al.*, 2005] and [Textor *et al.*, 2005]. He also contributed to an additional Aerocom study on the aerosol indirect effect by modifying the cloud droplet number concentration in a GEOS-4 GCM run with an SO_4 climatology from GOCART. The results show that the high SO_4 content over the industrialized regions of the northern hemisphere leads to more cloud water which is subsequently advected and increases the cloudiness downstream.

Other research activities included comparing ship-borne aerosol optical depth measurements over the Atlantic Ocean to GOCART model results, creating parts of a comprehensive emission inventory for a 21-year simulation, and advising the GMAO on the file specifications of the GEOS-5 product. Diehl also investigated the option of using MODIS fire counts to impose a

daily variation on the emissions from biomass burning.

Objectives for the Coming Year

A key goal will be to finish the creation of the emission inventory and to conduct a 21-year simulation of tropospheric aerosols from 1980 to 2000 to investigate the atmospheric response to changes caused by human activities and natural events. Plans are being made to enhance the quality of aerosol retrieval products from the OMI instrument using a combination of GOCART data and observational data. The GEST investigator also plans to implement the GOCART aerosol modules into the GMI framework to estimate the variability in aerosol distributions and radiative forcing due to the use of different meteorological fields and to implement a microphysics package in GOCART.

Task 916-54-206/ Grant 00001213: **A Global Modeling Initiative (GMI) Study of the Sensitivity of CTM Transport to Meteorological Fields: Model Development, Evaluation, and Preliminary Results**

GEST Investigator: Bryan N. Duncan

Collaborators: Susan Strahan (GEST), Jose Rodriguez (Univ. of Miami)

Abstract

Research has concentrated on completing the development and evaluation of the Global Modeling Initiative's (GMI) 3-D Combined Stratosphere-Troposphere chemical tracer model (COMBO CTM). As part of our continuing model evaluation effort, the GEST investigator worked with scientists from the AURA satellite program to interpret observations collected from mid-2004 through 2005 using the GMI model. He also began the implementation and evaluation of a new set of meteorological fields provided by the NASA Goddard Model and Assimilation Office (GMAO).

Description of Research

The goal of the Global Modeling Initiative (GMI) is to develop and maintain a state-of-the-art 3-D chemical tracer model (CTM) that can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry. Scientific application and evaluation of the GMI CTM will strengthen its credibility as an assessment tool and is a high priority of GMI activities. The GMI model is a modular CTM with the ability to carry out multi-year assessment simulations as well as incorporate different modules, such as meteorological fields, chemical mechanisms, and numerical methods that represent the different approaches of current models. Since January 2004, Bryan Duncan has been involved in the development and evaluation of the GMI Tropospheric (TROP) and Combined Stratosphere-Troposphere (COMBO) CTMs with the GMI science team. Model output, in conjunction with observations, has been analyzed, especially those collected by instruments on the AURA satellite. The researcher is also implementing several meteorological fields into the model to understand their impact on the CTM's transport.

Accomplishments during the Reporting Period

Bryan Duncan was involved in a number of development activities on the GMI COMBO CTM during the reporting period, though the focus here is on scientific accomplishments. As part of our continuing effort to improve the TROP and COMBO GMI CTMs, a wide array of observations were used with the objective to interpret satellite data, including those collected by NASA instruments.

Jerry Ziemke and Sushil Chandra, also of GEST, used ozone measurements from the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) instruments onboard the Aura satellite to derive global distributions of the tropospheric column ozone (TCO). Bryan Duncan compared the seasonal and zonal characteristics of the observed TCO with TCO derived from the model. The columns showed interesting similarities with respect to zonal and

seasonal variations. However, there were notable differences, particularly over regions impacted by desert dust; we are currently investigating the causes of these differences. The observed TCO was determined using the tropospheric ozone residual method which involved subtracting concurrent measurements of MLS stratospheric column ozone (SCO) from OMI total column ozone after adjusting for inter-calibration differences of the two instruments using the convective cloud differential method. The derived TCO, which covered one complete year of mostly continuous daily measurements from late August 2004 through August 2005, was used for studying the regional and global pollution on a time scale of a few days to months. A manuscript was submitted on this topic in January 2006 [Ziemke et al 2006]. Duncan is currently working with Ziemke and Chandra to compare the model SCO with the observed SCO.

Using Aura MLS data, Mark Schoeberl identified the stratospheric 'tape recorder' in carbon monoxide (CO). The CO tape recorder was well reproduced by the GMI COMBO CTM. Differences between the model and observations suggest that the model tropical convective parameterization does not transport trace gases high enough. Unlike the water vapor tape recorder, which is controlled by upper troposphere processes, the CO tape recorder is linked to seasonal biomass burning. Since CO has a lifetime of only a few months; the CO tape recorder barely extends above 20 km. The tape head for CO appears to be close to 100 hPa near the same location as the water vapor tape head. Both tape heads are below the equatorial tropopause suggesting that convection is not the dominant vertical transport process above 100mb. A manuscript was submitted on this topic in February 2006 [Schoeberl, et al].

The GEST investigator successfully implemented and tested an experimental set of meteorological fields for January through April 2001 into the GMI COMBO CTM from GMAO in collaboration with Steven Pawson and Hiroo Hayashi. This new set of fields shows promise, offering substantial improvement, most notably for rainfall and convection, over other sets of fields. Areas of improvement were identified in the model simulation as compared to observations from the TRACE-P field campaign, the MOPITT instrument, MOZAIC flights, Japan Airlines flights, and NASA's Global Precipitation Climatology Project (GPCP). The "proof of concept" phase is nearly completed and GMAO is generating a longer time period for additional study. Currently ongoing is an evaluation of the impact of these new fields on stratosphere-troposphere exchange (STE), which is excessive in other GMAO meteorological products.

Objectives for the Coming Year

Bryan Duncan will work with other GMI science team members to continue to evaluate the credibility of circulation produced by several meteorological fields that drive transport in the GMI COMBO CTM. He will assess the model's simulation of large-scale circulation, such as STE and tropospheric inter-hemispheric exchange (IHE), as well as smaller scale motions, including convection and pollution plume transport. Work will also continue with scientists involved with the AURA satellite. As an example, the GMI COMBO CTM will be used to understand the observed variability of OMI's total column ozone.

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

GEST Investigator: Nickolay Krotkov

Collaborators: Jay Herman (GSFC), P.K. Bhartia (GSFC), Arlin Krueger (JCET), Simon Carn (JCET)

Abstract

Research was focused on the development of applications of satellite UV remote sensing data, such as SO_2 and ultraviolet (UV) surface irradiance from NASA Total Ozone Mapping Spectrometer (TOMS) and EOS/AURA Ozone

Monitoring Instrument (OMI). The focus was on (1) developing a new SO_2 algorithm for EOS AURA OMI instrument; and (2) quantifying satellite UV data bias due to pollution aerosol absorption using ground-based remote sensing techniques. The OMI improved sensitivity now permits daily global measurement of passive volcanic degassing of SO_2 and of heavy anthropogenic SO_2 pollution to provide new information on the relative importance of these sources for climate studies. Direct ground-based measurements were conducted to quantify absorbing aerosol properties in UV as well as on clear sky direct aerosol forcing of surface UV irradiance. Radiative transfer modeling was extensively used for combining and cross validating different methods of measuring column aerosol absorption and to ensure consistent aerosol retrievals between UV and visible wavelengths.

Description of Research

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. The NASA Total Ozone Mapping Spectrometer (TOMS) data record [http://toms.gsfc.nasa.gov], which now spans more than 26 years, has played a key role in monitoring long-term changes in the ozone layer and has been used to study the progression and inter-annual variability of the polar ozone depletion, popularly known as the "ozone hole." By combining measurements of total ozone, clouds, aerosols and UV surface albedo from TOMS, an accurate long-term record of surface UV irradiance on a global scale has also been produced. Since high quality ground-based UV data are scarce and typically available only from mid 90s, TOMS-generated record of surface UV is the only long-term record (since 1978) available for the evaluation of environmental and health effects of UV radiation on a global scale. In addition, the TOMS SO_2 and ash volcanic emission data [http://toms.umbc.edu] have led to significant advances in several disciplines, from derivations of eruptive sulfur budgets and emission rates, to tracking of individual clouds and assessing global volcanism and atmospheric impacts. Re-analysis and enhancements of TOMS long-term SO_2 and UV data records necessary for global change studies—*i.e.*, satellite Climate data records (CDR)—as well comparison with ground based measurements is an important part of this research task. It also includes ground-based aerosol remote sensing measurements to quantify absorbing aerosol properties in UV as well as on clear sky direct aerosol forcing of surface UV irradiance. The NASA EOS Aura platform, launched on July 15, 2004, carries the Ozone Monitoring Instrument (OMI), a hyperspectral UV/Visible spectrometer with a 2600 km swath for daily, global contiguous mapping that was provided by the Netherlands Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI) to the NASA EOS Aura mission for continued monitoring of ozone and other trace gases. Our research includes development of an advanced SO_2 and UV algorithms for OMI as well as validation with concurrent satellite and ground-based measurements.

Accomplishments During the Reporting Period

A new algorithm (Band Residual Difference, BRD) has been developed to infer tropospheric and stratospheric sulfur dioxide (SO_2) distribution from OMI instrument on NASA EOS AURA platform [Krotkov, et al 2006]. The algorithm uses calibrated residuals at SO_2 absorption band centers produced by the NASA operational ozone algorithm. By using optimum wavelengths for retrieval of SO_2, the retrieval sensitivity is improved over NASA predecessor Total Ozone Mapping Spectrometer (TOMS) by factors of 10 to 20, depending on location. The ground footprint of OMI is 8 times smaller than TOMS. These factors produce two orders of magnitude improvement in the minimum detectable mass of SO_2. Thus, the diffuse boundaries of volcanic clouds can be imaged better and the clouds can be tracked longer. The AURA OMI SO_2 volcanic data set will continue the TOMS SO_2 record, which covers a quarter-century [http://toms.umbc.edu]. Using the BRD algorithm, we have been able to measure SO_2 emissions from every significant volcanic eruption that has occurred since OMI data became routinely available in September 2004.

The AURA/OMI BRD algorithm has permitted the first routine, space-based measurements of passive volcanic SO_2 degassing in the lower troposphere. Strong SO_2 sources can be tracked on a daily basis with OMI (in the absence of significant cloud cover), whilst for weaker sources a successful approach has been to generate weekly or monthly averages of OMI SO_2 data to increase the signal to noise ratio. We have also achieved very promising measurements of anthropogenic SO_2 emissions using the BRD algorithm. Anthropogenic SO_2 emissions have been measured by OMI over known sources of air pollution, such as the Ohio valley in the USA, eastern China, and Eastern Europe. These results show that OMI can observe SO_2 emissions in the planetary boundary layer (PBL) on a daily basis, thereby improving on GOME on ERS-2 and SCIAMACHY on ENVISAT, which need several days to acquire a contiguous global map and hence could miss short-lived pollution events. The improved sensitivity now permits daily global measurement of passive volcanic degassing of SO_2 and of heavy anthropogenic SO_2 pollution to provide new information on the relative importance of these sources for climate studies.

TOMS surface UV irradiance algorithm has been applied to new AURA OMI instrument in collaboration with the Finnish Meteorological Institute (FMI) [Tanskanen et al 2006]. The noontime Erythemal surface irradiances derived from the OMI measurements were compared with those provided by NASA from the Earth Probe TOMS measurements. Different overpass times of the Earth Probe and Aura satellites explain some of the small-scale differences, and positive bias was found in regions where the effect of absorbing aerosols was expected. TOMS surface UV estimates were also validated with ground-based spectral UV irradiances measurements from 4 European stations [Kazantzidis et al 2006]. The comparisons showed clear sky positive TOMS bias 5%-20% depending on location. It was found that the bias was increasing with the increasing of both aerosol extinction (AOT) and absorption optical thicknesses (AAOT) [Kazantzidis et al 2006; Arola et al 2005; Krotkov et al 2005b]. However, it was also found that correlation with AOT or single scattering albedo is significantly smaller than with AAOT [Krotkov et al 2005b; Arola et al 2005]. To explain the bias direct ground based measurements were conducted to quantify absorbing aerosol properties in UV as well as on clear sky direct aerosol forcing of surface UV irradiance. Radiative transfer modeling was extensively used for combining and cross validating different methods of measuring column aerosol absorption and to ensure consistent aerosol retrievals between UV and visible wavelengths [Krotkov et al 2005ab]. This is the first time the aerosol absorption effect is quantified with the actual ground based measurements of the aerosol UV optical properties. If measurements or climatology of AAOT are available in the UV spectral range, the TOMS/OMI UV product can be post corrected for absorbing aerosols using site-dependent regressions. Depending on the level of correction, the mean positive bias can be essentially removed and the standard deviations can be also reduced to ~6% -10%.

Objectives for the Coming Year

The BRD algorithm is currently being used operationally with AURA OMI data to produce initial Level 2 SO_2 data. However, the BRD algorithm sensitivity does not represent the maximum sensitivity theoretically achievable with OMI, hence future algorithm improvements (*i.e.* spectral fitting) should allow even weaker SO_2 sources to be monitored routinely. Krotkov plans to implement SF SO_2 algorithm operationally in 2006. These measurements are expected to produce the best estimates to date of the volcanic and anthropogenic contribution to global atmospheric SO_2 abundances.

The researcher will continue ground-based passive remote sensing of column aerosol and gaseous (SO_2, NO_2, O_3) absorption across UV-visible spectral range at NASA/GSFC site using a combination of instruments and techniques. An existing double-grating Brewer spectrometer has been modified so that it will be very suitable for simultaneously measuring tropospheric ozone profiles, aerosol properties, and trace gas amounts with the goal to determine daytime variability in tropospheric ozone, NO_2, SO_2 and

aerosols. For the lower troposphere, this is important since ozone and NO_2 photochemistry is directly involved in determining the amount of pollution in the boundary layer. Based on this research, it is clear that OMI-provided estimates of aerosol absorption have the potential of improving the quality of OMI UV data over polluted areas, by properly including the spectral attenuation effects of carbonaceous, urban/industrial and mineral aerosols. This work is currently undergoing, given its importance in monitoring changes in the surface radiation, particularly the UVA and photo-synthetically-active radiation (PAR).

Task 910-00-008: **Chemical Data Assimilation**

GEST Investigator: David Lary

Collaborators: Mark Schoeberl (GSFC), Anne Douglass (GSFC), Lynn Sparling (UMBC), Richard Stolarski (GSFC), Mian Chen (GSFC), Bryan Duncan (GEST), Joe Waters (JPL), Nathaniel Livesey (JPL), Gloria Manney (JPL), William Read (JPL), Michelle Santee (JPL), John Gille (NCAR)

Abstract

New earth observation platforms require data validation. Data assimilation is ideally suited to assist in this as it provides objective metrics of agreement between observations and numerical models. This is particularly useful when the assimilation system has already been used to study data from existing validated platforms with which one can compare the metrics from the new as yet unvalidated platforms. This is particular relevant to the recently launched NASA EOS Aura platform. When modeling atmospheric chemistry, whether it is air quality, stratospheric ozone, or chemistry-climate interactions, coupled ordinary differential equations (ODEs) are solved. The solution of these ODEs is computationally expensive. It is desirable to have a generic machine-learning-assisted ODE solver for stiff equations with automatic error monitoring and continuous training. The ODE solver would also provide an associated error estimate of the solution. This would be suitable for modeling atmospheric chemistry. The speed of such a solver should facilitate much higher resolution and longer duration simulations than have been possible to date.

Description of Research

Lary has been involved in two areas of research. The first area is the use of probability distribution functions and multi-constituent chemical data assimilation, with particular emphasis on EOS Aura validation. The second area is the use of neural networks to parameterize and accelerate various aspects of atmospheric chemical simulation.

Accomplishments During the Reporting Period

Much of the work has made use of AutoChem software, http://www.autochem.info, written by Lary. AutoChem has won four NASA awards [http://www.autochem.info/ Awards.html] and was the subject of a NASA tech brief [http://www.nasatech.com/Briefs/ Nov05/GSC_14862_1.html].

There has been a new release this year of AutoChem, V8, which has considerable assimilation data handling enhancements. A particular improvement is the optional intelligent filling of missing observational data with krigging between known data points.

The web site creation has been totally rewritten in support of NASA Aura validation. One of the three AutoChem sites, www.PDFCentral.info, is in current use for NASA Aura validation. It offers for the first time a multiplatform intercomparison of a huge observational database over the last decade and a half. An intercomparison on this scale has never been attempted before.

A huge observational database has also been included in AutoChem [http://www.autochem.info/constituentobservationaldatabase.html]. This is the culmination of 15

years of work to give a multi-constituent, multi-platform atmospheric constituent observational database all in the same format.

There has been a very large increase in the number of users. Science soft-Con [http://www.science-softcon.dc/uv-vis.htm] has signed an agreement to provide AutoChem to the academic community as a modeling and assimilation resource for research and education. Last year, this worldwide database, of which AutoChem is now a part, had more than 60,000 users at more than 2,000 institutions worldwide. In addition, this year an additional 10,000 copies of AutoChem will be distributed on the abstracts CD of the European Geosciences Union General Assembly 2006 to be held in Vienna, Austria, 2-7 April 2006. This distribution was paid for by the European Geosciences Union.

The leading engine design software company, Gamma Technologies [http://www.gtisoft.com/], has signed an evaluation license for AutoChem and is considering the use of AutoChem in its software suite. Gamma Technologies customers include 200 of the world's leading car and component manufacturers [http://www.gtisoft.com/aboutus.html]. There are 8 academic licenses for institutes in America, England, and Australia.

In the last year there have been more than 161,235 hits for the AutoChem suite of websites.

The researcher also received recognition of the patent pending for his Neurological Algorithm Wrapper from the UMBC Office of Technology Development [http://gest.umbc.edu/media/OTD_Newsletter-Winter_2005.pdf].

Multi-constituent chemical data assimilation aids satellite evaluation. Satellite instrument validation is obviously necessary but sampling issues often make practical application problematic. This research is aiding EOS Aura constituent evaluation/validation by using the multivariate technique of data assimilation cast in Lagrangian coordinates. An advantage of assimilation is that it propagates information from data-rich regions to data-poor regions. Data assimilation also offers a mathematical framework to check and quantify the chemical consistency of multispecies observations with one another and with photochemical theory through the use of objective skill scores. That is, the assimilated analyses examine both the consistency between different instruments observing the same constituent, and the photochemical self-consistency between multiconstituent observations and photochemical theory. The latter issue has not figured highly in previous satellite instrument evaluation. Our chemical data assimilation ingests observations from platforms such as ACE, HALOE, and POAM to prepare global stratospheric multiconstituent analyses. These analyses are then sampled in the same way as the Aura instruments and compared with the Aura observations using such tools as scatter diagrams, comparing probability distribution functions (quantile-quantile plots), and skill scores. The skill scores quantify various aspects of bias between observations and photochemical theory. Since the typical magnitude of these scores is known from previous assimilation studies they should be useful in highlighting any instrument biases that are present in the Aura observations. Additionally, chemical data assimilation adds value to the Aura data by providing synoptic analyses for scientific studies in the same way that meteorological data are used to produce meteorological analyses that are then used in scientific studies. This is of particular interest to Mark Schoeberl (GSFC), Anne Douglass (GSFC), Joe Waters (NASA JPL), Nathaniel Livesey (NASA JPL), Gloria Manney (NASA JPL), William Read (NASA JPL), Michelle Santee (NASA JPL), John Gille (NCAR), Doug Kinisson (NCAR), and Alyn Lambert (NCAR).

Neural networks are ideally suited to parameterize and accelerate various aspects of atmospheric chemical simulation. Neural networks have been used to describe the spatial and temporal dependence of tracer-tracer correlations. The neural network performs well even in regions where the correlations are less compact and normally a family of correlation curves would be required. For example, the CH_4-N_2O correlation can be well described

using a neural network trained with the latitude, pressure, time of year, and CH_4 volume mixing ratio (v.m.r.). A neural network using Quickprop learning and one hidden layer with eight nodes was able to reproduce the CH_4-N_2O correlation with a correlation coefficient between simulated and training values of 0.9995. Such an accurate representation of tracer-tracer correlations allows more use to be made of long-term datasets to constrain chemical models, such as the dataset from the Halogen Occultation Experiment (HALOE) which has continuously observed CH_4 (but not N_2O) from 1991 until the present. Work is now underway to use the neural networks to learn the behavior of ODEs and assist in their solution.

Objectives for the Coming Year

The coming year will be dominated by two major activities. The first major activity will be continued Aura validation. The second major activity will be to develop generic neural networks for a variety of applications in Earth Science.

Task 916-01-017: **Investigation and Application of the Match Technique and AVE Ozonesondes from Houston, Texas**

GEST Investigator: Gary A. Morris

Collaborators: P.K. Bhartia (GSFC), Mark Schoeberl (GSFC), Richard Stolarski (GSFC), Bojan Bojkov (GSFC), Leslie Lait (GSFC), Paul Newman (GSFC)

Abstract

Results from the GSFC trajectory model are combined with data from ozonesondes to derive ozone loss rates in the lower stratosphere for the Stratospheric Aerosol and Gas Experiment (SAGE) III Ozone Loss and Validation Experiment (SOLVE, January – March 2000) and for Airborne Arctic Stratospheric Expedition (AASE)-2 (January – March 1992) in an approach similar to the Match technique. Although loss rates were similar to those previously published, the largest previously published loss rates for January 1992 were not found. The current results are associated with substantially larger uncertainties than found in previous publications. The sensitivity of the Match technique to a variety of parameters was investigated as a data filter. It was concluded that only a filter based on potential vorticity seems necessary. The calculated ozone loss rates are also extremely sensitive to the trajectories calculated, particularly for January. Therefore, uncertainties associated with loss rates in January should be substantially larger than those previously published. Integrated ozone loss in both years are comparable to those published in numerous other studies and with the results of a potential vorticity (PV)/potential temperature (Theta) approach that was employed as well. The study suggests an alternate approach to Match using trajectory mapping that more accurately reflects the true uncertainties associated with Match and reduces the dependence upon filters that may bias the results in the original Match approach, in which ~95% of matched data are rejected.

Description of Research

The Match technique [Rex, 1993] has been widely applied to the problem of calculating ozone loss rates in the Arctic winter stratosphere and, just this past year, to the Antarctic. The technique relies upon the coordinated launches of multiple ozonesonde instruments from numerous stations in the Northern Hemisphere. Using a model of atmospheric dynamics, the observations can be linked by computing trajectories for the air masses in which the ozonesondes make their measurements. By examining the difference in ozone in the air mass between two “matched” ozonesonde measurements, the chemical component of ozone loss can be computed. To find the ozone loss rate, the change in ozone is simply divided by the total number of hours of sunlight illumination for the air mass between the observations. Previous publications by Rex *et al.* [1998, 2002] found rather large ozone loss rates, particularly in January 1992. Current

understanding of stratospheric chemistry is unable to reproduce the loss rates reported by Match. Furthermore, the error bars associated with the loss rates in the Match papers are extremely narrow. The goal of the present study is to reproduce the Match study for the 1992 and 2000 winter seasons, and to evaluate the error bars associated with the ozone loss rates produced by Match.

Accomplishments During the Reporting Period

The final version of a manuscript, which reports the above accomplishments, was submitted and accepted for publication in *Atmospheric Chemistry and Physics* (5, 2571-2592, 2005). In response to reviewers' comments, the amount of loss occurring during the nighttime hours in our model was evaluated. As was the case in the original Rex *et al.* investigations, insignificant nighttime losses were found.

The GEST investigator also participated in the Aura Validation Experiment (AVE) based at Ellington Field just outside Houston, Texas during June 2005. Eight ozonesondes were launched during the period June 8–22, 2005 in support of AVE.

Objectives for the Coming Year

Additional ozonesondes will be launched from Rice University in Houston, Texas in support of Aura validation. Ozonesondes will also be launched from Valparaiso, Indiana and Houston, Texas in support of INTEX-B and Milagro. Finally, Gary Morris will be examing the partitioning of ozone pollution sources.

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

GEST Investigator: Mark A. Olsen

Collaborators: Anne R. Douglass (GSFC), Mark R. Schoeberl (GSFC), Richard S. Stolarski (GSFC), William Gallus, Jr. (Iowa State Univ.)

Abstract

Stratosphere-troposphere exchange (STE) and stratospheric circulation and structure are a primary focus of this research. In particular, the influence by climate has been investigated. A model investigation shows that observed changing sea surface temperatures result in an increasing trend in the magnitude of extratropical STE. This is an indirect effect of increasing the greenhouse gas load in the atmosphere. Research also shows a novel method of detecting any trend of STE in the atmosphere using measurements of column HCl. In another experiment, the changes in the dynamics and structure of the Antarctic stratosphere as a result of the ozone hole are being examined.

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 for research models to accurately represent STE. This research focuses on the analysis of STE in global atmospheric data sets and model output. Science issues addressed include ozone trends in the upper-troposphere/lower-stratosphere; seasonal and interannual trends in STE of total mass and ozone mass; and the importance of STE to climate change.

Accomplishments During the Reporting Period

The interaction of climate and STE has been a primary focus of this research during the past year. The net extratropical STE in two fifty-year integrations of the GEOS-4 general circulation model (GCM) were examined using a mass balance diagnostic method. In one simulation observed Hadley Centre monthly mean sea surface temperatures from 1949 to 1998 were specified at the lower boundary. Annually repeating climatological mean sea surface temperatures were used in the other simulation. All other boundary conditions of the two simulations were identical. The radiatively important gases, such as carbon dioxide, were also held to a constant annual cycle. It was

shown that the sea surface temperature trends were responsible for forcing an increasing trend in the extratropical STE. The observed sea surface temperatures result in a greater tropospheric temperature gradient from the tropics to middle latitudes. The zonal mean flow around the subtropical jet increases and the vertical wave propagation is refracted more poleward. This drives an increased residual circulation resulting in greater STE. Previous studies have shown that greater greenhouse gas concentrations in the atmosphere can result in a stronger residual circulation and greater STE. This study is the first to show that an increasing trend in STE can be forced indirectly through greenhouse gas induced changing sea surface temperatures rather than by a direct radiative forcing.

Global circulation and climate models tend to agree that increased greenhouse gases result in a greater cross-tropopause transport, although the responsible mechanisms differ. However, no direct observations of the atmosphere have been made that can confirm the existence of increasing STE. Mark Olsen has proposed a method of detecting a trend in the residual circulation by using measurements of column HCl. The middle latitude HCl column has a late spring maximum and a minimum in the late summer. This seasonal cycle is controlled by the seasonal variations of the mass and composition of the lowermost stratosphere. The seasonal maxima are produced by wintertime downward transport of stratospheric air. Research reveals that the amplitude of the seasonal cycle is quantitatively related to the strength of the stratospheric residual circulation and STE. To investigate this relationship, the investigator has driven the GSFC Chemistry and Transport Model with the fifty years of GEOS-4 meteorological fields that exhibit an increasing trend in STE. Measurements of the HCl column can provide a marker of the magnitude of the residual circulation. The ground-based record of HCl measurements at Jungfraujoch have also been examined for evidence of a trend in the HCl seasonal amplitude that would be a signature of a long-term change in the stratospheric circulation. Currently, a well-sampled record of ground-based observations is not long enough to confidently isolate a signal of increased circulation. Results indicate that such a signal could be detected in a reasonable time with coordination by middle latitude measuring sites of the Network for the Detection of Stratospheric Change (NDSC).

Another climate experiment was performed with time-slice simulations of pre-ozone hole and near maximum ozone hole conditions. The GEST investigator has shown that the Antarctic polar vortex break up is significantly delayed with a fully developed ozone hole, consistent with a cooling of the lower stratosphere. A dynamical feedback mechanism forces a warmer upper stratosphere when planetary waves more readily propagate into the stratosphere under the conditions of a significant ozone hole. The research also reveals the differences in the magnitude of STE are negligible between the two simulations. However, the altered radiative balance results in a significantly higher tropopause and 380 K surface when a considerable ozone hole exists. This study can provide a baseline comparison for a new interactive chemistry GCM currently being developed and tested.

Objectives for the Coming Year

The previous fifty-year simulation with a trend in STE used annually repeating greenhouse gas concentrations in the radiation scheme. A complementary thirty-year integration of the GCM has been completed that specifies a trend in carbon dioxide. The output from this simulation will be examined. It will be determined if the response of STE to increased greenhouse gas loading is primarily forced through an SST mechanism, a direct radiative forcing, or an interaction of the two. A new study on the role of monsoon circulations in transporting water vapor from the troposphere to the stratosphere will also be started in the upcoming year. This project will begin with an intercomparison of water vapor data from instruments on the Aura and Aqua satellite platforms. Finally, smaller scale extratropical STE will be examined similar to previous work but in the context of the high-resolution observations from the Aura platform.

Task 622-44-16: **Closure in Model Prediction, *In-situ* Measurements and Remote Sensing of Aerosol Mass Concentration**

GEST Investigator: Santiago Gassó

Collaborators: Omar Torres (JCET), Jim Gleason (NASA), Si-Chee Tsay (GSFC), Norm O'Neill (Univ. of Sherbrooke, Canada)

Abstract

Five separate research activities were performed during the year 2005. A comparative study between *in-situ* and retrieved aerosol fine mode fraction during the ACE-Asia field campaign was done. The comparison suggested that retrieved fine mode fraction (FMF) from remote sensing can be used to discriminate between fine and coarse mode dominated aerosols. An upgrade to the pollution sources within the Navy Aerosol model was performed (NAAPS) and the outputs were compared with ground measurements of sulfate mass and AERONET optical depths. An analysis of MODIS true color images and AODs revealed dust activity in the Patagonia region and the mass fluxes advecting into the South Atlantic Ocean were estimated. A critical analysis of the NPOESS Preparatory Project aerosol algorithm was initiated.

Description of Research and Accomplishments

Remote retrievals of aerosol properties require an independent validation using *in-situ* measurements. This is particularly important for the FMF parameter that is used for discrimination between natural and anthropogenic aerosol. Our findings confirm that FMF can be used to distinguish the size distribution of the aerosol under observation is fine or coarse mode dominated. However, it was also found that the same parameter can lead to misleading interpretations when used in environments with multiple aerosol types present in the scene, common phenomenon in regions such as East and South Asia.

The Navy Aerosol Analysis and Prediction System (NAAPS) is a global aerosol transport model used the forecasting of visibility conditions. It models the distribution of three types of aerosols: smoke, dust and pollution (sulfates). The emission modules of the first two have some degree of modelization of the sources (like satellite based information of smoke plumes or assimilated wind speeds) whereas pollution is based in an inventory of industrial production (used as proxy for sulfur dioxide, SO_2) with no time variability and coarse resolution, that is, pollution sources are constant throughout the year. In addition, the inventory is based on industrial activity from the mid-1980s (GEIA data base). Two newer emission inventories based on data collected during the 1990s and with seasonal and monthly variability of emission were incorporated within NAAPS. The model was run for one month with the different inventories and compared the outputs against ground measured mass concentrations of sulfate (EPA network in East US) and aerosol optical depths from the AERONET network at different sites all over the world. The comparison study indicates that the addition did not improve the skill of the model significantly and it suggests that an upgrade of emission inventory may not be necessary.

The South Atlantic Ocean (SAO) is a region where the observed phytoplankton concentrations are limited by the availability of some of key nutrients, chiefly iron. A number of theories are being debated on what factors regulate this phytoplankton activity. Among them, the deposition of airborne iron-rich dust from Patagonia over the SAO has generated significant interest. However, satellite records show that dust activity in the region was minimal even though the global dust model indicated dust emissions. As a result, a field campaign was initiated to monitor and measure dust flows and chemical properties along Patagonia. It was found that dust emission does occur in Patagonia, with a very variable frequency and it is undersampled by satellite observations. These observations constitute the

first time that dust was observed and sampled in this region of the world.

Objectives for next year

The objective for the next year is to work on two tasks: (i) the analysis of dust observations in Patagonia and comparisons with surface measurements and (ii) a detailed comparison of aerosol retrievals made by the NPP algorithm (using MODIS radiances) with AERONET data.

Task 916-54-206: **The NASA Global Modeling Initiative (GMI) and Observationally Based Evaluation of Models**

GEST Investigator: Susan Strahan

Collaborators: Jose Rodriguez (Univ. of Miami), Anne Douglass (GSFC), Bryan Duncan (GEST)

Abstract

The results from chemistry and transport model (CTM) studies testing sensitivity to resolution and domain have been used to optimize the implementation of new meteorological fields in the GMI CTM. This improves the representation of transport processes in CTM simulations. A new version of the GMI CTM using a combined tropospheric and stratospheric chemical mechanism has been developed and is under evaluation. New diagnostics of transport near the tropopause have been developed from recently acquired aircraft trace gas data sets and are being used to evaluate the new model. The tropospheric and stratospheric versions of the GMI CTMs have participated in international model intercomparisons examining future emissions scenarios.

Description of Research

This research focuses on the evaluation of stratospheric processes in 3D atmospheric models using analyses of trace gas observations from aircraft and satellites. The data analyses improve our understanding of dynamical and chemical processes controlling atmospheric composition. When applied to model simulations, the analyses help to define model requirements for credibility. That is, which resolution, which model domain, and/or which set of chemical reactions does the model require to agree with observations. Model evaluation diagnostics, derived from observations, are primarily applied to the NASA Global Modeling Initiative (GMI) 3D-CTM and the Goddard CTM. These models are used to investigate anthropogenic influences on the stratosphere and estimate possible future trends in ozone based on changes in surface emissions.

Accomplishments During the Reporting Period

Higher model spatial resolution can improve model results, but it also means longer integration time. Thus, it is important that model resolution be optimized to maximize credibility while minimizing computational time. Strahan completed and published a study of the effects of meteorological field horizontal and vertical resolution and model lid height on the simulation of stratospheric constituents. This study identified the CTM resolution and domain needed for realistic representation of important stratospheric processes such as development of lower stratospheric transport barriers. The results of this study have been applied to new meteorological fields recently acquired for the GMI CTM. Observational diagnostics previously developed by this project were used to evaluate model credibility in simulations with the new meteorological fields.

The GMI modeling team at Goddard finished the development of a new CTM that has a combined chemical mechanism for both the troposphere and stratosphere (the 'Combo Model'). This model is used to investigate chemical and dynamical processes near the tropopause, a climactically sensitive region. Initial work evaluated the credibility of model processes in this region using measurements of CO, CO_2, O_3, and N_2O in the upper troposphere and lower stratosphere from a European aircraft campaign called SPURT. The correlations between these species, their seasonal variations, and their

structure as function of height above the dynamical tropopause are being used to assess the behavior of the Combo Model.

This model also differs from our stratospheric CTM by its method of photolysis rate calculation. Because we must understand how this affects the distribution of important photolytic species, such as O_3 and NO_x, a stratospheric ozone diagnostic has been created from 10-years of satellite O_3 measurements for evaluation of both model photolytic methods. Several model experiments have been conducted to test how the chemical mechanism and photolysis method influence the simulation of stratospheric ozone.

GMI models continue to participate in international model intercomparisons of future emissions scenarios. For the International Panel on Climate Change (IPCC), Strahan and co-workers integrated and submitted nine simulations predicting the effects of future ship emissions on tropospheric ozone levels. For the World Meteorological Organization (WMO) assessment of the future of stratospheric ozone, this project submitted results from two model integrations that simulate observed ozone changes since 1980 and forecast the recovery of stratospheric ozone in the 21st century using WMO prescribed changes to source gases. These model intercomparisons will appear in future IPCC and WMO publications.

Objectives for the Coming Year

The primary research focus will be on observational analyses of chemical and dynamical processes in the lowermost stratosphere using SPURT (aircraft) and AURA (satellite) data sets. This will improve understanding of this region and allow the development of new model process diagnostics. The diagnostics will be used to evaluate lower stratospheric behavior in the Combo Model. This model will be used to run simulations with forecast and assimilated meteorological fields, which can be compared with AURA constituent measurements. The overall science goal is to understand the composition of the lowermost stratosphere and how it is influenced by the upper troposphere, including sensitivity to future changes in tropospheric composition. This work will include comparisons between models with different chemical and photolytic calculations.

Management of GMI will continue as a secondary focus of this project.

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

GEST Investigator: Clark Weaver

Collaborators: Arlindo da Silva (GSFC), Mian Chin (GSFC), Lorraine Remer (GSFC), Brent Holben (GSFC)

Abstract

This task has two research foci: the development of an assimilation system for atmospheric aerosols and the impact of aerosols on the remote determination of atmospheric temperature and moisture profiles. The assimilation system utilizes radiances in the visible and near infrared as measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the Earth Observing System (EOS) satellite platforms. Satellite measured radiances are used to identify atmospheric aerosols over dark oceanic and land surfaces. The second study addresses the radiative impact of aerosols on the infrared radiances used in determining atmospheric temperature and moisture profiles. Radiances used in the second study are from the TIROS Operational Vertical Sounder (TOVS) High-resolution Infrared Radiation (HIRS) instruments on the NOAA operational satellites.

Description of Research

The two main research topics addressed under this task are the development of an aerosol assimilation system using MODIS radiances and the improvement of temperature and moisture

retrievals from TOVS radiances by including the radiative effects of mineral dust aerosols.

Accomplishments During the Reporting Period

An off-line system has been developed for the assimilation of aerosol optical properties utilizing visible and near infrared radiances measured by the MODIS instrument on the EOS satellite platforms. A version-2 MODIS assimilation system has been developed that inserts MODIS radiance information into an aerosol transport model. This version uses 7 channels over ocean and 3 channels over land. The assimilated aerosol distributions are validated against AERONET observations. A manuscript to *Journal of Atmospheric Science* is in review. A version-3 assimilation system that runs on-line with the finite-volume General Circuation Model (fvGCM) is being tested. This version also uses an additional MODIS channel at 412 nanometers. This will provide information on the absorption characteristics of the aerosols over both ocean and land, information on the surface reflectivity over bright surfaces and finally information in the chlorophyll absorption over ocean. Look-up tables for this new channel include a correction for the mirror polarization.

Mineral aerosols have strongly absorbing spectral features in the infrared. Consequently, there may be errors in TOVS retrieved temperature and moisture profiles in regions of heavy dust loading. Clark Weaver has modified the pre-Community Radiative Transfer Model (pCRTM) to include the effects of mineral aerosol absorption. The pCRTM was developed at the National Center for Environmental Prediction (NCEP) for satellite temperature and moisture. Although NOAA no longer funds this task, the GEST investigator is still advising scientists at NCEP about mineral aerosol absorption because accounting for this effect should improve their forecast models.

Objectives for the Coming Year

The analysis products of the MODIS aerosol assimilation system will expand to include chlorophyll concentration. The goal is to retrieve simultaneous chlorophyll and aerosol information. The researcher also needs to improve the surface reflectance estimate used in the retrieval/analysis over moderately bright surfaces. Ultimately, the goal of this effort is to provide a system capable of global assimilations of aerosol characteristics.

A project related to the aerosol assimilation system is to analyze radiances of the MODIS satellite observing different types of aerosols over coastal oceans. After accounting for satellite geometry and contributions of the ocean surface, the radiances will be analyzed to determine if there is a unique spectral signature for a given type of aerosol. This should provide validation for look-up-tables used in aerosol retrievals and assimilation.

Task 613-70-242/ Grant 00002041: **Nitrogen Dioxide from OMI Spectral Data**

GEST Investigator: Mark O. Wenig

Collaborators: Jim Gleason (PI, GSFC), Eric Bucsela (GEST), Edward Celarier (SGT)

Abstract

Since joining GEST in November 2005, Mark Wenig started developing the OMI NO_2 level 2 to level 3 data processing algorithm. In order to have a non-overlapping mozaic of data for the OMI product, the GEST researcher developed a tessellation procedure that corrects for the overlapping orbits at high latitude and overlapping pixels at the edges of a swath. For the averaging process a detailed analysis of the OMI NO_2 data was necessary. In addition to this, Wenig continued to work on a parameter estimation technique to analyze the resulting NO_2 images. This technique is called the structure tensor technique and allows the estimation of NO_2 lifetimes, source strengths and sinks from NO_2 image sequences.

Description of Research

The goal of this task is to use remote sensing techniques to further the understanding of the role of trace gases in tropospheric chemistry and air quality. For this task global NO_2 data measured with the Ozone Monitoring Instrument (OMI) that is on board the EOS-AURA satellite is used.

This satellite was launched in July 2004, so the imaging spectrometer OMI has provided almost 2 years of daily high resolution (~13x24 km^2 at nadir) NO_2 vertical column density maps. The DOAS based retrieval algorithm includes an estimation of the stratospheric and tropospheric fraction of total NO_2 column, an air mass factor (AMF) correction based on detected tropospheric NO_2 enhancements, and the generation of the gridded data product. This data product is used to learn more about dynamical and chemical processes that drive the observed variations in the image sequences.

Accomplishments during the Reporting Period

The tessellation of the OMI NO_2 orbit data is the last step of the generation of the gridded level 3 data product. This data product consists of NO_2 Vertical Column Densities stored on a 0.25° x 0.25° grid. Since the OMI orbits overlap at higher latitudes and so do the ground pixel within one orbit at the beginning and end of the scan line, several measurements have to be averaged. In order to calculate the optimal weights for all OMI pixels lying on the same grid cell, the numerical errors of the VCDs had been analyzed. Additional systematic uncertainties—for example, those caused by clouds—are incorporated into an effective error measure, which is then used to determine the weights for the averaging process.

Additionally the development of new data assimilation techniques using the structure tensor method to analyze the resulting data sets was part of my current activities. The mathematical framework for this technique had been implemented and tested on simulated aerosol data sets. This test showed that this technique could be used to estimate wind vector fields from image sequences of integrated dust columns if the resolution in time is in the order of hours. For OMI data this technique can be adapted in a way that the main fitting parameters are source strengths and sinks while using external wind vector fields as additional input.

Other activities included working on mathematical operator formalism for the Differential Optical Absorption Spectroscopy (DOAS) technique to describe dependencies of uncertainties on instrument characteristics. The current problems with the OMI scan mirror can result in the loss of the daily measured solar spectra. Therefore a DOAS algorithm, which can be run using external solar spectra or solar spectra measured on a different day might be needed. The operator formalism allows analyzing the influence of this problem on the trace gas retrieval.

Objectives for the Coming Year

A key goal will be to run the OMI NO_2 level 2 to level 3 processing algorithm operationally. The resulting sequences of global NO_2 concentration maps will form the basis for validation studies. For one of the planned validation studies, data from a Brewer MK3 double monochromator in direct-sun mode located at GSFC will be used. For another comparison data from EPA NOx emission reports will be used.

Tasks 916-21-144 and 916-43-181: **Tropospheric Ozone Derived From Satellite Measurements**

GEST Investigators: Jerry R. Ziemke and Sushil Chandra

Collaborators: P.K. Bhartia (GSFC)

Abstract

During FY 05, Jerry Ziemke and Sushil Chandra continued to maintain and develop the NASA Code 613.3 satellite-derived data sets of tropospheric column ozone (TCO) and stratospheric column ozone (SCO) for 1979-present. The ozone data products are obtained from Total Ozone Mapping Spectrometer (TOMS) ozone measurements using the Convective Cloud Differential (CCD) method. Two important new algorithms developed under this task are the Cloud Slicing (a generalization of the CCD method) and the inter-calibration residual methods. Cloud Slicing derives tropospheric ozone profile information, and the inter-calibration residual method (which uses CCD SCO for cross-calibrating) yields global measurements of TCO. From TOMS and SBUV measurements we developed a new comprehensive ozone data product covering low-to-high latitudes for 1979-present: (1) tropospheric ozone, (2) upper stratospheric ozone, and (3) lower stratospheric ozone. Their joint tasks include the development of both TCO and SCO measurements from the new Aura OMI and MLS instruments. Aside from their role in developing public-domain data products for NASA, their research has led to substantial new understanding of the dynamics and sources/sinks of global tropospheric and stratospheric ozone by combining both measurements and photochemical transport models.

Description of Research

The primary purpose of this task is to derive tropospheric ozone data products for NASA from satellite-based ozone measurements. The measurements include past TOMS data (1979-2005) and also the new Aura OMI and MLS data (August 2004-present). In addition to developing tropospheric ozone data products, a significant amount of scientific research is conducted in an effort to understand the nature of the observations. This analysis includes the incorporation of photochemical transport models (*e.g.*, MOZART-2, GEOS-CHEM, GMI, Goddard COMBO CTM) to quantify the many factors that contribute to the observed ozone characteristics. Their work involves developing scientific retrieval algorithms, validating derived data products using other satellite and ground-based (*i.e.*, ozonesonde) measurements, and conducting scientific research of the derived ozone data including model comparisons.

Accomplishments During the Reporting Period

In year 2005, Jerry Ziemke and Sushil Chandra developed a long-record (1979-present) of tropospheric and stratospheric ozone from TOMS satellite measurements extending from the tropics to the high latitudes in both hemispheres. This dataset was used to determine long-term changes in ozone in both the troposphere and stratosphere [Ziemke *et al.*, 2005]. The published article discusses the important issues of stratospheric ozone recovery and the long-term increases in tropospheric ozone related to increases in industrial pollution and stratosphere-troposphere exchange. The data are used to study the various Code 613.3 Global Modeling Initiative (GMI) models by cross-analysis of seasonal and inter-annual variability including trends and potential ozone recovery in the stratosphere.

In year 2005 there was a substantial amount of progress made toward developing a global public domain dataset of tropospheric ozone from the new Aura satellite measurements. The tropospheric column ozone data were determined by subtracting stratospheric column ozone (from Aura MLS) from total column ozone (from Aura OMI). In January 2006 a paper was submitted [*Ziemke et al.*, 2006] that characterizes many new features in global tropospheric ozone.

Maps were prepared of tropospheric ozone determined recently from the OMI and MLS instruments on board the new Aura satellite. Most tropospheric ozone in the Southern Hemisphere each year occurs during the months September-November because of combined ozone-producing effects from biomass burning, lightning, and stratosphere-troposphere exchange.

Objectives for the Coming Year

The GEST researchers will continue to maintain and update the stratospheric and tropospheric ozone data products from EP TOMS and validate them with SHADOZ and WOUDC ozonesondes. They will also continue to develop a public domain data record of daily measurements of global tropospheric column ozone from the new Aura OMI and MLS instruments. The evaluation of tropospheric ozone data to characterize pollution events and to study intra-seasonal variabilities such as the 1-2 month Madden-Julian Oscillation will be performed. Finally, they will continue cross-analysis of the derived tropospheric ozone data products with models.

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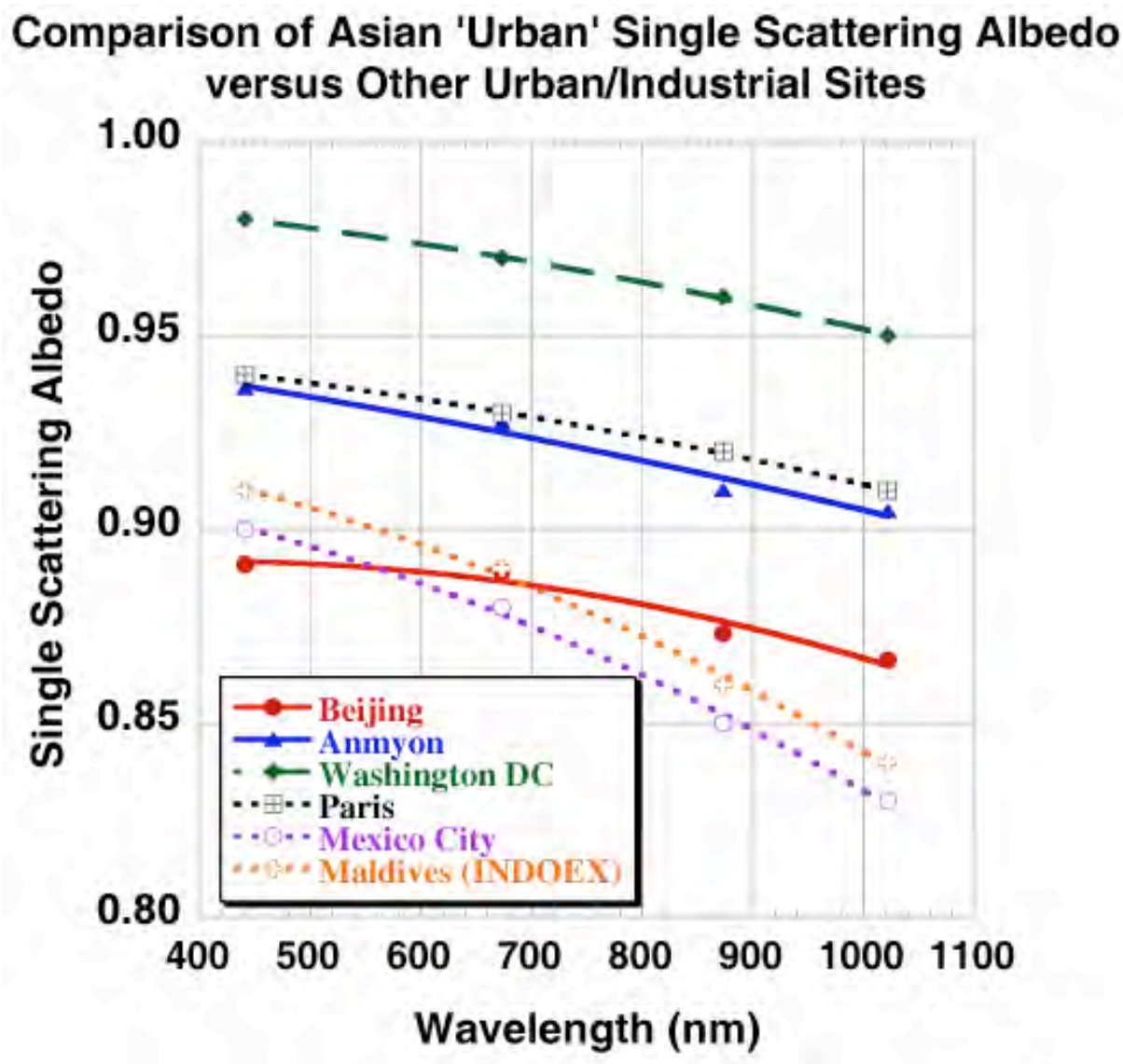
Terrestrial Physics Research Group



Spectral single scattering albedo of urban/industrial aerosol from globally distributed AERONET sites. The strong absorption in Beijing is similar in magnitude to that measured in Mexico City and in the Northern Indian Ocean (Maldives). Anmyon island, South Korea has moderate levels of absorption, similar to that measured near Paris, France. [Figure provided by Thomas Eck.)

Terrestrial Physics Research Group

The Terrestrial Physics Research Group combines researchers from areas which had previously been in the Terrestrial Physics Branch (biospheric processes and terrestrial remote sensing) at GSFC. The reorganization in the Earth Sciences Division has brought a somewhat diverse group of researchers together under the heading of terrestrial physics, yet the breadth of the group includes work on earth, land and air, focussing on parts of the Earth system other than the hydrosphere and cryosphere. These GEST scientists conduct multi-disciplinary research in many areas related to the remote sensing of the Earth, collaborating with NASA researchers and others on developing retrieval algorithms for the data interpretation, modeling techniques to represent physical processes, assimilation methods used to combine observations and models, and new instruments.

Bruce Guenther's research involves continuing development of the Government Team for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Program in the area of sensor calibration and Environmental Data Product validation. For NPOESS the activities include development of the NPOESS program to optimize usefulness of NPOESS and NPP data to NASA research and climate data records, and improve NASA staff presence in and influence on the NPOESS program.

Study of Earth's surface interannual variability using data from satellites and distributed ground stations is a major focus for Assaf Anyamba. The land surface patterns of interannual variability using time series vegetation index data derived from measurements made by various satellites. This research aims at understanding the dynamics and land surface response patterns to El Niño/Southern Oscillation (ENSO) as revealed by satellite time series measurements of vegetation. The analysis is used to understand dry and wet cycles over Southern and East Africa and vegetation trends and dynamics for the Sahel region, examination of the relationships between ENSO and vector-borne disease outbreak patterns and monitoring global agricultural regions.

Hongbin Yu works on the assessment of measurement-based aerosol direct radiative effect and forcing. Current assessment of the aerosol direct forcing as finalized in the Intergovermental Panel on Climate Change (IPCC) Assessment Report is largely model-based and has large uncertainties. In recent years, a great deal of effort has gone into improving measurements and datasets. It is thus feasible to shift the estimates of aerosol forcing from largely model-based to increasingly measurement-based. Yu's goal is to assess current observational capabilities and identify uncertainties in the aerosol direct forcing through comparisons of different methods with independent sources of uncertainties.

The research within the framework of the globally distributed Aerosol Robotic Network (AERONET) is centered on the analysis of measurements made by automatic sun-sky scanning radiometers. Remotely measured atmospheric aerosol optical parameters are important for various applications including computations of radiative forcing and satellite remote sensing. Aerosol optical depth, which may be derived from measurements of attenuated direct solar radiation, as well as the aerosol size distribution and single-scattering albedo, which may be derived from combined aerosol optical depth and solar almucantar sky radiance data, are pivotal parameters defining the aerosol optical state of the atmosphere. GEST researchers Thomas Eck and Alexander Smirnov study various aerosol types to better understand the dynamics of aerosol properties as a function of source region, transport, aging processes, and interaction with clouds.

Charles Gatebe's research has led to integration of NASA's Cloud Absorption Radiometer (CAR) to the new airborne platforms. They will enable new airborne radiation measurements worldwide to help study aerosol and surface optical properties. Multi-spectral and multiangular radiation field measurements are needed to characterize aerosol surface radiative properties. This effort includes a detailed assessment of the CAR data from various field studies and is tied to development of a new algorithm for inverting CAR

multispectral and multiangular radiance measurements by modifying the AERONET inversion code. The modification enables simultaneous retrieval of detailed surface and vertical variations of complete optical aerosol properties at discrete spectral wavelengths in the ultraviolet, visible, and near-infrared ranges.

The main objective of Alexei Lyapustin and Yujie Wang's research is development of the advanced aerosol retrieval-atmospheric correction algorithms for the EOS MODIS imaging spectrometer, and Landsat ETM+ imager. The new algorithm is based on a recently developed theory that rigorously describes 3-D radiation effects, gaseous absorption in the atmosphere, and surface bidirectional reflectance properties. Another important research area is development of the operational system (AERONET-based Surface Reflectance Validation Network, ASRVN) for validation of the surface reflectance products from MISR, MODIS and ETM+ sensors globally around AERONET sites. The AERONET atmospheric aerosol and water vapor data are used as well-calibrated ancillary information for the accurate atmospheric correction of satellite data. This approach has been used to validate the global surface reflectance products from MODIS and MISR over non-homogeneous surfaces at a moderate spatial resolution (~1km).

Oliver Botta has worked on the laboratory prototype for the Sample Analysis on Mars (SAM) instrument. The instrument suite dedicated to the Mars Science Laboratory consists of three major components, such as Gas Chromatograph, Quadrupole Mass Spectrometer and Tunable Laser Spectrometer, which are designed to analyze atmospheric samples or gases evolved from solid phase samples such as rocks and fines.

Hyung Rae Kim continues an Antarctic Comprehensive Model (ACM) study to sum up the internal part and to put together external part of the geomagnetic components. The extended ACM is about to develop the external magnetic field components, including ground and satellite data, as well as the data from 25 magnetic observatories in the Antarctica.

It should be clear from this brief summary and the detailed reports that follow that the GEST Terrestrial Physics Research Group is at the forefront of research activities in many important areas, with results from these investigations making their way into the literature and research underway at other institutions.

Alexander Smirnov

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 (GSFC), Christopher O. Justice (UMCP), Jennifer Small (SSAI), Doorn Bradley (USDA/FAS), Curt Reynolds (USDA/FAS), LT. Jean-Paul Chretien (DoD/WRAIR-GEIS), Sheryl Bedno (USAMRU & GEIS-Kenya), Kenneth Linthicum (USDA)

Abstract

This research focuses on the land surface patterns of interannual variability using time series vegetation index data derived from measurements made by NOAA Polar orbiting satellite series, SPOT Vegetation and MODIS Vegetation Index measurements. At the short time scale, El Niño / Southern Oscillation (ENSO) is a major mode of interannual climate variability influencing precipitation response patterns and vegetation dynamics in the global tropics. This research aims at understanding the dynamics and land surface response patterns to ENSO as revealed by satellite time series measurements of vegetation. Climate data sets including global sea-surface temperature measurements (SST), outgoing longwave radiation (OLR) and combined satellite and rain-gauge are used to validate the observed land surface anomaly patterns and to determine SST forcing on the vegetation response. This analysis is used to understand dry and wet cycles over Southern and East Africa and vegetation trends and dynamics for the Sahel region, examination of the relationships between ENSO and vector-borne disease outbreak patterns and monitoring global agricultural regions.

Description of Research

The primary objective of this research is improve the understanding of the land surface response patterns to interannual forcing associated with ENSO forcing using long-time series satellite vegetation measurements. This work is of critical relevance to NASA-GSFC work on ecosystem dynamics and applied agricultural and environmental monitoring, activities of the United States Department of Agriculture /Foreign Agricultural Service (USDA/FAS) in global agricultural monitoring and the United States Agency for International Development (USAID) Famine Early Warning System Network (Program) program. Additionally the research is a contribution to NASA's application programs on Public Health, and the Department of Defense's Global Emerging Infections Surveillance System (GEIS). The research utilizes an array of satellite and surface observations, including vegetation index measurements from NOAA-AVHRR, SPOT Vegetation, MODIS and LANDSAT, global sea-surface temperature (SST), outgoing longwave radiation (OLR) and precipitation data to determine the linkages between SST variability, precipitation patterns and land surface response patterns at a variety of time and space scales.

Accomplishments During the Reporting Period

Remotely sensed measurements from NOAA-AVHRR expressed as normalized difference vegetation index (NDVI) have generated a 23-year time series (1981-2004) appropriate to the long-term studies of the Sahel region. The close coupling between Sahelian rainfall and the green-up of vegetation has made it possible to utilize the data as a proxy for the land surface response to climate variability. Using these time series measurements Anyamba has identified two periods of differing anomaly pattern. First, 1982-1993 is marked by below-average NDVI and persistence of drought with a signature large scale drought during the 1982-1985 period. Secondly, 1994-2003 is marked by a trend towards "greener" conditions with region-wide above normal NDVI conditions with a maxima in 1994 and 1999. These patterns generally agree with recent region-wide trends in Sahel rainfall. However, taken in the context of long-term Sahelian climate history, these conditions

are still far below the wetter conditions that prevailed in the region from 1930 to 1965 [Anyamba and Tucker, 2005; Hermann *et al.*, 2005]. These trend patterns can therefore only be considered to be a gradual recovery from extreme drought conditions that peaked during the 1983-1985 period. Systematic studies of changes on the landscape using high spatial resolution satellite data sets such as those from LANDSAT, SPOT and MODIS will provide a detailed spatial quantification and description of the recovery patterns at the local scale. This research supports the United Nations Environment Program (UNEP), the United Nations Food and Agriculture Organization (FAO) and the United Nations Convention to Combat Desertification (UNCCD) assessment on "Changes in the Sahel." The variability and trends in agricultural production for this region closely mirror the departure patterns in NDVI. The NDVI data showed that 1984 was the year of the most severe drought resulting in the lowest production in 20 years, of about 500,000 metric tons of millet in Mali. This was the lowest point after several years of progressively decreased production from 1980 to 1985, following years of persistent drought during the 1970s. Similar patterns are observed for maize production in Kenya and Zimbabwe and beef production in Botswana [Anyamba *et al.*, 2005]. Above normal rainfall in the Sahel and northwest Africa in 2003-2004 primed the environment large scale outbreaks of the Desert Locust Schistocerca gregaria (Forksal) in the spring and summer of 2004 [Anyamba *et al.*, 2005]. Similar above normal conditions in along the Red Sea coastal region of the Arabian Peninsular created conditions necessary for outbreaks of mosquito-borne diseases [Anyamba *et al.*, 2006]. Currently the GEST investigator is continuing with a comparative evaluation of different vegetation indices from MODIS (NDVI, EVI), AVHRR-NDVI and SPOT Vegetation NDVI data as part of the research and development work to support the USDA/Foreign Agricultural Service agricultural monitoring activities.

Objectives for the Coming Year

Anyamba will complete the analysis and write-up on the findings on comparison between different vegetation indices from MODIS, SPOT Vegetation and AVHRR NDVI time series to provide a coherent multi-satellite data base for agricultural monitoring purposes. In addition, he will investigate the potential for using MODIS data to derive a vegetation-water stress index for large scale agricultural monitoring and work on development of new seasonal metrics for agriculture and environmental monitoring. The existing work on Rift Valley Fever (RVF) monitoring will continue in support DoD/GEIS activities with expected expansion to cover the Middle East region. Other work will include managing GSFC/GIMMS contributions in support of the Application of NASA EOS MODIS Data to Agricultural Assessment and Forecasting by the USDA Foreign Agricultural Service as part of the FAS/UMD/GSFC activities for this program and continue support to USAID/FEWSNET and DoD/GEIS Program activities.

Task 915-50-193: **Astrobiology - Sample Analysis at Mars (SAM)**

GEST Investigator: Oliver Botta

Collaborators: Paul Mahaffy (PI, GSFC)

Abstract

Work under this task is on the laboratory prototype for the SAM instrument, a GC-QMS-TLS instrument suite developed at GSFC for the MSL rover mission to Mars. The work involved determination of sensitivities of the current laboratory set-up as well as construction and testing of a gas flow split system and its effect on the operation and sensitivity of the QMS. Botta also pursued other projects, including the organic analysis of Antarctic ice samples using HPLC-UVF-ToF MS and nucleobase analysis of the Murchison meteorite.

Description of Research

The MSL is the next spacecraft to land on Mars. It consists of a rover with a payload capacity of ~75 kg, a mobility capacity of 20+ km and a designed mission lifetime on Mars of a year. The goals of MSL are: to assess the past or present biological potential of the target environment; to characterize the geology and geochemistry at the landing site; and to investigate planetary processes that influence habitability. The planned capabilities of the instrument package and the rover mobility will enable a determination of definitive mineralogy, chemical and isotopic analyses of both atmospheric and solid samples, precise measurements of several volatile elements, and finally a comprehensive search for organic molecules.

The instrument suite dedicated to the last three tasks is the SAM package, which is currently under development at GSFC. The suite consists of three major components (a GC, a QMS and a TLS), which are designed to analyze either atmospheric samples or gases evolved from solid phase samples, such as rocks and fines, via pyrolysis, combustion or chemical derivatization. Due to the fact that MSL is scheduled for launch in September 2009, the development of SAM is in Phase B already, with a PDR scheduled for the first week of March 2006. A laboratory prototype has been built at GSFC to help develop analytical protocols for the sample analysis with the SAM instrument on Mars.

In addition to this development work, Botta also worked on other projects related to the organic analysis of carbonaceous meteorites and Antarctic ice.

Accomplishments During the Reporting Period

The laboratory work with the prototype is relevant for three reasons: (1) The development of analytical protocols that can be implemented into the sequences of the FM, (2) the development of hardware components, and (3) the interpretation of the data returned from the FM on Mars. Obviously, the current focus is on tasks 1 and 2.

One of the issues that has to be dealt with is the pressure problem. The flow rates of the carrier gas (helium) have to be very high for a reasonable separation power for the GC columns. Therefore, the pressure inside the QMS could be so big that the filament could not operate. Botta has developed hardware for the laboratory prototype that can split the gas flow that comes off the column into the QMS, with most of the helium being pumped away at Martian ambient pressure. The results show that the mass spectrometer can be operated with the ends of the capillary tubes touching. However, backflow of air into the mass spectrometer caused interfering signals in the mass spectrometer, which led to a redesign of the split system.

With regard to other projects, the GEST investigator successfully analyzed samples of Antarctic ice that were collected during a meteorite collection expedition to the LaPaz ice field. The rationale for this study was the determination of organic contamination in these ices that may interfere with the analysis of Antarctic meteorites. Analysis of PAHs, which was carried out before Botta's arrival at GEST, has now been complemented with HPLC-UVF-ToF-MS measurements of amino acids in these samples in the Laboratory for Analytical Chemistry at the Goddard Center for Astrobiology [Glavin *et al.*, 2006]. These measurements have demonstrated that the ice samples, although collected at locations only a few hundred meters apart, are very heterogeneous with regard to their amino acid composition. In four of the six samples, the prototypical extraterrestrial amino acid AIB at concentration levels of up to 33 ± 11 parts per trillion (ppt) was detected, along with other amino acids.

Finally, Botta collaborated with a visiting student from the Leiden Institute of Chemistry on a study aimed at the measurement of stable carbon isotope ratios of nucleobases in carbonaceous chondrites.

Objectives for the Coming Year

Regarding the SAM instrument development, GEST will continue working on the prototype

system. Once the design of the split system is finished, the prototype will be reconfigured and the team will begin studies of the pyrolysis of materials that will lead to a better understanding of the behavior of minerals under the analytical conditions of the SAM instrument. The investigators will start with the analysis of primary mineral phases such as carbonates and sulfates and study the evolved volatiles with the QMS, TLS and gas chromatograph. After these initial studies, the research will analyze mixed phases, mainly in the form of known terrestrial minerals that have been characterized by other methods in collaborations with other laboratories, including Johnson Space Center and the Carnegie Institution of Washington.

Finally, a GEST researcher will progress into analyzing mixed materials, such as analog materials physically mixed with meteorite samples, aimed at the understanding of synergistic effects of different types of materials during the pyrolysis process.

Regarding the meteorite studies, a GEST investigator will analyze the Antarctic meteorite samples that were collected with the ice samples for their amino acid contents using HPLC-UVF-ToFMS. These measurements will be performed at the Goddard Center for Astrobiology. The results of these studies will be compiled and written up for publication

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Task 923-03-067: **AERONET – Ground-based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Thomas F. Eck

Collaborators: Brent N. Holben (GSFC)

Abstract
Eck's work involves establishing AERONET monitoring stations in SE Asia for field campaigns, as well as analyses of aerosol optical properties resulting from these retrievals. Specifically, he has published results of the analyses on the spatial and temporal dynamics of aerosol in the east-central Asia region (China, Korea, Japan), as well as long-range transport to the mid-Pacific (Hawaiian Islands). Large dynamics in both size distributions and spectral single scattering albedo were quantified in both the fine and coarse mode dominated aerosol cases. Eck received the Goddard Exceptional Achievement Award for the AERONET team at the Goddard Annual Honor Awards Ceremony on March 9, 2005.

Description of Research
The primary motivation for the investigation of the optical properties of atmospheric aerosols is for application to studies of the effects of aerosols on the atmospheric radiation balance and climate and for the validation of satellite retrievals of aerosol properties. The research in this GEST activity 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). 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 published a journal paper (in *JGR-Atmospheres*) as first author on the analysis of AERONET data from eastern-central Asia, from sites in northern China (Beijing, Dunhuang and Yulin), South Korea (Anmyon), and other sites in Mongolia and Japan. Large dynamics in both size distributions and spectral single scattering albedo were quantified in both the fine and coarse mode aerosol components for many of these sites. Transport of aerosols from Asia to mid-Pacific Hawaiian islands in spring (March-May) was also investigated with multi-year data sets from AERONET sites in Lanai, Mauna Loa, and Midway.

Eck collaborated with various researchers at GSFC and elsewhere (Naval Research Laboratory, Monterey, CA and University of Sherbrooke, Quebec) and co-authored ten papers on studies of biomass burning aerosol optical and physical properties, sea salt size distributions, MODIS satellite retrievals of aerosol optical depth and cloud contamination of these retrievals, and absorption properties of aerosols in the UV.

He traveled to Thailand from Oct 17-28, 2005 to re-establish AERONET monitoring sites in Mukdahan and Phi Mai, both in the northeast plateau region of Thailand. These sites are important for support of the upcoming BASE-Asia field campaign (Si-Chee Tsay, Code 913) in Feb - Apr 2006 (peak biomass burning season) that is centered on Phi Mai. Phi Mai is a planned future ABC (Atmospheric Brown Cloud) site for intensive measurement of aerosol properties and will thus be an important long-term monitoring site. Eck presented a seminar at Phi Mai, Thailand on October 21, 2005 to researchers, educators, and graduate students from Chulalongkorn University, Khon Kaen University, and Thai educators and investigators involved in the GLOBE project. The seminar was titled "Aerosol optical properties in Southeast Asia from AERONET observations" which discussed regional and seasonal variability in aerosol optics in Thailand and Vietnam and trans-boundary transport of aerosol from multiple source regions such as China and India to Southeast Asia. Study of the aerosol optical properties in Thailand and Vietnam continued, most recently including analysis of 7-day back trajectories for Mukdahan, Thailand and Bac Giang, Vietnam. Trajectories were binned into 7 categories of transit for 700 mb and higher pressure levels, for example whether the flow was from India, or China, or the South China Sea.

Eck attended the AGU Fall Meeting in San Francisco from December 5-9, 2005, presenting analyses on the spatial and temporal dynamics of aerosol optical properties in the United Arab Emirates (UAE) at the special session titled “Climatological Crossroads: The Atmosphere of Southwest Asia.”

Additionally, Eck received the AERONET team award for Goddard Exceptional Achievement on behalf on the team at the Goddard Annual Honor Awards Ceremony on March 9, 2005.

Objectives for the Coming Year

A primary objective for the next year is to complete the analysis of data from AERONET monitoring sites in Southeast Asia (Thailand and Vietnam) in order to study the dynamics of biomass burning and urban/industrial aerosol optical properties and the transport of aerosols in this region. A paper on this work will be written and submitted to the *Journal of Geophysical Research*, which will include the analysis of measured aerosol optical depth and retrievals of aerosol size distributions and single scattering albedo from sites that typically are dominated by fine mode aerosols. Another topic of focus will be writing a paper (also for JGR) on the analysis of data collected from the mesoscale network of AERONET sunphotometers located in the UAE in summer of 2004. This region often exhibits complex mixtures of pollution aerosol and non-spherical desert dust aerosol, therefore analysis will utilize retrievals from the enhanced Version 2 spheroid particle-shape retrieval algorithm developed by Dubovik, which also includes surface albedo and bidirectional reflectance distribution function (BRDF) products from MODIS as an input to the retrieval.

Task 923-32-162: **Spectral, Angular, and Vertical Characterization of Aerosols and Surface for Radiative Properties**

GEST Investigator: Charles K. Gatebe

Collaborators: Michael D. King (PI, GSFC), Oleg Dubovik (GSFC)

Abstract

Research under this task has led to the integration of NASA's Cloud Absorption Radiometer (CAR) to the South Africa Weather Service Aerocommander 690A (wing mount, June 2005) and the Sky Research Inc. (USA) Jetstream 31 (nose mount, February 2006). The new platforms will enable new airborne radiation measurements worldwide to help study aerosol and surface optical properties. This is made possible through a sophisticated aerosol inversion scheme, which is an extension of the AErosol RObotic NETwork (AERONET) inversion scheme developed under this task to allow simultaneous retrieval from airborne multi-spectral and multiangular radiation field measurements of aerosol optical properties above the aircraft as well as below the aircraft, and to thereby effectively remove the light scattering properties from the atmosphere to recover the complete bidirectional reflectance function of the underlying, non-Lambertian surface.

Description of Research

This study seeks to characterize aerosol surface radiative properties using multi-spectral and multiangular radiation field measurements. This involves a detailed assessment of the CAR data from selected field campaigns. This effort is tied to development of a new algorithm for inverting CAR multispectral and multiangular radiance measurements by modifying the AERONET inversion code of Sun/Sky radiance. In particular, the AERONET algorithm is adapted to the CAR geometry and spectral range to include a description of the surface bidirectional reflectance function properties and directional radiance measurements at several vertical levels. The modification enables simultaneous retrieval of detailed surface and vertical variations of complete optical aerosol properties at discrete spectral wavelengths in the ultraviolet, visible, and near-infrared window regions of the solar electromagnetic spectrum. In addition, the study includes tests and validation of the new algorithm for different types of aerosols from oil fire smoke, mineral dust, marine, biomass burning, and industrial emissions. The main test data is drawn from the CAR multispectral and directional measurements made during the Kuwait Oil Fire and Smoke Experiment (KOFSE; May–June 1991), Smoke, Clouds and Radiation Experiment in Brazil (SCAR-B; August–September 1995), Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX; July 1996), Southern African Regional Science Initiative 2000 (SAFARI 2000; August–September 2000), the Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS, July-August 2001) and the Intercontinental Chemical Transport-Phase-B (INTEX-B)/Megacity Initiative: Local and Global Research Observations (MILAGRO; March 2006). An important component of this study involves conducting co-located surface-based measurements with the surface measurements for AERONET, airborne measurements with the CAR, and satellite measurements with the Moderate-resolution Imaging spectroradiometer (MODIS) and Multi-angle Imaging Spectroradiometer (MISR).

Accomplishments During the Reporting Period

Gatebe led the new effort to integrate the Cloud Absorption Radiometer to two platforms: South Africa Weather Service Aerocommander 690A (wing mount, June 2005) and Sky Research inc. (USA) Jetstream 31 (nose mount, February 2006). A lot of effort went into conceiving, designing and developing the new mounting frames and fairings for CAR on the two platforms, performing structural tests, arranging for inspection with Civil Aviation Authorities (*e.g.*, South African Civil Aviation Authority, U.S. Federal Aviation Authority, and NASA

Airworthiness and Safety/Flight Readiness Review Boards), preparing source documentation, and conducting test flights to determine performance and handling characteristics of the aircraft, and tests for electromagnetic interference to ensure compatibility of the CAR installation with the aircraft radio and navigational systems. Both integrations were successful and as a result the CAR participated in the INTEX-B/MILAGRO Experiment aboard the J-31 and obtained very good data sets over Mexico to help characterize BRDF of different surface types (*e.g.*, ocean, clouds and cityscape) and to study urban pollution from Mexico city. Pictures on CAR integration to J-31 and participation in INTEX-B/MILAGRO Experiment, including preliminary results may be found at http://atmospheres.gsfc.nasa.gov/jpserver/web/default/ and http://car.gsfc.nasa.gov/data/intexb.php.

The representation of surface bidirectional reflectance continues to be a major factor in radiative transfer models. In order to understand the impact of spatial scale variability on BRDF representation, work has commenced on BRDF measurements of samples using a scatterometer at the Goddard Space Flight Center Diffuser Calibration Facility, which is located in a class 10,000 clean room. This work is being done in collaboration with Georgi T. Georgiev (Science Systems and Applications, Inc., Lanham, MD) and James J. Butler (Laboratory of Terrestrial Physics, NASA GSFC).

East Africa now has some new NASA technology to monitor aerosols. Thanks to efforts initiated and organized by Gatebe, which led to a visit to East Africa by a group from NASA (including leader Michael King, Brent Holben, and Ali Omar) to find a perfect location for the AERONET instruments. King's team met with science and technology officials and lectured at universities, high schools and community organizations about the AERONET project and NASA's interest in East Africa. At the conclusion of the mission, several ideal sites for the AERONET Sun photometers in East Africa were identified in Malindi, San Marco; Nairobi National Park, Nairobi and Mbita Lake Point, Lake Victoria, Makerere University Biological Field Station at Kibale National Park, Uganda and Eritrea Polytechnic University, Asmara, Eritrea. Several of these stations (*e.g.*, Nairobi National Park, ICIPE-Mbita and Kibale) are now operational. These AERONET sites will help fill in current gaps of missing information about aerosols in Africa (see also http://www.nasa.gov/vision/earth/everydaylife/aeronet.html).

Under this task, Gatebe participated in the following international conferences and meetings: the Greater Horn of Africa Climate Outlook Forum, Mombasa, Kenya (March 2-4, 2005), the International Geoscience and Remote Sensing (IGARSS) 2005, Seoul, Korea (July 25-29); the 9th International Symposium on Physical Measurements and Signatures in Remote Sensing (ISPMSRS), Beijing, China (October 17-19, 2005) and MILAGRO/INTEX-B Joint Science Team Meetings, Boulder, Colorado, USA (October 24-28, 2005).

Objectives for the Coming Year

Using the new inversion algorithm described in the foregoing sections, Gatebe plans to do retrievals of columnar aerosol size distribution, effective radius, and surface area and volume distribution, using CAR transmission spectra in combination with sunphotometer data from AERONET and/or AATS. The optical thickness spectra and retrieved products will be used for comparisons to products from surface measurements from AERONET. Considering that the project involves data from different geographical regions, the investigators will use the new algorithm to quantify characteristic differences between aerosols from the four regions. Particular emphasis will be placed on quantifying the wavelength- and humidity-dependent single scattering albedo of realistic multi-component aerosols, since this parameter is so important in determining aerosol radiative impacts on climate (including top-of-atmosphere forcing, surface forcing, stability changes, and cloud changes). Effects of shape on scattering phase functions will also be investigated, including characteristic shape changes that occur during downwind evolution.

The investigators will combine the algorithms developed with CAR data acquired while flying under plumes and hazes in downwind and crosswind transects to study how aerosol sizes and masses evolve during downwind transport, and how various sources contribute to regional mass budgets. Efforts will be made to use the airborne sunphotometer water vapor measurements to estimate the condensed water content of overlying aerosols and thereby assess the most appropriate aerosol optical property models to use in retrieving size distribution and mass for a particular type of aerosol.

The CAR data will be used to assess the degree of variability within satellite pixels that may be particularly important near localized sources like small biomass fires or for measurements in broken cloud fields. Aerosol models assumed in the satellite retrievals will be compared to the aerosol models developed in this investigation, and also to aerosol properties determined from in situ measurements. Where significant differences in assumed and actual aerosol properties are found, examples of adjusted satellite products will be produced, using the single scattering albedo and phase function of the actual aerosols. Possible shape effects for soil dust and industrial aerosols will be investigated, as well as effects of the vertical distribution of absorbing and nonabsorbing aerosols. Implications of these studies will be investigated not only for atmospheric products (*e.g.*, aerosols), but also for ocean color and land surface products as affected by atmospheric corrections.

Task 00001859: **Develop Multi-satellite Calibration Methods for Collaboration with ESA on Swarm Mission**

GEST Investigator: Luis R Gaya-Piqué

Collaborators: Patrick T. Taylor (PI, GSFC), Terence J. Sabaka (Raytheon), Michael E. Purucker (Raytheon)

Abstract

In April 2004 the European Space Agency (ESA) selected the project Swarm–The Earth's Magnetic Field and Environment Explorers for full implementation. The mission, expected to be launched in 2009 and with a four-year duration, consists of three satellites in a low-Earth orbit that will provide simultaneous high-precision measurements of the Earth vector magnetic field. The sampling of the magnetic field at multiple local times will help to disentangle signals from various magnetic sources and facilitate the resolution of the spatio-temporal aliasing prevalent in single-satellite missions. The Geomagnetism Group of the Planetary Geodynamics Lab at GSFC is developing the most complete and comprehensive models ever done for the description of the geomagnetic field. The launch of SWARM represents a big opportunity for the improvement of these models.

Description of Research

The Swarm mission represents a challenge for the groups that focus their efforts on modeling the Earth's magnetic field. This task has been focused on the development of software capable of managing the huge amount of data that the Swarm mission will provide, as well as exploiting the advantages given by such a mission in order to obtain a better representation of the magnetic field. On the other hand, some methods have been tested for a proper calibration of the satellite magnetometers. The work is done in collaboration with the Danish Space Research Center, and the results will be presented to the European Space Agency and, later, submitted for publication.

Accomplishments during the Reporting Period

Gaya-Piqué began as a GEST investigator in October 2005. Most of his time during the reporting period was focused on familiarizing himself with the Swarm mission and the research of his GSFC colleagues.

Objectives for the Coming Year

The task objective is to develop the software that will be able to take advantage of the Swarm mission for the improvement of the present magnetic field models. Once the physical equations that represent the studied phenomena are obtained, a FORTRAN code will be developed. It will be necessary to use parallel programming due to the huge amount of data involved and the enormous number of field parameters to be determined. On the other hand, it will be necessary to develop different strategies to take advantage of the unique opportunity that the launch of three simultaneous satellites represents for the description of the magnetic field.

Task 05-5-26563: **NPOESS Preparatory Project (NPP) System Calibration / Product Validation Studies**

GEST Investigator: Bruce Guenther (PI)

Collaborators: H. Ouaidrai (SSAI), J. Lyu (SSAI), J. Butler (GSFC), X. Xiong (GSFC), W. Esaias (GSFC)

Abstract

This research involves continuing development of the Government Team for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Program in the area of sensor calibration and Environmental Data Product validation (cal/val), development and oversight of the NPOESS-NPP VIIRS sensor engineering development and calibration, and continuing support for the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) calibration data product. The research includes but is not limited to identification and application of EOS lessons learned in cal/val to the NPOESS Preparatory Project (NPP) and NPOESS cal/val program. The GEST investigator also involves training of the NPOESS System Prime Contractor in tracking engineering development and calibration in support of sensor performance for scientific research and climate data set development. Transition from the NPP EDU Data Exchange Project (NEXT) to the NOAA CasaNOSA data system for sensor test data was completed in 2005.

Description of Research

For the NPP, the research involves education and training of the NPOESS prime contractor and the Integrated Program Office (IPO) team on the optimum application of EOS lessons learned for sensor calibration and data product validation through discussions, internal memos, presentations, and conference and refereed publications in the open literature. For NPOESS cal/val the activities include development of the NPOESS program to optimize usefulness of NPOESS and NPP data to NASA research and climate data records, and improve NASA staff presence in and influence on the NPOESS cal/val program. For the MODIS effort, the research involves continuing collaborative research with the Goddard MODIS leadership and with the MODIS Characterization Support Team (MCST) to remain cognizant of their key accomplishments and issues, to challenge their approaches and identify potential areas of improved calibration performance through analysis, presentations and publications in the peer-reviewed literature.

Accomplishments during the Reporting Period

Successful activities within NPOESS this year involved development of an (IPO-led) review of SDR performance requirements against testing for VIIRS to establish Government Team consensus of several “must have” tests which are being added to the VIIRS test program; serving as the calibration representative to the VIIRS engineering effort on behalf of the IPO cal/val lead, and identification of several important error sources (or undervalued uncertainty of error source) for the Reflected Solar Bands SDR products for VIIRS. The development of uncertainty budgets as a driving definition of sensor test program requirements.

The NEXT activity has been completed with the transition to CasaNOSA for storage and distribution to the Government Team. Transition of algorithm codes from NEXT to CasaNOSA was completed this year.

Objectives for the Coming Year

The main objectives for the NPP activity are continuing integration of the NPP Project Science Team into the NPP cal/val effort, analysis of NPP sensor EDU test data for initial verification of sensor radiometric calibration concepts, and providing detailed comments and analysis on sensor test and analysis concepts. Development of a path forward for requirements verification and requirements compliance to integrate sensor calibration requirements and environment data product validation into the test program is the major thrust of the coming period.

Project 00000975: **Antarctic Comprehensive Model from Airborne, Shipborne, Ground, Satellite Magnetometer Data (continued)**

GEST Investigator: Hyung Rae Kim

Collaborators: Patrick Taylor (GSFC)

Abstract

An Antarctic Comprehensive Model (ACM) study continued to sum up parts of the interla geomagnetic components, including the internal part (from core-generated and crustal sources), as well as beginning put together the external part of the geomagnetic components (from magnetospheric and ionospheric currents). Spherical cap harmonic expansions that represent the internal field will be explicitly implemented up to a maximum index of 180 (equivalent to a 75 km wavelength or to order 540 for global spherical harmonics, in the region below 60°S latitude). The most recent global spherical harmonic CHAMP model was computed at n and m of 90 or 440 km wavelength, respectively [Maus *et al.*, 2006]. Their internal geomagnetic field model, called MF4, was more representative of the field in equatorial and mid-latitudes (up to ±60°) than in the high latitudes since MF4 only partially accounted for the complicated external fields predominant in Polar Regions. The extended ACM will be developed to present the external magnetic field components as well as the internal, using ground and satellite data and data from 25 magnetic observatories in the Antarctica. The external field modeling techniques were already developed by many researchers.

Description of Research

The internal part of the crustal magnetic field over the Antarctica was developed. The main geomagnetic field and its secular variations were successfully modeled by de Santis *et al.* [2002] and Gaya-Piqué *et al.* [2005] using a spherical cap harmonic analysis with the degree and order 13. However, for the spatially high-resolution higher order and degree of spherical harmonics, coefficients are required to represent the crustal field components. For spherical cap harmonics for the cap size of 30° over Antarctica, harmonic expansion of index 120 (corresponding to 360 in global spherical harmonics) will produce a 1° or 110 km wavelength resolution at the surface. This factor will expedite computation speed because the number of the unknowns for the spherical cap harmonics is only 11 % of the ones for the global spherical harmonics that represent the equivalent wavelengths of the anomalies. Kim increased the maximum order to about 0.75° wavelengths at the surface. The external field modeling will be characterized by the polar external field components applying spherical cap harmonic expansions from the ground observatory and satellite dawn/dusk data in which Polar Electrojet (PEJ) are mostly present. Langel *et al.* [1996] introduced to the model the induced field from the magnetospheric currents, using Magsat data. Ritter *et al.* [2004] also found PEJ magnetic field signatures in CHAMP satellite data, inferring that the polar ionospheric

and field-aligned current fields have a good agreement with the ground observatory network data. Based on these studies, the GEST investigator will develop the external field model in the region south of 60°S latitude, using a spherical cap harmonic analysis. Torta *et al.* [1997] produced the spherical cap harmonic model for only the ionospheric current field and its induced field from the European observatory data and Weimer [2001] constructed field-aligned current model from DE-2 and ground data using the spherical cap expansions. The concurrent measurements from several satellites, orbiting at different local times and locations (future SWARM constellation mission), will enable the researcher to model explicitly these external fields, because the gradient measurements from SWARM data will be useful to regularize FAC, which tends to show great disturbance in these component measurements. This will provide the necessary computer analyses in advance for the SWARM mission.

Accomplishments during the Reporting Period

The investigator made further progress in the computation of spherical cap harmonic expansions with high indices equivalent to the wavelengths criteria for the representation of magnetic anomalies. The results were presented at the AGU Spring Meeting in New Orleans, LA and at the IAGA 2005 Scientific Assembly meeting in Toulouse, France. The spherical cap index (necessary for half-angle cap of 30°) was up to 90, which is equivalent to degree 270 for spherical harmonics. ADAMP compilation was modeled with this technique and compatibility estimated from these spherical cap coefficients. Recently, the maximum index of the spherical cap harmonics coefficients has been extended up to 180, which corresponds to degree and order of 540 for global spherical harmonics. This allows resolving the features equivalent to about 75 km of wavelengths over the Antarctic regions at the surface level. Parallel programming made it possible to compute 3.27x104 unknown coefficients. Extended work for Antarctic regions and its surroundings included modeling the magnetic thickness variations from magnetic observations and the gravity-derived thickness data. This work helped to model geothermal heat flux, inferring thermal evolution of Antarctic tectonics as well as the dynamics of glaciers and ice sheets. The results of this study were also presented at the AGU Fall meeting in San Francisco, CA last December.

In addition to current Antarctic magnetic anomaly modeling, crustal analysis of Maud Rise, Antarctica, was attempted using the magnetic and gravity data. Relocation of the Cretaceous Quiet Zones (CQZ) over the study area was suggested and reconstruction of tectonic plates was reevaluated. The extensive study over this region was published by Kim *et al.* [2005]. More of the Antarctic geopotential field studies with OSU colleagues were made in the analyses of interrelation between magnetic and gravity data and of external ionospheric magnetic field. Correlations and anti-correlations between the magnetic and gravity data over the Antarctic regions provided new insights on the enigmatic crustal tectonics of Queen Maud Land, Enderby Land and other regions of Antarctica. Collaboration with Dr. Potts at OSU was focused on the comparison of several polar activity indices (*i.e.*, Ap, Kp, and PCI) with ionospheric total electron content (TEC). Both studies were presented at the AGU Spring meeting in New Orleans, LA.

Besides Antarctic research, gravity tensor gradients by Gauss-Legendre quadrature integration was evaluated for the future ESA-sponsored GOCE satellite mission. The extensive study for gravity modeling is being revised for the publication in the *Geophysical Journal International*. The Icelandic and North Atlantic crustal analysis was also performed and published in the journal [Leftwich *et al.*, 2005] and innovative modeling using Bayesian inference for Pannonian basins using gravity data was developed and described [Kis *et al.*, 2005] as well.

Objectives for the Coming Year

The investigator plans to present a comprehensive crustal magnetic model both at the AGU Spring meeting in Baltimore, Maryland and at the First Swarm International Science Workshop in Nante, France. This presentation is a part of the results from the Antarctic Comprehensive Model (ACM) project,

which attempts to represent the internal and the external geomagnetic field components over the Antarctic continent and its surroundings. For the coming year, the external components of the model are being developed using ground and satellite data as well as the data from the 25 magnetic observatories in Antarctica. Additionally, the investigator will continue to work with OSU colleagues on the GRACE gravity interpretation over the Wilkes Land, Antarctica, and the results will be presented at the SCAR (Scientific Committee of Antarctic Research) meeting in Hobart, Australia. He also will take part in the collaborative research regarding the role of geologic control on glacial drainage to map major geological boundaries on the ice covered areas in Greenland. A couple of publications will be prepared in this coming year, one based on the gravity gradient study using Gauss-Legendre integration and the second regarding geomagnetic field modeling from KOMSAT satellite data.

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

GEST Investigator: Kyu-Myong Kim

Collaborators: William K. Lau (GSFC)

Description of Research

The goal of this research is to understand the effect of aerosol radiative forcing on the global monsoon water cycle. Various satellite observations including MODIS, TOMS, and TRMM, and *in-situ* observations are being used to diagnose the relations between aerosol distribution and the evolution of monsoon water cycle. Modeling experiments forced with aerosols from the GOCART model are also conducted to understand the mechanisms involved. Relative roles of "Global Dimming effect" and "Elevated heat-pump effect" on monsoon circulation will be investigated based on GCM experiments with/without the atmosphere-ocean interaction.

Objectives for the Coming Year

The focus of this new task will be on the possible large-scale climatic impact of Saharan dust on the hydrologic cycle over the Caribbean during the boreal summer and South America summer monsoon system during boreal winter. The GCM experiment will be carried out with the temporal-spatial distribution of GOCART aerosol. To focus on the short-term effect of aerosol forcing due to year-to-year variations of aerosol, the model will be forced with aerosol distributions from two different years. The effect of air-sea coupling will also be investigated by comparing the experiments with and without air-sea coupling.

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)

Abstract

The researchers obtained an accurate semi-analytical solution for 3D radiative transfer over non-homogeneous and anisotropically reflecting surfaces, and developed a new fast algorithm for the broadband radiative transfer. These developments lead to an accurate parameterized solution that can be efficiently used in remote sensing. The current work is dedicated to developing the advanced atmospheric correction (AC) algorithm for the Earth Observing System (EOS) imaging spectrometer MODIS, and for the Landsat ETM+ imager. As a part of this effort, Lyapustin is also developing an AERONET-based Surface Reflectance Validation Network (ASRVN). ASRVN is

designed to produce high quality surface reflectance by accurate atmospheric correction of MODIS, MISR and ETM+ data around AERONET sites, using AERONET aerosol and water vapor data as a well-calibrated ancillary information. The ASRVN is also uniquely poised for the calibration analysis of the Earth observing sensors, which has been recently demonstrated in the MODIS-MISR cross-calibration study.

Description of Research

The main objective of this research is the development of advanced aerosol retrieval-atmospheric correction algorithms for the EOS MODIS imaging spectrometer and the Landsat ETM+ imager. The new algorithm is based on a recently developed theory that rigorously describes 3-D radiation effects, gaseous absorption in the atmosphere, and surface bidirectional reflectance properties [Lyapustin and Knyazikhin, 2001; 2002; Lyapustin, 2003]. Another important research area is development of the operational system, ASRVN, for validation of the surface reflectance products from MISR, MODIS and ETM+ sensors globally around AERONET sites. The AERONET atmospheric aerosol and water vapor data are used as well-calibrated ancillary information for the accurate atmospheric correction of satellite data. This approach has been used to validate the global surface reflectance products from MODIS and MISR over non-homogeneous surfaces at a moderate spatial resolution (~1km). The ASRVN data products and its recently developed service functions have been used to perform a cross-calibration analysis for two major instruments of Earth Observing System: MODIS and MISR.

Accomplishments during the Reporting Period

Past year research focused on the calibration applications of the ASRVN system, in collaboration with the MODIS and MISR teams. MODIS and MISR are two major Earth Observing System instruments flown onboard the Terra satellite. Their synergistic use could greatly benefit the broad user community by ensuring the global view of the Earth with high-quality products. The GEST investigators' study compared two surface albedo products derived from MODIS and MISR L1B data by ASRVN and found a positive MISR-MODIS albedo bias of + (0.01-0.03). Cross-sensor calibration inconsistencies were identified as a primary cause of the albedo biases. To establish an independent MODIS-MISR calibration link, they developed an independent method based on regression of MODIS and MISR L1B data over water clouds. The empirical regression results have been adjusted for the differences in the MISR-MODIS respective spectral responses using radiative transfer simulations. The MISR-MODIS band gain differences estimated with this technique are +6.0% in the blue, +3.3% in the green, +2.7% in the red, and +0.8% in the NIR band. About half of the difference in the blue band was found to be due to the difference in the MODIS-MISR solar irradiance models.

In parallel, Lyapustin has developed a new method for the retrievals of the surface reflectance and aerosol optical thickness (AOT) based on simultaneous processing of two images acquired on different days. The new Near-Constant Contrast (NCC) method retrieves AOT on both days, assuming that the surface reflectance has been stable. The NCC method is found to be very sensitive to noise. As a result, at a certain noise level it can only retrieve the AOT difference between the two days, losing the sensitivity to the absolute magnitude of AOT on any given day. For an operational application, he is complementing the NCC method with the Dark Dense Vegetation (DDV) method.

Objectives for the Coming Year

This effort, supported by NASA NPP and EOS grant funding (2004-2006), will be concentrated on three tasks. The first is the development of the advanced global atmospheric correction algorithms for MODIS and Landsat. The algorithm will implement a combination of the NCC and DDV methods. The second task will be a validation of MODIS surface reflectance products with ASRVN. Finally, a cross-calibration analysis of MODIS on TERRA and AQUA platforms using ASRVN albedo product will be performed. As a part of a NPP grant, Lyapustin will continue analysis of the VIIRS aerosol retrieval and atmospheric correction algorithms/codes of NGST VIIRS contractor.

Task 923-03-067: **AERONET - Ground Based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Alexander Smirnov

Collaborators: Brent N. Holben (GSFC)

Abstract

Research performed during the last fiscal year focused on the implementation of Version 2 of the AERONET aerosol optical depth processing algorithm and a coordinated release of this algoritm to the scientific community. The refinement of the AERONET cloud screening algorithm and associated sensitivity study allowed researchers to estimate its impact on the operational processing and long-term statistics. Ship-based data acquisition with a hand-held sunphotometer in areas underrepresented in the AERONET system (over the oceans, especially in the South Ocean) provided a unique dataset and an opportunity for comparison with satellite retrievals and the GOCART model. Five peer-reviewed papers co-authored by the GEST investigator were published during this time period.

Description of Research

Remotely measured atmospheric aerosol optical parameters are important for various applications including computations of radiative forcing and satellite remote sensing. Aerosol optical depth, which may be derived from measurements of attenuated direct solar radiation, as well as the aerosol size distribution and single-scattering albedo, which may be derived from combined aerosol optical depth and solar almucantar sky radiance data, are pivotal parameters defining the aerosol optical state of the atmosphere. The major advantage of these kind of remote sensing measurements over direct *in-situ* aerosol sampling or laboratory analysis is their large-scale (column integrated quantities) and non-intrusive nature.

Accomplishments during the Reporting Period

The foundation of the AERONET measurements program is aerosol optical depth. Smirnov has an improved processing algorithm using a new set of formulas and data sets for computations. New ozone and NO_2 climatology were implemented; water vapor processing was standardized based on the newly created filter database; improvements were made to account for water vapor, methane, and carbon dioxide absorption in some channels; and certain updates were made to the computational formulas (*e.g.*, to optical air mass formula, ozone optical air mass formula).

An automated cloud screening algorithm has been successfully deployed operationally since 1998; however, certain shortcomings became evident with the growth of the data archive. Certain tools and thresholds were tested to improve the performance of the cloud screening procedure and recommendations were made. Sensitivity tests showed that any changes in the current algorithm (if done without an appropriate care) would alter the established statistics either yearly or monthly or both. However, certain recommendations can be made and a modified algorithm (if implemented) will increase a number of accepted measurements, especially in the conditions of highly variable urban/industrial aerosol, and will preserve the existing integrity of the AERONET database and long-term statistics.

Study of the long-term regional aerosol variability is important especially in the areas where AERONET monitoring stations are absent. Atmospheric optical properties over the oceans are still scarse. Substantial radiative effects of the sea-salt aerosol, better understanding of the climate change forcing, very few systematic measurements over the oceans, especially in the South Ocean, create a demand for more data acquisition. Recently the AERONET established a few new island sites in the South Ocean; however, large areas south of 35º still have no coverage. Ship-based measurements can at least partly fill the gap that exists in our knowledge on the global aerosol distribution over the oceans.

Aerosol optical depth measurements over the oceans included a transect in the Atlantic from North Sea to Cape Town, a crossing in the South Atlantic to Argentina and measurements along the coast of Antarctica. In the open oceanic areas not influenced by continental sources, aerosol optical depth values were close to background oceanic conditions. Spectral dependence, especially in the high latitude Southern Atlantic, can be considered as quasi-neutral. Back-trajectory analysis allowed statistical division of the aerosol optical parameters and showed similar properties for the North Atlantic polar marine, South Atlantic subtropical marine and South Atlantic polar marine air mass. Ship-borne aerosol optical depth comparisons to the GOCART model and satellite retrievals revealed systematic biases. Satellite retrieved optical depths are generally higher (depending on the sensor), especially in low optical depth conditions. The GOCART model simulated optical depths correlate well with the ship measurements and, despite a notable disparity with the observations in a number of cases, about 30% agree within the measurement accuracy.

Objectives for the Coming Year

The researcher will focus on the development and implementation of the modified AERONET cloud screening procedure, expanding data collection over the oceans and data analyses, participation in the UAE^2 data analyses, and establishment of additional AERONET sites.

Task 923-32-162: **AERONET-based Surface Reflectance Validation Network (ASRVN) and its Application**

GEST Investigator: Yujie Wang

Collaborators: Alexei Lyapustin (GEST), Jeffrey L. Privette (GSFC)

Abstract

Validation is a critical component of the Earth Observing System (EOS), aimed at establishing the accuracy of satellite-derived products on the regional and global scales; under different atmospheric and surface conditions. Due to spatial heterogeneity of the land surface, validation of surface reflectance through direct ground-truth measurements requires significant amount of effort and a global application does not seem feasible. The researchers present an alternative approach of indirect validation of surface reflectance product around Aerosol Robotic Network (AERONET) sunphotometer sites. The idea is to collect the best ancillary information on atmospheric aerosol and water vapor, and perform an independent atmospheric correction of satellite measurements based on accurate radiative transfer theory, that is not constrained by the time requirements of operational processing. It has merits that ground-based measurements do not provide, such as the capacity to allow spatial analysis over relatively large non-homogeneous area of study, and can be easily extended to a regional and then global scale within the AERONET infrastructure. Moreover, because this system collects satellite data for different instruments simultaneously at the same geographical location, it can also support instrument cross-calibration analysis. Based on this system, the GEST investigator analyzed MISR BRF and albedo product around two AERONET sites and found that MISR generally provides accurate retrievals of BRF and albedo in both clear and hazy atmospheric conditions, correctly reproducing the parameter time series and spatial distribution. In addition, he also analyzed the calibration difference of the TOA reflectance between TERRA MODIS and MISR instruments. It was found that the estimated band gain differences creates a systematic bias between MODIS and MISR albedo of 0.01-0.03 in the visible bands with MISR measurements being higher.

Description of Research

The main objective of this research is developing an AERONET-based Surface Reflectance Validation Network (ASRVN). This includes collecting the best ancillary information on atmospherics aerosol and water vapor

through AERONET stations, developing generic sensor/resolution independent aerosol retrieval - atmospheric correction algorithm, and comparing retrieved surface reflectance with MISR/MODIS surface reflectance products. This system can automatically receive MISR and MODIS Level 1B subsets over a 32x32 km^2 area around the 166 AERONET sites globally, perform an independent atmospheric correction of satellite measurements based on accurate radiative transfer theory that is not constrained by the time requirements of operational processing. The researchers are also routinely processing ETM+ data as they become available. The ASRVN and operational products have the same spatial and spectral resolution, and this allows for testing of the full processing path of operational algorithms that have to make an independent cloud screening and aerosol retrievals. Also, results for each instrument depend on its calibration. This allows a cross-instrument calibration analysis based on a large statistics of the land cover types and surface brightness around AERONET sites globally.

With the support of the ASRVN system, researchers can perform a thorough comparison between MISR BRF and albedo products and the GEST investigators' retrievals. As the first step, they performed local analysis of MISR surface BRF and albedo over GSFC and Mongu AERONET sites. The results show that MISR generally provides accurate retrievals of BRF and albedo in both clear and hazy atmospheric conditions, correctly reproducing the parameter time series and spatial distribution.

Accomplishments during the Reporting Period

In the past year, the GEST investigators have successfully established an ASRVN system which currently covers 32x32km areas around 166 AERONET stations. A series of protocols have been set up to automatically receive and subset MISR L1B data, MISR geometric data and MISR cloud mask data, AERONET aerosol data, MODIS L1B data, MODIS geometric data and MODIS cloud mask data. Rigorous 3-D radiative transfer atmospheric correction algorithm for both MISR and MODIS atmospheric correction has been integrated into this system. A series of software has been developed for AERONET/MISR/MODIS data synchronizing, data format converting, data sub-setting, image re-projecting and database management. This system can be run operationally. Certain data analysis tools have also been developed and include pixel albedo/BRF time series retrieval, cloud mask generation, spatial statistic tool, data completeness checking tool and image viewing tool. Considering algorithm improvement, they have also integrated a "transient" model [Gao *et al.*, 2000] in they algorithm, to eliminate the problem of negative values at high angles in the Li-Sparse linear hybrid model.

As a preliminary step of validation, a local comparison was conducted between the present research retrievals and MISR BRF and albedo products over two sites (GSFC, Greenbelt, Maryland and Mongu, Zambia) for the available MISR direct pass data of Collection 4 for 2003-2004. With some non-significant bias, the MISR land surface albedo/BRDF products agree well with research retrievals, which leads to a conclusion that MISR Collection 4 offers high quality surface reflectance products, based on the limited number of analyzed sites.

The GEST investigator also demonstrated the application of the ASRVN system on cross-instrument calibration. He studied the calibration differences between the MODIS land channels and the four MISR bands, using two independent methods. The first is based on matching surface albedo independently derived from MODIS and MISR measurements around AERONET sites, using AERONET aerosol and water vapor data. The retrievals show a systematic bias of 0.01-0.03 between MODIS and MISR albedo in the visible bands (with the MISR values being higher), which can only be explained by a calibration difference. The second method compares measurement-based and theoretical regressions of MODIS – MISR reflectance at the top of the atmosphere over liquid water clouds. The band gain differences estimated with this technique are 5.8% in the blue, 3.1% in the green, and 1.8% in the red band. The results from both methods agree qualitatively. The results are consistent with known differences in the absolute radiometric

standards used to calibrate the two instruments. External constraints on surface albedo might help resolve the difference between the two radiometric scales, allowing for the removal of the systematic bias.

Objectives for the Coming Year

The GEST investigator will continue accumulating statistics to validate MISR surface albedo/BRF products, and to establish coefficients to adjust the calibration difference between MODIS and MISR TOA reflectance. He will also apply the new algorithm to perform atmospheric correction on real MODIS data. A prototyping MODIS atmospheric correction algorithm is under development. Due to a "bowtie" effect [Wolfe *et al.*, 1998] and the triangular shape of the MODIS system point spread function [Nishihama *et al.*, 1997], the current MODIS gridding/aggregate algorithm cannot accurately represent the surface reflectance/radiance information for a given grid cell. The researcher plans to develop a new gridding/aggregate algorithm to represent surface information for grid cells more accurately. This is an important step for the successful new MODIS atmospheric correction algorithm.

Task 920-63-217: **Development of Bird Migration Model using Climate and Other Remote Sensing Data**

GEST Investigator: Konrad Wessels

Collaborators: J. A. Smith (PI, GSFC), A. Farmer (USGS)

Abstract

Many North American bird species migrate vast distances between their breeding areas in the north (*e.g.*, Alaska) and wintering grounds in the south (*e.g.*, Texas or South America). The spatial distribution and quality of stopover sites (*e.g.*, wetlands) effect their survival, reproductive success and population dynamics. In order to understand the influence of habitat transformation and deterioration on the conservation of migratory birds, this research aims to adapt a dynamic state variable model based on bird flight energetics to be driven by spatial, near-real time climate data (*e.g.*, wind ,air temperature and soil moisture - GMAO) and land surface remote sensing data.

Description of Research

The main objective of this new research task is to illustrate the benefit of implementing the bird migration models in the spatial domain using near real-time GMAO climate data and other remote sensing data. The results will aid the management of crucial wildlife refuges and demonstrate the impact of a changing landscape and changing climate on migratory species.

Objectives for the Coming Year

During the next year the GEST investigator will attempt to secure funding to apply the bird migration models to avian influenza surveillance efforts. Advanced bird migration models are essential tools in mapping the probability distribution of migration bird species, thus predicting where an infected bird was and where it can be in the days to follow.

Task 913-57-211: **An Assessment of Measurement-based Aerosol Direct Radiative Effect and Forcing**

GEST Investigator: Hongbin Yu

Collaborators: Yoram Kaufman (Co-PI, GSFC), Mian Chin (Co-PI, GSFC), Lorraine Remer (GSFC)

Abstract

Current assessment of the aerosol direct forcing as finalized in the Intergovermental Panel on Climate Change (IPCC) Third Assessment Report is largely model-based and has large uncertainties. In recent years, a great deal of effort has gone into improving measurements and datasets. It is thus feasible to shift the estimates of aerosol forcing from largely model-based to be increasingly measurement-based. The goal of this task is to assess current observational capabilities and identify uncertainties in the aerosol direct forcing through comparisons of different methods with independent sources of uncertainties, focusing on satellite and ground-based measurements supplemented by global chemical transport model simulations. The researcher is also exploring a data assimilation approach to enhance the capability of a model for quantifying the aerosol radiative forcing. The assessment is contributing to a synthesis and assessment product, "Aerosol Properties and Their Impacts on Climate" that is being developed by the Climate Change Science Program (CCSP) for supporting policymaking and adaptive management; and is serving as a resource in the preparation of the IPCC Working Group I Fourth Assessment.

Description of Research

Aerosols affect the Earth's energy budget directly by scattering and absorbing radiation and indirectly by acting as cloud condensation nuclei and, 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. Past assessment efforts of the direct effect of aerosol on climate were done through modeling efforts and large uncertainties exist. New satellite sensors (*e.g.*, MODIS, MISR, POLDER, and CERES) introduced in the last decade, the AERONET global network of ground-based sun/sky radiometers, and a number of intensive field experiments provide the opportunity to attempt a measurement-based assessment of the aerosol direct effect on climate. The researcher's goal is to assess current observational capabilities and identify uncertainties in the aerosol direct forcing through comparisons of different methods with independent sources of uncertainties. Specifically, he plans to assess the aerosol optical depth, direct radiative effect (DRE) by natural and anthropogenic aerosols, and direct climate forcing (DCF) by anthropogenic aerosols, focusing on satellite and ground-based measurements supplemented by global chemical transport model (CTM) simulations.

Accomplishments during the Reporting Period

The researcher has assessed a number of satellite-based, model-satellite-integrated, and model-based estimates of aerosol direct effect and forcing on both global and regional scales. On regional assessments, he has also included AERONET measurements [Zhou *et al.*, 2005] and results from more than a dozen of intensive field experiments. The assessments are documented in a paper published in *Atmospheric Chemistry and Physics* [Yu *et al.*, 2006] and major data sets are online [http://aerocenter.gsfc.nasa.gov/gamma/database.php]. In the paper, he also assessed current measurement capabilities in characterizing aerosols and estimating the direct effect, discussed outstanding issues, and proposed future research.

The multi-spectral MODIS measures global distributions of aerosol optical depth (τ) on a daily scale, with a high accuracy of $\pm 0.03 \pm 0.05\tau$

over ocean. The annual average τ is about 0.14 over global ocean, of which about 21% ± 7% is contributed by human activities, as estimated by MODIS fine-mode fraction. The multi-angle MISR derives an annual average τ of 0.23 over global land with an uncertainty of ~20% or ±0.05. These high-accuracy aerosol products and broadband flux measurements from CERES make it feasible to obtain observational constraints for the aerosol direct effect, especially over global the ocean. A number of measurement-based approaches estimate the clear-sky DRE (on solar radiation) at the top-of-atmosphere (TOA) to be about -5.5±0.2 Wm-2 (median ± standard error from various methods) over the global ocean. Accounting for thin cirrus contamination of the satellite derived aerosol field will reduce the TOA DRE to -5.0Wm-2. Over the oceans the surface DRE is estimated to be -8.8±0.7 Wm-2. Over land, an integration of satellite retrievals and model simulations derives a DRE of -4.9±0.7 Wm-2 and -11.8±1.9 Wm-2 at the TOA and surface, respectively. The clear-sky aerosol DCF at the TOA derived at is -1.3±0.8 Wm-2. These measurement-based estimates are much larger than CTM simulations.

This assessment also identifies several issues that require significant future effort. Estimates of aerosol forcing over land is less well constrained than over ocean. Uncertainties in estimates of aerosol forcing are also larger on regional scales than on a global scale. The aerosol forcing under cloudy condition remains relatively unexplored and quite uncertain. In addition, knowledge of the much more complex and likely more important aerosol indirect effects that modify cloud properties and abundance are much less certain. A coordinated research strategy needs to be developed for integration and assimilation of satellite measurements into models to constrain model simulations. Enhanced measurement capabilities soon to be online and high-level scientific cooperation will further advance our knowledge.

In addition to Yu *et al.* [2006], other publications resulting from this year's effort include Zhou *et al.* [2005] and Anderson *et al.* [2005].

Objectives for the Coming Year

The GEST investigator will address challenges and opportunities of improving estimates of aerosol direct forcing in the presence of clouds. He plans to work together with NOAA scientists to integrate his satellite-based assessment with their *in-situ* measurement-based assessment [Bates *et al.*, 2006] and generate the CCSP synthesis and assessment report on "Aerosol Properties and Their Impacts on Climate." He is also developing an algorithm to estimate fluxes of dust and pollution from and to continents based on satellite measurements.

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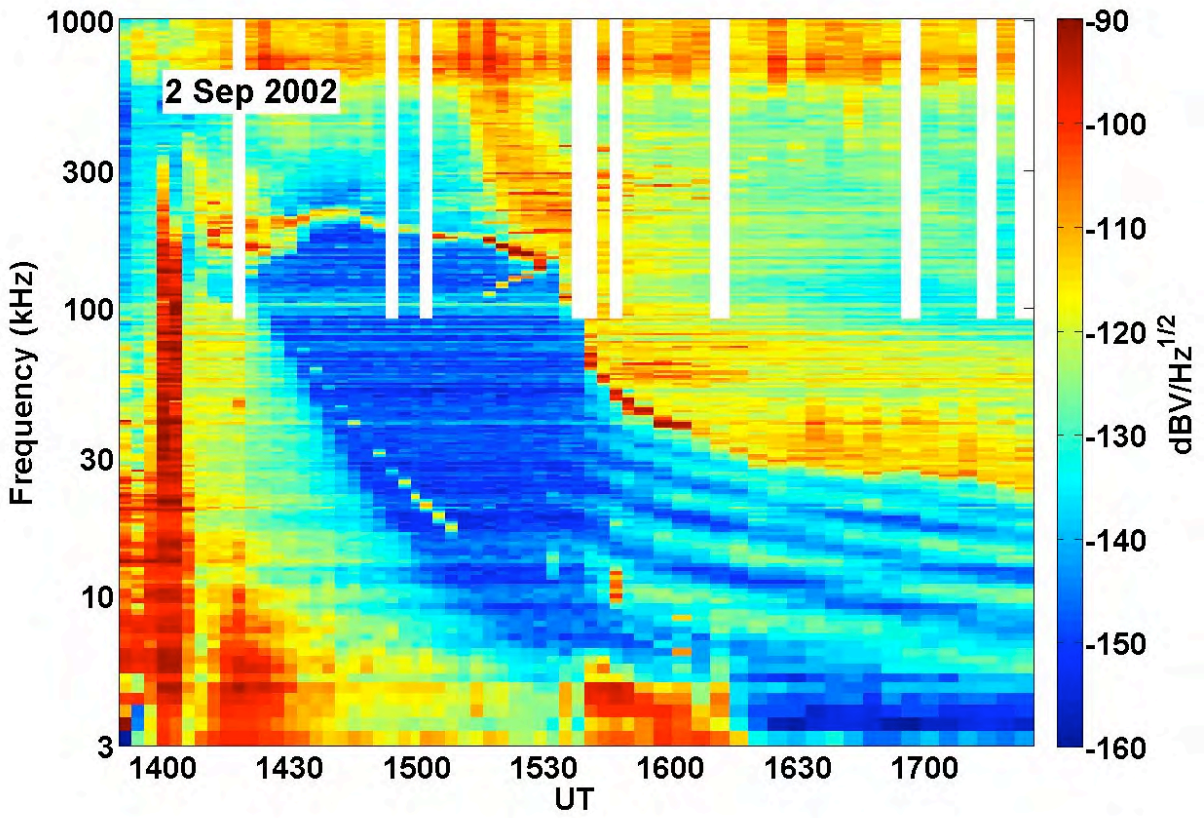
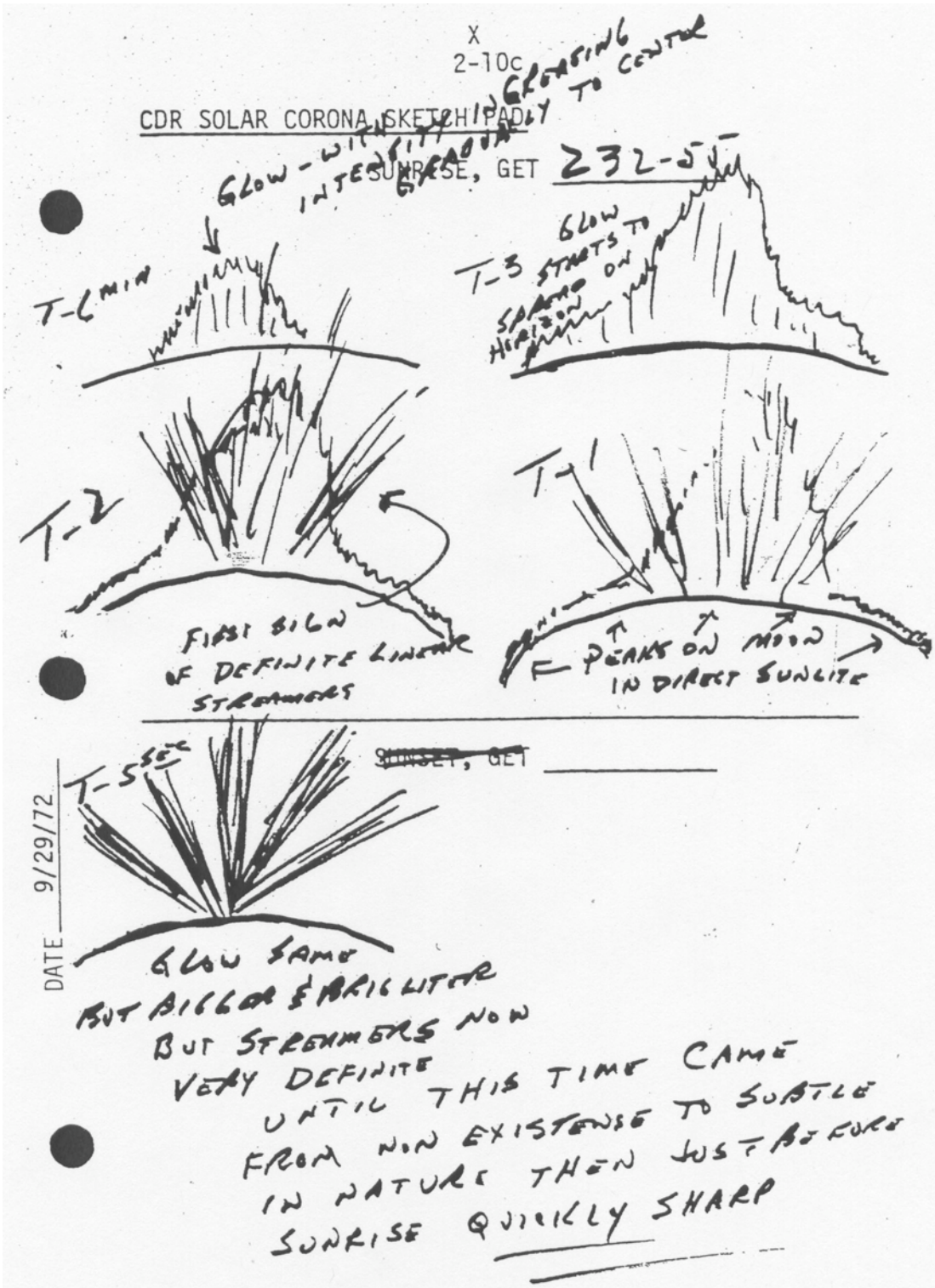
Heliophysics Research Group



Example of a passive dynamic spectrum collected on September 2002 by the IMAGE RPI instrument displaying various natural emissions observed in the Earth's inner magnetosphere. (Figure provided by Phillip Webb.)



Sketches of sunrise with "horizon glow" and "streamers" viewed from lunar orbit by astronaut E.A. Cernan (commander) during Apollo 17. Time before the first appearance of the Sun is indicated in minutes (T-6 min, T-3, T-2, T-1) and seconds (T-5 sec) [Stubbs et al. 2006]. Graphic provided by Timothy Stubbs.

Heliophysics Research Group

Due to a recent reorganization, the new Heliophysics division within NASA was created to study the science of the Sun-Solar System connection. The term Heliophysics comes from the prefix *helio,* which means 'of the Sun and environs' and the noun *physics*, 'the science of matter and energy and their interactions.' As outlined in NASA Heliophysics Roadmap [Draft, April 2006] the three science objectives of the new division are:

> **1) Open the Frontier to Space Environment Prediction**:
> Understand the fundamental physical processes of the space environment - from the Sun to Earth, to other planets, and beyond to the interstellar medium.
>
> **2) Understand the Nature of Our Home in Space**:
> Understand how human society, technological systems, and the habitability of planets are affected by solar variability interacting with planetary magnetic fields and atmospheres.
>
> **3) Safeguard the Journey of Exploration**:
> Maximize the safety and productivity of human and robotic explorers by developing the capability to predict the extreme and dynamic conditions in space.

Following the creation of the Heliophysics Division at GSFC, GEST recognized that the best approach to meet the needs of the new NASA division was to copy this organizational structure by setting up a new parallel Heliophysics Research Group within GEST. The purpose of this expansion of GEST is to provide a home for the GEST space scientists working in this research field by bringing them together into a single group. This will strengthen the research ties between these peers, but still allow for strong connections and encourage the cross pollination of ideas with other discipline groups within GEST.

The founding members of the Heliophysics Research Group are Judit M. Pap, Timothy J. Stubbs, and Phillip A. Webb. Each member is currently working on a variety of topic areas, as the following selected examples demonstrate. During the past year, Pap undertook investigations addressing the phenomenon of solar variability and its connection to climate change including developing an understanding of the relationship between variations in solar irradiance and the magnetic fields of active solar regions and the full-disk magnetic field strength data. Stubbs is studying lunar dust transport and surface charging in collaboration with colleagues at NASA/GSFC and UC Berkeley that will have important implications for future robotic and human exploration of the Moon. Webb is developing a technique to fit the ionospheric electron density (Ne) topside profiles obtained from satellite topside sounders allowing the O^+/H^+ transition altitude and electron/ion temperatures to be extracted and, separately, developing an automatic fitting technique to determine plasmaspheric Ne from IMAGE RPI dynamic spectra.

As of April 2006, the Heliophysics Research Group consists of seven research scientists (the four recent additions to the founding members are too new to have their research covered in this annual report). It is envisaged that during the coming year this group will grow to at least a dozen scientists researching Sun-Solar System connections. This is an exciting development at NASA and GEST is proud to be able to support and extend the research and development of this new division.

Phillip Webb

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Grants NAG5-11624, NAG5-13513, NAG5-13513-1, NNG06GA58G: **Solar Irradiance Variability and Climate Implications**

GEST Investigator: Judit M. Pap

Collaborators: Stuart Jordan (GSFC), Charles Jackman (GSFC), Harry Jones (GSFC, emeritus), Adam Szabo (GSFC)

Abstract

In the past year, the GEST investigator has performed work under three NASA grants. The objectives and results of two of these grants funded investigations addressing the phenomenon of solar variability and its connection to climate change and are outlined in this report. The first investigation focuses on developing an understanding of the relationship between variations in solar irradiance (both bolometric and at various wavelengths from EUV to IR) and the magnetic fields of active solar regions (sunspots and faculae) as measured from satellite by the Solar and Heliospheric Observatory (SOHO)/ Michelson Doppler Imager (MDI) experiment and the full-disk magnetic field strength data as measured at the Kitt Peak Solar Observatory. A second investigation addresses the issue of the differences in the level of solar maxima and minima at various cycles, especially at the time of cycle 23 when the level of solar magnetic activity was low but both total and UV irradiance showed high irradiance maximum levels. Current results also show that there are significant differences between total solar irradiance and various solar activity indices used for irradiance modeling during the declining portion of cycle 23.

Description of Research

Variations in solar output are studied using observations from various surface and space-based sources, such as the Kitt Peak magnetic field observations, images from the Precision Solar Photometric Telescopes (PSPT), SOHO/MDI, and the Variability Irradiance and Gravity Oscillations (VIRGO) and Solar Extreme Ultraviolet Monitor (SEM) experiments on SOHO. To analyze these ground and space-borne data, state-of-the-art image and time series analysis techniques are utilized. Results serve to both characterize the variations in solar output, examining the links between different indices, and to understand the reasons for the variations. The ultimate goal is to understand the physical origin of irradiance variations to reconstruct and predict solar-induced climate changes. The work includes leading several international efforts and collaborations with a number of scientists in different institutions as well as developing collaborative research efforts between the forthcoming Solar Dynamics Observatory and the French PICARD experiment.

Accomplishments during the Reporting Period

During the last year, Judit Pap continued to study the origin of solar irradiance variations. Results show that both total irradiance (integrated over the entire solar spectrum) and UV irradiance increased more during the weak solar cycle 23 than the rest of the magnetic indices. Photometric results indicate that during solar cycle 23 less and smaller sunspots and faculae occurred in general, except for the few large activity outbursts. Although less sunspot darkening would explain the high total irradiance values during the weak cycle 23, it however cannot explain the high UV irradiance values, indicating that other physical processes are present. It has also been found that during the declining portion of solar cycle 23 total solar irradiance, similar to the full disk magnetic flux, has already reached the same minimum level as during the last cycle. In contrast, the UV irradiance, He-line equivalent width at 1083 nm, the CaK index, 10.7 cm radio flux and the sunspot number were still above their respective minimum level. These results indicate the need to better understand the physical origin of the

used irradiance surrogates for long term irradiance modeling to thus better predict the past and future climate changes.

To further study this problem, analysis of the high resolution MDI images began during the investigator's work at the Jet Propulsion Laboratory (JPL). She found that using magnetic field and intensity values to identify sunspots and faculae for the time interval including the maximum of cycle 23 may separate the strong facular fields from the weaker network fields. Further studies on this topic are in progress. These results may have climatology significant since current irradiance models used in climate studies assume that there is a linear relation between irradiance variations and magnetic activity represented either by the area or number of sunspots. Comparison of the SOHO/MDI sunspot and faculae area and intensity data were also compared to the results derived from the PSPT images taken at the Rome Solar Observatory's Solar Physics Group. During the last year, further collaboration has been developed with scientists at the National Solar Observatory at Kitt Peak using the new SOLIS data to analyze solar magnetic activity. In addition, the work described above is part of a three-year effort financed by the International Space Science Institute in Bern, Switzerland.

As part of the same study the so-called Photometric Sunspot Index (PSI) from the MDI images was compared with the currently used PSI indices. The results, published in the Conference Proceedings of the 35th COSPAR General Assembly (Adv. Space Research), show that the MDI sunspot areas are systematically larger than the published PSI indices, which factor has to be taken into account in further irradiance models. Comparison of the MDI faculae areas with UV irradiance data, as represented with the Mg II core-to-wing ratio, shows that the chromospheric UV irradiance has a good correlation with the facular magnetic fields. This result, on one hand, confirms that the classification of faculae is properly performed. On the other hand, it indicates that the UV irradiance variations are mainly governed by the changes in the magnetic fields, whereas the origin of total irradiance variations is governed by more complex mechanisms.

During the last year the GEST investigator continued to study the debated question: whether total irradiance was higher during the minimum of cycle 21 than during the minimum of cycle 22. It has been found that the "declining trend" in the ERBS total irradiance during solar minimum is related to the effect of sunspots. The relationship between various total irradiance data was studied in detail and a new factor adjusting the ACRIM I data to the ACRIM II level was calculated. For this purpose Pap developed a new method based on time series decomposition techniques, while one of the most used composite to so-called PMOD composite includes empirical models when compiling the composite. Results show that total irradiance may indeed be somewhat higher during the minimum of cycle 22 than during cycle 21, however the difference is within the current measurement accuracy. The differences found between the minimum level of total irradaince and other solar indices used in modeling should be further investigated.

During the last year the investigator still spent a considerable time marketing AGU Monograph 141, "Solar Variability and its Effect on Climate," edited by Judit Pap and Peter Fox, published in 2004. This activity included writing an article for AGU Newsletter EOS about the book and in general about climate change as well as to review summaries that appeared about the book in various journals, the most prominent one being *Solar Physics*. In addition to marketing this Monograph, Pap was heavily involved in programmatic tasks. In particular, she completed part of the senior science review of the ACRIMSAT satellite for NASA. She spent considerable time to develop joint science plan between the SDO/HMI and the French PICARD experiment. In this process, she worked together with the HMI PI (Phil Scherrer, Stanford University) and the PICARD PI (Gerard Thuillier, CNRS), as well as with the SDO project scientist at GSFC (Dean Pesnell).

An additional accomplishment by the investigator in 2005 was to organize, as co-

convener, the "Solar Variability and Earth's Climate" workshop held in Rome, Italy, June 26 – July 3, 2005. Pap provided assistance in editing the conference publication as well. She also was a co-convener of a special session on irradiance variations during the AGU 2005 Fall meeting, where she gave an invited lecture on irradiance variations and differences between solar indices used for modeling. The investigator continued to lead Working Group 1 of The 4 "Space Climatology" of the SCOSTEP "Climate and Space Weather of the Sun-Earth System" (CAWSES) program. She worked with the SCOSTEP Bureau as one of the US National Disciplinary Scientists on solar-terrestrial physics. Pap is also a member of an international research group, "Solar Magnetism and Irradiance Variations," which is a three-year effort within the International Space Science Institute, Bern, Switzerland. The investigator is also part of an NSF funded US-Slovakian program to study solar variability, flares and CMEs.

Objectives for the Coming Year

The key objective for the coming year is to continue the intercomparison of various total solar irradiance data sets, including the SORCE/TIM total irradiance and SORCE/SIM spectral irradiance data starting in 2003 and improving the currently available composite. As part of this research, Pap will compare the SOHO/VIRGO and ACRIMSAT total irradiance. The "SORCE" irradiance data will be part of this study as soon as the data become publicly available..This work is a collaborative effort with Dr. Claus Frohlich, VIRGO PI and Dr. R.C. Willson, ACRIMSAT PI.

An additional goal is to study solar EUV irradiance variability, with emphasize on the rapid variations related to solar flares. A new aspect of this work is to study the relation between the evolution of active regions, solar flares and CMEs as well as work toward physical modeling (3-D MHD modeling) of active regions.

The investigator was offered a position as a consultant for the Heliophysical Observatory of the Hungarian Academy of Science and to collaborate with scientists of the San Fernando Observatory, California State University at Northridge. Both observatories have an extended database of sunspot areas and their position. A new collaborative effort started with the National Solar Observatory at Kitt Peak to use the SOLIS magnetic field data and photometric observations. The main goal of these studies is to examine the structure, evolution and magnetic configuration of sunspots and based on these statistics to develop a method to predict solar flares and their effect on the Earth's atmosphere. In addition to the MDI and SOLIS data, the PSPT data produced in Rome will also be used. A major part of this work is to publish existing results, and to study major activity outbursts during solar cycle 23, re-examining all major activity outbursts back to 1978 when both total and UV irradiance observations started from space. As part of the research, we will also add X-Ray and energetic particle data to the analysis. This effort is a collaborative effort between Judit Pap, Claus Frohlich and Richard Willson (VIRGO and ACRIMSAT PI-s, respectively), Don McMullin (EUV irradiance, Praxis/NRL) and various GSFC scientists working on CMEs and solar wind. This project is also an important part of the forthcoming Solar Dynamics Observatory's two experiments, providing results and analysis tools.

An additional goal is to develop a detailed joint plan for active collaborative research between the HMI experiment on SDO and the French PICARD experiment. For this purpose, the investigator will host and work together at GSFC/GEST with Dr. Sabatino Sofia of Yale University for modeling the solar interior, and with the PICARD science team to develop and finalize plans to analyze solar irradiance and to establish the relation between total irradiance and the solar diameter.

Task 612-68-238: **Comprehensive Survey of Cusp Electrodynamics Using FAST Satellite Fields and Particle Data**

GEST Investigator: Timothy J. Stubbs

Collaborators: Robert F. Pfaff (PI, GSFC), Robert J. Strangeway (UCLA), Charles W. Carlson (UC, Berkeley), James P. McFadden (UC, Berkeley)

Abstract

Timothy Stubbs joined GEST on December 16, 2005 to undertake a study of the Earth's magnetospheric cusps using data from the FAST spacecraft. The statistical analysis of this high-quality data set will resolve some of the outstanding questions about the large-scale electrodynamics of the cusp and dayside regions. This is critical for understanding the transport of mass and momentum from the solar wind the Earth's magnetosphere. He will also analyze multipoint Cluster observations of the cusp, which should demonstrate how it is a dynamic structure on various spatial scales, and reveal important information about reconnection processes coupling the solar wind to the magnetosphere. In addition, Stubbs will study lunar dust transport and surface charging in collaboration with colleagues at NASA/GSFC and UC Berkeley. This will have important implications for future robotic and human exploration of the Moon.

Description of Research

The goal for the FAST cusp study is to extract information from over 10 years of FAST data about ion and electron precipitation into, and outflow from, the cusp and dayside ionosphere. This is the first attempt to create such a comprehensive study and will reveal how seasonal effects and solar wind conditions control coupling between the solar wind and magnetosphere. The aim for the multipoint Cluster studies is to show how the cusp is a dynamic structure on various spatial scales, which will likely reveal how fluctuations in the latitude of the open/closed field line boundary are caused by pulsing in the reconnection rate (*i.e.*, coupling efficiency between the solar wind and magnetosphere). The objective for my electrostatic lunar dust transport work is to complete predictions for lunar surface charging under various conditions, including during extreme space weather events, such as coronal mass ejections. Stubbs also intends to produce models that can predict the dust concentrations above the lunar surface.

Accomplishments during the Reporting Period

Stubbs is establishing a computer system that will analyze and automatically transfer FAST ion and electron data from UC Berkeley. He has also begun the integration of standard IDL FAST data analysis routines with his occurrence frequency analysis code. In his lunar research, the GEST investigator has developed the first iteration of a model to predict dust concentration above the lunar surface. This model combines the empirical models based on observations during the Apollo era with dynamic dust fountain model [Stubbs *et al.*, 2006]. He has also made progress toward publishing predictions of lunar surface charging under normal and extreme conditions. An article describing his lunar research will be soon be published in the Smithsonian *Air & Space* magazine.

Objectives for the Coming Year

The objectives for the FAST cusp study are to have completed the first analysis of the data in the next year, which will allow the production of occurrence frequency distributions of ion and electron fluxes sorted by pitch angle, energy, season, hemisphere, altitude and solar wind conditions. From this wealth of new information researchers should be able to select the most important results for publication, as well as to guide future analyses and integration with data from other FAST instruments. With the Cluster analysis completed, a case study of the traversal of the northern cusp by the Cluster spacecraft on August 25, 2001 will be submitted for publication. Stubbs also hopes to facilitate in the completion of other Cluster studies with

collaborators at NASA/GSFC. He intends to publish his predictions of lunar surface charging under normal and extreme conditions, as well as his semi-empirical predictions of dust concentrations in the lunar exosphere.

Task 612-65-223 **Studies of the Mesosphere, Ionosphere and Plasmasphere**

GEST Investigator: Phillip A. Webb

Collaborators: Richard. A. Goldberg (PI, GSFC), Robert F. Benson (GSFC), Joseph M. Grebowsky (GSFC)

Abstract

In the past year work has been undertaken in four different research areas. The simulations of meteoric impacts on the atmosphere of Venus have been undertaken showing the formation of metallic layers (Na^+ and Mg^+) around 120 km altitude. An analysis of data collected by the DROPPS (Distribution and Role of Particles in the Polar Summer Mesosphere) sounding rocket campaign has been used to show that ice particles in polar mesospheric summer echoes (PMSEs) have sizes of the order of a few nanometers. A technique to fit the ionospheric electron density (Ne) topside profiles obtained from satellite topside sounders has been successfully developed, allowing the O^+/H^+ transition altitude and electron/ion temperatures to be extracted. Finally, the automatic fitting technique to determine plasmaspheric Ne from the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) Radio Plasma Imager (RPI) dynamic spectra has been refined, and the formation of a database for release to the scientific community is in preparation.

Description of Research

This research concerns four four different areas: (1) the study of meteoric impact and ablation processes on an atmosphere to determine the composition and altitude distribution of the resulting neutral and ion constituents; (2) the study of the formation of nanometer-sized ice particles seeded by atmospheric meteoric particles whose presence are believed to be responsible for polar mesospheric summer echoes (PMSEs) in the Earth's atmosphere; (3) the analysis of electron density (Ne) profiles in the Earth's topside ionosphere obtained from satellite sounders to extract composition and temperature information; (4) the development of an automatic fitting technique to extract Ne from dynamic spectra collected by the IMAGE satellite's RPI instrument.

Accomplishments During the Reporting Period

The first research topic has been to study meteoric impact and ablation processes on an atmosphere to determine the composition and altitude distribution of the resulting neutral and ion constituents. During the past year these meteoric studies have been undertaken for the atmosphere of Venus. It has been found that the main metallic ion species of Na^+ and Mg^+ form layers around 120 km altitude, which corresponds to the bottomside of the Venus' ionosphere. However, the modeled Mg^+ peak altitude (< 120 km) was lower than any total electron density peak observed by spacecraft radio occultation measurements at Venus. A further analysis has now shown that the metal species Fe has its counterpart ion layer above 120 km in a region where there are sometimes traces of electron density enhancements.

The second topic was the investigation of data collected by the DROPPS (Distribution and Role of Particles in the Polar Summer Mesosphere) rocket program. Two rockets were launched during early July 1999 from Andoya Rocket Range (ARR), Norway. The purpose was to investigate the polar summer mesosphere, particularly polar mesospheric summer echoes (PMSE). Both DROPPS payloads included front mounted side by side Particle Impact Detector (PID) charge and mass telescopes. Computer simulations have shown that the PID telescopes have the potential to detect atmospheric ice particles within the mesosphere having dimensions of a few nanometers. Ice particles of nanometer size are believed to be responsible for

PMSEs that were observed at an altitude of ~82-87 km over Andoya during the first DROPPS launch sequence. By comparing PID observations with the computer simulations we can obtain information concerning the properties of the PMSE particles, including their "rocky" core size, ice mantle thickness and distribution. We have obtained results from an analysis of the two detectors on the first flight that suggested particles with radii of approximately two nanometers were present in the PMSE layer.

The third topic involved determining the mid-latitude O^+/H^+ transition altitude (where the H^+ and O^+ number densities are equal) from ionospheric topside ionograms by fitting Ne profiles to analytical H^+ and O^+ functions [*e.g.*, Webb *et al.*, 2005]. This mid-latitude transition altitude is of importance because it is where the topside altitude distribution of the dominant ions transitions from the main ionosphere into the plasmasphere, where H^+ is the dominant ion and magnetospheric-ionospheric interaction processes are important. A technique has been developed to allow this fitting to be undertaken and this technique has been applied to ISIS satellite topside ionograms covering a variety of local times, latitudes, and solar-storm conditions.

The final topic has been to develop an automated fitting technique to extract Ne from dynamic spectra obtained from the RPI on the IMAGE satellite [*e.g.*, Benson *et al.*, 2004]. This technique is often able to provide *in-situ* Ne measurements along extended portions of the orbit of IMAGE. The technique has been developed and implemented in a computer program, which also allows the user to manual correct any points fitted by the automatic technique. The fitting technique has been thoroughly tested and work has now started on assembling a database of the past five years of IMAGE RPI observations, with the aim to make these data available to the scientific community in the middle of 2006.

Objectives for the Coming Year

The major component of the coming year's research will be a new project working on magnetometer observations from NASA ST-5 satellite constellation and similar magnetometer observations from the ESA/NASA Cluster satellite constellation. Magnetometers measure variations in the local magnetic field, allowing information about ionospheric and magnetospheric currents to be derived. The other major aim of the coming year is to complete work on the projects that have been undertaken in the past year and to publish the results in refereed journals. If a pending NASA proposal to the New Investigator Program is successful, then further work will be undertaken on analyzing the dynamic spectra fitting technique and applying it to similar data sets collected from other satellite missions.

Information Science and Educational Technology Research Group

GEST-produced educational products help students learn that the Sun's dynamic nature affects our life on Earth. (Graphic courtesy of Susan Hoban.)

William Ruesing, a middle school teacher from Westminster, Maryland, describes how he will use material from Dr. Hoban's "Fundamentals of Lunar Exploration" in his classroom.(Photo courtesy of Susan Hoban.)

Information Science and Educational Technology Research Group

With the advent of digital detectors and the subsequent application of large format and hyperspectral imaging in Earth and space science, the skyrocketing need for computing power and intelligent data analysis and archiving has become of paramount interest to NASA. At the GEST Center, the end-to-end data collection, assimilation and analysis process is studied from the computer and information science perspective. The application of emerging technologies for the benefit of education is also an important component of the Information Science & Educational Technology (IS&ET) Faculty Group.

These activities also contribute to the US and International 10-year GEOSS (Global Earth Observing System of Systems) implementation plan adopted at the third Earth Observation Summit in February 2005 in Brussels, Belgium. To aid this international effort, the U.S. national Science and Technology Council's Interagency Working Group on Observations (IWGEO) has prepared a strategic plan as a first step toward the development and implementation of the US Integrated Observing System (IEOS). The U.S. plan mirrors the international GEOSS by focusing on nine societal benefit areas, and an end-to-end integrated systems approach.

Many image processing and analysis routines are computationally intensive and lend themselves to parallel processing. GEST scientists are developing and improving software for high-performance, parallel computer architectures. One GEST research activity in the parallel computing area is designed to give a user an easy route to add paraellel capability to an already existing structured mesh application. IS & ET faculty are also working on new approaches to parallel programming, which are needed for machines with tens or hundreds of thousands of processors, expected to be available by the end of the decade.

Ultimately, the information and knowledge from NASA's Earth and space science missions are to be communicated to scientists, educators, learners, the general public and makers of science policy. GEST faculty contribute policy-level scientific planning and technological guidance to NASA HQ's Science missions in the area Earth system science. GEST faculty also work to provide effective multimedia materials for the communication of NASA science concepts to scientists, educators, students and the pulic at large. It is now well established that a critical national need exists to address the issue of flagging performance of our nation's students in science and mathematics. Decreasing numbers of students in the U.S. are embarking upon careers in science, technology, engineering, and mathematics (STEM)—a trend that contributes to our national shortage of well-trained scientists, engineers, and computer scientists. This problem is of paramount interest to NASA. GEST researchers investigate the effectiveness of information technologies in addressing these issues of national importance and apply the results to the professional development of STEM educators.

Susan Hoban

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Grant **Earth+: Dynamic NASA Earth Science Exploration For Blind Learners**

GEST Investigators: Susan Hoban, Daniel Laughlin, Laurie Cook

Collaborators: Robert Shelton (NASA JSC), Nicolas Linares (Univ. of Puerto Rico)

Abstract

The goal of Earth+ is to advance science and math education for blind students by developing a map sonification capability to be used as a mission-planning tool. This tool will be integrated in existing standards-based, science and math activities currently used with sighted students. An Earth+ model lesson will be developed for an "extreme Earth science" scenario requiring decision-making based on remote sensing. Test audiences have been identified through the National Federation of the Blind and the Maryland School for the Blind. GEST researchers will integrate the Map Sonification Tool into an educational module and develop an evaluation plan.

Description of Research

Spatial thinking is an essential part of intelligence and very conspicuous in the subject of science. Analysis and interpretation of scientific data are frequently approached through visual representation, even at the simplest level, such as interpreting graphs and images. An additional modality for the interpretation of spatial data may involve the use of sound queues, thus suggesting an alternative approach for teaching science to blind learners. A tool for using sound to explore mathematical representations, MathTrax [http://prime.jsc.nasa.gov/mathtrax/] has been developed by Shelton *et al.* at the NASA Johnson Space Center (JSC). GEST researchers are currently working with Shelton's team to build on the foundation of MathTrax to develop a tool to facilitate the exploration of two-dimensional image data. The tool will be applied to an educational setting to teach concepts in Earth science to visually impaired learners.

Accomplishments during the Reporting Period

Hoban and Laughlin were co-investigators on the *Rapid Prototyping of Sonification Schemes to Inform the Development of Tool to Make NASA Images Accessible to Blind Students* proposal funded by GSFC Director's Discretionary Fund. The project succeeded in creating a proof-of-concept sonified image in the summer of 2005 and has a paper submitted to the International Community of Auditory Display (ICAD 2006) conference. Hoban and Laughlin successfully proposed with the Johnson Space Center and the University of Puerto Rico for *EARTH+: Dynamic NASA Earth Science Exploration For Blind Learners.* This NASA Science Mission Directorate-funded project was selected for three years of funding. The grant funding for this project arrived in the final quarter of the reporting period. An Instructional Designer was hired to assist the team with the development and evaluation of the model lesson. The GEST Team met with the NASA JSC team in January to develop a schedule for this first project year. Hoban *et al.* (2006) describes the prototype and the experimental set-up.

Objectives for the Coming Year

The first model lesson will be completed. Images of cold water trails formed by hurricanes will be used in a lesson where the student must predict the likely area of landfall of a hurricane. Students at the Maryland School for the Blind will participate in an evaluation of the first build of the map sonification tool. Student attitudes towards science as well as learning gains will be tested. Feedback from this implementation will inform further development of the tool.

Task 930-03-068: **Science Information Systems**

GEST Investigators: Susan Hoban

Collaborators: Nand Lal (GSFC)

Abstract
Work under this task includes participation in NASA's Applied Information Systems Research Program on issues relating to information science and educational technology for NASA's science missions. Activities include research and development in advanced technologies for NASA missions and science research programs. The GEST investigator also advised a master's degree student in the Computer Science and Electrical Engineering Department at UMBC who graduated in May 2005.

Description of Research
With the data deluge produced by the advent of digital detectors and the increasing computing power available to scientists on their desktops and in centralized computing centers, there is a growing need for efficient and effective software tools to facilitate analysis, interpretation, and management of science data. This task seeks to study and support the development of such tools, particularly as they pertain to NASA's missions and scientific research programs. Of particular interest is the concept of a Virtual Observatory and related technologies, such as the Semantic Web and Fault-Tolerant Computing.

Accomplishments during the Reporting Period
The GEST investigator organized the annual Principal Investigator's Meeting at NASA Ames Research Center, held April 4 – 6, 2005.

The GEST investigator organized and served as a panel chair and reviewer for the Applied Information Systems Research program proposal review panel, held in Greenbelt, MD, October 18 - 20, 2005.

The GEST investigator continues collaboration on a redesign of the content management system for the Applied Information Systems Research program, and is working with colleagues at Ames on the infusion plan for the AISRP Code Repository.

The investigator also served on the master's degree committee of Mr. Somesh Kumar in the Computer Science and Electrical Engineering Department at UMBC. Mr. Kumar graduated in May 2005.

Objectives for the Coming Year
A workshop for investigators of the Applied Information Systems Research Program will be organized, and participation in the annual panel review will take place. A redesign of the content management system for AISRP will continue. The AISRP Code Repository will be made public at the Spring AGU meeting and promoted at the summer AAS meeting.

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

GEST Investigators: Susan Hoban

Collaborators: Ed Grayzeck (GSFC)

Abstract
Work under this task includes participation in NASA's Planetary Data System on issues relating to information science and educational technology for using data from NASA's planetary missions to advance education in science, technology, engineering and mathematics. The GEST investigator is working

with the Goddard collaborator to design a educational program that will encourage college and graduate students to pursue Planetary Science through the use of data from NASA's planetary missions.

Description of Research

NASA's Planetary Data System is the ultimate repository for all data from NASA's planetary science missions. The GEST investigator is working with the Goddard collaborator to design a College Student Investigator program. This program will support student interns at Planetary Data System nodes to design and conduct research projects based on data from NASA's planetary missions.

Accomplishments during the Reporting Period

The funding for this project came through late in the reporting period. The GEST investigator has begun a draft plan for the Planetary Data System (PDS) College Student Investigator (CSI) program. The first draft was presented at the PDS Management Council meeting at Washington University, St. Louis, MO, in October 2005.

Objectives for the Coming Year

The GEST investigator will continue developing the PDS College Student Investigator plan. The GEST investigator will represent the Planetary Data System at various NASA Education and Public Outreach forums as well as non-NASA sponsored conferences and workshops.

Task **Variability in the UV Spectrum of 3C 279: Testing Models for the Gamma-Ray Emission in Blazars**

GEST Investigator: Anuradha Koratkar

Collaborators: Eric Perlman (JCA/UMBC), Ian Evans (SAO)

Abstract

Gamma-ray emission dominates the power output of many luminous blazars, yet we do not know the physical scale on which it is produced, *i.e.,* where in the jet most of the kinetic power is dissipated. We know the production of Gamma-rays depends critically on the blazar line emission: ambient photons from broad emission lines (primarily LyAlpha) are upscattered to Gamma-ray energies by relativistic electrons in the blazar jet. Rapid large-amplitude Gamma-ray variability implies that both electrons and LyAlpha photons must vary rapidly. This suggests some broad-line clouds are photoionized by synchrotron flares in the jet (the "mirror model"). We proposed a critical test to determine if Gamma- rays are produced on the scale of the broad line region, using multi-epoch STIS UV snapshots of 3C 279 to find and characterize its LyAlpha variability. This will validate the mirror model for generating the intense Gamma-ray emission from blazars, which could then be quantified with the much more resource intensive coordinated Gamma-ray and HST observations. 3C 279 is the best-studied blazar from radio to Gamma-ray wavelengths, showing frequent large flares over days to months. Variability in the UV continuum and LyAlpha will directly reveal any coupling between the jet ionizing flux and the broad-line region emission, providing clues to the physics and energetics of all radio-loud AGN.

Description of Research

Blazars are the most luminous and violently variable active galactic nuclei (AGN), varying on time scales of hours to days (Ulrich *et al.* 1997). Their broadband emission originates in a relativistic jet, which converts a small fraction of its kinetic energy into radiation while transporting the remainder to extended radio lobes. Unified models classify blazars as typical radio-loud objects whose jets are directed into our line of sight and thus brightened by relativistic beaming (*e.g.*, Urry & Padovani 1995). For this reason, studying blazars advances our understanding the physics of all radio-loud AGN.

Accomplishments during the Reporting Period

Most of the energy radiated by the accretion disk around a supermassive ($10^6 - 10^9$ solar masses)

black hole—the phenomenon that drives active galactic nuclei – comes out in the ultraviolet. The prevailing, thermal disk models predict that these emissions originate within 50 gravitational radii (RG) from the black hole. To date, the only observational test of this prediction has come from observations of a single gravitational lens system. Our observations of 3C 279 show that most of its ultraviolet emission comes from a region 23 AU (23 RG for an assumed 10^8 solar mass black hole) in size. This comes from observations of an eclipse of the accretion disk by a passing cloud, which lasted only ~1 month.

Objectives for the Coming Year

The project is completed and the research is being written up for submission to a journal.

Task 130-05-085: **Learning Technologies**

GEST Investigators: Susan Hoban, Anuradha Koratkar, Daniel Laughlin, Marci Delaney

Collaborators: Robert Gabrys (PI, GSFC), Horace Mitchell (GSFC),Wade Sisler (GSFC), Shane Keating (GST), Shirly Zongker (UMBC), Willard Smith (Tennessee State Univ.)

Abstract

The IS&ET Learning Technologies team collaborates with NASA Education to coordinate the NASA Learning Technologies Project. NASA Education tasked this team to lead research on the educational uses of computer and video games. The team coordinates the NASA Exploring Space Challenges. *NESNews*, a monthly newsletter for for NASA Explorer Schools, is produced by this team.. The group coordinates acquisition, installation and operation of the Goddard Space Flight Center node of NASA's Digital Learning Network. The team broadened its educational technology research this year to include the effectiveness of learning technologies in science, technology, engineering and mathematics (STEM) teacher education.

Description of Research

The Learning Technologies Project (LTP) is NASA's educational technology research and development incubator. LTP supports activities that deliver NASA content through revolutionary technologies to enhance education in the areas of science, technology, engineering and mathematics. Hoban and Laughlin coordinate LTP research and development activities with NASA Education. Laughlin leads the research initiative on the educational uses of computer and video games. Hoban, Laughlin and Gayol began development of an educational product technical evaluation tool. The team also began research to support the development of an e-Education strategic roadmap for NASA.

The NASA Explorer Schools (NES) Program seeks to advance the agency's goal to inspire the next generation of explorers and to motivate students to pursue STEM careers. GEST investigators participate in three prominent NES activities: the monthly NES newsletter, NASA Exploring Space Challenges, and the Digital Learning Network. *NES News* is a monthly electronic newsletter distributed to the NES teachers, administrators, students, and their families. Laughlin edits and Delaney develops the content and layout for this publication. The *NASA Exploring Space Challenges* are a suite of academic competitions rooted in science, mathematics and the language arts at the middle school level. Delaney coordinates this project. NASA's Digital Learning Network (DLN) is a video conferencing and web casting system dedicated to educational use. Hoban and Laughlin coordinate the Goddard node of the DLN.

The Fundamentals of Lunar Exploration, Extended (FLEX) project is a follow-on to the pilot by the same name funded by NASA Exploration System Mission Directorate. FLEX is a series of professional development opportunities for STEM educators. These courses are offered in the traditional face-to-face mode, a blended model (partially face-to-face and partially online), and as a distance learning

product using a combination of webcasting and videoconferencing. The courses are offered for credit through various institutions, including UMBC, Maryland State Department of Education and Oklahoma State University. A unique twist to this activity is the inclusion of undergraduate STEM majors from minority universities who spend time at a NASA Center and then serve as Teaching Assistants for the courses.

Accomplishments during the Reporting Period
A draft technical paper on the educational uses of computer and video games was submitted to NASA Headquarters.

The *NES News* continued to be distributed online to the NES schools and to the general public through NASA's Educator Resource Center Network and NASA's Central Operation of Resources for Educators. *NES News* has been in circulation for three years. In 2005, *NES News* was transferred to the NASA Portal and was certified as being accessible to the visually impaired. The final issue of *NES News* was published in January 2006 due to a funding cut [http://learners.gsfc.nasa.gov/NESNews].

The success of the *NES Challenge* in FY05 led to the development of a suite of math, science and language arts competitions called the *NASA Exploring Space Challenges (NASA ESC)*. The first two competitions were *Mission: Moon Math* and *Mission: Fuel Your Imagination! Moon Math* is an activity with multi-media curricular support for math and science content. The four video segments with Delaney as host and content guidance for teachers developed by Hoban were served from the *NASA ESC* website. The model is being picked up across NASA and, in 2006, a national *Moon Math* event will occur via the DLN. The *Fuel Your Imagination! Challenge* is a writing activity for grades 3-8 to incorporate real science, math or engineering facts into a science fiction story. Curricular support materials were created by Houghton Mifflin and NASA personnel [http://son.gsfc.nasa.gov/nes/challenges].

Hoban successfully proposed with Gabrys (GSFC), Zongker (UMBC) and Smith (Tennessee State University) to NASA Exploration Systems Mission Directorate for "Fundamentals of Lunar Exploration," a three-credit STEM teacher education course that was offered in Summer 2005. The course was over-subscribed by a factor of two. Four students from Tennessee State University spent the summer at Goddard and served as Teaching Assistants for the course. Based on this successful implementation, the team proposed again and was selected for "Fundamentals of Lunar Exploration, Extended (FLEX)" to develop a suite of course offerings focused on lunar exploration. FLEX is a two-year project.

Objectives for the Coming Year
Research on educational games will continue, including the publishing of a paper in the NASA Technical Report series.. The NASA Exploring Space Challenges will continue. FLEX will offer at least four courses to STEM educators using varying delivery modes. Team members will each collaborate on at least one new funding proposal.

Task 130-67-234: **Advanced Multimedia/Information Technologies**

GEST Investigators: Stefanie Misztal, Silvia Stoyanova

Collaborators: Wade Sisler (GSFC)

Abstract
The NASA Goddard Space Flight Center uses resource tapes to provide outside media producers with NASA-produced animations, data-visualizations, and footage. Compilations of large amounts of video clips, these tapes allow media agencies easy access to a wealth of NASA information that might not otherwise make its way into news shows, websites, and independent documentaries. The chief objective

of the media specialist position is to act as a liaison between NASA scientists and the general public. The goal is to produce video and web-based products that communicate scientific research in ways that are both entertaining and educational, leaving the audience with a greater awareness of ongoing NASA science missions.

Description of Research

Various multimedia products are under development to communicate NASA science to scientists, educators, students and the general public.

Accomplishments during the Reporting Period

Major media production accomplishments for this past year include a climate change resource tape, a video file and companion web story for the upcoming Sun-Earth Day events, and an educational documentary for young people about the sun. All of these products have been designed so the public will have easy access to NASA science through various technological venues including, but not limited to: news programs, independently produced documentaries, and web-based activities.

In the final stages of editing, a climate change resource tape will soon be released for public access. Amassing nearly six years of information, this video showcases the best of Goddard-produced climate change graphics. Everything from shrinking ice caps to melting glaciers to climate change models can be found in one place. Produced in conjunction with ongoing data collection and research, these graphics help communicate the work of both satellites and scientists to the greater public. In addition, a companion web page that lists a sampling of graphics available on the tape has been made available [http://www.nasa.gov/centers/goddard/earthandsun/climate_change.html].

Another venue for press coverage of NASA events, video files provide visual aids for press releases of current research and upcoming missions. While resource tapes act as a convenient archive of the best video releases of the recent past, video files provide supporting media for press releases on the actual day of an event.

In celebration of 2006's Sun-Earth Day, NASA broadcasted a live telescope feed of the March 29th eclipse from Side, Turkey. To provide supporting visual material for this event, a video file was produced and released for media use the week before the event. A companion web page was also designed that included a link to the eclipse webcast, NASA photography of prior eclipses, and a schedule of important events for the upcoming eclipse. It was released the week before the events so interested parties could plan which available resources they wanted to tap into on March 29th. The video file for Sun-Earth Day focuses on the eclipse as well as the importance of the sun-earth connection. It includes an animation of the path of the total and partial eclipse, time-lapse footage of past eclipses, data-visualizations of the solar corona from the SOHO satellite, and animations of the upcoming ST-5 and STEREO missions. In addition, an educational documentary about the sun is included for educators who may wish to share this material with their classes.

A video entitled "Sun For Kids" was produced that documents an astronomy class at Maryland's Parkland Magnet Middle School. By using sunspotters to safely look at the solar surface, these students study the sun's 11-year cycle. From violent solar storms to earth's protective magnetosphere, they learn how the sun's dynamic nature affects all of us here on earth. Produced and directed by Silvia Stoyonova, this product required the collaboration of a number of media producers, including Stefanie Misztal, Fred Kemman, and David Stroud. An educational outreach tool, the video was designed to inspire children and young adults to see science in both a practical and entertaining way, and to even possibly consider it as a future career [http://www.nasa.gov/vision/universe/solarsystem/sun_for_kids_main.html].

Objectives for the Coming Year

One of the main goals of the multimedia/information technologies group will be to continue furthering public awareness of

NASA scientific research. Proven tools such as video files and companion web stories will continue to be a major asset to the public affairs office, and will be produced as new stories arise. In addition, new formats for public access to this information are being explored including possible podcasting of videos such as the "Sun For Kids" documentary. Also, Goddard is just beginning to implement Viewspace, a new, magazine-style, visual presentation that can be projected in museums. These packages can be updated regularly from the web with new images and information as they arise. With a plethora of visual tools such as these, avenues for reaching the interested public should remain increasingly open.

Task 930-12-115: **PARAMESH**

GEST Investigator: Kevin Olson

Collaborators: Daniel Spicer (PI, GSFC)

Abstract

The research conducted in the past year by Kevin Olson has been focused on developing and improving software for high-performance, parallel computer architectures. Specifically, this work has focused on maintaining and improving a software package known as PARAMESH. PARAMESH is a software package designed to give a user an easy route to parallelizing an already existing structured mesh application. Also, work has focused on applying PARAMESH to several specific applications. PARAMESH has been successfully employed by a group at the University of Chicago for astrophysical applications known as the FLASH code. FLASH is currently seeing wide application within the astrophysical community. At the Goddard Space Flight Center, a group lead by Dr. Joan Centrella is using PARAMESH for their work of developing large scale computer codes to simulate the propagation of gravitational waves resulting from violent events in the Universe. This work is now being funded by the NASA/AISR project.

Description of Research

Use of large parallel computer architectures for scientific simulation purposes is not a straight forward exercise and requires a great deal of expertise in order to write software which uses these machines in an efficient manner. The GEST investigator's work during the past years has focused on this task. This work has been to further develop and extend a software package known as PARAMESH. PARAMESH is a package designed to give an application developer a method of parallelizing code using a logically cartesian mesh for a researcher who already has in-hand existing, serial code. Further, the package provides a user with a dynamic, adaptive mesh refinement capability. PARAMESH handles all interprocess communication and load balancing automatically, while providing the user with a logical, and simple interface through callable Fortran 90 subroutines. PARAMESH is currently being used for various applications in the Earth and Space Sciences. These include applications ranging from the simulation of marine clouds, the Earth's magnetosphere, Solar coronal events, Astrophysical X-ray bursts, Type I Supernovae, Gamma-ray bursts, Galaxy Cluster Collisions, and Gravitational Waves.

Accomplishments during the Reporting Period

During the past year PARAMESH has been extended and improved in several areas. One of the areas where PARAMESH lacked performance was in its I/O and checkpointing facilities. What was available in PARAMESH, while functional, did not provide a portable data format nor did it take advantage of the parallel I/O capabilities available on today's parallel architectures. Parallel I/O capabilities have now been added to PARAMESH using the MPIIO parallel IO functions which are part of the MPI-2 standard. Previously, PARAMESH had been extended to enable parallel IO using the HDF5 library developed at NCSA.

PARAMESH, while originally developed in Fortran, now comes with a C-interface for those

who wish to program in C. PARAMESH also now comes with support routines for multigrid algorithms.

Objectives for the Coming Year

Some of the main objectives for the upcoming year will be to attract new developers who will participate fully in writing and maintaining the PARAMESH code base. It is hoped that this will greatly speed the development of PARAMESH, facilitate finding and fixing of bugs in PARAMESH, and result in a better product. One of the specific goals for the upcoming year is to make sure that the latest version of Paramesh is incorporated and works well with the latest version of the FLASH astrophysics code [http://www.flash.uchicago.edu]. This work is currently underway and good progress is being made. Finally, work will continue to support one of the main users of PARAMESH, the group lead by Dr. Joan Centella (GSFC). This code is an important test bed to help improve the overall performance of PARAMESH. Kevin Olson has now moved to Drexel University, so this work will no longer be performed as a GEST activity.

Task 902-00-006: **Policy-Level Science/Technology Support to NASA/HQ and the U.S. Climate Change Science Program (CCSP)**

GEST Investigator: Sushel Unninayar

Collaborators: Lola Olsen (PI, GSFC)

Abstract

This task provides policy-level scientific planning and technological guidance to support NASA HQ's Science missions and vision on interagency (U.S.) and international programs and projects dealing with all aspects/themes of the U.S. Climate Change Science Program (CCSP, which incorporates the U.S. Global Change Research Program [USGCRP] and the President's initiative on Climate Change Research [CCRI]); the World Climate Research Program (WCRP); the International Geosphere-Biosphere Program (IGBP); the Integrated Global Observing Strategy (IGOS); and the recently initiated International Group on Earth Observations following the Earth Summit on developing a plan for the creation of a Global Earth Observation System of Systems (GEOSS); the Global Climate Observing System (GCOS); the international WCRP Global Energy and Water Cycle Experiment (GEWEX); the new Global Observing Systems' initiative of the World Meteorological Organization (WMO/GOS); NASA/ESE's and GCRP/CCRI's cross-cutting climate modeling, observing systems, and data assimilation initiatives; follow-up on the environmental themes of the UN Committee on the Peaceful Uses of Outer Space Scientific and Technical Subcommittee (UN-COPUOS/STSC); interfaces with the UN Framework Convention on Climate Change (UNFCCC); interfaces with the science assessments of the Intergovernmental Panel on Climate Change (IPCC); and interactions with the boards, committees, and panels of the National Academies of Sciences (NAS), the National Research Council (NRC), and others.

Description of Research

NASA Headquarters assigned this task to GEST through the Global Change Data Center (GCDC) in GSFC's Earth Science Directorate (Code 600). 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), Sub-Committee on Global Change Research. The task also supports NASA HQ in a variety of other NASA internal, interagency, and international programs, such as the NASA Energy and Water Cycle Science program (NEWS); 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 IGOS, and now the Earth Observing System of Systems (GEOSS).

Accomplishments during the Reporting Period

Work over the reporting period involved continued and extensive interactions with the CCSP regarding the development and initial implementation phases of the long-term strategic scientific plans as directed by the OSTP and the Office of Management and Budget (OMB). A new CCSP priority implementation project for FY07 was developed for the Global Water Cycle program (GWC) jointly with the GWC Interagency Working Group (IWG). A new activity was initiated with the GWC-SSG to develop a strategic implementation plan for the next decade. Initial concepts will be further developed into a White Paper for review by the broader scientific community in FY06. New strategic mechanisms were proposed to the CCSP for the integration of activities between the GWC and the other science and applications elements of the CCSP. Other activities included: (1) Author: Policy level guidance to the interagency USGCRP/CCSP and NASA-HQ on future coordination actions required on Earth system modeling, observations/monitoring and data assimilation; (2) Principal author (with NASA-HQ: Presentation by the US delegation to the UN-COPUOS/STSC on remote sensing of the environment in January 05, Vienna, Austria; (3) Principal author (with NASA/HQ and NASA-Stennis): Taking the Pulse of the Planet (Using NASA research results for a Global Earth Observation System of Systems; (4) Principle author (with 10+ US agencies): Global water Cycle program of the US-GCRP/CCSP—Our Changing Planet—2006. The GEST investigator also wrote and reviewed sections of all other inputs to the U.S. CCSP. The GEST investigator was a member of the Review Panel established to propose the best candidates for funding under the agency-wide plans for NASA's Energy Water Cycle Study (NEWS). The GEST investigator chaired a keynote session at the International Conference on the Remote Sensing of the Environment for Sustainable Development, St. Petersburg, Russia, June 2005.

Research continued on the improvement of Earth/climate observing systems, atmosphere-land surface/vegetation/gudrology-ocean-cryosphere coupled data assimilation and prediction models, and improving the flow of data/information to decision support systems. The latter included end-to-end integrated systems approaches to enable NASA assets to deliver the necessary products for operational resource management and the strategic planning of long-term policy.

Objectives for the Coming Year

Work for the coming year will continue policy-level science/technology support to NASA's Science programs, U.S. Interagency programs, and, and other activities as developed by NASA's engagement in international programs. Follow-on research will continue support to a large swath of national and international activities and projects by developing concise plans for their implementation.

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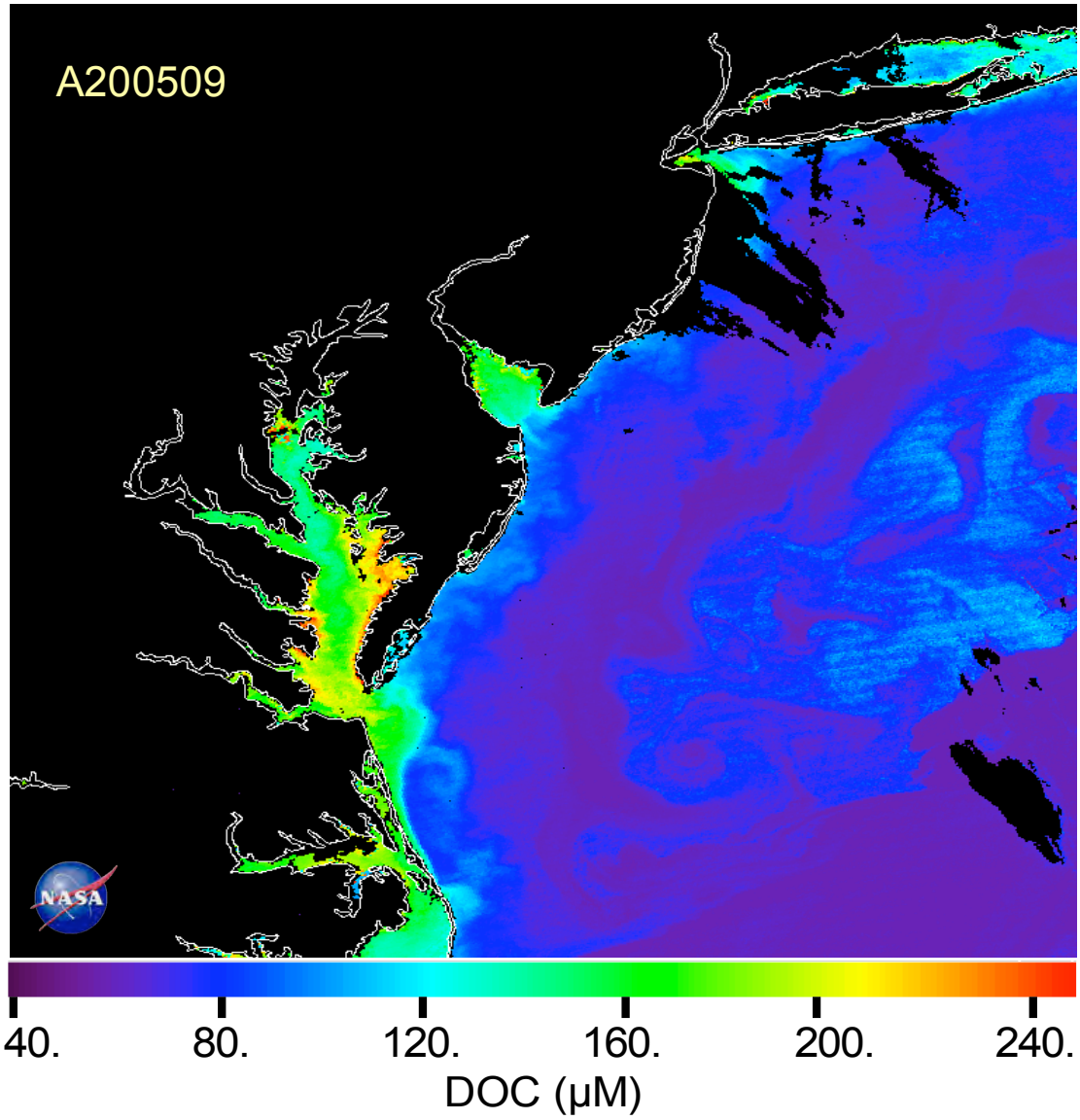
Hydrological Science Research Group



The above figure shows estimates of dissolved organic carbon (DOC) for April 5, 2005 in the Mid-Atlantic Bight based on NASA Aqua-MODIS imagery. DOC values were computed with an empirical algorithm derived from in situ data of DOC, measurements of the chromophoric dissolved organic carbon (CDOM) absorption coefficient, and apparent optical properties. The DOC algorithm uses the ratio of MODIS radiance channels at 531 nm and 551 nm. The color scale is linear from 40 (purple) to 250 (red) μM DOC. Figure provided by A. Mannino (GSFC), M. E. Russ (GEST), and S. Hooker (GSFC).

Hydrological Sciences Research Group

The GEST Hydrological Sciences Research Group integrates research into the terrestrial hydrosphere and oceans with studies of the atmosphere, geosphere, and biosphere. The group studies a wide variety of Earth surface and near-surface processes, including surface hydrology dynamics and their interactions with climate, and oceanography components and their link to climate variability. The research is conducted in the context of Earth System Science, and is performed within observational and modeling frameworks. For example, one of the largest efforts in the group is that of land surface state modeling and data assimilation. This effort merges remote sensing data of different land surface variables (such as soil moisture or snow) with corresponding outputs from land surface physical models. The integration is achieved through data assimilation methodologies and advanced computational technologies, and the final land surface representation can be used to initialize numerical models of global climate. By taking such holistic approaches, the group seeks to acquire and integrate a diverse set of remote sensing, model, and field measurements over a range of different spatiotemporal scales to enhance our understanding of physical processes and, eventually, improve our ability to predict future Earth system changes.

Research on terrestrial hydrosphere-biosphere-atmosphere interactions has continued to advance within the group. A major element of this effort is through integration of land surface models implementation at local, regional, and global scales. The heritage numerical land modeling systems, specifically the National Land Data Assimilation System (NLDAS) and its global counterpart, Global Land Data Assimilation System (GLDAS), have adopted the award-winning Land Information System (LIS) software, which has been co-developed by group members. LIS uses high-performance computing to increase modeling resolution in terms of both space and time discretization. With LIS, global land surface integrations on a spatial grid of 1 km x 1 km are now possible. The LIS framework is now widely used science investigations that focus on analyzing optimal fields of land surface states, and energy and water fluxes, as well as for the development of new modeling concepts.

Several group members are involved with the development and applications of LIS. For example, progress is being made in the use of LIS products to improve flood and drought risk analysis and forecasting for water resources management in the Columbia River basin. One project has demonstrated the advantage of estimating water and energy fluxes at relatively fine spatial resolutions. Land surface models within the LIS framework have been coupled to high-resolution atmospheric models such as the Weather Research and Forecasting (WRF) model and the Goddard Cumulus Ensemble (GCE) model. A project that is integrating the high resolution modeling of land-atmosphere ammonia exchanges into LIS is another example on-going LIS development. Also, observation-based data and products from some of the new generation of satellite instruments (*e.g.*, Aqua and Terra) continue to be examined for their utility in estimating land surface conditions. For example, two projects are concerned with assimilating observations of soil moisture and snow water equivalent from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) on the Aqua platform. Finally, LIS products are being evaluated for improving decision support tools using in water resource management. This effort aims to couple NASA products with water resources infrastructures in other U.S. agencies such as the Department of Agriculture and the Department of the Interior.

A second major theme in the Hydrological Sciences Research Group addresses the utility of state-of-the-art satellite observations from EOS and heritage satellite systems for the estimation of key hydrological variables. Progress continues to be made in developing methods to better estimate global snow mass from AMSR-E data. Much of this work has focused on defining the uncertainties associated with the estimation of these variables. Operationally, this is a very challenging task. Novel approaches in applying state-of-the-art electromagnetic models for microwave remote sensing of snow on the ground as well as falling snow are also being developed. These models will further our understanding of how remote sensing

observations can be more effectively coupled with hydrologic models of land surface processes. Finally, remote sensing technology is being used to support decision making in public health issues in the Arctic.

In ocean and near-shore studies carried out within the group, airborne lidar remote sensing continues to be used for phytoplankton biomonitoring. Another study directly supports the planned Aquarius mission, a NASA Earth System Science Pathfinder mission to estimate sea surface salinity. In particular, the study investigates errors that affect retrievals of sea surface salinity retrievals from NASA's planned Aquarius mission. Moreover, the correction of biases in TOPEX and Jason-1 altimeter data is also an important part of the group's activity, resulting in advances in understanding the role of Arctic climate in the global climate system. Another project is concerned with field experimentation that facilitates the use of MODIS imagery to derive dissolved organic carbon (DOC) and chromomorphic dissolved organic matter (CDOM) in surface waters. Our understanding of these different variables in the global energy and water cycle systems will increase with these exciting science developments derived from the current and next generation of advanced technology Earth observing instruments.

The overlapping science issues encountered throughout the Hydrological Sciences Research Group are accompanied by common technical themes that weave through these studies, such as data manipulation, visualization and storage issues, remote sensing techniques and the continual need to assist with new instrument concept developments, and field campaign planning concerns. While the Hydrological Sciences Research Group is diverse in its scope, these common technical themes and our interdisciplinary approaches to investigating regional and planetary-scale processes help highlight our common interests. Furthermore, research into land and hydrospheric processes has become such an important issue across NASA that members in this group are tasked with coordinating and implementing NASA's Global Water Cycle research initiative. This is a truly interdisciplinary effort to integrate broad-based hydrological science research both within NASA and in the wider scientific community. Successful implementation of this initiative should facilitate better understanding of land surface states, and ultimately will help us better predict hydrological cycle state variations from local to global scales.

Rolf Reichle

Task 000-00-174: **The Use of NASA Land Data Assimilated Products to Improve Flood and Drought Risk Analysis and Forecasting for Water Resources Management in the Columbia River Basin**

GEST Investigator: Kristi R. Arsenault (PI)

Collaborators: Paul Houser (GMU/CREW), Steven Hunter (DOI/USBR), David Matthews (USBR-Retired), Steffen Meyer (DOI/USBR)

Task 000-00-619: **NASA National Applications for Water Management**

GEST Investigator: Kristi R. Arsenault

Collaborators: David Toll (PI; GSFC), Paul Houser (GMU/CREW), Ana Pinheiro (NRC), Jonathan Triggs (GEST), Joe Nigro (SSAI), Jared Entin (NASA HQ)

Abstract

The main focus of this research is to help expand water resource management agencies' *in-situ* databases with more spatially distributed observed and modeled moisture and energy flux variables using NASA's suite of satellite and model products. These products, which include Land Information System (LIS) land surface model output and satellite data from MODIS, are being further developed to be benchmarked and eventually incorporated into such agencies' operational decision support systems (DSSs). The LIS models have been customized to run with several enhanced MODIS products (*e.g.*, leaf area index, snow cover) to help validate and benchmark the U.S. Bureau of Reclamation's DSSs. Several different parameter datasets, including soil, elevation and high resolution land cover datasets, have been incorporated into the LIS LSMs to help enhance their parameterization and output. Finally, calibration to some parameter datasets and additional corrections to *in-situ* datasets have been made to ensure the best quality data for the validation and benchmark studies.

Description of Research

Current water resource management agencies, like the U.S. Bureau of Reclamation (Reclamation), rely mostly on point measurement data for many of their hydrological prediction and DSSs. In helping to expand their databases with more spatially distributed observed and modeled moisture and energy flux variables, LIS modeled and remotely sensed products, like snow cover, vegetation, land surface temperature, are being further developed to be benchmarked and eventually incorporated into Reclamation's operational DSSs, RiverWare and the AWARDS ET Toolbox. Also, the different satellite products are being tested in the LIS LSMs to try and produce more physically realistic data products, concentrating mostly on evapo-transpiration, snow water equivalent, and runoff, which are identified as essential to water resource managers. The main research goals of the collaborative projects with Reclamation include developing integrated observation-based modeling systems that meet the needs of the Reclamation regional offices. Areas of interest for these projects include the Truckee-Carson Rivers, Columbia River, and the Middle Rio Grande River Basins.

Accomplishments during the Current Year

Several projects this past year have focused mainly on the development and validation of different remotely sensed products for the use in land surface models as part of the LIS software package. Key products from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the EOS Terra and Aqua satellites were further quality-controlled, enhanced and integrated into LIS LSMs (*e.g.*,

CLM2, Noah, and Mosaic). These MODIS, version 4 (MODIS.v4) land products include land cover classifications and mask (MOD12), the continuous vegetation fractional cover (MOD44b), BRDF/albedo (MOD43b), leaf area index (LAI; MOD15), land surface temperature (LST; MOD11), and snow cover (MOD10). Validation of the MODIS.v4 land cover classification and LAI products have been done outside of LIS and compared to previous MODIS versions and AVHRR land cover and LAI products. The MODIS.v4 products were further enhanced, and an improvement was found when validated against the other datasets and other independent studies. The MODIS.v4 snow cover product was processed for the Columbia River Basin region and validated against SNOTEL and compared with the LIS LSMs. MODIS snow cover was found to identify snow in grid pixels correctly most of the time (when no cloud cover was detected) and has been determined to be suitable for use in several of the LSMs.

Three of the main LIS LSMs (CLM2, Noah v.2.7, and Mosaic) have been used in several inter-model comparison studies for the different Reclamation project regions (Columbia River and Carson-Truckee River Basins). CLM2 has been found to perform the best for capturing snow water equivalent and related snow processes over the other two LSMs and compares well with *in-situ* USDA SnoTEL data. However, one problem was discovered with the accuracy of SnoTEL position and elevation data in this study, and as a result a short paper has been prepared for submission which documents the problems with using the dataset for high resolution snow validation studies. An evapotranspiration (ET) intermodel comparison has been made as well, but it has been difficult to determine which model performs the best due to local effects on the *in-situ* measurements and the way the LSMs have been parameterized. Corrections to the ET flux measurements and newly re-calibrated LSM studies are underway to address these problems for better validation studies.

Another ongoing project in the Middle Rio Grande River Basin region has involved vegetation products from AVHRR and MODIS. These datasets were used to parameterize the Noah and CLM2 LSMs and to measure how sensitive the models are to these parameters. The two different satellite-derived vegetation class products revealed differences in evapotranspitation summaries by several inches for one growing season. Based on this simple result, accurately defining vegetation classes and parameterizing the LSMs proved critical to obtaining more realistic ET values, which the water resource managers rely upon, especially in semi-arid regions. In response to this need, higher resolution land cover classification datasets have been incorporated and tested in the LIS LSMs along with other higher resolution parameters, like soil and elevation datasets. To validate and benchmark the NASA satellite products, the LIS models and Reclamation's DSS, the AWARDS ET Toolbox, two new eddy covariance flux towers for measuring *in-situ* ET, energy and moisture flux terms have been installed and are now operating in Albuquerque, NM, with the help of the Middle Rio Grande Conservancy District, Reclamation, and New Mexico Tech.

Relatively high resolution soil classifications and parameters were evaluated extensively as to how they are best used within the LSMs. Also, new soil classes (*e.g.*, granite and exposed bedrock) are being incorporated into the models, since significant areas in the Western U.S. and in other parts of the world have these soil types and not the classic sand-silt-clay fractions. Incorporating these new soil classes is improving the LSMs representation of the river basins' soil conditions and therefore runoff, baseflow, and other moisture variables. Higher resolution and more accurate elevation datasets (*e.g.*, the 30-m National Elevation Dataset [NED]) are now being used in the models and show some slight improvement over the standard USGS GTOPO30 elevation dataset. Finally, for such high resolution modeling studies as described here, the needed parameter datasets have been cross-checked with the land cover dataset and improved for use within LIS LSMs, due to the need to remove existing artifacts in a datasets based on their previous formats and projections.

Objectives for the Coming Year

The intercomparison modeling studies have been conducted with only three of the LIS LSMs, and for the coming year, the plan is to finish testing and have the VIC LSM fully working and run on the same parameters (non-calibrated at this time) as the other three models. In addition, the Army Corps of Engineers multi-layered snow model, SNTHERM, will be tested and included as well as part of the model validation studies. The Reclamation DSS, RiverWare, and its modeling component software (the PRMS-MMS runoff scheme) will be run with LIS LSM and MODIS products as part of the benchmarking studies for NASA Headquarters. To derive the runoff fields and hydrographs, the runoff modeling component of PRMS-MMS will be incorporated into LIS. For the modeled ET validation studies and DSS benchmark work, the latest IKONOS 4-m satellite derived land cover classification and high resolution NSSL's QPE-SUMS precipitation products will be incorporated into the LIS LSMs to compare the different energy and moisture budget methods. Finally, the Validation and Verification and the Benchmark reports for RiverWare and AWARDS ET Toolbox are aimed to be completed this coming year, based on the work described above.

Task 972-21-143: **Advanced Laser Fluorescence Technologies for Coastal Biomonitoring**

GEST Investigator: Alexander M. Chekalyuk

Collaborators: John Gerlach (GSFC, WFF)

Abstract

This task focus was on the development of advanced laser fluorescence (ALF) technology for coastal and estuarine bio-environmental monitoring. There is a need in new measurement strategies, technological solutions, sensors, and platforms to provide information with adequate spatial and temporal coverage to address the priority areas, such as water quality, habitat biodiversity, and environmental change. The ALF technology seeks to improve measurements of pigment concentration, including chlorophyll-a and phycobiliprotein pigments; assess phytoplankton physiological/nutrient status; provide characterization of the phytoplankton, as well as fluorescence assessment of chromophoric dissolved organic matter; and measurements of water turbidity. These critical variables will provide valuable, currently missing information, which can be utilized along with standard water quality data for improved bio-environmental characterization of coastal and estuarine environments, and for satellite validation/calibration.

A new ALF instrument was built for flow-through measurements onboard a small vessel. Three successful field measurement campaigns conducted in the reported period in diverse aquatic environments with the ALF instrument resulted in acquiring unique data for identifying the key ALF technological solutions and developing the spectral deconvolution (SDC) algorithms that account for optical complexity of the coastal and estuarine waters. A new satellite measurement scenario, "Fluorescence LIDAR Active-Passive Suite," which incorporates the ALF findings, was developed and submitted to NASA ESTO Working Group.

Description of Research

A 2-year project, "Advanced Laser Fluorescence (ALF) Technology for Estuarine and Coastal Environmental Biomonitoring," was completed in December 2005. Research activities included development of new analytical algorithms and instruments, laboratory analyses, and shipboard field measurements. The new technological developments address spatial and temporal variability of marine ecosystems, their driving forces and impacts; biological carbon sources and sinks in the ocean; natural and human environmental impacts and their consequences in coastal areas; and spatial/temporal gaps in satellite validation/calibration over meso- and synoptic scales. ALF development and initial operational utilization have yielded valuable bioenvironmental information to enhance our understanding of coastal and estuarine ecosystems and shown potential for improving

capabilities of monitoring natural estuarine environments. Comparative analysis of ALF surveys along with NOAA water quality data will provide important feedback to prevent and mitigate anthropogenic contamination and degradation of coastal and estuarine ecosystems, as well as new data sources for satellite calibration/validation and new algorithm development, including airborne and satellite measurements.

Accomplishments during the Reporting Period

Development of the compact, laptop-footprint prototype ALF system was finished in March-April 2005. The ALF instrument includes blue and green diode lasers, a hyperspectral CCD sensor with a fiber light collector, a pump-during-probe sensor of variable fluorescence, a flow-through sample unit with a miniature pump, a USB GPS navigation module, and a laptop PC with a USB controller. The ALF software was developed under the LabView software environment. The system can operate on AC power or internal rechargeable battery; in the latter case providing up to 6 hours of continuous high-speed (tested at 33 miles/hour) underway measurements in a waterproof Pelican case. It can also be used for discrete sample analyses and long-term flow-through monitoring at stationary settings.

The ALF instrument was successfully tested during 2 estuarine field campaigns at the Sough Slough (OR) and Chesapeake Bay (VA) in April and July 2005. The tests included a laboratory study of ALF fluorescence signatures for water samples collected in a range of bio-environmental conditions. A high-resolution data set, which provides information about phytoplankton biodiversity, physiological status, pigment biomass, water turbidity and concentration of dissolved organic matter, was acquired in about 2 hours of the underway motorboat ALF monitoring. Supporting data included measurements of standard water quality parameters (STD, dissolved oxygen, and water turbidity) at selected site locations; more detailed information was provided by HPLC and optical microscopic analysis of collected water samples. A more extensive ALF survey was conducted in the Chesapeake Bay and York River in July 2005 in close collaboration with Virginia Institute of Marine Science. Results of the ALF motorboat mapping showed significant meso- and small-scale spatial variability in the ALF bio-optical characteristics. The key water quality variables recorded with the supporting flow-through DataFlow system, which operated along with the ALF instrument on board a motorboat. The acquired data sets allowed quite comprehensive characterization of bio-environmental situations in the surveyed area, which would not be possible with 'conventional' monitoring techniques. In June 2005 the ALF prototype was deployed in the Pacific coastal zone of San Diego for high-resolution measurements of small-scale spatial variability in a bloom of the non-toxic 'red tide' dinoflagellate *L. polyedrum,* an organism that blooms regularly off the Southern California coast. This study was conducted in close collaboration with Scripps Institute of Oceanography (University of California, San Diego, CA). These initial tests provided valuable information to evaluate ALF performance in different coastal marine environments and respectively adjust the ALF measurement and analytical protocols. It also showed the ALF potential as a useful tool for detection and monitoring dynamics of phytoplankton coastal blooms, which may be extended in the future towards harmful algal bloom applications.

New automatic spectral deconvolution algorithms have been developed to account for spectral complexity of coastal and estuarine aquatic environments, where spectral bands of the seawater constituents are overlapped, thus affecting the accuracy of retrieval of individual components if the signal is not treated properly. The analysis, based on the extensive field tests in diverse environments, suggests that spectral deconvolution of hyperspectral seawater emission measurements is critical for accurate concentration assessment of seawater constituents. Additional significant improvement in the accuracy of the concentration assessments can be achieved by normalization of spectrally-deconvolved fluorescence intensities to the intensity of synchronously measured water Raman scattering, an 'internal standard' that allows to account for signal variability caused by

absorption and scattering in the sampling volume and during light propagation in the media. An important methodological result of our initial ALF field deployments is that it is feasible to retrieve accurate quantitative assessments of phytoplankton physiological status and chlorophyll concentration using sampling from the surface exposed to bright ambient light. The new algorithms will be implemented in the future airborne and satellite measurement scenarios. In particular, a new satellite measurement scenario, “Fluorescence LIDAR Active-Passive Suite,” which incorporates the ALF findings, was developed and submitted to NASA ESTO Working Group.

Objectives for the Coming Year

A new 3-year project funded under NASA Oceans&Ice 2004 NRA, “Superactive-Active-Passive (SAP) Shipboard/Airborne/Satellite Analysis of Phytoplankton Pigment, Group, and Physiological Variability in Coastal Ocean,” was initiated in the reported period. The research addresses two priority NRA research topics, "Dynamics in coastal zones" and "Identification of phytoplankton taxonomic or functional groups from space or airborne sensors." It also contributes to "Providing the scientific basis for next generation ocean and ice remote sensing technologies." The project goals are (1) to develop new laser fluorescence methods for improved airborne/shipboard phytoplankton pigment characterization in coastal environments, (2) to integrate the new methods and instruments with the pump-and-probe laser fluorescence technique for assessment of phytoplankton physiology, and (3) to initiate operational utilization of the new suite of analytical techniques for “observing variability and change in coastal regions” (the NRA request). The core element of the project activities is a series of shipboard/airborne/satellite coastal surveys. The new methods will be tested and optimized over a broad range of bio-environmental conditions in these areas. The surveys will include airborne/shipboard active laser fluorescence analysis of chlorophyll-*a* and accessory pigments, assessment of phytoplankton physiological status and identification of dominant and sub-dominant algal groups. Recommendations for optimization of future satellite passive and active (LIDAR) sensors will be formulated.

Task 974-52-198: **Evaluation of the Factors in the Modeling Water and Energy Fluxes Within the Framework of Land Data Assimilation Systems (LDAS) and Implementation of the Advanced Data Assimilation Schemes into Land Information System (LIS)**

GEST Investigator: Jiarui Dong

Collaborators: Christa D. Peters-Lidard (PI, GSFC), David L. Toll (PI, GSFC), James L. Foster (GSFC), Rolf Reichle (GEST), Paul R. Houser (GMU), Sujay V. Kumar (GEST), Randal Koster (GSFC), Jeffrey P. Walker (Australia)

Abstract

The U.S. Bureau of Reclamation (USBR), the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Agriculture (USDA) have identified Evapotranspiration (ET) as critical for determining water availability and affecting various applications. This task’s goal is to improve the Land Data Assimilation System (LDAS) simulated ET through the Land Information System (LIS) by incorporating primarily MODIS satellite derived products for the Mosaic land surface model, the Community Land Model (CLM2), and the Noah land surface model. The LIS is the next generation of LDAS for the Air Force Weather Agency (AFWA) combining real time precipitation observations and analyses, global forecast model data, vegetation, terrain, and soil parameters with the operational Noah soil hydrology model to generate fields of soil moisture, soil temperature, and other important land surface characteristics.

The research focus is on implementing advanced data assimilation schemes into LIS.

Description of Research

The overall objective of the research for the first project is to provide improved ET and surface water and energy fluxes within the framework of Land Data Assimilation Systems (LDAS) to federal agencies such as the USBR, the EPA, and the USDA. Also, the North American Regional Reanalysis (NARR) may provide an extremely valuable data set to address regional and long-term variations in the water fluxes and are an integral part of the study. Satellite derived data are used and evaluated to further improve and develop ET and surface water and energy balance estimates.

Transitioning and implementing the advanced data assimilation methods into the LIS is a critical step towards assimilating observations of skin temperature, soil moisture, and other land surface conditions. The LIS provides a capability to produce analyses of these land surface characteristics on the same grid at the same resolution. Assimilating real surface observations in the LIS will result in improved analyses of land surface characteristics. This early research is focusing on assimilation of remotely sensed snow water equivalent (SWE) observations over the North America into LIS.

Accomplishment During the Reporting Period

The joint analysis of NARR and North American LDAS data versus GAPP-ARM *in-situ* reference data provides a unique look at the water and energy flux estimation from different model approaches. For the *in-situ* measurements, the third and fourth Coordinated Enhanced Observing Period (CEOP3&4) data was used that were measured at half-hour frequency and available from October 2002 to December 2004. The GAPP-ARM Southern Great Plains sites are selected for initial study as they provide fluxes (sensible heat, latent heat, and ground heat fluxes) and surface meteorological conditions. Comparison shows that large biases are found on partitioning sensible heat and latent heat fluxes in most models during summer season. Possible factors, such as model forcing, land cover classification and model physics, affecting the energy fluxes are investigated through the Land Information System (LIS) over the South Great Plains (SGP) reference sites for the period from October 2002 to December 2004. It was found that both model forcing data, land cover classifications and model physics had significant influences on the energy flux estimation. This study will suggest the optimal forcing data and model for the future operational predictions. A technical presentation was given at the 5th International Scientific Conference on the Global Energy and Water Cycle (GEWEX'05) and a journal paper is in preparation.

Successful model prediction of snow evolution is challenging due to immature knowledge of snow evolution physics, simplifications in model parameterizations, high spatial and temporal variability of snow cover, and errors in the model forcing data. The remotely sensed SWE estimates from the Scanning Multichannel Microwave Radiometer (SMMR) were found to still suffer from (a) signal saturation in the deep snow pack, (b) mixed pixel contamination in the coastal regions, and (c) liquid snow water contamination during early and late snow season [Dong *et al.*, 2005]. As both model predictions and remotely sensed estimates contain different amounts of errors at different times and locations, the most accurate estimate of snow pack status will result from assimilation of remotely sensed estimates into a land surface model, and *in-situ* measurements used to verify improvement. In order to attain this optimal estimate of snow pack state, it is essential that the assimilation scheme account for relative uncertainty of both model predictions and observations. Dong *et al.* [2005] have made a thorough uncertainty assessment of the Foster *et al.* [2005] semi-empirical SWE retrieval algorithm, quantifying the observation uncertainties in a meaningful way.

The GEST investigator has successfully applied the EKF method to assimilate the SMMR snow water equivalent observations, and spatially complete and temporally continuous uncertainty maps for both remotely sensed observations and land surface model SWE estimates have been generated and evaluated in their study. Therefore, this innovative approach is suitable

for assimilating remotely sensed AMSR-E observations (since AMSR-E also measures the total SWE in the snow pack), and overcomes the difficulty associated with model layer geometry and unique snow processes related to growth and ablation. A series of numerical experiments have demonstrated that assimilation of remotely sensed SWE estimates results in improved SWE estimates when compared to *in-situ* measurements. However, when poor quality observations are assimilated or the model simulation transitions quickly beyond the 100mm SWE cut off, the assimilation algorithm is no longer able to improve the snow pack simulation. Comparison between the open loop and assimilation simulations shows that runoff and upward short and long wave radiation are also modified through assimilation of remotely sensed SWE. However, such changes in water and energy balance terms have not been verified as improvements using field measurements. A paper entitled "Scanning multichannel microwave radiometer snow water equivalent assimilation" was submitted to the *Journal of Geophysical Research-Atmospheres* for publication.

Objectives for the Coming Year

Dong will continue his effort on both the NOAA-GAPP and AFWA projects. He will focus on expanding the LIS capabilities to support the advanced data assimilation schemes including direct insertion, extended Kalman filter (EKF), and ensemble Kalman filter (EnKF) implementations. Completion of the development of the above schemes with LIS Noah land surface model is planned, with the ability to extend to other land surface models, and also conduct some synthetic case analyses to demonstrate their performances by some "identical twin experiments" including the development of tools to support perturbations (forcing, model states, parameters) and the ensemble propagation techniques.

Task 974-52-196: **Coupling High Resolution Earth System Models Using Advanced Computational Technologies**

GEST Investigator: Joseph L Eastman

Collaborators: Christa D. Peters-Lidard (PI, GSFC)

Abstract

The first objective of this research project is to apply advanced computational technologies to the problem of coupling high-resolution (*e.g.*, 1 km) Earth system models. The second goal is to investigate the linkage of the land surface and atmosphere and the effects on convective modeling. The Land Information System (LIS) is a high-resolution, high-performance land surface modeling and data assimilation system to support a wide range of land surface research activities and applications. Using advanced computational technologies and software tools, LIS has been coupled to other high resolution atmospheric models, including the Weather Research and Forecasting (WRF) and Goddard Cumulus Ensemble (GCE) models. Through the coupled modeling system, the GEST investigator is examining the effects of different land surface models and the assimilation of different datasets on cloud resolving convective modeling results.

Description of Research

The two way interaction of the land surface and the atmosphere occurs over wide ranging spatial and temporal scales. These interactions over multiple scales are communicated through the exchange of water, energy, and carbon. The ability of the land surface and atmospheric models to represent these exchanges through parameterizations and physically based algorithms is critical to understanding and predicting the land-atmosphere continuum in terms of climate and allocation of resources on both short and long time scales. In the short term the capability to accurately simulate and predict the evolution of convective systems is of primary concern to weather forecasters and emergency planners. The goal of a coupled land surface and atmospheric modeling system is to

improve this capability through high resolution modeling and the assimilation of new, emerging high resolution satellite data into this system.

Accomplishments during the Reporting Period

The work in the past year has focused on the improvement and application of coupled LIS and WRF (LISWRF) and LIS and GCE (LISGCE) modeling systems. The use of LIS as the land surface model (LSM) component of the atmospheric models allowed the use of multiple LSMs in testing the coupled systems. The models were first employed in an idealized manner to check the integrity of the system. This lead to an investigation of the impact of differing radiation updates frequency on model results and subsequent submission of a manuscript. This study also pointed to the need for a new approach to radiation parameterization techniques, since more frequent updates led to a doubling of computational requirements. Funding was pursued without successs through a NASA NRA to develop a Look Up Table (LUT) approach to radiation parameterization. Nevertheless, the proof of concept developed for the proposal led to a peer-reviewed publication.

After successful application and testing, the LISWRF model software was used to investigate the impact of mesoscale fluxes, the result of land and soil state heterogeneity, on the development of convection for case days occurring during the International H_2O Program (IHOP) field project. This project, aimed towards improved assimilation and observation of water in various phases, provided significant data sources used to validate the LISWRF system, as well as populate a NASA-based server for future validation and assimilation. Eastman employed the LIS offline system to produce the "best" initial conditions for the land surface state through multi-year spin-up integrations employing recently developed high resolution data products. Since mesoscale atmospheric models do not have sophisticated assimilation systems for the land surface initial conditions, he was able to demonstrate significant improvement in simulated convective events using LIS integrations to provide these ICs.

Another advance using the coupled model system was in investigating the robustness of land surface heterogeneity parameterizations in representing the subgrid scale variability that exists when modeling resolutions coarser than those of the initializing datasets. This investigation demonstrated the inability of these parameterizations to represent adequately the subgrid scale variability. This inability was found to be even more significant when moist processes were prevalent during the integrations.

Objectives for the Coming Year

Further demonstrate the capabilities of the LISWRF system and expand the system to the Continental U.S. (CONUS) scale using telescoping nests, since 1km resolution modeling on grids this size is not currently feasible. This will allow the exploration of the impacts of assimilating high resolution datasets on a variety of scales, also expanding on the previous work on land surface heterogeneity. The system will also be used for simulating more case studies of varying lengths in order to examine possible enhancements to the length of predictability by using LIS produced initial conditions. Plans are also under way to implement ecological and carbon models into the LIS software system. Finally, the GEST investigator will be exploring the effects of pre-storm land surface characteristics on land falling tropical cyclones using the LISWRF system.

Task 972-37-169: **Empirical Algorithm Refinement for TOPEX/Poseidon and Jason-1 Altimeter Range Bias Corrections Through Use of Operational Global Wave Model Data**

GEST Investigator: Hui Feng

Collaborators: John Gerlach (PI, GSFC/WFF), Douglas Vandemark (Univ. of New Hampshire), Bertrand Chapron (IFREMER/France), Brian Beckley (Raytheon/ITSS), Janet Campbell (Univ. of New Hampshire), Pat McCormick (Hampton Univ.)

Abstract

Satellite ocean altimeter range measurements are biased below the true mean sea level due to ocean surface wave characteristics. The bias is termed the sea state bias (SSB). Lacking complete information on the physical processes controlling the SSB, the current operational SSB correction models utilize a heuristic combination of altimeter-based significant wave height and wind speed data. Such a simple correction, though effective, does not fully parameterize the complexities of sea surface wind wave climate on the SSB. This study explores the feasibility of utilizing an operational global wave model to extract and apply reliable high-order wave nonlinearity wind wave statistics to obtain SSB model improvement. This year, a new approach for assessing and improving SSB algorithms has been developed by applying a fuzzy logic clustering analysis to a merging dataset including the outputs from a global surface wind wave model, satellite altimeter and scatterometer measurements. Initial assessment indicates that a global wave model does bring additional surface wind wave information valuable for the SSB corrections.

Description of Research

The sea state bias (SSB) remains the largest source of error in altimeter range measurements. Its correction becomes critical for accurate altimetry range measurements of the sea level. The latest theory and observations have indicated that the high-order wave properties, such as long wave orbital velocity and short-scale surface wave slope variances, directly drive the SSB and its variability. The current operational SSB correction model relies on two parameters available directly on board of altimetry: the altimeter-derived wind speed and significant wave height. Though effective, the two-parameter SSB model is limited because (a) the altimeter-derived wind speed is not uniquely mapped to the *in-situ* wind, and is dependent actually on the overall sea state and (b) the utilization of wind speed and wave height, even if they are "accurate," does not parameterize the SSB physically. The objective of this task is to assess the use of a global wave model to extract the reliable high-order wave field parameters directly related to the SSB. The long-term goal is to develop improved operational SSB correction solution by including additional surface wind wave information from global wave model outputs.

Accomplishments during the Reporting Period

A third generation global wave model (WaveWatch III) developed by NOAA/NWS/NCEP has been run operationally for the data generation of wave field parameters that include high-order wave spectral parameters. Four distinct wind forcing fields were used to drive the wave model for wind forcing sensitivity analysis. The wind field data, the corresponding WaveWatch III model-estimated wave field parameters, and altimeter TOPEX-observed (2000-2003) and Jason-1 (August, 2002-2003) data were all collocated by spatial and temporal interpolation onto the standard NASA/GSFC altimeter pathfinder locations (*i.e.*, the TOPEX and Jason1 ground tracks). There are over 1.5 million data records available each year. The merged datasets were used in the analyses described here.

First, the impact of wind forcing on a global wind-wave model was assessed using the TOPEX altimeter: The study presents assessment of an operational wave model,

focusing upon the model sensitivity to wind forcing products. Four wind fields are used to drive the model, including the NCEP/NCAR reanalysis and three other products that assimilate various satellite wind measurements having high spatial resolution, including the QuikSCAT scatterometer. Three wave field statistics (significant wave height, mean zero-crossing wave period, and mean square slope) were compared with collocated TOPEX altimeter derivatives to gauge the relative skill of differing wind-forced model runs, as well as to demonstrate an extended use of the altimeter beyond simply supplying wave height for wave model validation and assimilation. Results suggest that model output is critically sensitive to the choice of wind field product. Higher spatial resolution in the wind fields does lead to improved agreement for the higher-order wave statistics.

A new approach for assessing and refining SSB models was developed by applying a fuzzy logic clustering analysis to a comprehensive dataset from both the outputs by a global ocean wave model, and altimeter measurements. The approach provides an objective means to define regimes of nonlinear surface wave variability, to partition wave model and altimeter data into classes, and subsequently to build class-specific wave correction models in the standard wave height and wind speed data domain. Six regimes were objectively identified using input parameters related to the wave height, wave age, and short-scale slope variance. The study focused on detecting and quantifying where the present-day global sea state bias model fails. Some new results emerge. In general, the methodology yields results as anticipated by numerous studies over the past decades including regional impacts, the effect of swell, and expected ambiguity associated with wave age and steepness. The preliminary analysis results were presented in the Ocean Surface Topography Science Team Meeting, Venice, Italy, 16-18 March 2006.

Objectives for the Coming Year

The investigator will run the wave model for the years of 2004-2005 to extend the merged database containing collocated wave model outputs and altimeter (TOPEX-B and Jason1) measurements. The objectives for the coming year also include further assessment of the new fuzzy logic clustering approach for partitioning the global ocean into wind wave nonlinearity-based regimes, development of wave regime-based SSB correction models, and development of an operational solution with the new methodology.

Task 614-66-228: **Enhancement and Application of Hydrological Functionalities in the NASA-GSFC Land Information System (LIS)**

GEST Investigator: Matthew Garcia

Collaborators: Christa D. Peters-Lidard (GSFC), James Geiger (GSFC), Sujay Kumar (GEST), Yudong Tian (GEST), Joseph Santanello (UMD), David Mocko (SAIC), David Goodrich (USDA), M. Susan Moran (USDA), Michael Tischler (USACE), David Gochis (NCAR), David Yates (NCAR), John McHenry (Baron AMS), Tom Burnet (Baron AMS), Carlie Coats (Baron AMS), Jerry Condrey (Baron AMS)

Abstract

The GEST investigator participated in two specific projects during the reporting period that involve enhancements to the hydrological capabilities and functionalities of the NASA-GSFC Land Information System (LIS). Activities oriented on these projects, and in relation to several project proposals, have contributed substantially to Garcia's principal goal of full LIS-based land-surface hydrologic capability for the purposes of research investigations on, and applications to, remote sensing of the terrestrial hydrologic cycle and flood and water resources management problems.

Description of Research

In the reporting period, the GEST investigator has performed ongoing work for the Army Remote Moisture System (ARMS), a GIS-based application of NASA/GSFC Land Information System (LIS) technology for the determination of near-surface soil moisture content and resulting vehicle trafficability at high spatial resolution for tactical decision-making. Specifically, Garcia has developed a program for surface gauge network analysis and the evaluation of spatial interpolation functions by a method similar to Monte Carlo ensemble simulations but with more exhaustive analysis of interpolation results from subsets of the gauge population.

Garcia also began collaborative involvement in a project with scientists at NCAR and Baron Advanced Meteorological Systems (Baron AMS) oriented on the application of distributed hydrological models for land surface and stream routing processed in a national system for Romania under their Destructive Waters Abatement (DESWAT) Program. This work has involved the integration and development of software components for the enhancement of hydrologic functionality in the Noah LSM component of LIS.

Accomplishments during the Reporting Period

In support of the ARMS research described above, a computational method for the detailed analysis of surface (precipitation) gauge networks was developed by Garcia. This program supports the evaluation and comparison of spatial interpolation functions for the distribution of precipitation observations at gauged sites to other locations in a study region. In results of this work to be presented at the 2006 AGU Joint Assembly and in a subsequent manuscript submission to the AGU journal *Water Resources Research*, it has been found that the relatively simple inverse-distance method of spatial interpolation retains greater accuracy, determined as a measure of the resemblance of a field generated with only a portion of the gauge network present to that produced by the full network, than a more sophisticated method of spatial interpolation (multiquadric-biharmonic) that has previously been compared favorably with geostatistical analysis methods.

Garcia was an invited speaker at the NOAA-NWS Next-Generation QPE (Q2) Science Workshop in late June, 2005, at NOAA-NSSL in Norman, OK. Garcia was privileged to present various aspects of current work at NASA-GSFC-HSB in precipitation estimation, commonly from satellite measurements, and to confer with other workshop participants on potential collaborative opportunities between NASA-GSFC-HSB and other federal agencies. In general, the response of other workshop participants (representing primarily the various operational components of NOAA) to the GEST investigator's presentation was surprise at the level of NASA's interest and work in hydrological sciences. The enthusiasm for collaboration with potential partner agencies and researchers on topics of common interest, in both remote sensing and land surface hydrology, was welcome in the operational community represented at that workshop.

Finally, Garcia has led a collaborative effort at the improvement of hydrologic functionality in the NASA-GSFC Land Information System by the incorporation of software enhancements by DESWAT project partners at NCAR, including the Unified Noah land surface model and the Noah Distributed hydrologic enhancements to that LSM for the lateral redistribution of storm runoff and soil moisture. In collaboration with NCAR and Baron AMS project partners, Garcia developed a stream routing methodology for linkage with the Unified Noah Distributed components of this LIS-R (routed) version that handles both the initial spatial analysis of the target watershed domain as well as the execution of traditional stream flow routing algorithms. Early results from LIS-R simulations of a case study precipitation event in an Appalachian headwater basin are highly encouraging and will be presented at the 2006 AGU Joint Assembly and in a subsequent manuscript submission to the AMS *Journal of Hydrometeorology*.

Objectives for the Coming Year

Garcia will continue with the development of enhanced hydrologic functionalities in LIS for

application to the DESWAT project and to new projects with the Air Force Weather Agency, with whom the LIS team is currently focusing much of its work. Project related tasks will include the implementation and calibration of LIS-R in Romanian basins for the DESWAT project, and Garcia has assumed primary responsibility for the development of climatological weighting methods for the spatial interpolation of precipitation in LIS for the AFWA projects. In addition to ongoing project-related work, the GEST investigator has participated in the development of a merged NASA proposal and project that will become active in the coming year.

Early in the coming year, Garcia also will lead a proposal to the Precipitation Science component of the NASA ROSES-2006 announcement of opportunities, in collaboration with scientists at Colorado State University, NASA-GSFC and AFWA, and oriented on the improvement of satellite-based microwave retrievals of precipitation over land areas. This proposal and project is focused on the improvement of results from the current TRMM retrieval algorithms as well a significant and comprehensive contribution to Global Precipitation Measurement (GPM) Mission science, ground validation, algorithm development, and applications efforts.

Task 975-00-002: **Retrievals of Snowfall Using Microwave Measurements**

GEST Investigator: Min-Jeong Kim

Collaborators: James Wang (PI, GSFC), Gail Jackson (GSFC), James Weinman (Univ. of Washington), Ralf Bennartz (Univ. of Wisconsin)

Abstract

Snowfall in the atmosphere is one of the most difficult hydrometeors to measure from space. It significantly affects the global energy balance and hydrological cycle. A physical algorithm to retrieve snowfall from measurements over land with high frequency observations from the Advanced Microwave Sounding Units (AMSU-B) was developed during the reporting period. The AMSU-B radiometer has 5 channels (89, 150, 183.3±1, 183.3±3, 183.3±7 GHz) and can minimize this surface emission problem because water vapor absorption effectively shields most of the surface emission.

Description of Research

For the last several decades, ground-based radars and snow gauges have been used to monitor snowfall rate. However, spatial coverage of radar and snow gauge networks outside of the USA, Europe, and Japan is sparse. Snowfall rate measurement from space can overcome this spatial sampling limit.

Regardless of its necessity in weather forecasting, hydrological and climate research, the measurement of falling snow has been mainly derived from space borne microwave radiometry over oceanic regions where the measurements are not affected by surface snow. Although such empirical relationships or statistical techniques may be operationally useful, physical models are needed to understand how the measured brightness temperatures depend on various surface and atmospheric parameters. The goal of this study is to develop a physically based retrieval algorithm to retrieve precipitating snow using space-borne microwave measurements.

Accomplishments during the Reporting Period

Employing atmospheric and hydrometeor profiles generated by the PSU-NCAR MM5 mesoscale model simulations and calculated brightness temperatures in an *a priori* database, a Bayesian algorithm was used to set up a physical algorithm to retrieve snowfall rate and fraction of snow cover using AMSU-B observed brightness temperatures. The study implemented during the reporting period addressed the difficulty of parameterizing (in snowfall retrieval algorithms) the single-scattering properties of snow crystals at millimeter-wavelengths due to the complex shapes, sizes,

and orientations of these crystals. A simple yet accurate parameterization representing the electromagnetic properties of nonspherical snow particles at millimeter-wave frequencies was employed. This parameterization was developed by analyzing Discrete Dipole Approximation (DDA) calculations of the single scattering parameters of nonspherical snow particles. Applications of the retrieval algorithm to blizzard cases over New England and retrievals were implemented. The uncertainty of snowfall retrievals caused by different snow particle shapes and sizes were estimated.

This study focused on parameterizations of "dry" snow particles. It is common for snow particles to melt over the ocean surface and over the land if the atmospheric temperature is above 0°C. Therefore, an accurate and fast parameterization method to represent the electromagnetic characteristics of melting snow particles is necessary.

Objectives for the Coming Year

The study will be focusing on how melting processes of various nonspherical snow particles affect the single scattering properties at microwave frequencies. Idealized morphologies of melting snow particles will be set up based on microphysical observations during several stages of the melting process. These snow particle models will be employed using the DDA calculations. Single scattering parameters calculated at frequencies between 14 GHz and 340 GHz will be analyzed and compared with simple spherical approximations such as the mixed medium dielectric constant approach. The sensitivity of brightness temperatures and radar reflectivity to melting snow particle morphology will be quantified.

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

GEST Investigator: Paolo de Matthaeis

Collaborators: David LeVine (GSFC)

Abstract

This work is in support of the Aquarius mission to measure global sea surface salinity (SSS) from space for climate studies. The science instruments will include an L-band radiometer, whose received signal is sensitive to salinity, and a scatterometer that corrects for the effect of the ocean's surface roughness. The retrieval of salinity is a complex process that involves an accurate processing of the radiometer measurements, and requires a good understanding and estimation of all environmental and geophysical effects producing errors.

Description of Research

The goal of NASA's Aquarius mission is to measure global sea surface salinity (SSS) from space for large-scale and climatic studies. The science instruments will include a set of three radiometers to perform L-band (1.413 GHz) measurements of brightness temperature, which are sensitive to salinity, and a scatterometer that corrects for the effect of the ocean's surface roughness induced by the surface wind. The retrieval of salinity is a complex process that requires the knowledge of other environmental information and an accurate processing of the radiometer measurements. In addition to the previously mentioned effect of the surface wind and temperature, other contributions such as the emission from the atmosphere, the Faraday rotation in the ionosphere, and the presence of down-welling radiation from the celestial background that is reflected from the surface into the radiometer affect the accuracy of the Aquarius measurements. The presence of rain and land within the antenna footprint should also be taken into account. Therefore, for a correct retrieval of the SSS, a model needs to be developed that includes all these effects.

Accomplishments during the Reporting Period

Since joining GEST in November 2005, de Matthaeis has been working on identifying error sources in space-based passive L-band brightness temperature measurements. First, direct leakage of sun radiation into the

radiometer antennas was studied, with particular attention to the effect of the antenna pattern discretization. Second, sunglint and specular reflection of the solar radiation from the ocean into the antennas was investigated. In addition, he compared different scattering models for the ocean surface that are being considered to study the sunglint effect as well as backscattering from the sea surface.

Objectives for the Coming Year

The investigation of the sun contamination problem and the modeling of the backscattering from the ocean surface will be continued and completed. Once these effects are fully quantified, they will be incorporated in the simulation model of the AQUARIUS instrument. The effect of the cosmic background radiation and the atmospheric layer will then be considered.

Task 971-00-002: **Land Data Assimilation at the NASA Global Modeling and Assimilation Office**

Grant 00001252 **Assimilation of AMSR-E Data and Application to the Initialization of Soil Moisture Reservoirs in a Seasonal Forecasting System**

Grant 00001513 **Global Estimates of Evaporation from Variational Assimilation of Multi-platform Land Surface Temperature into a Dynamic Model of the Surface Energy Balance**

GEST Investigator: Rolf H Reichle

Collaborators: Michele Rienecker (PI, GSFC), Randal Koster (GSFC), Matt Rodell (GSFC), Dara Entekhabi (MIT), Wade Crow (USDA), Tom Jackson (USDA), Aaron Berg (Univ. of Guelph, Canada)

Abstract

A hydrometeorological forcing data set [Berg *et al.*, 2005] was developed and used in the successful assimilation of soil moisture retrievals from a historic satellite sensor. With this assimilation system, a long assumed property of global soil moisture fields derived from data assimilation was demonstrated: that the assimilation product is superior to either satellite data or model data alone [Reichle and Koster 2005]. Because part of the errors in satellite soil moisture retrievals are due to time-invariant error sources, rescaling may significantly reduce the perceived magnitude of errors in the retrievals and expand the geographic areas over which retrievals demonstrate value for land surface modeling applications [Crow *et al.*, 2005]. Progress in the operational use of AMSR-E soil moisture retrievals for seasonal forecast initialization and in the development of land surface (skin) temperature capabilities was documented in presentations at the 2006 Annual Meeting of the American Meteorological Society.

Description of Research

Research for this project at the NASA Global Modeling and Assimilation Office (GMAO) involves the development, implementation, and testing of an advanced land data assimilation system—a system that is designed to merge satellite measurements of land surface states (*e.g.*, soil moisture or snow) with corresponding estimates from land models that integrate surface meteorological observations (including precipitation and radiation). The improved estimates of land surface conditions from the assimilation are then used to initialize GMAO seasonal climate forecasts. Since atmospheric dynamics are chaotic at time scales beyond two weeks, seasonal climate forecasting relies strongly on the correct initialization of the slow components of the Earth system, namely the oceans and the land surface. Another application of land assimilation is the production of land surface temperature estimates that are needed, for example, by the NASA Clouds and the Earth's Radiant Energy System instrument team.

Accomplishments during the Reporting Period

During 2005, the development continued of an advanced land data assimilation system that makes use of soil moisture retrievals from the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) for operational seasonal forecast initialization. Key science issues addressed during the report period were the analysis of AMSR-E soil moisture retrievals and comparison with retrievals from the historic Scanning Multichannel Microwave Radiometer (SMMR). The comparison indicates that there are severe biases between the two satellite retrieval data sets in the time mean soil moisture retrievals as well as in higher-order moments. This finding negates the common assumption that the climatologies of the AMSR-E and the SMMR retrievals should be close.

The hydrometeorological forcing data set [Berg *et al.*, 2005] was used in the successful assimilation of the historic SMMR soil moisture retrievals [Reichle and Koster, 2005]. The assimilation results demonstrated, for the first time at the global scale, that soil moisture fields derived from data assimilation are superior to estimates based on the land surface model or the satellite data alone. Progress in the operational use of AMSR-E soil moisture retrievals for seasonal forecast initialization and in the development of land surface (skin) temperature capabilities was documented in presentations at the 2006 Annual Meeting of the American Meteorological Society.

In a study carried out with colleagues at USDA, NASA, and the University of Texas, San Antonio, Reichle assessed the impact of time-invariant errors on the utility of soil moisture retrievals from satellite sensors [Crow *et al.*, 2005]. Errors in remotely sensed soil moisture retrievals originate from a combination of time-invariant and time-varying sources. For land modeling applications such as forecast initialization, some of the impact of time-invariant sources can be removed given known differences between observed and modeled soil moisture climatologies. The results indicate that rescaling may significantly reduce the perceived magnitude of errors in satellite soil moisture retrievals and expand the geographic areas over which retrievals demonstrate value for land surface modeling applications.

During the past year, Reichle also contributed two chapters to a forthcoming AGU book on "Research and Economic Applications of Remote Sensing Data Products." The first chapter presents an overview of data assimilation methods in the Earth Sciences [Reichle, 2006] and the second chapter maps a path to a soil moisture mission [Jackson *et al.*, 2006]. Moreover, he completed and published a brief study on synergies between a soil moisture mission and the Global Precipitation Mission in collaboration with colleagues at USDA, MIT, and NASA [Crow *et al.*, 2006].

Objectives for the Coming Year

The incorporation of AMSR-E surface soil moisture retrievals into the quasi-operational GMAO seasonal climate prediction system is the first objective for the next year. Because external factors are delaying the transition to the new "GEOS5" coupled model for NASA GMAO seasonal forecasts, this involves derivation of a mapping between land surface states from the NASA Catchment land surface model (which is used in the land assimilation system and in GEOS5) to the Mosaic land surface model (which is used in GMAO seasonal forecast operations). The second objective is to bring the development of land surface (skin) temperature retrievals to maturity so that sensitivity studies with the land assimilation system can be conducted in the context of the on-going GMAO "MERRA" reanalysis project. This effort will be a first step towards a fully coupled land-atmosphere assimilation system that includes soil moisture, snow, and land surface temperature.

Task 971-60-215: **Dissolved Organic Carbon (DOC) and Chromophoric Dissolved Organic Matter (CDOM) in Surface Waters in Support of NASA's New Investigators Program (NIP) Project**

GEST Investigator: Mary Elizabeth Russ

Collaborators: Antonio Mannino (PI, GSFC)

Abstract

Oceanic continental shelf regions, such as the Mid-Atlantic Bight (MAB), are important in the global carbon cycle due to the potential of these areas to produce, transport and store large quantities of carbon. Approximately 20% of total ocean primary production occurs within continental shelves, and these regions may provide a substantial link between terrestrial organic matter and the ocean. The primary storage of organic carbon within all ocean environments is in the form of dissolved organic carbon (DOC), however the fate of DOC is not well constrained in coastal ocean environments. In these areas, understanding the composition, size and turnover rates of the distinct DOC fractions is necessary to complete the global carbon cycle. This study was designed to measure the degradation rate of labile and semi-labile DOC and the impact of the microbial community on the absorption of chromophoric dissolved organic matter (CDOM). Further, photo-oxidation experiments are being developed to address the possible link between the degradation of CDOM and the production of labile DOC.

Description of Research

NASA's NIP project focuses on understanding the temporal and spatial variability of dissolved organic matter (DOM) and CDOM in the surface waters of the Chesapeake Bay and MAB. The approach is to use satellite data products, field measurements, and laboratory experiments to examine the distribution, sources, and sinks of DOM and CDOM, and to develop empirical relationships to quantify DOC from CDOM absorption. By exploring these issues, an improved carbon cycle model may evolve which more accurately predicts how natural processes and anthropogenic activities impact coastal ecosystems.

Accomplishments during the Reporting Period

Eight extensive research cruises were completed during this period. Six monthly Chesapeake Bay (CB) or Chesapeake Bay Plume (CBP) cruises, in May through September, and November, and two Biophysical Interactions in Ocean Margin Ecosystems (BIOME) cruises, in March and July. During the March and July BIOME cruises, and the November CBP cruise, surface water (1 – 4.5 m) was collected to begin initial laboratory experiments designed to measure the degradation rate of labile and semi-labile DOC, and the impact of the microbial community on CDOM on a seasonal basis. In order to evaluate the variations in DOC lability on a spatial scale, the sites chosen for water collection encompassed two CB stations, a CBP station, and two MAB stations, one coastal, and one inner shelf station, which has the potential to be influenced by the CBP outflow. Both the spring and summer incubation experiments (duration of 174 days, and 190 days, respectively) were completed during this period and the third experiment sampled through day 92 (duration 190 days).

The meticulous interpretation of these preliminary microbial experiments was performed during this period, in order to refine the direction of the five future lability experiments planned in 2006. Graphs of DOC concentration (μM) versus time (days) were plotted and degradation rates (range: 0.015 ± 0.014 day-1 to 0.043 ± 0.010 day-1) and curve fits (R2 range: 0.91 to 0.99) were calculated for each experiment and station via GraphPad Prism nonlinear regression one phase exponential decay equation. Spectral slopes (S values) were also calculated, for the July and November experiments, from CDOM absorption coefficients using the GraphPad Prism software. March degradation rates followed a trend similar

to initial DOC concentrations; higher rates and concentrations at the CB station as opposed to the inner shelf MAB station. The CB had, thereby, a more labile DOC than the inner shelf MAB. One possible fresh source of DOC is spring ecosystem production in the CB, which was, in turn, rapidly utilized by the microbial community. In July, a reverse trend was apparent, since the CB and CBP stations had the highest initial DOC concentrations but the lowest degradation rates, as compared to the two MAB stations. A fresh marine DOC source, potentially from summer ecosystem production in the MAB, resulted in greater DOC lability within the MAB than in the CB and CBP, where the DOC was more refractory. Finally, in November, the degradation rates and initial concentrations are similar to March, and the CB and CBP stations had both higher rates and initial DOC concentrations, in contrast to the MAB inner shelf station. The inner shelf MAB, therefore, had a less labile DOC component than the CB and CBP, reflecting a reduction in ecosystem production in the fall within the MAB, and/or an influence of mixing between the CBP and the inner shelf MAB. In general, these observations, from the March, July and November 2005 microbial experiments, revealed a distinct variation in DOC lability within, and between, the CB, CBP and MAB. The next series of experiments, in 2006, will continue this spatial and temporal study, and add an inter-annual component.

Finally, CDOM absorption coefficients, within the ultraviolet (355 nm) and the visible (412 nm) spectrum, were plotted versus DOC concentrations (μM) for the July and November experiments. A quantification of the impact of microbial degradation on the CDOM absorption coefficient may influence future satellite DOC algorithms, and is thereby, a necessary component for utilizing remote sensing in the evaluation of DOC on a global scale. From these initial microbial lability experiments, a correlation (R^2 >= 0.70) between these parameters was present for the CB, CBP and inner shelf MAB station at 355 nm, and for the CBP station at 412 nm in the summer. In November, the same correlation was evident for the CB and CBP stations at 355 nm, and for the CB at 412 nm.

Objectives for the Coming Year

One objective is to continue and expand on the 2005 microbial lability experiments. Surface water is scheduled to be collected during March, April, July, October and December of 2006, at the same stations as the first three experiments. However, two additional stations will be added to future experiments, to incorporate both a middle shelf and outer shelf MAB station. This sampling regime will allow for a greater temporal and spatial comparison of DOC microbial lability than in the 2005 experiments. In addition, photo-oxidation experiments will coincide with the microbial lability experiments in 2006, in order to evaluate the potential for the production of labile DOC from the photo-decomposition of CDOM. Publications, based on the microbial degradation and photo-oxidation experiments, are also projected for 2006.

Task 975-31-154: **Electromagnetic Models for Microwave Remote Sensing of Snow and Applications**

GEST Investigator: Marco Tedesco

Collaborators: Ed Kim (GSFC), Thorsten Markus (GSFC), James Wang (GSFC)

Abstract

The retrieval of snow parameters from space-borne instruments is important for correct analysis of many human-related activities. Measured backscattering coefficients or brightness temperatures are strongly influenced by snow parameters such as depth, grain size, and fractional volume, for example. Passive microwave data collected during the past 30 years supported the development of several algorithms for the retrieval of snow water equivalent (SWE) and snow depth. The

development and improvement of the algorithms for the retrieval of SWE and snow depth from space-borne data is as important as the development of electromagnetic models. Recently launched satellites offer the possibilities of approaching the problem in a multi-sensor/satellite fashion. Also, the increased computational capabilities of computers offer the possibilities to explore new retrieval techniques based on the inversion of theoretical equations.

Description of Research

The investigator developed and improved microwave radiative transfer models of snow, ice, and frozen soil by using data ground-, airborne-, and satellite RS observations collected during Cold Land Processes Experiment (CLPX) in 2002-03. This research continued through this reporting period and results have been published in peer-reviewed publications as well as in conference proceedings. Additionally, Tedesco developed retrieval techniques based on genetic algorithms for the extraction of multiple parameters from spaceborne passive microwave data. The effect of the atmosphere on the retrieval performance has been also considered.

Accomplishments during the Reporting Period

The analysis of the CLPX data continued, using data collected at different scales and their modeling through electromagnetic models driven by snow inputs parameters derived from field measurements. In particular, the data collected by the Polarimetric Scanning Radiometer (PSR) over the Intensive observation Scale Areas (1 km x 1 km) have been modeled by using the Dense Medium Radiative Theory (DMRT) and a spatial scaling analysis has been performed. Results were reported in a paper published in 2005 [Tedesco *et al.*, 2005].

The investigator compared the performance of four different microwave emission models (the DMRT, the Helsinki University of Technology (HUT) model, the Strong Fluctuation Theory (SFT) model and the Microwave Emission Model of Layered Snowpacks (MEMLS) of the University of Bern). Results were reported in a paper accepted for publication in 2006. This has improved the understanding of the physical assumptions made for the different models and helped to evaluate the capabilities of the models to reproduce the measured brightness temperatures. The analysis helped also to check the consistency of the results of the different electromagnetic models considered.

A comparison of Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover area (SCA) and microwave SCA was performed with and without correcting for the atmospheric effects. Results were reported in a letter accepted for publication in 2006.

The ability of forward Dense Medium Radiative Transfer (DMRT) modelling, combined with snowpack measurements to reproduce the radiobrightness signatures observed by the University of Michigan's Truck-Mounted Radiometer System (UMTMR) at 19 and 37 GHz during the 4th Intensive Observing Period (IOP4) in March, 2003, have been also analyzed. Unlike the earlier IOP3, conditions during IOP4 include both wet and dry periods, providing a valuable test of DMRT model performance. Observations of upwelling and downwelling tree radiobrightness were used to formulate a simple model for the effect of trees within the field of view. In addition, a comparison was made for the one day of coincident observations by the University of Tokyo's Ground-Based Microwave Radiometer-7 (GBMR-7).

Objectives for the Coming Year

Development and implementation of both theoretical emission models and retrieval techniques will continue. The GEST investigator will research how grain size growth and changes in atmospheric conditions can be accounted for by improving the current retrieval techniques making use of static coefficients, both in space and time. He will also investigate the use of the 85 GHz channels. Multiple satellite datasets will be combined to improve remote sensing of snow. In particular Tedesco will combine active (*e.g.*, QuikSCAT) and passive (*e.g.*, AMSR-E, SSM/I) data to improve the mapping of snow cover area (SCA) and the retrieval of SWE and snow depth. MODIS data will also be used to validate the results in conjunction with ground

based data and distributed parameters of snow parameters derived from snow pack models driven by meteorological forcing data. Finally, Tedesco will implement and test a technique for the retrieval of surface grain size and soot concentration in snow by using a recently developed theoretical tool which uses snow particles as fractals by combining different MODIS products. The technique will be initially tested on ground-based data and, then, applied to satellite measurements.

Task 974-44-183: **High Resolution Modeling of Land-Atmosphere Ammonia Exchanges**

GEST Investigator: Yihua Wu

Collaborators: Christa D. Peters-Lidard (GSFC), Donna Schwede (EPA)

Abstract

Land-atmosphere ammonia exchanges have significant impacts on atmospheric chemistry, acidification of ecosystems and biodiversity of terrestrial ecosystems, and can cause regional atmospheric pollution and associated public health impacts, in addition to shifts in nutrient balance and in composition of plant species. Understanding and predicting these impacts is of interest to a large community served by both NASA and the EPA. To that end, researchers have established an interagency partnership to focus on this critical problem.

Description of Research

The goal of this project is to merge and leverage existing model capabilities for biochemical deposition (EPA) and land-atmosphere (NASA) observation and modeling to account for the bi-directional ammonia exchanges at high resolution by considering nitrogen transfers, transformations and equilibrium in both soils and plants. The objective of the work is to extend and prototype existing land surface and ammonia exchange modeling capabilities at NASA and EPA in a common framework. By adopting a common framework, we can apply NASA's unique observational and modeling assets, as implemented in the existing Land Information System (LIS), for potential use in the EPA's Models-3/Community Multiscale Air Quality (CMAQ) modeling and decision support system.

Accomplishments during the Reporting Period

Ammonia compensation point is a strong function of leaf temperature and the ratio of $[NH_4^+]/[H^+]$ in plant apoplast. Wu proposed a feedback mechanism affecting $[NH_4^+]/[H^+]$ from the bi-directional exchanges: when deposition occurs, NH_3 concentration in the apoplast increases, leading to an increase in NH_4^+ and a decrease in H^+; when emission occurs, NH_3 concentration in the apoplast decreases, resulting in a decrease in NH_4^+ and an increase in H^+. Therefore, the ratio of $[NH_4^+]/[H^+]$ in the apoplast increases due to deposition, but decreases due to emission. With this feedback, a diurnal variation is expected of NH_4^+, H^+ and their ratio: NH_4^+ increases while H+ decreases during evening hours between 5:00 PM and 7:00 AM Local Time (LT); NH_4^+ decreases while H+ increase during day hours between 7:00 AM and 5:00 PM; the ratio is as the same as NH_4^+. This is because the effect of leaf temperature on ammonia compensation point (ACP) is so dominant that ammonia deposition most likely occurs during evening hours between 5:00 PM and 7:00 AM while ammonia emission most likely occurs during the day hours between 7:00 AM and 5:00 PM. This feedback mechanism may explain why ammonia and ammonium aerosol deposition can be both beneficial and harmful to plants and ecosystems, depending on nitrogen supply conditions and plant species. Nitrogen is an essential mineral element required by plants in greater quantities than any other mineral element. However, high concentration of free NH_4^+ is toxic to plants and needs to be detoxified. Atmospheric deposition can be a nitrogen source for higher nitrogen consumption plants under low nitrogen supply

conditions, but a pollutant for lower nitrogen consumption plants under high nitrogen supply conditions. The effect of ammonia emission can be the opposite: a lost of nitrogen for higher nitrogen consumption plants under low nitrogen supply conditions, but a possible way for ammonium detoxification in plants or prevent step for ammonium toxin under high nitrogen supply conditions. Incorporation of the feedback mechanism into the ammonia compensation point scheme might provide a tool to evaluate the effects of atmospheric ammonia on terrestrial vegetation and the plant tolerance to ammonium toxin.

It is well documented that leaf surface water influences the development of various foliar bacterial and fungal pathogens. Some studies suggest that leaf surface water plays a role in the deposition of pollutants on crops. The researcher's field measurements of ammonia fluxes indicate that leaf surface water appears to enhance ammonia deposition to plants. The potential for the formation of free water on leaves is always present. Leaf surface water can originate from three sources: the air (dewfall and precipitation), the soil (dewrise) and the plant itself (guttation). Depending on environmental conditions, water on the leaf surface can be a thin film, discrete droplets, or a continuous liquid layer. Early studies found that a thin water film in the nanometer range is always present on surfaces at normal humidities for a range of different hydrophilic materials. Leaf surface water can be a barrier for non-soluble gases (such as CO_2), or an intermediate medium (*i.e.*, temporary sink and source) for soluble gases (such as NH_3 and SO_2). Leaf surface water also plays an active role in chemical processes. Dry deposition to the leaf surface for most gas species is reversible. For example, thin water films on plant surfaces may behave as perfect sinks for NH_3 for a limited period of time during wet periods after rain or during dewfall. However, as a dew layer or intercepted rainwater evaporates from the leaf surface, NH_3 could be released from the evaporating water drops since the NH_3 molecule is not immediately 'destroyed'. Therefore, it is very important to consider the role of water when investigating the exchange of ammonia between the atmosphere and biosphere. In this study, a mechanistic model of ammonia uptake and emission from leaf surface water is being developed and evaluated. Fluxes measured over soybean during the summer of 2002 in Duplin County, North Carolina show that deposition occurred at night and during the first few hours after sunrise while emission was observed during the late morning and early afternoon. One emission peak occurred around 11:00 AM while a second peak occurred near 15:00 PM. Results from the new MLBC model clearly demonstrate that the two peaks are the result of leaf surface water evaporation and stomatal emission, respectively.

Objectives for the Coming Year

The first objective will be to incorporate the new model into the NASA LIS system. Secondly, Wu plans to conduct more field experiments to get the necessary data to test the hypothesis proposed in Wu *et al.* [2005]. Finally, he plans to run more tests with the model using a dataset from a corn field.

Task 900-35-168: **Remote Sensing Information Support for Public Health Issues in the Arctic**

GEST Investigator: Boris S. Yurchak

Collaborators: Nancy G. Maynard (PI, GSFC)

Abstract

Public health issues in the Arctic are impacted by the state of reindeer husbandry that in turn depends on ecological conditions of tundra winter and summer pastures. Because reindeer husbandry operates in very remote areas where infrastructure is scarce, satellite remote sensing provides a unique opportunity to monitor the main ecological parameters of the pastures. This research concentrated on Synthetic Aperture Radar (SAR) data analysis of selected areas in the Chukotka forest-tundra and particularly the study of fire scars radar time-series backscatter. Based on measurements of fire scar spots in

target areas and undamaged tundra at reference sites, researchers demonstrated the sensibility of the radar signature patterns and parameters to the state of the soil in summer and to the snow cover in winter. The study was carried out within the frames of the project “Reindeer Mapper” and was supported by the NASA Land-Cover Land-Use Change Program and NASA’s Radar Research Program (NASA #51-621-21-01-20). Synthetic Aperture Radar data are provided by the European Space Agency and Alaska Satellite Facility.

Description of Research

An extensive analysis of the seasonal trend during 2.5 years of the European Remote Sensing Satellite-2 (ERS-2) Synthetic Aperture Radar (SAR) backscatter from the three test sites of a fresh fire scar of 2002 tundra fire and two adjacent undamaged tundra sites in Chukotka, Russia was performed. The study utilized about 40 SAR images of the area obtained from August 2002 to January 2005 with the periods of survey equal to 16 and 35 days. The SAR data were provided by the Alaska Satellite Facility located in Fairbanks, Alaska, USA. The study was focused mainly on earlier not conducted comparative study of the SAR signatures of five test objects in winter, when there is a snow cover. For the comparative study three highly-reflected zones of the fire scar, differed from each other by their mean reflectivity, were used as radar-bright targets, and two low-reflected objects in an adjacent undamaged area of a forest- tundra were selected as radar dark (reference) targets. Upon processing the radar backscatter coefficient the local incidence angle was calculated on the basis of an approximation of a spheroidal Earth and locally flat terrain of tundra. The SAR data processing was done with the help of “ENVI” software, while the geocoding was performed with the help of “All maps of Russia” vector maps set issued by ”Ignit.Inc.” For estimation of the snow cover depth in the studied area the data of three meteorological stations located in the region of survey were utilized. The primary meteorological data were extracted from the archive of the weather conditions of "Russia’s Weather" Internet-server supported by Hydrometeorological Center of the Russian Federation and by the Space Monitoring Information Support Laboratory of the Institute of Space Researches of the Russian Academy of Sciences.

Accomplishments during the Reporting Period

Based on the theoretical results of Ulaby *et al.* [1984] and Shi and Dozier [2000] the existence of three modes of the radar backscatter from the snow-covered ground is experimentally verified. These modes are determined by so-called parameter of interaction representing a ratio between the radar backscatter coefficient of the frozen ground under a snow cover and the volumetric backscatter of snow itself. The changing of the regimes during the same winter season and between seasons was detected. As a result of joint analysis of the SAR and meteorological data, the experimental verification of the dry snow masking effect on both mean and fluctuating spatial characteristics of the radar backscatter, is obtained for the first time. For the quantification of this effect, the snow contrast of a pair of high and low reflected test sites is taken into consideration. A notable negative correlation of the snow contrast and meteorological depth of snow up to 30-40 cm was observed in this experiment. The loss of the correlation between the radar characteristics and the snow depth of more than ~40 cm is not clear now and would be investigated in future with a fieldwork support. In the spring of 2004 a sharp reduction of the reflectivity of all objects, caused by the phenomenon of a wet snow, was detected. The results of the summer measurements of radar signatures of the fire scars verified the known estimations of their high reflectivity and also found out the concurrences of summer minima of radar backscatter coefficients with maxima of summer decadal temperatures due to temperature impact on the soil wetness.

Objectives for the Coming Year

The primary objective is to utilize the experience of SAR data processing and application for a new task regarding Antarctic coastal ice probing.

Task 971-32-161: **Air-Sea-Ice Interaction**

GEST Investigator: Yunhe Zhao

Collaborators: Antony K. Liu (PI, GSFC)

Abstract

Satellite-derived Arctic sea ice motion data and the pressure field data from the International Arctic Buoy Programme (IABP) during winter seasons of the period from December 1988 to March 2003 are used to study the Arctic sea ice motion circulation regimes and the interaction between sea-ice motion and pressure field. While previous studies found that wind forcing is a major driving force of Arctic sea ice motion, this research demonstrated that the feedback of sea ice motion on the pressure field in the Arctic in winter is also significant. An interaction mechanism of Arctic sea-ice motion and pressure field has been proposed. The satellite-derived sea ice motion data are also used to study the role of sea ice motion in the annual change of minimum sea ice extent in the Arctic. Preliminary results indicate that the large annual changes of minimum sea ice extent in the Arctic since 1990 can be partially explained by sea ice motion pattern changes. With a ~30 minute acquisition time offset and almost the exactly same path, the Synthetic Aperture Radar (SAR) images from two SAR sensors on ERS-2 and ENVISAT, respectively, have been used for ocean feature tracking. The wave refraction around the Dongsha Island and a mystery ship near an eddy can be tracked by sequential SAR images. A case study to derive the ocean surface drift over the southern part of Luzon Strait near Philippines has been demonstrated by using a wavelet transform based feature tracking procedure. The satellite-derived flow field is compared with wind data from QuikSCAT and the qualitative comparison shows a generally consistent pattern of ocean surface drift.

Description of Research

This research focuses on satellite ocean and sea ice remote sensing data analysis and imaging processing, especially by wavelet analysis of satellite data from SSM/I, QuikSCAT, SeaWinds, and AMSR-E for sea ice motion, deformation, and dynamics in the Arctic. The objectives are to develop effective and efficient algorithms for deriving sea ice motion and deformation using satellite data for sea-ice dynamics and joint research on climate variability study based on these data sets. The goals are to study the environmental effects on sea ice dynamics and to further understand the physical processes in the earth climate system.

Accomplishments during the Reporting Period

The daily sea-ice motion maps in the Arctic derived from NSCAT, QuikSCAT, SeaWinds, SSM/I, and AMSR-E data by a wavelet analysis method have been merged and used to study Arctic sea ice motion circulation regimes, the interaction of sea ice motion and pressure field in the Arctic, and the role of sea ice motion in the annual change of minimum sea ice extent in the Arctic. It is found that the temporal mean Arctic sea-ice motion map from the 15 winter seasons in the period from December, 1988 to March, 2003 has two distinct features: the Beaufort Gyre in the Canadian Basin and a cyclonic circulation system in the Eurasian Basin that originates from Laptev Sea. Both the strengths and sizes of the two distinct features change annually from one winter season to another. Among the 15 winter seasons studied, seasons with a strong or normal Beaufort Gyre alternate with seasons with a weak or no Beaufort Gyre every one to three winter seasons. Using Principal Component Analysis (PCA), it is found that the first and second modes of PCA of monthly Arctic sea-ice motion in winter are mostly driven by the first and second modes of PCA of monthly pressure field, respectively. Both the mode-one component of monthly Arctic sea-ice motion anomaly in winter and the mode-one component of monthly pressure field anomaly alternate between anticyclonic and cyclonic circulation systems. It is also found that in winter in the Arctic the mode one component of monthly sea-ice motion anomaly has

significant feedback effect on the mode two component of monthly pressure field anomaly. An interaction mechanism of Arctic sea-ice motion and pressure field has been proposed. The merged satellite-derived sea ice motion data in the Arctic are also used to study the role of sea ice motion in the annual change of minimum sea ice extent in the Arctic. The preliminary results indicate that large annual deceases or increases of minimum sea ice extent in the Arctic occurring since 1990 are partially due to the sea ice motion pattern changes. A paper jointly written with A. K. Liu reporting these results has been submitted for publication.

With all-weather day and night imaging capability, the Synthetic Aperture Radar (SAR) can penetrate clouds, smoke, haze, and darkness and acquire high quality images of the Earth's surface. However, due to the high resolution of SAR data, the coverage of a SAR sensor is always limited, and the repeating cycle of a single SAR is usually too long for ocean surface feature tracking. With a ~30 minute acquisition time offset and almost the exactly same path, the SAR images from two SAR sensors on ERS-2 and ENVISAT, respectively, have been collected and used for ocean feature tracking. Internal wave refraction by coral reef around Dongsha Island in the South China Sea on April 16, 2003 has been observed from sequential ERS-2 and ENVISAT SAR and MODIS images. The mystery ship near an eddy can be tracked by sequential SAR images. A case study to derive the ocean surface drift over the southern part of Luzon Strait near Philippines on April 27, 2005 has been demonstrated by using a wavelet transform based feature tracking procedure. To validate the results, wind data from QuikSCAT are compared with the satellite-derived flow field. The qualitative comparison shows a generally consistent pattern of ocean surface drift. Nonlinear internal wave-wave interaction and the phase shifts resulted from the wave-wave interaction were also studied.

Objectives for the Coming Year

The study on the interaction of Arctic sea ice motion on the pressure field and the effect of sea ice motion on the recent decline of annual minimum sea ice extent in the Arctic will continue. The wavelet transform based tracking procedure for deriving ocean surface drift from pairs of ERS-2 and ENVISAT SAR images will be improved and optimized. Its results will be validated and calibrated. Nonlinear internal wave evolution process in the South China Seas (SCS) will be investigated by using SAR images and concurrent long-term mooring data, especially near the shelf break and in the deep water.

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Global Energy and Water Cycle Experiment (GEWEX)

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Task 971-32-161: **International Global Energy and Water Cycle Experiment (GEWEX) Project Office (IGPO)**

GEST Investigator: Richard (Rick) Lawford

Collaborators: Soroosh Sorooshian (Univ. of California, Irvine), Susanna Eden (Univ. of Arizona), Pavel Groisman (National Climate Data Center), Einar-Arne Herland (European Space Agency), Jin Huang (NOAA), Chu Ishida (Japanese Aerospace and Exploration Agency), Toshio Koike (Univ. of Tokyo), Annukka Lipponen (United Nations Educational Scientific and Cultural Organization), Jan Polcher (Laboratoire de Météorologie Dynamique du CNRS), John Roads (Scripps Institute of Oceanography), William Rossow (NASA), Robert Schiffer (GEST), Paul Try (Science and Technology Corporation), Gilles Sommeria (World Climate Research Programme), Ronald Stewart (McGill Univ.), Avinash Tyagi (World Meteorological Organization), Peter van Oevelen (European Space Agency), Charles Vorosmarty (Univ. of New Hampshire), Yuping Yan (Beijing Climate Center), Olga Zolina (Univ. of Bonn), Wolfgang Grabs (World Meteorological Organization), Sam Benedict (Coordinated Enhanced Observing Period), Arthur Askew (International Association of Hydrological Sciences), Antti Herlevi (GEO Secretariat), Pavel Kabat (International Geosphere-Biosphere Programme)

Abstract

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 water resources around the world. Scientists from over 30 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; modeling 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 modeling land-atmosphere coupling and cloud system processes, global data set development, water resource applications, and the effective use of Earth Observations in climate science.

Rick Lawford serves as the Director of the International GEWEX Project Office which is responsible for coordinating the activities of the GEWEX project and its interactions with outside research and operations groups and space agencies. This position provides management, service and coordination functions for more than 1000 scientists worldwide who are working on the water and energy cycle science and it supports the information and management needs of the World Climate Research Programme. During 2005, Lawford also held the position of chair of the Executive of the Integrated Global Water Cycle Observation (IGWCO) theme of the Integrated Global Observing Strategy (IGOS) Partnership and took the lead in implementing this program through the international partners of IGOS (including space agencies) by developing plans and strategies and initiating projects for integrated observation of water cycle variables. At the request of NASA, he has also served as the coordinator for the Northern Eurasia Earth System Partnership Initiative (NEESPI).

Description of Research

The research undertaken within GEWEX is directed at the development and application of planetary Earth science and observations to address 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. Metrics of scientific success include improvements in the ability to close regional and global water budgets through improved observations and modelling capabilities.

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 systems combined with state-of-the-art assimilation 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 and hydrologic models. Model development depends on process understanding derived from field studies. GEWEX contributes to the development of global observation and data systems and continues to provide oversight to the Coordinated Enhanced Observing Period (CEOP).

GEWEX places a strong emphasis on increasing our 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 the feedbacks in the climate system. This understanding is incorporated into climate models through improved parameterisations and leads to more accurate predictions at both weather and climate time scales. The value of these improvements is assessed in collaborative studies with the water resource and applications communities who are encouraged to apply these predictions and to determine how they can benefit for economic and social development.

Lawford's role is to direct the office that coordinates these research activities and plan for the future activities and meetings, coordinate implementation, help to synthesize the results and establish processes for making the results useful for different communities. The information and synthesis roles are aided by the GEWEX website (www.gewex.org), the organization of scientific meetings and conferences, and the preparation of review articles for different publications. The promotion of the program is done through the *GEWEX Newsletter* and participation in committees involved in the development of observational systems. In addition, Lawford facilitates opportunities for GEWEX projects by liaising with potential funding agencies. Within the framework provided by the program, he applies his expertise to gain a better understanding of regional and global water resource issues and to promote the development of better Earth Observation systems (especially space-based systems) that could support GEWEX science.

Accomplishments during the Review Period

Lawford played a central role in formulating the plans, arrangements and scientific program for the 5th International Scientific Conference on the Global Energy and Water Cycle that was held in June 2005 in Costa Mesa, California. More than 290 experts from more than 25 countries participated in the meeting. In addition to preparing the scientific agenda, Lawford worked with Robert Schiffer and Soroosh Sorooshian to secure funding for a number of participants at the meeting. He also promoted the conference through brochures and briefings. More than 330 papers and posters were presented at the conference. A number of these papers are being considered for a Special Issue of the *Journal of Hydrometeorology* for which Lawford will be the guest editor. He also helped to plan a pan-WCRP monsoon workshop that was held in Irvine, California the week before the International Scientific Conference.

During 2005, Lawford addressed a number of planned activities by promoting GEWEX in the scientific community by organizing several workshops and scientific sessions at international conferences. In particular, sessions

related to GEWEX were organized for the Fall American Geophysical Union (AGU) meeting in San Francisco, California and for the January 2005 American Meteorological Society conference in San Diego, California. In addition, he informed the scientific community about GEWEX goals and activities by providing more than 12 seminars and talks on GEWEX at international and national science conferences. (Appendix A provides a list of the major meetings where Lawford represented GEWEX, IGWCO or NEESPI or some combination of these projects.) In addition, he has developed overviews of the GEWEX project that have been consolidated into journal articles such as Sorooshian *et al.* [2005] and Lawford *et al.* [2006].

During the past year, Lawford led the development of a roadmap for Phase II of the GEWEX project. This roadmap outlines the planned activities of GEWEX relative to each of its objectives over the next 6 years. The roadmap is the basis of on-going dialogue with each of the Panels and CEOP regarding the milestones when these outputs would become available.

In 2005, Lawford worked with the European GEWEX Coordinator to promote the development of the GEWEX project in Europe. This effort included assisting with the organization and conduct of a special session on GEWEX and Europe at the European Geophysical Union (EGU) meeting. The GEST investigator also completed negotiations with the Chinese Meteorological Administration for a Chinese GEWEX Coordinator. Through the IGPO, Lawford has provided support for the GEWEX program by overseeing the preparation of four newsletters during the past year, as well as monitoring their distribution to more than 2200 subscribers. Newsletter themes during 2005 included monsoons, extreme events, Earth Observations and the prediction of precipitation. Lawford continues to guide other outreach activities including the maintenance of the GEWEX website which receives an average of 300 hits per day, completion of a Phase I accomplishments brochure and the production of a number of manuscripts and reports for publication or Panel reviews.

Lawford provided GEWEX inputs to a number of documents in 2005 including the Implementation plan for the Global Climate Observing System (GCOS) as well as a proposal to NASA for a Solutions network. He also reviewed proposals for NASA, NOAA, and Canadian Fund for Climate and Atmospheric Sciences (CFCAS), a book proposal submitted to the AGU as well as several manuscripts submitted to EOS and AGU journals. He has also supported the chair of the GEWEX Scientific Steering Group (SSG) and the chairs of GEWEX panels by assisting in the development of meeting minutes, and negotiating and/or carrying out follow-up on action items arising from meetings. Support to the SSG also included coordination of the preparations for the GEWEX SSG-18 meeting in Dakar, Senegal, both in terms of providing briefings and written material and in developing strategies to implement recommendations from the meeting. This support also included preparing reports on GEWEX and IGWCO for the Joint Scientific Committee Meeting of WCRP.

During the past year Lawford has been responsible for the implementation of the Integrated Global Water Cycle Observations (IGWCO) theme report, and for leading in the provision of a number of Work Packages in the water area for the Group on Earth Observations (GEO). He has also been responsible for consolidating these views and to use them in the development of the IGWCO implementation plan. In this role he organized the first IGWCO planning meeting in Tokyo and made numerous reports and presentations. During the year, IGWCO plans for an intercomparison of high resolution precipitation products and for a workshop on remote sensing and water quality were advanced. Within the IGWCO framework and in collaboration with the Global Water System Project (GWSP), Lawford continued to promote the development of indicators to enhance the dialogue between scientists and policy makers. In 2005, he led the preparation of an IGWCO brochure that has been printed and distributed extensively. In addition, he planned and organized workshops for IGWCO capacity building including a successful meeting held in

Buenos Aires, Argentina in October 2005 which was attended by more than 100 people. Plans are ongoing for a workshop of East Asian scientists and decision makers in Thailand in September 2006. In April 2005, Lawford participated in the Commission of Sustainable Development (CSD) meetings in New York and in information tables where large quantities of WCRP, GEWEX and IGWCO literature were distributed.

Over the past year Lawford also served as the coordinator for the NEESPI program. A number of meetings were held with US agencies to seek support for the program and for an International NEESPI project office. During the year, under his guidance, the NEESPI web site was upgraded and moved from NASA to an independent site and plans were developed for an international NEESPI workshop in Vienna. Through collaborations with NASA and the NEESPI chief scientist, progress was made in having NEESPI accepted as an iLEAPS endorsed project and serious consideration is also being given for endorsement of the project by IGBP, the Global Land Project and GEWEX.

Objectives for the Coming Year:

The GEST investigator will continue to strengthen links between GEWEX and other closely related activities including the Global Water System Project (GWSP), CLIVAR and the Group on Earth Observations (GEO). He will continue to provide 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 a pan-GEWEX meeting as well as the GEWEX SSG-19 meeting, and preparing minutes of meetings and writing reports and articles to inform the science community about the project. During the coming year there will be a need to review the structure of GEWEX. This review could lead to major changes in the relationships between CEOP and GHP as well as helping to rationalize the roles of GPCP and GPCC and to clarify GEWEX aerosol and climate responsibilities. During the past year the GEWEX SSG approved the initiation of a number of projects (LandFlux, ISLSCP data project, Hydrologic Applications Project, aerosol and climate). As IGPO Director, Lawford will be responsible for assisting the lead scientists in implementing these projects. It will be necessary to support the lead scientists and to ensure that the expectations of the GEWEX SSG are met in terms of the conditions placed upon these approvals. In addition he will develop and support the implementation of the Integrated Global Water Cycle Observations theme by chairing the Scientific Advisory Group and by representing WCRP on the theme executive committee and continuing to lead the implementation of the theme.

The pan-GEWEX meeting planned for October 2006 in Frascatti, Italy will be an important meeting for GEWEX since it will provide an opportunity to promote cross-cut activities and to determine which actions will be addressed in the implementation of the GEWEX Roadmap. Lawford will be responsible for setting the agenda for this meeting and organizing the event so that it produces the maximum benefit for GEWEX.

China has identified Dr. Yuping Yan as the new Chinese GEWEX Coordinator. During the coming year Lawford will work closely with her to ensure that she effectively promotes GEWEX in China. He will also work with the European GEWEX coordinator to strengthen European participation in GEWEX.

As a result of recent decisions in the World Climate Research Programme, Lawford will now be responsible for managing the travel budget for the GEWEX meetings and for coordinating the Extremes and Monsoons cross-cuts across all of WCRP. New responsibilities from WCRP will also place increased demands on time and energy spent on publicizing GEWEX data products and developing and implementing a vigorous public information strategy. He will also be responsible to provide GEWEX input to an extensive review of WCRP that ICSU will be leading.

Lawford will also provide input to a coordination of events at the World Water Forum IV in Mexico City, Mexico and the Earth System Science Partnership conference in

Beijing, China. As part of his efforts to make GEWEX science more visible, he will also make presentations and organize sessions on behalf of GEWEX at other conferences including the Western Pacific AGU meeting and possibly the Fall AGU meeting.

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Goddard Visiting Fellows Program in the Earth Sciences

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NASA Goddard Space Flight Center and GEST Visiting Fellows Program in the Sun-Earth Exploration

The Goddard Earth Sciences and Technology Center (GEST) and the NASA Goddard Sun-Earth Exploration Division each year seek highly qualified Ph.D. scientists for collaboration in scientific research relating to the observation, analysis and modeling of physical processes within the Sun-Earth system, and to relevant global change issues on the Earth. Selected candidates are offered appointments as Visiting Fellows to pursue independent research in collaboration with scientists in the Laboratories within the Sun-Earth Exploration Division, and have full access to NASA computing facilities and other resources at either the Goddard Space Flight Center in Greenbelt, MD or at the Goddard Institute for Space Studies in New York, NY. The solicitation occurs in November through February each year and is aimed at all levels from post-doctoral to senior scientists. We particularly encourage university faculty interested in sabbatical arrangements to apply. The program will accept exceptional candidates throughout the year.

Research Areas

Research interests in the Sun-Earth Exploration Division include attaining knowledge and understanding of the components of the Sun-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. The principal components of research and corresponding research interests are as follows:

Atmospheric Research:
Involves the structural, dynamic, radiative, and chemical properties of the Earth's troposphere, stratosphere, mesosphere and thermosphere and the atmospheres of other planets. Research interests include ozone, clouds, aerosols, precipitation, regional and global climate, fronts, gravity waves, cyclones, thunderstorms, and convective systems. Data derives from various space-based and airborne optical, UV, and IR passive radiometers and laser sensors, and in situ spectrometers.

Terrestrial Physics Research:
Involves global land surface properties, both vegetative and biological. Research interests include biospheric processes, vegetation monitoring, and biosphere-atmosphere interactions. Data derives from space and ground based lasers, laser altimeters, field campaigns involving measurements in local ecosystems and the climate/oceanic/biospheric system.

Hydrospheric Research:
Involves the oceanic, cryospheric and hydrologic sciences. Research interests include the natural variability of the physical climate system on seasonal-to-interannual time scales, the global carbon cycle, global land ice and sea ice cover, the global hydrological and energy cycles, and interactions between the physical climate system and biogeochemical cycles. Data derives from optical, microwave, and laser sensors and in situ hydrologic measurements.

Sun-Earth Connection Research:
Involves solar variability factors that influence the solar irradiance and the Earth's climate system. Research interests include solar ultraviolet variability effects on the ozone layer and climate; modeling of

long-term trend in the solar constant based on observation of photospheric blemishes (*e.g.*, sunspots and faculae); studies of solar magnetic activity; and physical hypotheses governing Sun-weather effects.

Information Science and Technology Research:
Involves computer science, computer engineering, and computational science research in support of NASA Sun-Earth science. Research interests include numerical algorithms and high performance/parallel computing; data assimilation and data fusing; adaptive multi-resolution modeling; 3-D visualization; feature recognition and multi-dimensional data visualization; and data mining and data management of extremely large distributed data sets. Data derived from various space-based and airborne sensors, field campaigns, and models.

Appointments to the GVF Program are for one year with negotiable start dates. Visiting Faculty appointments will be made at UMBC. Compensation for these prestigious appointments is competitive and generous travel allowances are made for visitors.

During this reporting period, three Goddard Visiting Fellows were in residence: Dr. Zev Levin of the Department of Geophysics and Planetary Sciences, University of Tel Aviv; Dr. Toshihiko Takemura, Research Institute of Applied Mechanics, Kyushu University; and Dr. David Salstein of AER, Inc. Due to two selected candidates declining the fellowship because of other offered positions, one additional GVF was selected in January 2006, Dr. Raimund Muscheler of NCAR, who came to GSFC to aid in the initiation of activities in the GSFC Sun-Climate Center.

For the 2007 round of Goddard Visiting Fellows, a large number of selections were made and the following candidates will arrive in the next year:

1) Dr. Pieternel Levelt, Physicist, Atmospheric Composition and Research Division, Climate Research and Seismology Department, KNMI (Dutch National Meteorological Research Institute), Holland. Dr. Levelt is Principal Investigator on OMI. She will work with P. K. Bhartia (Code 613.3), Arlin Krueger (JCET) and Ernie Hilsenrath (JCET) on broadening access and use of OMI data. She will begin her visitation in the summer of 2007.

2) Dr. Alexander Lipatov, Physicist and Mathematician, Russian Academy of Sciences and the Physics Department of the University of Alberta. Dr. Lipatov was a colleague of Sagdaev and will work with Drs. Hartle and Meyer and with the Community Coordinated Modeling Center (CCMC; Michael Hesse and Marsha Kuznetsova, Code 612.3) on magnetospheric problems. He will come for a one-year stay.

3) Dr. Michael Schulz, Chemist, Laboratoire des Sciences du Climate et de l'Environnement, Gif-sur-Yvette France. He is the PI on the AEROCOM project (http://nansen.ipsl.jussieu.fr/AEROCOM/) He will work with Oleg Dubovik (614.4) and Mian Chin (613.3). He will visit for four months.

4) Prof. Tad Anderson, Atmospheric Scientist, Department of Atmospheric Sciences, University of Washington. He will work with Allen Chu and Ray Hoff (JCET) and Mian Chin (613.3) on CALIPSO - A-train integration of clouds and aerosol data. He will come for a one year period.

5) Dr. Nicholas Meskhidze, Atmospheric Chemist, Georgia Institute of Technology. He will work on links between air pollution and ocean productivity, contact Santiago Gasso (GEST, 613.3). He will come as a Research Associate (post-doctoral fellow) for a one year period.

6) Qingyuan Zhang, National Resource and Environmental Study, University of New Hampshire. His area of research is remote sensing of photochemical active radiation in vegetation and gross primary productivity. He will work in Code 614.4 with Huemmrich (JCET), Middleton and Ranson. He will visit as a research associate for one year.

7) Harshvardan, Professor, Dept. of Earth & Atmospheric Sciences, Purdue University. An expert in atmospheric radiative transfer, Dr. Harshvardan will visit UMBC and GSFC from May to June 2006 and work with Dr. Cahalan's group.

Raymond Hoff, Director

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Educational Programs

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Educational Programs

GEST has continued to be active in education and mentorship in 2005, with successful programs providing a "once in a lifetime" experience to a host of students.

Graduate Student Summer Program (GSSP)

The intent of the GSSP is to encourage graduate students in the Earth sciences to conduct genuine research at GSFC during 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 work they would like to do 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, Goddard Institute for Space Studies (GISS) and Wallops Flight Facility (WFF).

The GSSP 2005 summer program ran from June 6 to August 12, 2005. Combined efforts with the majority of the GSFC summer education programs (Office of Education) helped to bring down costs for housing and shuttle transportation.

Ten students were selected to participate in GSSP 2005. The student population included two doctoral students and eight Master's students. The GSFC students were housed in apartments at the University of Maryland, College Park and were shuttled to GSFC daily. Two students were placed at WFF, while the remaining students were at GSFC.

Individual meetings were conducted with each student after three weeks into 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. Each WFF student was reached by telephone and received at least one visit from a GEST staff member.

A seminar series was held in combination with the JCET/GEST Founder's Symposium held in mid-July. A variety of GSFC, GEST, and JCET scientists were invited to speak on the most popular research happening at GSFC.

The students reported positive relationships with their mentors. In particular, two students will be extending their graduate research with their summer mentors. All students participated in research that will be utilized in their thesis. One of the WFF students came to GSFC for the student seminars.

At the end of the program, students presented their work in a seminar with their peers and mentors. This year's format was a "Discussion Round Table" and proved to be a more relaxed atmosphere than previous events. Each student gave a 10-15 minute seminar on the work completed this past summer. The students' last requirement was to submit a paper to GEST, all of which are available for public review on the GEST website [http://gest.umbc.edu/student_opp/students.html].

Below is a list of the projects completed during GSSP 2005. Names marked with an asterisk indicate GEST faculty members.

2005 GSSP Alumni Project Reports

Evaluating Coastal Change Using NASA Experimental Advanced Airborne Research Lidar (EAARL): Examples from Parramore Island, Virginia
Geoffrey Wikel
Mentors: Wayne Wright, NASA WFF; Amar Nayegandhi, USGS

Cross-Validation of AMSR-E Soil Moisture Retrievals, the Surface Soil Moisture Simulations from NASA's Global Land Data Assimilation System (GLDAS) and the field observations over SMEX04 region, Arizona
Alok Kumar Sahoo
Mentors: Xiwu Zhan, Kristi Arsenault*, GEST

Preliminary Dual-Polarization Data Analysis with NASA's NPOL Radar
David Lerach
Mentor: John Gerlach, NASA WFF

Evaluation of tropical cyclogenetic processes into the NASA fvGCM
Marganelly Fuentes
Mentor: Oreste Reale*, GEST

A direct readout technology suite for real-time applications
Swarvanu Dasgupta
Mentor: Patrick Coronado, Kelvin Brentzel, GSFC

Inferring aerosol-cloud interactions over the Indian subcontinent during winter 2000-2005 using MODIS data
Ritesh Gautam
Mentor: Christina Hsu, GSFC

The TRMM Precipitation Radar observations of West African storms
Samson Hagos
Mentor: Guojon Gu*, GEST

A pilot study of emission estimates of CO and Aerosols from wildland fires and their validation
Sanjeeb Bhoi
Mentor: Mohan Gupta*, GEST

Generating river discharge estimates for the Bay of Bengal using the NASA GSFC Land Information System
John Brown
Mentor: Christa Peters-Lidard, GSFC

Discrete dipole approximation wrapper introduction and documentation
Hezekiah Carty
Mentor: Kwo-Sen Kuo*, GEST and Eric A. Smith, GSFC

GEST Student Summer Interns

GEST hosted nine self-directed summer interns working with GEST faculty mentors on specific projects in the Earth Sciences and Education Technology. These interns performed actual science research and presented their results at the end of the Program. These students were housed along with the GSSP summer students and JCET summer interns.

GEST Graduate Fellowship

Tetyana Vdovina was awarded a one-year GEST Graduate Fellowship (August 2005-2006). Vdovina is working on her PhD in the Department of Applied Mathematics. Her advisor is Dr. Susan Minkoff. Vdovina's current research is to statistically quantify material parameters describing the Earth on different scales. During her fellowship, her paper was accepted in the Summer of 2005 and appeared in December in the Society for Industrial and Applied Mathematics' *Multiscale Modeling and Simulation* journal. Since the summer, she has completed a convergence analysis of the numerical method for upscaling the acoustic wave equation which forms the core of her thesis. She is working to finish numerical studies to be included in a second journal paper. She has also fleshed out the theory for the algorithm for elasticity. Both of the latter two tasks have moved her closer to completion of her thesis expected in December 2006.

Valerie Casasanto and Marci Delaney

Short-Term Visitors

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Short-Term Visitors

GEST 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 are typically coming to GSFC for hands-on training or obtaining data for their own research at their home institution.

GEST facilitated the visits of approximately 74 short-term visiting scientists in the reporting period. During the past year, those scientists who visited GSFC under the auspices of GEST included:

NAME	AFFILIATION	CODE VISITED
Ackerman, Thomas	Pacific Northwest Laboratory	613.2
Alduchov, Oleg	RIHMI-WDC, Moscow, Russia	614.3
Artaxo, Paulo	University of Sao Paulo	613.2
Atlas, David	NASA GSFC	613.2
Bailin, Sidney	Knowledge Evolution, Inc	610
Barker, Howard	Environment Canada	613.2
Beaudoin, Andre	Natural Resources Canada	614.4
Blake, Donald	University of CA, Irvine	613.2
Borne, Kirk	NASA GSFC	610
Boudreau, Jonathan	Fluxnet-Canada Rsch Network	614.4
Castanho, Andrea	MIT	613.2
Chen, Jen Ping	Natl Taiwan Univerisity	613.1
Chen, Jhih-Ying	National Central University	613.1
Chernykh, Irina	RIHMI-WDC, Moscow, Russia	614.3
Choi, Iidae	Seoul National University	613.1
Cumbane, Julia J.	Edouardo Mondlane University	610
Curtis, Scott	Eastern Carolina University	613.1
Drolet, Guillaume	Fluxnet-Canada Rsch Network	614.4
Ehrendorfer, Martin	University of Innsbruck	610.1
Fedele, Francesco	University of Vermont	610.1
Feingold, Graham	NOAA/ETL	613.2
Fetter, Gerald	Council Rock School District	130.3
Fontenla, Juan	University of Colorado	613.2
Frank, William	Penn State University	613.2
Glackman, Penny	Merio Elementary School	130.3
Gobakken, Terje	Agric University of Norway	614.4
Gregoire, Tim	Yale University	614.4
Gustavo, Luis	Nat'l Research Council/Univ.Prgms	614.3
Hahnenberger, Maura	University of Utah	613.2

NAME	AFFILIATION	CODE VISITED
Harshvardhan	Perdue University	613.2
Hartmann, Peter	University of Bonn	613.1
Himesh, Shivappa	C-MMACS, Bangalore, India	614.3
Houze, Robert	University of Washington	613.2
Huang, Shaopeng	University of Michigan	613.2
Kahn, Ralph	NASA JPL (Cal Tech)	613.2
Kang, In-Sik	Seoul National University	613
Karnieli, Arnon	Ben Gurion University (BGU) Inst.Desert Resrch	613.2
Kean, Rachelle	Hempfield Area High School	130.3
Kim, Dae-Hyun	Seoul National University	610.1
Lin, Yuh-Lang	North Carolina State University	613.1
Lin, Yuh-Lang	North Carolina State University	613.1
Liu, Hongyu	NASA Langley	613.3
Martins, Zita	Leiden Institute of Chemistry	699
Matthes, Katja	National Center for Atmospheric Res	610.1
Naesset, Erik	University of Norway	614.4
Nair, K. Shadananan	Cochin University, India	614.3
Nesbitt, Steve	Colorado State University	613.1
Perlwitz, Judith	GISS	610.1
Petters, Jonathan	Penn State Universtiy	613.2
Pham, Hanh	University of Michigan	614.6
Pinheiro, Ana	NRC	614.3
Ramanathan, Veerabhadran	University of Ca, San Diego	613.2
Randall, David	Colorado State University	613.2
Rosich, Jordi	GRAHI-UPC, Spain	613.1
Rublev, Alexey	Russian Research Centre	613.2
Rudich, Yinon	The Weizmann Institute of Science	613.2
Santanello, Joseph	Boston University	614.3
Schwartz, Joel	Harvard School of Public Health	613.2
Shen, Samuel	University of Alberta	613
Sindoni, Giampiero	Universita Degli Studi di Roma	698
Sohn, B.J.	Seoul National University	613.1
Stahl, Goran	Swedish University of the Agrigultural Sciences	614.4
Sun, DeZheng	NOAA - CIRES	613.2
Tabacniks, Manfredo	University of Sao Paulo	613.2
Throckmorton, Heather	University of Maine	614.2
Ung, Chhun-Huor	Natural Resources Canada	614.4
Vant-Hull, Bryan	University of Maryland	613.2
Walker, Jeffrey	University of Melbourne	614.3

NAME	AFFILIATION	CODE VISITED
Waquet, Fabien	Lab d'Optique Atmosph. U. Lille	613.2 / 611
Wood, Eric	Princeton University	613.1
Zhou, Xiaobing	NM Inst of Mining and Techn	614.6
Zhuravleva, Tatiana	Institute of Atmospheric Optics	613.2

GEST's short-term visiting scientist program continues to grow and proves to be a needed service to the Earth Science community.

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APPENDICES

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Chin, M., T. Kucsera, L. Giglio, and T. Diehl (2006), Using MODIS fire count data as an interim solution for estimating biomass burning emission of aerosols and trace gases, presentation before MODIS Science Team Meeting, Baltimore, Maryland, 4-6 January.

Chubarova, N., E. Nezval, J. Verdebout, N. Krotkov, and J. Herman (2005), Long term irradiance changes over Moscow and comparisons with UV estimates from TOMS and Meteosat, paper presented at SPIE annual meeting, San Diego, Calif., 31 July.

Comstock, J., R.-F. Lin, D. O'C. Starr, and P. Yang (2006), Simulations of cirrus clouds using an explicit cloud model: integrating ARM water vapor and forcing data for analysis of cirrus microphysical properties. Submitted to The 12th Conference on Cloud Physics, Madison, Wisconsin, 10-14 July.

Comstock, J., R.-F. Lin, D. O'C. Starr, and P. Yang (2006), Simulations of cirrus clouds using an explicit cloud model: integrating ARM water vapor and forcing data for analysis of cirrus formation and evolution. Submitted to The 16th Atmospheric Radiation Measurement (ARM) Science Team Meeting, Albuquerque, NM, 27-31 March.

Comstock, J., R.-F. Lin., and D. O'C. Starr (2005), Investigation of high ice supersaturation in cirrus clouds using ARM data and an explicit cloud model, The 15th Atmospheric Radiation Measurement (ARM) Science Team Meeting, Daytona Beach, FL, 14-18 March.

Cooper, O. R., A. Stohl, M. Trainer, A. Thompson, J. C. Witte, S. J. Oltmans, B. J. Johnson, J. Merrill, J. L. Moody, G. Morris, D. Tarasick, G. Forbes, P. Nedelec, F. C. Fehsenfeld, J. Meagher, M. J. Newchuch, F. J. Schmidlin, and S. Turquety (2005), Larger tropospheric ozone enhancements above mid-latitude North America during summer: In situe evidence from IONS and MOZAIC ozone monitoring network, and the role of lightning NO_x, EOS Trans. AGU, 86(52), Fall Meet. Suppl., Abstract, A53D-03.

Cooper, O. R., M. Trainer, A. Thompason, J. C. Witte, S. J. Oltmans, B. J. Johnson, J. Merrill, J. L. Moody, G. Morris, D. Tarasick, G. Forbes, P. Nedelec, F. C. Fehsenfeld, J. Meagher, M. J. Newchurch, and F. J. Schmidlin (2005), Large upper tropospheric ozone enhancements above mid-latitude North America during ICARTT: In situ evidence from the IONS and MOZAIC ozone monitoring network, presented at the ICARTT Data Analysis Workshop, University of New Hampshire, Durham, NH, 9-12 August.

Curran, R. (2005), Climate Change Science Program Workshop, Climate Science in Support of Decision Making, Arlington, VA, 14-16 November.

Curtis, S., A. Salahuddin, R, F. Adler, G. J. Huffman, and G. Gu (2005), An Analysis of the Climatology and Variation of Precipitation Extremes with GPCP and TRMM, paper presented at 5th International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, California, June.

de Matthaeis, P., and R. H. Lang (2005), Accuracy of Physical Optics Solutions for Dielectric Cylindrical Structures Used in Vegetation Models, paper presented at the 2005 APS / URSI Symposium, Washington, DC, July.

Diehl, T. L., and M. Chin (2005), Assessing the Uncertainty Range of Aerosol Distributions Simulated by a Global CTM due to Different Meteorological Fields, paper presented at AGU Fall Meeting, San Francisco, CA, 5-9 December.

Diehl, T., and M. Chin (2005), Assessing the Uncertainty Range of Aerosol Distributions Simulated by a Global CTM due to Different Meteorological Fields, Aerocenter Seminar, Greenbelt, Maryland, 13 December.

Duncan, B., H. Hayashi, S. Strahan, A. Douglass, S. Pawson, and J. Rodriguez (2005), Credibility of tropospheric transport in a CTM simulation with forecast field, AGU Fall Meeting, San Francisco, CA, 5-9 December.

Eastman, J. L., C. D. Peters-Lidard , S. V. Kumar, and Y. Tian (2005), High resolution convective modeling study using WRF coupled to the Land Information System (LIS), paper presented at the WRF/MM5 User Workshop 2005, Boulder, CO, June.

Eastman, J. L., C. D. Peters-Lidard, S. V. Kumar, and Y. Tian (2005), The Impact of Radiation Update Frequency on WRF Numerical Simulations, Weather Research and Forecasting Model Users Workshop, Boulder, CO, 27-30 June.

Eastman, J. L., C. D. Peters-Lidard, S. V. Kumar, Y. Tian, and P. R. Houser (2005), High Resolution convective modeling study using WRF coupled to LIS. Weather Research and Forecasting Model Users Workshop, Boulder, CO, 27-30 June.

Eastman, J. L., C. D. Peters-Lidard, S. V. Kumar, Y. Tian, and P. R. Houser (2005), High Resolution convective modeling study using WRF coupled to LIS. Weather Research and Forecasting Model Users Workshop, Boulder, CO, 27-30 June.

Eastman, J. L., C. D. Peters-Lidard, S. V. Kumar, Y. Tian, and P. R. Houser (2006), Evaluation of land surface spinup and their impacts on high resolution convective modeling, 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, 86th American Meteorological Society Annual Meeting, Atlanta, GA, 29 January - 2 February.

Eck, T. F., B. N. Holben, O. Dubovik, A. Smirnov, A. Sinyuk, J. S. Reid, D. Giles, J. S. Schafer, M. Sorokin, and W. W. Newcomb (2005), Temporal and spatial variability of aerosol optical properties in the UAE, AGU Fall Meeting, Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract A33A-0855, San Francisco, CA, 5-9 December.

Errico, R. M. (2005), Fundamentals of atmospheric predictability, invited seminar at the Naval Postgraduate School, Monterey, CA, 23 August.

Errico, R. M. (2005), Issues regarding the assimilation of precipitation observations, invited presentation at the International Workshop on the Assimilation of Satellite Cloud and Precipitation Observations in NWP Models, sponsored by the NOAA/NASSA/DoD Joint Center for Satellite Data Assimilation, Lansdowne, VA, May.

Errico, R. M. and W. Tan (2005), Normal mode initialization, seminar at the Global Modeling and Assimilation Office, NASA, Greenbelt, MD, June.

Errico, R. M., R. Yang, M. Masutani, and J. Woollen (2005), The use of OSSEs for characterizing background and analysis errors, invited seminar at the Naval Research Laboratory, Monterey, CA, 16 August.

Errico, R. M., R. Yang, M. Masutani, and J. Woollen (2005), The use of observation system simulation experiments (OSSEs) for characterizing background and analysis errors, invited seminar at the Institute for Meteorology and Geophysics, University of Innsbruck, Innsbruck, Austria, May.

Errico, R. M., R. Yang, M. Masutani, and J. Woollen (2005), The use of OSSEs for characterizing background and analysis errors, presentation at the WMO Symposium on the Assimilation of Meteorological and Oceanographic Observations, Prague, Czech Republic, April.

Eylander, J., C. D. Peters-Lidard, and S. V. Kumar (2005), The AFWA next generation land data assimilation system, Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) Conference, Monterey, CA, 12-14 October.

Feng, H., D. Vandemark, B. Chapron, N. Tran and B. Beckley (2006), Use of fuzzy logic clustering analysis to address wave impacts on altimeter sea level measurements: Part I data classification, Ocean Surface Topography Science Team Meeting Venice, Italy, 16-18 March.

Feng, H., D. Vandemark, J. R. Morrison, J. W. Campbell and H. Sosik (2006), Assessment of satellite ocean color products near Martha's Vineyard Coastal Observatory (MVCO) using SeaPRISM measurements, AGU/ALOS Ocean Sciences Meeting, Honolulu, HW, 20-24 February.

Feng, H., D. Vandemark, J. R. Morrison, T. Moore, J. Salisbury, J. Campbell and H. Sosik (2005). Evaluation of SeaWiFS and MODIS-Aqua ocean color and aerosol products off the Coast of Martha's Vineyard, Ocean Color Research Team meeting, Portland, OR, 12-14 April.

Gaiero D., B. Villoslada, S. Gassó, S. Bidart, E. Koestner, and F. Chemale, Jr. (2005), Holocene environmental catastrophes in South America: From the lowlands to the Andes and Airborne transport of aerosols into the South Atlantic Ocean: assessment of sources, horizontal fluxes, iron fertilizing potential and impact on climate, Miramar, Córdoba, Argentina, 11-17 March.

Garcia, M. (2005), NOAA - NWS Quantitative Precipitation Estimation: a NASA perspective, NOAA-NWS Next-Generation QPE (Q2) Science Workshop, Norman, OK, 28-30 June.

Gassó, S. (2005), First Observations of Dust transport from Patagonia into the Southern Atlantic Ocean, presentated to the AERO Center, GSFC, 19 April.

Gassó, S., D. M. Gaiero, B. Villoslada, and E. Liske (2005), Observations and Measurements of Dust Transport from the Patagonia Desert into the South Atlantic Ocean in 2004 and 2005, presented to AGU Fall Meeting, San Francisco, CA, 5-9 December (*Eos Trans.*, AGU, 86(52)).

Gatebe, C. K, M. D. King, O. Dubovik, A. Sinyuk, G. Wind, G. T. Arnold, and P. B. Russell (2005), Characterization of aerosols and surface optical properties from airborne spectral measurements of directional reflectance, IGARSS 2005, Seoul, Korea, 25-29 July.

Gatebe, C. K. (2005), Airborne measurements of bidirectional reflectance of natural ecosystem in southern Africa, Kenya Agricultural Research Institute, Nairobi, Kenya, 1 March.

Gatebe, C. K. (2005), Airborne Measurements of bidirectional reflectance of natural ecosystem in southern Africa, Kenya Meteorological Department, Nairobi, Kenya, 28 February.

Gatebe, C. K. (2005), Characterization of aerosols and surface optical properties from airborne spectral measurements of directional reflectance, Morgan State University, Baltimore, Maryland, 17 November.

Gatebe, C. K. (2005), Spectral, angular, and vertical characterization of aerosols for radiative properties, Aerocenter Seminar Series, 14 June.

Gatebe, C. K. and M. D. King (2005), Airborne spectral measurements of surface-atmosphere anisotropy for several surfaces and ecosystems, The 9th International Symposium on Physical Measurements and Signature in Remote Sensing (ISPMSRS), Beijing, China, October 17-19.

Gatebe, C. K., G. T. Georgiev, J. J. Butler and M. D. King (2006), Insights from laboratory and airborne BRDF measurements for satellite remote sensing, The 4th International Workshop in Multiangular Measurements and Models, Sydney, Australia, 20-25 March.

Gatebe, C. K., M. D. King and A. Omar (2005), NASA Initiative in the Greater Horn of Africa, The 15th Climate Outlook Forum, Mombasa, 3 March.

Gaya- Piqué, L. R., H. R. Kim, R. R. B. von Frese, M. Chiappini, P. T. Taylor, and A. V. Golynsky (2005), Spherical cap harmonic modeling of the Antarctic magnetic anomaly map, AGU Spring Meeting, New Orleans, LA, 23-27 May.

Gaya-Piqué, L.R., H. R. Kim, R. R. B. von Frese, M. Chiappini, P. T. Taylor, and A. V. Golynsky (2005), Spherical cap representation of the ADMAP compilation, IAGA 2005 Scientific Assembly, Toulouse, France, 18-29 July.

Gleason, J. F., E. Bucsela, E. Celarier, M. Wenig, J. P. Veefkind, K. F. Boersma, E. Brinksma (2005), Nitrogen Dioxide (NO_2) Total and Tropospheric Vertical Column Densities from OMI on EOS Aura, paper presented to AGU Fall Meeting 2005, San Francisco, CA, 5-9 December.

Goldberg, R. A., P. A. Webb, W. D. Pesnell, and H. D. Voss (2005), The nature of icy dust particles in the polar summer mesosphere from rocket measurements during DROPPS, AGU Fall Meeting, San Francisco, CA, 5-9 December.

Groisman, P., and R. Lawford (2005), Northern Eurasia Earth Science Partnership Initiative (NEESPI), US-Russia Bilateral on Meteorological Data Exchange, Obninsk, Russia, 24-29 October.

Groisman, P., S. Bartalev, R. Lawford and C. Schmullius (2005), Northern Eurasia Earth Science Partnership Initiative (NEESPI) Science Plan Overview and First Steps, European Geophysical Union (EGU), Vienna, Austria, 27 April.

Groisman, P., S. Bartalev, R. Lawford, and C. Schmullius (2005), Northern Eurasia Earth Science Partnership Initiative (NEESPI), 31st International Symposium on Remote Sensing of Environment, St. Petersburg, Russia, 19-24 June.

Groisman, P., S. Bartalev, R. Lawford, C. Schmullius, and I. Koval (2005), Northern Eurasia Earth Science Partnership Initiative (NEESPI), 5th International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, California, 24 June.

Gu, G., R. F. Adler, G. J. Huffman, and S. Curtis (2005), Global Rainfall Variability and Changes Derived from the GPCP Monthly Product—Interannual Variability, Volcanic Impact, and Long-Term Change/Trend, paper presented at 5th International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, CA, June.

Guenther, B., A. Wu, and X. Xiong (2005), Study of Terra MODIS reflective solar bands calibration stability and mirror side difference using simultaneous MODIS and MISR observations, Proceedings of SPIE – Passive Optical Remote Sensing of the Atmosphere and Clouds IV, 5652, 200-209.

Han, M., S. A. Scott, P. O. G. Persson, and J.-W. Bao (2005), A modeling study of the along-front variability of a Pacific narrow cold frontal rainband, 11th Conference on Mesoscale Processes, Albuquerque, NM, October.

Han, M., S. A. Scott, P. O. G. Persson, and J.-W. Bao (2005), A modeling study of the along-front variability of a Pacific narrow cold frontal rainband, PMM Science Team Meeting, Monterey, CA, December.

Hernandez Sr., O., R. R. von Frese and H. R. Kim (2005), Tectonic analysis of Northwestern South America from satellite and surface magnetic data, AGU Fall Meeting, San-Francisco, CA, 5-9 December.

Heymsfield, G. M., L. Belcher, L. Tian, L. Li and A. Heymsfield (2005), Florida Convective Updraft Structure Using Dual Wavelength Airborne Radar Measurements. 32nd Conference on Radar Meteorology, Albuquerque, NM, 24-29 October.

Heymsfield, G. M., L. R. Belcher, L. Tian, L. Li, and A. Heymsfield (2005), Florida Convective Updraft Structure Using Dual Wavelength Airborne Radar Measurements. AMS 32nd Radar Conference, Albuquerque, NM, 23-29 October.

Holben, B. N., A. Smirnov, T. F. Eck, O. Dubovik, A. Sinyuk, A. Vermeulen, I. Slutsker, D. Giles, W. W. Newcomb, M. Sorokine, A. Ho, D. Tanre, and P. Goloub (2005), A preview of the Version 2.0 algorithm advances for the AERONET database, IEEE Workshop on remote sensing of atmospheric aerosols, Tucson, AR, 5-6 April.

Holben, B. N., A. Smirnov, T. F. Eck, O. Dubovik, A. Sinyuk, A. Vermeulen, I. Slutsker, D. Giles, W. W. Newcomb, M. Sorokine, A. Ho, D. Tanre, and P. Goloub (2005), A preview of the Version 2.0 algorithm advances for the AERONET database, IEEE Workshop on remote sensing of atmospheric aerosols, Tucson, AR, 5-6 April.

Hou, A. Y., S. Zhang, X. Lin, and P. Norris (2005), Exploring New Pathways in Cloud/Precipitation Assimilation. International Association of Meteorology and Atmospheric Sciences (IAMAS) Conference 2005, Beijing, China, 2-11 August.

Houser, P. R., C. D. Peters-Lidard, S. V. Kumar, and Y. Tian (2005), The Land Information System, NASA Earth Science Technology Conference, College Park, MD, 28-30 June.

Houser, P. R., D. Belvedere, B. Imam, R. Lawford, F. Policielli, R. Schiffer, C. A. Schlosser, H. Gupta, D. Toll, C. Welty, C. Vorosmarty, and D. Matthews (2005), The Water Cycle Solutions Network, Climate Science in Support of Decision Making, Arlington, VA, 14-16 November.

Jacob, S. D. (2005), Evaluation of HYCOM Upper Ocean Mixing Parameterizations, invited paper presented at the Coupled Hurricane Ocean Modeling meeting, Camp Springs, MD, April.

Jacob, S. D. (2005), Ocean Response Modeling and Evaluation, invited paper presented at the Air-Sea Interactions in Tropical Cyclones Workshop, Camp Springs, MD, May.

Jacob, S. D. (2005), Oceans, Ice and Coastal Zone, invited presentation at the GEST/ JCET Founders Symposium, Greenbelt, MD, July.

Jacob, S. D., L. K. Shay, and G. R. Halliwell (2005), Evaluation of Upper Ocean Mixing Parameterizations, invited paper presented at the Interdepartmental Hurricane Conference, Jacksonville, FL, March.

Jacob, S. D., L. K. Shay, and G. R. Halliwell (2006), Upper Ocean Response during Extreme Forcing Events, paper presented at the 13th Layered Ocean Modeling Conference, Miami, FL, February.

Jacob, S. D., L. K. Shay, G. R. Halliwell, and D. LeVine (2005), Evaluation of Upper Ocean Mixing Parameterizations during Hurricanes, paper presented at the 12th Layered Ocean Modeling Conference, Miami, FL, January.

Kabanov, D. M., M. V. Panchenko, V. V. Polkin, S. M. Sakerin, B. N. Holben, A. V. Smirnov, S. A. Beresnev, S. Y. Gorda, V. A. Poddubnyi, S. V. Nikolashkin, M. A. Tashchilin, and G. I. Kornienko (2005), Results of atmospheric aerosol monitoring over Asian part of Russia in 2004 (Program AEROSIBNET), XII International Symposium on Atmospheric and Ocean Optics, Atmospheric physics, Tomsk, Russia, 27-30 June.

Kabanov, D. M., M. V. Panchenko, V. V. Polkin, S. M. Sakerin, B. N. Holben, A. V. Smirnov, S. A. Beresnev, S. Y. Gorda, V. A. Poddubnyi, S. V. Nikolashkin, M. A. Tashchilin, and G. I. Kornienko (2005), Results of atmospheric aerosol monitoring over Asian part of Russia in 2004 (Program AEROSIBNET), XII International Symposium on Atmospheric and Ocean Optics, Atmospheric physics, Tomsk, Russia, 27-30 June.

Kelly, R., J. Foster, and M. Tedesco (2005), The AMSR-E Snow Water Equivalent Product: Algorithm Development, Validation and Status, Eastern Snow Conference, Waterloo, Ontario, 7-10 June.

Kim, E. J., M. Tedesco, and J. P. Walker (2006), Observed Scaling Behavior of Snow and Soil Moisture Signatures from the CLPX and NAFE Campaigns, MicroRad 2006, Puerto Rico, February.

Kim, E. J. and M. Tedesco (2005), Spatial Scaling of Snow Observations and Microwave Emission Modeling During CLPX and Appropriate Satellite Sensor Resolution, AGU 2005 Fall Meeting, San Francisco, CA, 5-8 December.

Kim, E. J., and M. Tedesco (2006), An integrated snow radiance and snow physics modeling framework for cold land surface modeling, MicroRad 2006, Puerto Rico, February.

Kim, E., M. Tedesco, R. Kelly, and G. Liston (2005), Scaling Behavior of Brightness Temperatures and retrieved Snow Water Equivalent During CLPX, International Geoscience and Remote Sensing Symposium, Seoul, Korea, 25-29 July.

Kim, H. R., L. R. Gaya-Pique, R. R. B. von Frese, A. V. Golynsky, P. T. Taylor, and J. W. Kim (2005), Antarctic Lithospheric Magnetic Anomaly Attributes, IAGA 2005 Scientific Assembly, Toulouse, France, 18-29 July.

Kim, H. R., R. R. B. von Frese, A. V. Golynsky, P. T. Taylor, and J. W. Kim (2005), Modeling Antarctic magnetic crustal thickness using Ørsted, CHAMP and ADMAP data, AGU Fall Meeting, San Francisco, CA, 5-9 December.

Kim, J. W., J. S. Hwang, H. R. Kim, S.- H. Lee, and K. D. Min (2005), Geomagnetic field analysis from KOMPSAT-1, International Geoscience and Remote Sensing Symposium (IGARSS 2005), Seoul, Korea, 20 July.

Kim, M.-J., J. R. Wang, R. Meneghini, J. A.Weinman, and G. Skofronick-Jackson (2005), Microwave remote sensing of falling snow. IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Seoul, Korea, July.

Kotlyakov, K., R. Lawford, and P. Groisman (2005), Northern Eurasia Earth Science Partnership Initiative (NEESPI), CliC Science Steering Committee, Copenhagen, Denmark, 9 November.

Krotkov, N., A. Krueger, S. Carn , R. Dickerson, J. Stehr, J. Hains, L. Marufu, C. Li, and Z. Li (2005), Validating AURA OMI tropospheric SO_2 data with aircraft in-situ measurements, presentation at AURA validation meeting, Lanham, MD, 21-25 September.

Krotkov, N., J. Herman, A. Cede, and G. Labow (2005), Partitioning between aerosol and NO_2 absorption in the UVA, paper presented at SPIE annual meeting, San Diego, CA, 31 July.

Krotkov, N., S. Carn, A. Krueger, P. K. Bhartia, and K. Yang (2005), Band Residual Difference algorithm for retrieval of SO_2 from the AURA OMI, presentation at Aura Science Team Meeting on Atmospheric Constituents with Participation from ENVISAT, GOME, and ACE, Hague, Netherlands, 8-10 November.

Krotkov, N., S. Carn, A. Krueger, P. K. Bhartia, and K. Yang (2005), 1st Year of SO_2 data from OMI, presentation at First Year of AURA/OMI observations meeting, FMI, Helsinki, Finland, 2-4 November.

Kumar S. V., C. D. Peters-Lidard, J. Eastman, Y. Tian, and P. R. Houser (2006), Evaluation of the impact of land surface heterogeneity representations on mesoscale fluxes, paper presented at the 86the AMS Annual Meeting, Atlanta, GA, 29 January - 2 February.

Kumar S. V., C. D. Peters-Lidard, W.-K. Tao, Y. Tian, J. Eastman, X. Zeng, S. E. Lang, and P. R. Houser (2006), Advanced computing , data access and distribution technologies , and interoperable tools enable high resolution coupled land - atmosphere prediction, poster presented at the 86the AMS Annual Meeting, Atlanta, GA, 29 January - 2 February.

Kumar, S. V., C. D. Peters-Lidard, J. L. Eastman, and P. R. Houser (2005), High Resolution coupled land-atmosphere system using LIS and WRF enabled by ESMF. Weather Research and Forecasting Model Users Workshop, Boulder, CO, 27-30 June.

Kumar, S. V., C. D. Peters-Lidard, J. L. Eastman, Y. Tian, and P. R. Houser (2006), Evaluation of the impact of land surface heterogeneity on mesoscale fluxes, 20th Conference on Hydrology, 86th American Meteorological Society Annual Meeting, Atlanta, GA, 29 January-2 February.

Kumar, S. V., C. D. Peters-Lidard, W.-K. Tao, J. L. Eastman, Y. Tian, R. Shi, X. Zeng, S. Lang, and P. R. Houser (2006), Advanced computing, data access and distribution technologies and interoperable tools enabling high resolution coupled land-atmosphere prediction, 20th Conference on Hydrology, 86th American Meteorological Society Annual Meeting, Atlanta, GA, 29 January-2 February.

Kumar, S. V., J. Eylander, and C. D. Peters-Lidard (2005), High Resolution Land Surface Modeling with the next generation land data assimilation system. American Geophysical Union Fall Meeting, San Francisco, CA, 5-9 December.

Lang, S. L., X. Zeng, W.-K. Tao, C. D. Peters-Lidard, J. L. Eastman, S. V. Kumar, and Y. Tian (2006), High-resolution CRM simulations from IHOP: Land-atmosphere interactions. 20th Conference on Hydrology and 18th Conference on Climate Variability and Change. Atlanta, GA, February.

Lang, S., X. Zeng, W.-K. Tao, C. D. Peters-Lidard, J. L. Eastman, S. V. Kumar, and Y. Tian (2006), High resolution CRM simulations form IHOP: Land atmosphere interactions, 18th Conference on Climate Variability and Change, 86th American Meteorological Society Annual Meeting, Atlanta, GA, 29 January-2 February.

Lawford, R. (2005) An Emerging Agenda to Help Secure Access to Clean Water for Future Generations, Spatial Information for Civil Society, Enschede, The Netherlands, 15 December.

Lawford, R. (2005), A Perspective on NEESPI (Northern Eurasia Earth Science Partnership Initiatives) Issues, IGBP/ NEESPI Meeting, San Francisco, CA, 4 December.

Lawford, R. (2005), A View of GEWEX from the International GEWEX Project Office (IGPO), GEWEX Hydrometeorology Panel Meeting, Melbourne, Australia, 27 September.

Lawford, R. (2005), An Introduction to IGWCO and the Water Element within GEOSS, National Academy of Sciences - Committee of Hydrologic Sciences, Washington, DC, 29 June.

Lawford, R. (2005), An Introduction to Water Cycle Programs, Seminar at Beijing Normal University, Beijing, China, 2 August 2.

Lawford, R. (2005), An Overview of GEWEX and its Linkages with CLIVAR, US CLIVAR Summit, Keystone, CO, 16 August.

Lawford, R. (2005), An Overview of GEWEX and the Context it provides for the International Satellite Land Surface Climatology Project (ISLSCP), International Satellite Land Surface Climatology Project Workshop, University of Maryland, Baltimore County, Baltimore, MD, May.

Lawford, R. (2005), An Update on GEWEX, Meeting of the GEWEX Radiation Panel, Paris, France, 6 October.

Lawford, R. (2005), Applying Planetary Water and Energy Cycle Science and Observations to Regional Issues in East Asia and Mongolia, First Conference on Global Change in Mongolia, Ulanbataar, Mongolia, 28 July.

Lawford, R. (2005), Applying Planetary Water and Energy Cycle Science and Observations to Regional and Local Decision Making in the Water Sector, Climate Science in Support of Decision Making, Arlington, VA, 14-16 November.

Lawford, R. (2005), COPES and GEWEX: A Search for Balance and Mutual Benefit, National Academy of Sciences - Committee on Hydrologic Sciences, Washington, DC, 29 June.

Lawford, R. (2005), GEWEX and AMMA, Interagency Briefing on AMMA at the Climate Change Science Program Office, Washington, DC, 9 August 9.

Lawford, R. (2005), Introduction to Capacity Building and the Role of IGWCO and GEWEX, IGWCO/CONAE Capacity Building Workshop in South America, Buenos Aires, Argentina, 26 October.

Lawford, R. (2005), Introduction to the IGWCO (Integrated Global Water Cycle Observations) Theme, the GEOSS (Global Earth Observations System of Systems) Water Activities and the Global Energy and Water Cycle Experiment (GEWEX), Meeting of NERC-Funded Scientists with GEWEX and IGWCO Leaders, London, England, 27 October.

Lawford, R. (2005), Introduction to the Integrated Global Water Cycle Observations (IGWCO) Theme and the GEOSS Water Cycle Societal Benefit Area, Asian Water Cycle Workshop, Tokyo, Japan, 2 November.

Lawford, R. (2005), Local Action on Capacity Building in Latin America, Preparatory Meeting of Non-Governmental Organizations of North America for the World Water Forum IV, Mexico City, Mexico, 30 November.

Lawford, R. (2005), Potential Areas for NASA/GSFC Contributions to GEWEX and Related Programs, NASA Seminar, Goddard Space Flight Center, Greenbelt, MD, 1 December.

Lawford, R. (2005), Recent Activities of the Integrated Global Water Cycle Observations (IGWCO) Theme and the Global Earth Observations System of Systems Water Cycle Societal Benefit Area, GEWEX Hydrometeorology Panel Meeting, Melbourne, Australia, 28 September.

Lawford, R. (2005), Status Report on GEWEX and WCRP Monsoon Activities, MAHASRI (GAME Follow-on) Planning Meeting, Tokyo, Japan, 1 November.

Lawford, R. (2005), The Global Energy and Water Cycle Experiment (GEWEX) and Mountain Hydroclimatology, American Geophysical Union - Fall Meeting, San Francisco, CA, 9 December.

Lawford, R. (2005), The Global Energy and Water Cycle Experiment (GEWEX), Asian Water Cycle Workshop, Tokyo, Japan, 3 November.

Lawford, R. (2005), The Global Energy and Water Cycle Experiment and Related Water Cycle Activities, Seminar at the Chinese Academy of Meteorological Sciences (CAMS), Beijing, China, 3 August.

Lawford, R. (2005), The Integrated Global Water Cycle Observations (IGWCO) Theme, US Space Exploration Science Workshop, University of Maryland, College Park, Maryland, 9 March.

Lawford, R. (2005), The Northern Eurasia Earth Science Partnership Initiative (NEESPI), Chinese Academy of Sciences Briefing, Beijing, China, 2 August.

Lawford, R. (2005), WCRP and IGWCO perspectives on the Global Precipitation Mission (GPM), Global Precipitation Mission Workshop, Tokyo, Japan, 7 November.

Lawford, R. and P. Groisman, 2005: The Northern Eurasia Earth Science Partnership Initiative (NEESPI): Initiative Description and First Steps, GEWEX Hydrometeorology Panel Meeting, Melbourne, Australia, September 29, 2005

Lawford, R. G. (2005), A Short Introduction to the Global Energy and Water Cycle Experiment (GEWEX), Fourth CEOP Science Meeting/First IGWCO Planning Workshop, Tokyo, Japan, 28 February.

Lawford, R. G. (2005), An Introduction to the Global Energy and Water Cycle Experiment (GEWEX), Seminar, Meteorological Institute, Bonn University, Bonn, Germany, 22 February.

Lawford, R. G. (2005), An Opportunity for Scientists to Participate in Addressing Global Climate and Water Issues, Splinter Session on GEWEX at the European Geophysical Union (EGU), Vienna, Austria, 24-29 April.

Lawford, R. G. (2005), Background to GEWEX and the Role of the GEWEX Americas Prediction Project within GEWEX, National Academy of Sciences Review of the GEWEX Americas Prediction Project (GAPP) Science and Implementation Plan, Washington, DC, 30 March 30.

Lawford, R. G. (2005), Climate as a Basis for Integrating Between Themes, IGOS Theme Team Leaders Meeting, Tokyo, Japan, 2 March.

Lawford, R. G. (2005), Combining Global Water Cycle Observations and Science to Address Issues Related to the Protection and Development of the World's Water Resources, invited keynote address to UN/Austria/European Space Agency Symposium on Space Systems: Protecting and Restoring Water Resources, Graz, Austria, 13 September.

Lawford, R. G. (2005), GEWEX and its contributions to Climate Science and Earth Observations, American Meteorological Society Annual Meeting, San Diego, CA, January.

Lawford, R. G. (2005), GEWEX Overview: A Brief Introduction to GEWEX/ iLEAPS Linkages, iLEAPS Scientific Steering Group, Vienna, Austria, 29 April.

Lawford, R. G. (2005), International Hydroclimate Research and Observation Programs and their Contributions to Predicting Climate Variability and Change and Assessing their Significance for Sustainable Water Development, invited presentation to International Conference on Integrated Assessment of Water Resources and Integrated Global Change: A North-South Analysis, Bonn, Germany, 23 February.

Lawford, R. G. (2005), Introduction to the Integrated Global Water Cycle Observations Theme of the Integrated Global Observing Strategy Partnership, Joint Fourth CEOP Science Meeting/First IGWCO Planning Workshop, Tokyo, Japan, 28 February.

Lawford, R. G. (2005), Past and Possible Future GEWEX Contributions to Emerging Earth Observation Programs, 5th International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, California, 23 June.

Lawford, R. G. (2005), Report of the Activities of the International GEWEX Project Office for 2004, Annual Meeting of the GEWEX Scientific Steering Group, Kunming, China, 31 January.

Lawford, R. G. (2005), Review of Action Items from the 2004 GEWEX Executive Meeting, Annual Meeting of the GEWEX Scientific Steering Group, Kumming, China, 31 January.

Lawford, R. G. (2005), Review of the Integrated Global Water Cycle Observations Theme Activities Since November 2004, Integrated Global Observing Strategy Partnership Meeting, Geneva, Switzerland, 26 May.

Lawford, R. G. (2005), Summary of the Session: Building Capacity for the Application of Space Technologies for Water-Related Challenges, UN/Austria/European Space Agency Symposium on Space Systems: Protecting and Restoring Water Resources, Graz, Austria, 15 September.

Lawford, R. G. (2005), Update on the Integrated Global Water Cycle Observations Theme, Committee of Earth Observation Systems - Strategic Implementation Team, Geneva, Switzerland, May.

Lawford, R. G. (2005), Update on the Integrated Global Water Cycle Observations Theme of IGOS-P, Joint Scientific Committee for the World Climate Research Programme, Guayaquil, Ecuador, 18 March.

Lawford, R. G., and P. Groisman (2005), An Introduction to the Northern Eurasia Earth Science Partnership Initiative (NEESPI): History, Objectives & Strategy, National Science Foundation Briefing, Washington, DC, 21 April 21.

Lawford, R., and P. Groisman (2005), Overview of NEESPI: Where We've Been and Where We're Going., NEESPI Interagency Meeting, Washington, DC, 7 June.

Lawford, R., and P. Try (2005), GEWEX Through the Years, 5th International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, CA, 22 June 22.

Lee, M.-I., and M. J. Suarez (2005), Coupled "swamp" aqua-planet experiments, APE Workshop, Univ. Reading, UK, April.

Lee, M.-I., and S. D. Schubert (2005), Issues for global modeling / diurnal cycle activities, NAME Data Workshop, Mexico City, Mexico, March.

Lee, M.-I., M. J. Suarez, K.-M. Kim, and K.-M. Lau (2005), Diurnal and semi-diurnal cycles of convection in an aqua-planet GCM, APE Workshop, Univ. Reading, UK, April.

Lee, M.-I., S. D. Schubert, M. J. Suarez, J. T. Bacmeister, P. J. Pegion, I. M. Held, J. J. Ploshay, N.-C. Lau, A. Kumar, H.-K. Kim and J.-K. E. Schemm, H.-K. Kim, and S.-H. Yoo (2005), Warm Season Diurnal Cycle Simulations Over North America - Sensitivities to Model Resolution, NOAA's 30th Annual Climate Diagnostics and Prediction Workshop, State College, PA, October.

Lee, M.-I., S. D. Schubert, M. J. Suarez, P. J. Pegion, B. Kirtman, K. Pegion, A. Kumar, B. Jha, and D. E. Waliser (2005), An Analysis of Subseasonal Variability in the NCEP CFS and NASA NSIPP Coupled GCMs, NOAA's 30th Annual Climate Diagnostics and Prediction Workshop, State College, PA, October.

Li, J.-L., D. E. Waliser, J. H. Jiang, D. L. Wu, W. Read, J. W. Waters, H. Su, A. M. Tompkins, L. Donner, J.-D. Chern, W.-K. Tao, R. Atlas, K. N. Liou, Y. Gu, D. Genio, M. F. Khairoutdinov, and A. Gettelman (2005), Comparisons of EOS Microwave Limb Sounder (MLS) Cloud Ice Measurements with Model Representations: Initial Results. The 5th International Scientific Conference on the Global Energy and Water Cycle, Orange County, CA, 20-24 June.

Li, J.-L., D. E. Waliser, J. H. Jiang, W. Read, J. W. Waters, D. Wu, A. M. Tompkins, L. Donner, J.-D. Chern, W.-K. Tao, R. Atlas, Y. Gu , K. N. Liou, D. Genio, M. F. Khairoutdinov, and A. Gettelman (2005), Discoveries on Upper-Tropospheric Cloud Ice from MLS: Comparisons with Analyses and GCMs. AGU 2005 Fall Meeting, San Francisco, CA, 5-9 December.

Li, L. G. M. Heymsfield, J. Knuble, and S. Rodriguez (2005), A dual-beam X-band Doppler radar for tropical storm research on high altitude UAVs. 32nd Conference on Radar Meteorology, Albuquerque, NM, 24-29 October.

Li, X., W.-K. Tao, A. Khain, and J. Simpson (2005), Interaction of cloud microphysics and dynamics simulated in a PRE-STROM squall line case. AGU 2005 Joint Assembly, New Orleans, Louisiana, 23-27 May.

Li, X., W.-K. Tao, A. Khain, and J. Simpson (2006), Aerosol impact on deep precipitation processes: A modeling study. ESSIC Seminar, Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, March.

Li, X., W.-K. Tao, A. Khain, and J. Simpson (2006), Aerosol impacts on Precipitation Processes: A Modeling Study. Aero Center Seminar, NASA/GSFC, January.

Li, X., W.-K. Tao, A. Khain, J. Simpson, and C. Kummerow (2005), Brightness temperature simulated by a cloud-resolving mode. IAMAS 2005, Beijing, China, August.

Li, X., W.-K. Tao, A. Khain, J. Simpson, and D. Johnson (2005), Interaction of cloud microphysics and storm dynamics: A case study. Workshop on Cloud Aerosol Interaction, Miami Beach, FL, March.

Liao, L., and R. Meneghini (2005), Snow retrieval by airborne radar. The 32th International Radar Conference, Albuquerque, NM, 24-28 October.

Liao, L., and R. Meneghini (2005), Spaceborne dual-wavelength radar techniques for retrieval of hydrometeor profiles. IGARSS'05, Seoul, Korea, 25-29 July.

Liao, L., and R. Meneghini (2005), Validation of TRMM PR over Melbourne, FL for the period 1998-2005, PMM Workshop, Monterey, CA, December.

Lin, X., A. Hou, and S. Zhang (2005), Assimilation of precipitating and cloud processes, paper presented at the Precipitation Science Team Meeting, Monterey, CA, December.

Lin, X., A. Hou, C.-L. Shie, W.-K. Tao, and Y. Zhou (2006), Observational evaluation of long-term 3-D cloud simulations forced by GEOS reanalysis: Statistics of rainfall and cloud over the CRYSTAL-FACE region, AGU 1006 Joint Assembly, Baltimore, MD 23-26 May.

Lin, X., A. Hou, C.-L. Shie, W.-K. Tao, and Y. Zhou (2006), Observational evaluation of long-term 3-D cloud simulations forced by the NASA GEOS analyses, paper presented at the American Geophysical Union General Assembly, Baltimore, MD.

Liu, A. K., M. K. Hsu, and Y. Zhao (2006), Ocean surface drift by wavelet tracking using ERS-2, and ENVISAT, Proceedings of SeaSAR 2006, Advances in SAR Oceanography from ENVISAT and ERS missions, Frascati, Italy, 24-26 January.

Liu, H., J. H. Crawford, R. B. Pierce, D. B. Considine, J. A. Logan, B. N. Duncan, P. Norris, S. E. Platnick, G. Chen, R. M. Yantosca, and M. J. Evans (2005), Radiative effect of clouds on tropospheric chemistry: Sensitivity to cloud vertical distributions and optical properties. 2005 Fall AGU Meeting, San Francisco, CA, 5-9 December.

Lyapustin A., and Y. Wang (2005), ASRVN - a global network for surface reflectance validation, 9th International Symposium on Physical Measurements and Signatures in Remote Sensing, Beijing, China, 17-19 September.

Lyapustin, A. (2006), Near-Constant Contrast (NCC) method of atmospheric correction over land, MODIS Science Team Meeting, Baltimore, MD, 4-6 January.

Lyapustin, A. and Y. Wang (2006), Atmospheric correction around AERONET sites: Development of global land validation dataset, MODIS Science Team Meeting, Baltimore, MD, 4-6 January.

Lyapustin, A., and Y. Wang (2005), Analysis of MODIS-MISR calibration difference over land, MISR Science Team Meeting, Pasadena, CA, 12-14 December.

Lyapustin, A., and Y. Wang (2006), Analysis of MODIS-MISR calibration difference, MODIS Science Team Meeting, Baltimore, MD, 4-6 January.

Lyapustin, A., Y. Wang, J. Martonchik, J. Privette, and B. Holben (2005), Development of the AERONET - based Surface Reflectance Validation Network (ASRVN), 31 International Symposium on Remote Sensing of Environment, St. Petersburg, Russia, 21-24 June.

Maynard, N. G., and B. S. Yurchak (2005), Data and Information Exchange System for the "Reindeer Mapper" project, Regional GOFC-GOLD workshop "Observations of Land Cover and Needs of Research Projects in Northern Eurasia," Saint Petersburg, Russia, 18-19 June.

Maynard, N. G., B. S. Yurchak, Y. A. Sleptsov, J. M. Turi, and S. D. Mathiesen (2005), Space Technologies for Enhancing the Resilience and Sustainability of Indigenous Reindeer Husbandry in the Russian Arctic, Proceedings of the 31st International Symposium on Remote Sensing of Environment, Saint Petersburg, Russia, 20-24 June.

Maynard, N. G., B. S. Yurchak, Y. A. Sleptsov, J. M. Turi, and S. D. Mathiesen (2005), Combining Technologies & Traditional Knowledge, Third World Reindeer Herders' Congress, Yakutsk, Russia, 17-20 March.

Meneghini, R., and L. Liao (2005), On the equivalence of the dual-wavelength and polarimetric equations for estimation of the raindrop size distribution. The 32th International Radar Conference, Albuquerque, NM, 24-28 October.

Meneghini, R., L. Liao, and L. Tian (2005), The potential for water vapor and precipitation estimation with a differential-frequency radar, The 32nd International Radar Conference, Albuquerque, NM, 24-28 October.

Meng, C. J., K. Mitchell, C. Lu, H. Wei, C. Peters-Lidard, and P. Houser (2005), Assessment of the land surface energy and water budgets using NOAA Global Forecast System and NASA Land Information System, GEWEX 5th International Scientific Conference on the Global Energy and Water Cycle, Orange County, CA, June.

Meng, C. J., K. Mitchell, C. Lu, H. Wei, J. Eastman, C. Peters-Lidard, P. Houser, and M. Rodell (2005), Optimal land initialization for the NCEP Global Forecast System using the NASA Land Information System, AMS Annual Meeting, San Diego, CA, January.

Meng, C. J., K. Mitchell, H. Wei, and J. Gottschalk (2005), Using GLDAS to derive optimal land states for CFS/Noah testing in the NOAA Climate Test Bed, NOAA 30th Annual Climate Diagnostics and Prediction Workshop, State College, PA, October.

Nerger, L. and W. W. Gregg (2006), Constraining a global three-dimensional ocean biogeochemical model by SeaWiFS ocean Chlorophyll data using a local SEIK filter, 2006 Ocean Sciences Meeting, Honolulu, HI, 20-24 February.

Novak, M., J. R. Morrison, H. Feng, J. Campbell, and T. Moore, Predictability of the Spectral Shape Of CDOM in Different Optical Water-types: Implications for Semi-analytical Algorithm Development, AGU/ALOS Ocean Sciences Meeting, Honolulu, HW, 20-24 February.

Olsen, M. A. (2005), Seasonality and location of ozone STE, presented at the SPARC/IGAC Workshop on Processes Governing the Chemical Composition of the Extra-Tropical UTLS, Mainz, Germany, May.

Olsen, M. A., A. R. Douglass, R. S. Stolarski, and M. R. Schoeberl (2005), Stratosphere-troposphere exchange trend from changing sea-surface temperatures, paper presented at the American Geophysical Union (AGU) Fall Meeting, San Francisco, CA, 5-9 December.

Olsen, M. A., R. S. Stolarski, M. L. Gupta, J. E. Nielsen, and S. Pawson (2005), A model study of the effect of ozone depletion on lower-stratospheric structure, paper presented at the American Meteorological Society (AMS) Middle Atmosphere Meeting, Cambridge, MA, June.

Olson, W. S., and M. Grecu (2005), The Training of a Satellite Passive Microwave Algorithm Using Combined Radar-Radiometer Estimates of Precipitation and Latent Heating, IAMAS, Beijing, China, 2-11 August.

Olson, W. S., M. Grecu, C.-L. Shie, and S. A. Braun (2006), Estimation of precipitation and latent heating distributions in tropical convection from a combined analysis of passive microwave and spaceborne radar observations, the AMS 27th Conference on Hurricanes and Tropical Meteorology, Monterey, CA, 24-28 April.

Oltmans, S. J., A. M. Thompson, B. J. Johnson, O. R. Cooper, J. T. Merrill, G. A. Morris, M. J. Newchurch, F. J. Schmidlin, and D. W. Trasick (2005), Tropospheric ozone across North America during Summer 2004, EOS Trans. AGU, 86(52), Fall Meet. Suppl, Abstract, A51D-0093.

O'Neill, N. T., A. Smirnov, T. F. Eck, S. Sakerin, and D. Kabanov (2005), Analysis of dust and marine aerosol optical depth spectral-curvature information in the UV to SWIR wavelength regions, AGU Fall Meeting, San-Francisco, CA, 5-9 December (Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract A33A-0854).

O'Neill, N. T., A. Smirnov, T. F. Eck, S. Sakerin, and D. Kabanov, Analysis of dust and marine aerosol optical depth spectral-curvature information in the UV to SWIR wavelength regions, AGU Fall Meeting, Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract A33A-0854, San Francisco, CA, 5-9 December.

O'Neill, N. T., A. Smirnov, T.F. Eck, S. Sakerin, and D. Kabanov (2005), Analysis of dust and marine aerosol optical depth spectral-curvature information in the UV to SWIR (Short Wave Infrared) wavelength regions, AGU Fall Meeting, San Francisco, CA, 5-9 December.

Pap, J. M., and G. Thuillier (2005), Invited talk and panel leadership for CAWSES Theme 4 “Space Climatology” Working Group 1, Solar Variability and Earth's Climate, CAWSES meeting, 26 June – 3 July.

Pap, J., and L. Floyd (2005), Evaluation of Solar Indices Used in Semi-Empirical Irradiance Models, AGU 2005 Fall Meeting, San Francisco, CA, 5-9 December.

Pap, J., P. McIntosh and R. Wilson (2005), Solar Irradiance Modeling and New Perspectives, Solar Variability and Earth's Climate, CAWSES meeting, 26 June - 3 July.

Persson, P. O. G., J.-W. Bao, S. A. Braun, D. P. Jorgensen, B. A. Walter, and M. Han (2005), Comparison of simulated kinematic and moisture fields with airborne in-situ and Doppler radar observations in a convective cold front over the eastern Pacific Ocean, 11th Conference on Mesoscale Processes, Albuquerque, NM, October.

Peters-Lidard, C. D, S. V. Kumar, Y. Tian, J. Geiger, M. Garcia, M. Rodell, P. R. Houser, E. F. Wood, J. Sheffield, K. Mitchell, J. Meng, P. Dirmeyer, B. Doty, and J. Adams (2005), The production and value of high resolution land surface data assimilation products from the NASA/GSFC Land Information System, 5th International Scientific Conference on the Global Energy and Water Cycle, Orange County, CA, 20-24 June.

Peters-Lidard, C. D. , S. V. Kumar, W.-K. Tao, J. L. Eastman, X. Zeng, S. Lang, and P. R. Houser (2005), Coupling high resolution earth system models using advanced computational technologies, NASA Earth Science Technology Conference, College Park, MD, 28-30 June.

Peters-Lidard, C. D., W.-K. Tao, M. Bosilovich, M. Rodell, W. Lau, J. Snatanello, and J.-D. Chern (2005), NASA model and observation products for the study of land atmosphere coupling and its impact on water and energy cycles. NASA NEWS team kick-off meeting, New York, NY, 7-9 September.

Peters-Lidard, C. D., W.-K. Tao, S. V. Kumar, J. L. Eastman, X. Zeng, S. E. Lang, Y. Tian, and P. R. Houser (2006), High-Resolution Convective Modeling using WRF and GCE coupled to LIS. 20th Conference on Hydrology and 18th Conference on Climate Variability and Change. Atlanta, GA, February.

Peters-Lidard, C. D., W.-K. Tao, S. V. Kumar, J. L. Eastman, X. Zeng, S. Lang, Y. Tian, and P. R. Houser (2006), High Resolution Convective Modeling using WRF and GCE coupled to LIS, 20th Conference on Hydrology, 86th American Meteorological Society Annual Meeting, Atlanta, GA, 29 January – 2 February.

Peters-Lidard, C., W.-K. Tao , P. R. Houser , S. Kumar , J. Eastman , S. Lang , Y. Tian and X. Zeng (2005), High - resolution Convective Modeling using WRF Coupled to NASA's Land Information System (LIS), paper presented at the Fifth WRF Land Surface Modeling Workshop, Boulder, CO, September.

Piketh, S. J., K. Ross, J. Reid, R. Bruintjes, T. Eck, and A. Mandoos (2005), Characteristics of atmospheric aerosols over the United Arab Emirates, AGU Fall Meeting, San Francisco, CA, 5-9 December.

Potts, L. V., L. R. Gaya-Pique, H. R. Kim, Y. Yi, R. R. B. von Frese, and S. Wells (2005), Comparison of Polar Magnetic Activity Indices and Ionosphere Total Electron Content, AGU Spring Meeting, New Orleans, LA, 23-27 May.

Qu, J. J., X. Hao, W. Wang, L. Wang, M. Kafatos, and L. Wu (2005), A Study of African Dust Storm and Its Effects on Tropical Cyclones over Atlantic Ocean from Space, IGARSS 2005 Proceeding, CD-ROM publication, Seoul, Korea, 25-29 July.

Reichle, R. H., R. D. Koster, and P. Liu (2006), Assimilation of global AMSR-E surface soil moisture into the NASA Catchment land surface model, 86th AMS Annual Meeting, Atlanta, GA, 29 January - 2 February.

Reichle, R. H., S. Mahanama, R. D. Koster, J. D. Radakovich, and M. G. Bosilovich (2006), A new look at the assimilation of satellite retrievals of land surface temperature into a land surface model, 86th AMS Annual Meeting, Atlanta, GA, 29 January - 2 February.

Reichle, R. H., S. Mahanama, R. D. Koster, J. D. Radakovich, and M. G. Bosilovich (2006), A new look at the assimilation of satellite retrievals of land surface temperature into a land surface model, 20th Conference of Hydrology at 86th AMS Annual Meeting, Atlanta, GA, 29 January - 2 February.

Russ, M. E. and A. Mannino (2006), Microbial lability of dissolved organic carbon in the Chesapeake Bay and Mid-Atlantic Bight, poster presented at the 2006 Ocean Sciences Meeting, Honolulu, Hawaii, February.

Schmid, B., R. Ferrare, C. Flynn, R. Elleman, D. Covert, A. Strawa, E. Welton, D. Turner, H. Jonsson, J. Redemann, J. Eilers, K. Ricci, A. Hallar, M. Clayton, J. Michalsky, A. Smirnov, B. Holben, and J. Barnard (2005), How well can we measure the vertical profile of tropospheric aerosol extinction?, European Aerosol Conference 2005, Ghent, Belgium, 28 August-2 September.

Seneviratne, S. I., R. H. Reichle, and R. D. Koster (2005), Assimilation of basin-scale water-balance estimates of monthly terrestrial water-storage variations in a catchment-based land surface model, 5th International Scientific Conference on the Global Energy and Water Cycle, Orange County, CA, 20-24 June.

Seneviratne, S. I., R. H. Reichle, R. D. Koster, and M. Hirschi (2005), Assimilation of basin-scale estimates of terrestrial water storage variations in a catchment-based land surface model, General Assembly of the European Geosciences Union, Vienna, Austria, 24-29 April.

Shie, C.-L., W.-K. Tao, A. Hou, and X. Lin (2006), Simulated convective systems using a cloud resolving model: Impact of large scale temperature and moisture forcing using observations and GEOS3 reanalyses. Paper presented at the American Meteorological Society Tropical Conference, Monterey, CA, April.

Shie, C.-L., W.-K. Tao, A. Hou, and X. Lin (2006), Simulated convective systems using a cloud resolving model: Impact of large-scale temperature and moisture forcing using observations and GEOS-3 reanalysis, the AMS 27th Conference on Hurricanes and Tropical Meteorology, Monterey, CA, 24-28 April.

Shie, C.-L., W.-K. Tao, A. Hou, X. Zeng, X. Lin, and Y. Zou (2006), Simulated long-term cloud systems using a cloud resolving model. paper presented at the American Geophysical Union General Assembly, Baltimore, MD, May.

Shie, C.-L., W.-K. Tao, A. Hou, X. Zeng, X. Lin, Y. Zhou, W. Olson, and H. Juang (2006), Simulated long-term cloud systems using a cloud resolving model, AGU 1006 Joint Assembly, Baltimore, MD, 23-26 May.

Shie, C.-L., W.-K. Tao, and A. Hou (2005), Preliminary results of simulated convective system using a Goddard Cumulus Ensemble (GCE) Model with large-scale temperature and moisture forcing

using observations and GEOS-3 numerical results, Pan GCSS Meeting 2005, Athens, Greece, 16-20 May.

Shige, S., Y. N. Takayabu, W.-K. Tao, and C.-L. Shie (2006), Spectral retrieval of latent heating profiles from TRMM PR data.: Algorithm improvement and heating estimates over tropical ocean regions, the AMS 27th Conference on Hurricanes and Tropical Meteorology, Monterey, CA, 24-28 April.

Smirnov, A., B. N. Holben, O. Dubovik, T. F. Eck, I. Slutsker, and D. Giles (2005), Historical overview of the aerosol optical depth measurements over the oceans, IEEE Workshop on remote sensing of atmospheric aerosols, Tucson, AR, 5-6 April.

Smirnov, A., B. N. Holben, O. Dubovik, T. F. Eck, I. Slutsker, and D. Giles (2005), Historical overview of the aerosol optical depth measurements over the oceans, IEEE Workshop on remote sensing of atmospheric aerosols, Tucson, AR, 5-6 April.

Smirnov, A., B. N. Holben, O. Dubovik, T. F. Eck, I. Slutsker, P. Goloub, M. V. Panchenko, and N. T. O'Neill (2005), Aerosol Robotic Network of Sun/sky radiometers (AERONET) - an internationally federated network for aerosol optical properties characterization: past, present and future, 31 International Symposium on Remote Sensing of Environment, Saint Petersburg, Russia, 20-24 June.

Smirnov, A., B. N. Holben, S. M. Sakerin, D. M. Kabanov, I. Slutsker, L. A. Remer, R. Kahn, A. Ignatov, M. Chin, T. L. Diehl, M. Mishchenko, L. Liu, T. L. Kucsera, D. Giles, T. F. Eck, O. Torres, and O. Kopelevich (2005), Ship-based aerosol optical depth measurements in the Atlantic Ocean, comparison with satellite retrievals and GOCART model, AGU Fall Meeting, San-Francisco, CA, 5-9 December (Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract A22B-03).

Smirnov, A., B. N. Holben, S. Sakerin, D. Kabanov, I. Slutsker, L.A. Remer, R. Kahn, A. Ignatov, M. Chin, T. L. Diehl, M. Mishchenko, L. Liu, T. L. Kucsera, D. Giles, T. F. Eck, O. Torres, and O. Kopelevich (2005), Ship-based Aerosol Optical Depth Measurements in the Atlantic Ocean, Comparison with Satellite Retrievals and GOCART Model, paper presented at the AGU Fall Meeting, San Francisco, California, 5-9 December.

Smirnov, A., S. Sakerin, B. Holben, D. Kabanov, I. Slutsker, D. Giles, and O. Kopelevich (2005), Ship-based aerosol optical depth measurements in the Atlantic Ocean, European Geosciences Union General Assembly 2005, Vienna, Austria, 24-29 April (Geophysical Research Abstracts, Vol. 7, 08458, 2005).

Sorooshian, S., and R. Lawford (2005), Report to the JSC on the GEWEX Project, Joint Scientific Committee of the World Climate Research Programme 26th Session, Guayaquil, Ecuador, 16 March.

Stajner, I., K. Wargan, H. Hayashi, L.-P. Chang, and S. Pawson (2005), Diverse applications of occultation data in ozone assimilation, Solar Occultaion Satellite Science Team Workshop, Columbia, MD, June.

Stajner, I., K. Wargan, H. Hayashi, L.-P. Chang, S. Pawson, L. Froidevaux, and N. Livesey (2005), Assimilation of OMI and MLS ozone data, Aura Science Team Meeting, Pasadena, CA, March.

Stenchikov, G., D. Diner, R. Kahn, A. Smirnov, and B. N. Holben (2005), Transport and microphysics of aerosols released by collapse and fire of the World Trade Center on September 11, 2001 as observed by AERONET and MISR, AGU Fall Meeting, San-Francisco, CA, 5-9 December (Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract A22B-06).

Stodt, R., K. Arsenault, A. Pinheiro, J. Nigro, and P. Houser (2005), Investigating the Use of LIS and Satellite Products to Improve Evapotranspiration Estimates, Paper (H43H-07) presented at American Geophysical Union (AGU) Fall Meeting, San Francisco, CA, 5-9 December.

Strahan, S. E. (2005), Trends from long-term data records and models: what do they tell us about our ability to predict?, invited presentation to the Spring Meeting of the American Geophysical Union, New Orleans, LA, 23-27 May.

Strahan, S. E. (2006), The extratropical tropopause region in the GMI-FVGCM 2ox2.5o Combo Model: Evaluation with aircraft data sets, Atlanta, GA, 11-13 January.

Strahan, S. E. and B. C. Polansky (2005), Implementation issues in chemistry and transport models, presented to the Process Oriented Validation of Chemistry Climate Models Workshop, Boulder, CO, 17-19 October.

Stubbs, T. J., J. S. Halekas, W. M. Farrell, R. R. Vondrak, and G.T. Delory (2006), Global modeling of the electrostatic lunar surface potential, Lunar Planet. Sci. Conf. XXXVII, #2217.

Sud, Y. C., M. Chin, G. K. Walker, T. Diehl and W. K. M. Lau (2005), Influence of aerosols on McRAS-Clouds employing GOCART sulfate-aerosol climatology and specified aerosol activation and rainout algorithms in the GEOS-4 GCM, paper presented at the 4th AEROCOM Workshop, Oslo, Norway, 15-17 June.

Sun, C., M. Rienecker, C. Keppenne *et al.* (2005), Salinity impacts in the GMAO ocean data assimilation, JCSDA Science Workshop on Satellite Data Assimilation, NOAA Science Center, Camp Spring, MD, 20-21 April.

Sun, C., M. Rienecker, C. Keppenne, J. Jacob, R. Kovach, and N. Kurkowski (2006), Sensitivity of Salinity Assimilation Implementations on Global Ocean Analysis, 2006 Ocean Sciences Meeting, Honolulu, Hawaii, 20-24 February.

Sun, J., X. Xiong, D. Wang, H. Oudrari, W. Barnes, and B. Guenther (2005), MODIS calibration results from Lunar observations, CALCON 2005.

Tanskanen, A., A. Määttä, N. Krotkov, J. Kaurola, T. Koskela, A. Karpetchko, V. Fioletov, and G. Bernhard (2005),Validation of the OMI surface UV data, presentation at American Geophysical Union (AGU) Fall Meeting, San Francisco, CA, 5-9 December.

Tao, W.-K., J. Chern, S. Lang, C. Peters-Lidard, X. Li, J. Simpson, S. Kumar, C.-L. Shie, and X. Zeng (2006), Goddard multi-scale modeling systems, the 4th US-Korea Workshop on Mesoscale Meteorology and Regional Climate, Seoul, Korea, 13-15 February.

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Wu, M. L., S. D. Schubert, and M.-I. Lee (2005), Role of Easterly Waves and the MJO in Gulf of California Moisture Surges, NOAA's 30th Annual Climate Diagnostics and Prediction Workshop, State College, PA, October.

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Yu, H., Y. J. Kaufman, M. Chin, L. A. Remer, N. Bellouin, O. Boucher, S. A. Christopher, R. Kahn, and N. G. Loeb (2005), Assessment of Terra-based estimates of aerosol direct forcing, Terra Fusion Workshop, Williamsburg, VA, 15-17 August.

Yurchak, B. S., and N. G. Maynard (2005), Remote Sensing & Space Technologies For Reindeer Husbandry - Synthetic Aperture Radar Application. Third World Reindeer Herders' Congress. Yakutsk, Russia, 17-20 March.

Yurchak, B. S., and N. G. Maynard (2005), Time-Series SAR Observations of Chukotka Sub-Arctic Lakes and Forest-Tundra Fire Scars. Proceedings of the 31st International Symposium on Remote Sensing of Environment, Saint Petersburg, Russia, 20-24 June.

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Zeng, X., W.-K. Tao, M. Zhang, S. Lang, S. Xie, and C.-L. Shie (2005), Dimensionality sensitivity of precipitation for ARM cases, the DOE/ARM Cumulus Parameterization Modeling Workshop Group 2005 Fall Meting, Stony Brook, New York, 12-13 October.

Zhao, Y., A. K. Liu, and M. K. Hsu (2005), Internal wave refraction by bottom features and wavelet tracking of surface drift from SAR images, ONR NLIWI Progress and Planning meeting, San Francisco, CA, 24-26 August.

Zhao, Y., and A. K. Liu (2005), Arctic Sea Ice Motion Characteristic and Its Application, NASA HQ Review of GSFC Physical Oceanography Research Program, GSFC, Greenbelt, MD, 18 July.

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Zhou, Y., S.-C. Tsay, P.-S.Yeh, and W. Wiscombe (2005), Lossless Data Compression of Hyperspectral Data using Physical Model: How much improvement can it provide? COAA spring workshop, Collage Park, MD, April.

Ziemke, J. R., S. Chandra, and P. K. Bhartia (2005), A 25-year data record of atmospheric ozone from TOMS Cloud Slicing: Implications for trends in stratospheric and tropospheric ozone, presentation at Solar Occultation Satellite Science Team Workshop, Columbia, Maryland, 6-9 June.

Ziemke, J. R., S. Chandra, and P. K. Bhartia (2005), Aura OMI/MLS tropospheric ozone, presentation at Aura Validation Meeting, Greenbelt, MD, September.

Ziemke, J. R., S. Chandra, and P. K. Bhartia (2005), Stratospheric column ozone from OMI and MLS, presentation at Aura Validation Meeting, Greenbelt, Maryland, September.

Ziemke, J. R., S. Chandra, and P. K. Bhartia (2005), TES and OMI total column ozone comparisons, presentation at Aura Validation Meeting, Greenbelt, Maryland, September.

Grant Proposals and Status

(sorted by funding agency)

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Land Information System Assimilation Enhancements	AFWA	Peters-Lidard (GSFC)	Kumar (GEST)	Funded
Next generation land data assimilation and land surface modeling system	AFWA	Peters-Lidard (GSFC)	Kumar (GEST)	Funded
Land Information System precipitation climatology improvements	AFWA	Peters-Lidard (GSFC)	Kumar (GEST), Y. Tian (GEST), Garcia (GEST)	Funded
Distributed Modeling Support for the Romanian Destructive Water Abatement (DESWAT) program	Baron Advanced Meteorological Systems, Inc.	Kumar (GEST), Garcia (GEST)	Gochis (NCAR), Yates (NCAR)	Funded
Validation of New Generation Satellite Data for Agricultural and Rangeland Applications in the Tropics	Danish National Research Council	Fensholt (Univ. of Copenhagen, Denmark)	Anyamba (GEST), Shisanya (Kenyatta Univ., Kenya)	Funded
DoD-GEIS utilization of remotely sensed satellite data to monitor and forecast Rift Valley fever and other vector-borne disease outbreaks	DoD - Walter Reed Army Institute for Research	Anyamba (GEST), Tucker (GSFC)	Chretien (DoD), Bedno (DoD), Linthicum (USDA/CMAVE)	Funded
Advances in 3-dimensional atmospheric radiation: I3RC toolbox, interactive aerosol retrieval, and cloud inhomogeneity parameterization	DoE	Cahalan (GSFC)	Wen (GEST), Oreopoulos (JCET)	Funded
Multi-scale Modeling Studies of Cloud and Precipitation Processes Using ARM Data	DoE	Tao (GSFC)	Chern (GEST), Peters-Lidard (GSFC)	Pending
Re-calibration of ARM MFRSR spectral irradiance data for estimation of column atmospheric absorption under clear and cloudy conditions	DOE-ARM	Krotkov (GEST)		Not Awarded
Identification and Detection of Coastal HAB species and other Conditions Favoring the Outbreaks by Remote Sensing	EPA	Warner (JCET)	Chu (JCET), Berkoff (GEST)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Evaluation of Antarctic and Tropical Forest sites for Calibration and Cross-Calibration of Spaceborne L-band Radiometers. Submitted to ESA	ESA	Ed Kim (GSFC)	Walker (Univ. of Melbourne), Tedesco (GEST), Le Vine, Bindschadler (GSFC)	Funded
The Application of NASA EOS MODIS Data to Agricultural Assessment and Forecasting by the USDA Foreign Agricultural Service	Foreign Agricultural Service (USDA) and NASA	Justice (UMCP)	Anyamba (GEST), Tucker (GSFC), Doorn (USDA/FAS), Reynolds (USDA/FAS)	Funded
Integrating MODIS and NPP VIIRS Observations into the USDA FAS Decision System	Foreign Agricultural Service (USDA) and NASA	Justice (UMCP)	Hansen (South Dakota State Univ.), Descloitres (SSAI), Reynolds (USDA/FAS), Anyamba (GEST), Tucker (GSFC), Masuoka (GSFC), Tarpley (NOAA)	Funded
The Sensitivity of Regional Climate to Anthropogenic Emissions from Urban Areas in Latin American Countries	IAI	Darrel Baumgarden (UNAM, Mexico)	Gassó (GEST)	Not Awarded
Great Lakes Region Ozonesonde Network (GLRON)	Indiana Space Grant Consortium	Morris (GEST)		Funded
Airborne Transport Of Aerosols Into The South Atlantic Ocean: Assessment Of Sources, Horizontal Fluxes, Iron Fertilizing Potential And Impact On Climate	Inter-American Institute for Global Change Research	Diego Gaiero (National Univ. of Córdoba, Argentina)	Gassó (GEST), Farid Chemale Jr. (Univ. Federale, Brasil), Susana Bidart (Univ. Nacional, Argentina)	Funded
Climate Variability and Agricultural Production in the Semi-Arid Lands of Eastern Kenya	International START-IGBP Secretariat	Shisanya (Kenyatta Univ., Kenya)	Anyamba (GEST)	Funded
Subseasonal and synoptic variability in the tropical eastern Atlantic and its neighboring continent	NASA	Adler (NASA)	Huffman (SSAI), Gu (GEST), Curtis (ECU)	Funded
Continuation of the Stratospheric General Circulation with Chemistry Project	NASA	Douglass (GSFC)	Olsen (GEST), Kawa (GSFC)	Pending
Arctic Climate Study Using Sea Ice Motion Derived from QuikSCAT, Midori-2 SeaWinds, and Other Satellite Data	NASA	Antony Liu	Zhao (GEST)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Near Real - time NASA Volcanic Cloud Data for NOAA, FAA, and USGS Decision Support Systems	NASA	Krueger (JCET)	Carn (JCET), Krotkov (GEST), Serafino (NOAA), Marianne Guffanti (USGS), Yang (GEST)	Funded
The Use of NASA Land Data Assimilated Products to Improve Flood and Drought Risk Analysis and Forecasting for Water Resources Management in the Columbia River Basin	NASA	Arsenault (GEST)	Houser (GMU), D. Matthews (USBR-retired), S. Hunter (USBR), Steffen Meyer (USBR), and Warren Sharp (USBR)	Funded
Moist physics development for GEOS-5 using single column models with parameterized dynamics	NASA	Bacmeister (GEST)		Funded
Improving gravity wave parameterization for next generation troposphere/middle atmospheric general circulation models	NASA	Bacmesiter (GEST)		Funded
Improved estimates of CO_2 fluxes using CO_2/CO correlations: An integration approach through observations and simulations	NASA	Bian (GEST)		Pending
Improving Water Supply and Demand Forecasting Using NASA Earth Science Data with USBR Decision Support Systems	NASA	Boyle (U. Nevada/DRI)	D. Toll (GSFC), K. Arsenault (GEST), R. Allen (U. Idaho), Steve Bowser (USBR), D. Frevert (USBR), R. Stodt (USBR), D.Clark (USBR)	Pending
Backtrajectory, AERONET, MODIS, GOCART, MPLNET, Aerosol Synergism (BAMGOMAS)	NASA	Brent Holben (GSFC)	Weaver (GEST)	Funded
Wavelength and time dependence of solar forcing of Earth's atmosphere-ocean system	NASA	Cahalan (GSFC)	Wen (GEST), Pilewskie	Funded
I3RC workshop and 3D community tools applied to assessments and improvements of cloud retrievals from Terra, Aqua, and THOR offbeam data	NASA	Cahalan (GSFC), Marshak (GSFC)	Frank Evans, Oreopoulos (JCET), Varnai (JCET), Wen (GEST)	Funded
Tropospheric ozone data products derived from TOMS measurements and comparisons with 3D chemical transport models	NASA	Chandra (GEST)	Ziemke (GEST)	Funded
The validation of Aura ozone measurements using Cloud Slicing	NASA	Chandra (GEST)	Ziemke (GEST), Xuexi Tie (NCAR)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Enhancing the Department of Defense Global Emerging Infections Surveillance & Response System (DoD-GEIS) through Integration of NASA Earth-Sun System Research Results	NASA	Chretien (DoD)	Anyamba (GEST), Linthicum (USDA/ CMAVE), Tucker (GSFC)	Pending
Study of the Effect of Dust Radiative and Microphysical Properties on Precipitation and Enerty Budget Using a A-Train Setellite Measurements and Cloud-Resolving Model	NASA	Chu (JCET)	deSouza-Machado (JCET), Torres (JCET), Shie (GEST), R.-F. Lin (GEST), Demoz (JCET), Ellsworth Welton, X. Li (GEST)	Pending
Plasma Beam and Regolith Interactions in the Presence of Metal Surfaces	NASA	Clark (L3 Communications)	Keller, Nuth, Stubbs (GEST), Farrell, Curtis, Rilee	Not Awarded
Electrostatic Dust Removal and Collection Devices for Planetary Surfaces	NASA	Clark (L3 Communications)	Keller, Nuth, Stubbs (GEST), Farrell, Curtis, Rilee	Pending
Improved Estimates of Aerosol Direct and Indirect Effect on Climate Through Inclusion of Aerosol Microphysics and Aerosol Indirect Effect Paramerizations in GMAO's GEOS-5 Atmospheric GCM Aerosol	NASA	Colarco (UMCP)	Bacmeister (GEST)	Funded
Observational and theoretical constraints on lunar surface and dust charging processes	NASA	Delory (UC Berkeley)	Halekas (UC Berkeley), Stubbs (GEST)	Funded
A Global Modeling Initiative (GMI) Study of the Sensitivity of Transport to Meteorological Fields	NASA	Duncan (GEST)	Chin (GSFC), Loretta Mickley, Olsen (GEST)	Funded
A New Paradigm for Parameterizations in Earth System Models	NASA	Eastman (GEST), Peters-Lidard (NASA)	Kumar (GEST), Tian (GEST), Pielke	Not Awarded
Evaluation of multi-scale microwave forward models and hydrological retrievals for the North Slope of Alaska and forested snow-covered areas	NASA	Ed Kim (GSFC)	Tedesco (GEST)	Not Awarded
Assessing current and future passive microwave water and energy cycle observational capabilities through multi-satellite resampling	NASA	Ed Kim (GSFC)	Tedesco (GEST), Armstrong (NSIDC), Brodzik (NSIDC)	Not Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Multi-Sensor, Multi-Parameter Radiance-Based Assimilation for Snow and Cold Lands	NASA	Ed Kim (GSFC)	Tedesco (GEST), J. Foster, D. Hall, R. Kelly, J. Walker	Pending
Global estimates of evaporation from variational assimilation of multi-platform land surface temperature into a dynamic model of the surface energy balance	NASA	Entekhabi (MIT)	Reichle (GEST), Margulis (UCLA)	Funded
The connection between Martian atmospheric electricity and reactive chemistry	NASA	Farrell (GSFC)	Mahaffy, Delory, Marshall, Renno, Glavin, Zworkin, Stubbs (GEST), Atreya	Not Awarded
Estimating Earth's Climate by Assimilating Satellite Observations of the Ocean and Atmosphere with a Coupled Earth System Model	NASA	Fukumori	Tong Lee, Michael Ghil, Dmitri Kondrashov, Anthony Rosati, Shian-Jiann Lin, George Philander, Sun (GEST)	Funded
Retrievals of Precipitating Snow and Light Rain Using Synergistic Multi-Sensor Active and Passive Observations	NASA	Gail Skofronick Jackson	M.-J. Kim (GEST), Grecu (GEST), Olson (JCET), J. R. Wang (GSFC), Johnson (JCET)	Pending
Distributed modeling support for the Romanian Destructive Waters Abatement (DESWAT) program	NASA	Garcia (GEST)	Sujay Kumar (GEST), David Gochis (NCAR), David Yates (NCAR)	Funded
Closure in Model Prediction, In-Situ Measurements and Remote Sensing of Aerosol Mass Concentration	NASA	Gassó (GEST)	Si-Chee Tsay (GSFC), Norm O'Neill (Univ. of Sheerbrooke, Canada)	Funded
Analysis of the performance of the VIRSS Aerosol Land and Ocean Algorithm	NASA	Gassó (GEST)	Omar Torres (JCET), Jim Gleason (NASA)	Funded
Spectral, Angular, and Vertical Characterization of Aerosols AND Surface for Radiative Properties	NASA	Gatebe (GEST), King (GSFC)	Dubovik (CNES, France)	Funded
Spectral and Angular Characterization of Ocean Reflectance Using Multiple Sensors with Emphasis on Coastal Zones	NASA	Gatebe (GEST), King (GSFC)	Dubovik (CNES, France), McClain (GSFC)	Not Awarded
Atmospheric Data Assimilation Development	NASA	Gelaro (GSFC)	Bacmeister (GEST)	Funded
Forecasting Vector-borne Diseases for Public Health using Earth-Sun Science	NASA	Glass (John Hopkins Univ.)	Anyamba (GEST)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Polar Magnetic Properties and Mass Dynamics from Ørsted and CHAMP Satellite Geopotential Observations (extended)	NASA	H.R. Kim (GEST)		Funded
Lunar Surface Charging and Dust Transport During Extreme Space Weather Events	NASA	Halekas (UC Berkeley)	Stubbs (GEST), Brain, Fillingim	Pending
A Skewed-PDF Model for Moist-Turbulence and Shallow-Convection in Data Assimilation Systems	NASA	Helfand (NASA)	Bacmeister (GEST), Norris (GEST)	Not Awarded
Improved Understanding of TRMM PR Derived Products Using Aircraft Radar Observations	NASA	Heymsfield (GSFC)	L. Tian (GEST), L. Li (GEST)	Funded
CRYSTAL-FACE Analyses	NASA	Heymsfield (GSFC)	L. Tian (GEST), L. Li (GEST)	Funded
Studies of Tropical Cyclone Genesis and Tropical Cirrus Using ER-2 Radars	NASA	Heymsfield (GSFC)	L. Tian (GEST), Racette, L. Li (GEST)	Funded
High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)	NASA	Heymsfield (GSFC)	Lihua Li (GEST), James Careswell, Daniel Schaubert	Funded
Assimilation of Cloud/Precipitation Information from CloudSat and A-Train in a Cloud-Resolving Model for Improving Global Forecast and Climate Systems	NASA	Hou (GSFC)	Tao (NASA), Norris (GEST), Posselt (CSU)	Pending
Demonstrating NASA Snow Observations and Modeling in Operational Decision Support	NASA	Houser (GMU)	D. Cline (NOHRSC), Arsenault (GEST), L. Rundquist, (RFC), D. Luna (RFC)	Pending
Ground validation activities at mid-latitude coastal site	NASA	J.-J. Wang (GEST)		Pending
Synergistic use of multiple satellite instruments to derive tropospheric ozone in anticipation of improved measurement capabilities from OMI and other data products from EOS-CHEM	NASA	Jack Fishman (LARC)	Chandra (GEST), Ziemke (GEST)	Funded
Variability of Oceanic Vertical Structure, Transports and Air-Sea Fluxes on Seasonal to Decadal Time Scales	NASA	Jacob (GEST)		Not Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Aquarius: Global Modeling of Sea Surface Salinity	NASA	Jacob (GEST)	Le Vine (GSFC)	Funded
Estimates of Sea Surface Roughness from GLAS	NASA	Jacob (GEST)	Beckley (SGT), Luthcke (GSFC), Le Vine (GSFC), Ray (GSFC)	Pending
Surface Variability and Subsurface Structure of North Pacific	NASA	Jacob (GEST)		Pending
Improved polar precipitating snow/snow depth maps through the synergistic analysis of satellite multi-sensor physically-consistent atmospheric and surface retrievals	NASA	Foster (GSFC)	Markus (GSFC), G. Jackson (GSFC), Tedesco (GEST), M.-J. Kim (GEST), J. Wang (GSFC), Bindschadler (GSFC), Bliven (GSFC)	Pending
Improved derivation of snowfall in polar and sub polar regions through synergistic multi-sensor satellite analysis	NASA	Foster (GSFC)	Skofronick-Jackson (GSFC), J. Wang (GSFC), Bindschadler (GSFC), Ed Kim (GSFC), Bliven (GSFC), Tedesco (GEST), M.-J. Kim (GEST)	Pending
Air Quality Monitoring and Source Strength Estimation using OMI Image Sequence Analysis	NASA	Gleason (GSFC)	Wenig (GEST)	Pending
Critical Climate Issues by Extension of Analysis Developed for Geoscience Laser Altimeter System Data	NASA	Spinhirne (GSFC)	Lancaster (GEST)	Pending
The Global Distribution and Effects of Aerosol and Clouds from ICESat, Application of Combined Atmospheric and Surface Analysis	NASA	Spinhirne (GSFC)	Lancaster (GEST)	Pending
Improvement to the Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)	NASA	James Wang (GSFC)	Frank Evans, Paul Racette, Heymsfield (GSFC), Lihua Li (GEST)	Funded
Ground water sustainability and management in the Magrheb Region of North Africa	NASA	Jasinski (NASA)	T. Engman (SSAI), C. Voss (USGS), F. Lemoine (GSFC), K. Arsenault (GEST), M. Roddell (GSFC), I. Verstraeten (USGS)	Pending
Measurements of Trace Gas (NO_2, SO_2, HCHO, O_3) Amounts, Aerosol Properties, and UV Irradiance for Aura Validation Using Overlapping Spectral Measurements from Four Different Instruments	NASA	Jay Herman (GSFC)	Labow (SSAI), Cede (SSAI), Krotkov (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Utilization of Space Based Lidar Data in Numerical Aerosol Models to Study Dust Outbreak Phenomenology	NASA	Jeffrey Reid (NRL)	Gassó (GEST), Douglas Westphal (NRL)	Pending
Using Infrared Satellite Data for Assimilation and Model Evaluation	NASA	Joanna Joiner (GSFC)	Atlas (NOAA), Duncan (GEST), Weaver (GEST), Kevin Bowman	Funded
OMI Tropospheric NO_2 Column Retrievals	NASA	Kenneth Pickering (GSFC)	Bucsela (GEST)	Pending
Effects of land-atmosphere coupling strength and soil moisture initialization uncertainty on subseasonal rainfall and temperature prediction	NASA	Koster (GSFC)	Suarez (GSFC), Reichle (GEST), Bacmeister (GEST)	Not Awarded
Effect of soil moisture initialization uncertainty on subseasonal rainfall and temperature prediction	NASA	Koster (GSFC)	Reichle (GEST), Suarez (GSFC), Shepherd (GSFC)	Pending
Mapping SO_2 emissions with NASA AURA Ozone Monitoring Instrument (OMI) and GOCART model for air quality and climate science	NASA	Krotkov (GEST)	Arlin Krueger (JCET), S. Carn (JCET), R. Dickerson (UMCP)	Funded
Analysis and Simulation of the Influence of the Saharan Air Layer on Tropical Cyclogenesis Using Data from NAMMA-06 and A-Train Satellite	NASA	L. Wu (GEST)		Pending
The Swift Neurological Acceleration of Atmospheric Photochemistry and Aerosol Calculations [SNAPA]: Development and Application to Atmospheric Chemistry and Aerosol Simulations with a Focus on UT/LS Ozone	NASA	Lary (GEST)	Douglass (GSFC), Hamse Mussa (GSFC), Duncan (GEST), Herzog (GFDL), Kenneth Pickering, Dale Allen (UMCP)	Funded
Assimilation of Constituents for Evaluation and Intercomparison of Aura Observations (ACEi-Aura)	NASA	Lary (GEST)		Funded
The Swift Neurological Acceleration of Atmospheric Photochemistry and Aerosol Calculations [SNAPA]: Development and Application to Atmospheric Chemistry and Aerosol Simulations with a Focus on UT/LS Ozone	NASA	Lary (GEST)	Dale Allen (UMCP), Douglass (GSFC), Duncan (GEST), Herzog (GFDL)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
An Objectively Optimized Sensor Web	NASA	Lary (GEST)	Connerton (GSFC), Seablom (GSFC), Schoeberl (GSFC), Talabac (GSFC), Tornetta (GSFC)	Pending
Heads-Up! Health, Environment and National Assessment Decision Support Systems for Urban Pollution	NASA	Lary (GEST)	Neff (UMBC), Boothe (CDC), Stephanie Davis (CDC), Zonderman (NIH), Evans (NIH), Round (MA Env. Agency), Sattler (UM Baltimore), Baier-Anderson (UM Baltimore), Squibb (UM Baltimore), Kelley-Moore (UMBC)	Pending
Multiple factors affecting the African Easterly Jet (AEJ) and cyclone development over the tropical Atlantic	NASA	Lau (GSFC)	Reale (GEST), da Silva (NASA)	Pending
A General Framework and System Prototype for the Self-Adaptive Earth Predictive Systems (SEPS)—Dynamically Coupling Sensor Web with Earth System Models	NASA	Liping Di (George Mason Univ.)	James Smith (GSFC), Lary (GEST)	Pending
Unified Non-Lambertian 3-D Retrieval and Validation of Land Surface Reflectance From MODIS	NASA	Lyapustin (GEST)	Y. Wang (GEST), I. Slutsker	Funded
Analysis and Validation of the Aerosol and Surface Reflectance EDRs over Land for the Visible/Infrared Imaging Radiometer Suite	NASA	Lyapustin (GEST)	Y. Wang (GEST), J. Privette	Funded
Integration of energy and water cycle research products in a global land surface modeling and assimilation system	NASA	M. Rodell (NASA) and R. Reichle (GEST)	C.D. Peters-Lidard (NASA), J. Meng (GEST), S.V. Kumar (GEST)	Funded
Cryospheric Experimental Synthetic Aperture Radiometer (CESAR): A UAV-mounted synthetic aperture radiometer for cryospheric applications	NASA	Markus (GSFC)	Bindschadler (GSFC), Geoffrey Bland, Peter Hildebrand, Lawrence Hilliard, Richard Kelly,Wes Lawrence, David LeVine, Christopher Ruf, Christopher Shuman	Not Awarded
Integration of Energy and Water Cycle Research Products in a Global Land Surface Modeling and Assimilation System	NASA	Matthew Rodell	Houser (GMU), Peters-Lidard (GSFC), J. Meng (GEST), Reichle (GEST), S. Kumar, H. Kato	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Use of Neural Network Techniques in the Physics Parameterizations of Atmospheric General Circulation Models	NASA	Max Suarez (GSFC)	Lary (GEST)	Funded
The Impact of Emissions and Long-range Transport on Regional Air Quality: An Analysis with a Global-regional Atmospheric Modeling System	NASA	Mian Chin (GSFC)	Dale Allen, Huisheng Bian (GEST), Allen Chu, Thomas Diehl (GEST), Bryan Duncan (GEST), Georg Grell, Tom Kucsera, Hongbin Yu (GEST)	Pending
An Interactive Approach to Improve the Qualities of CALIPSO Data and Global Aerosol Transport Model for Climate and Air Quality Studies	NASA	Mian Chin (GSFC)	Dubovik (GSFC), Richard Ferrare, Ralph Kahn, Orga Kalashnikova, Ali Omar, Spinhirne (GSFC), David Winker, Hongbin Yu (GEST)	Pending
Aerosol radiative forcing and effects on tropospheric chemistry: Modeling and uncertainty analysis in the GMI framework	NASA	Mian Chin (GSFC)	Bian (GEST)	Funded
An integrated approach of enhancing the quality of Aura aerosol retrieval, supporting Aura validation, and analyzing Aura data	NASA	Mian Chin (GSFC)	Bian (GEST)	Funded
The Impact of emissions and long-range transport on regional air quality: An analysis with a global–regional atmospheric modeling system	NASA	Mian Chin (GSFC)	Bian (GEST)	Pending
An Integrated Approach of Supporting Aura Validation, Enhancing the Quality of Aura Aerosol Retrieval, and Analyzing Aura Data	NASA	Mian Chin (GSFC)	Allen (UMCP), Bian (GEST), Diehl (GEST), Dubovik (GEST), Remer (GSFC), Torres (JCET), Wenig (GEST), Yu (GEST)	Funded
Aerosol Radiative Forcing and Effects on Tropospheric Chemistry: Modeling and Uncertainty Analysis in the GMI Framework	NASA	Mian Chin (GSFC)	Bian (GEST), Diehl (GEST), Duncan (GEST), Liu (GEST)	Funded
The Impact of emissions and long-range transport on regional air quality: An analysis with a global-regional atmospheric modeling system	NASA	Mian Chin (GSFC)	Allen (UMCP), Bian (GEST), Diehl (GEST), Duncan (GEST), Grell (NOAA FSL), Kucsera (SSAI), Yu (GEST)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Aerosol radiative forcing and effects on tropospheric chemistry: Modeling and uncertainty analysis in the GMI framework	NASA	Mian Chin (GSFC)	Hongyu Liu, Duncan (GEST), Bian (GEST), Diehl (GEST)	Funded
An Integrated Approach of Supporting Aura Validation, Enhancing the Quality of Aura Aerosol Retrieval, and Analyzing Aura Data	NASA	Mian Chin (GSFC)	Allen (UMCP), Bian (GEST), Diehl (GEST), Dubovik (GEST), Remer (GSFC), Torres (JCET), Wenig (GEST), Yu (GEST)	Funded
Use of atmospheric vertically-resolved GLAS/ICESat aerosol data to evaluate GOCART aerosol and underlying Goddard GEOS-DAS models	NASA	Gupta (FAA)	Bacmeister (GEST), Chin (GSFC), Colarco (GSFC), da Silva (GSFC), Diehl (GEST), Ichoku (SSAI), Palm (SSAI), Spinhirne (GSFC)	Pending
Validation of Non-Coincident Trace Species Measured by AURA Using Trajectory Mapping and Statistical Analysis	NASA	Morris (GEST)	Lynn Sparling (UMBC), Lary (GEST), Mark R. Schoeberl (GSFC)	Funded
Additional Ozonesondes in Houston, Texas in Support of INTEX-B and AURA Validation	NASA	Morris (GEST)	Few (Rice Univ.), Fraser (Rice Univ.), Celarier (GSFC)	Funded
Additional Ozonesondes in Northwest Indiana in Support of INTEX-B and AURA Validation	NASA	Morris (GEST)	Wolf (Valparaiso Univ.)	Funded
Validation of Non-Conicident Trace Species Measured by AURA Using Trajectory Mapping and Statistical Analysis	NASA	Morris (GEST)	Sparling (UMBC), Lary (GEST), Schoeberl (GSFC)	Funded
Improving the representation of cloud processes in GEOS-5: Advanced cloud parameterizations and data assimilation of EOS satellite observations	NASA	Norris (GEST)	Bacmeister (GEST), da Silva (NASA), Hou (GSFC), Oreopoulos (JCET), Platnick (NASA)	Not Awarded
Model Investigations of Upper-Tropopshere/Lower-Stratosphere Water Vapor and Transport into the Stratosphere	NASA	Olsen (GEST)	William Gallus, Jr. (Iowa State Univ.)	Funded
A Prototype Satellite Simulator Model for Combined Radar - Radiometer Precipitation Estimation	NASA	Olson (JCET)	Grecu (GEST)	Funded

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Calibration and Analysis of Global Latent Heating Estimates Using Passive and Active Microwave Sensor Data	NASA	Olson (JCET)	Grecu (GEST), Shie (GEST)	Funded
Improved clouds and radiation in GEOS-5 from global analysis, parameterization and assimilation of A-Train cloud retrievals	NASA	Oreopoulos (JCET)	Norris (GEST), Bacmeister (GEST), Platnick (NASA), da Silva (NASA)	Pending
Validation of Global Circulation Model Cloud Parameterization using GLAS Atmospheric Channel Measurements	NASA	Palm (SSAI)	Norris (GEST), Oreopoulos (JCET), Randall (CSU), Hart (SSAI)	Pending
Variations in Total Solar and Spectral Irradiance Related to Solar Magnetic Activity	NASA	Pap (GEST)		Funded
Long-term Solar Irradiance Variations Over Solar Cycles 21 to 23	NASA	Pap (GEST)		Funded
Bayesian Classification of Multidimensional Magnetograms , Comparison with Solar Irradiance	NASA	Pap (GEST)		Pending
Investigating the Magnetization and Density of the Middle and Lower Crust in Selected Tectonic Regions Using Long-Wavelength Satellite Geopotential Data	NASA	Patrick Taylor	H. R. Kim (GEST), 5 others (International)	Pending
Geopotential Studies of the Martian Crust	NASA	Patrick Taylor	H. R. Kim (GEST), James Frawley	Pending
Atmospheric Modeling, Assimilation, and Source-Sink Estimation for the Carbon Cycle	NASA	Pawson (GSFC)	Collatz (GSFC), Kawa (GSFC), Reichle (GEST), Bacmeister (GEST), Stajner (SAIC), Tangborn (JCET)	Funded
Atmospheric Modeling, Assimilation and Source-Sink Estimation for the Carbon Cycle	NASA	Pawson (GSFC)	Bacmeister (GEST)	Funded
Meteorological and constituent forecasting in support of field mission and validation experiments	NASA	Pawson (GSFC)	Kawa (GSFC), H. Hayashi (GEST), E. Nielsen	Funded
Comprehensive Survey of Cusp Electrodynamics Using FAST Satellite Fields and Particle Data	NASA	Pfaff (GSFC)	Stubbs (GEST), Strangeway, Carlson, McFadden	Funded

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Effect of Pre-Storm Land Surface Charactristics on Land Falling Tropical Cyclones	NASA	Pielke	Eastman (GEST), Nicholls, Nyogi	Not Awarded
Constraining the CO_2 missing sink	NASA	Randy Kawa (GSFC)	Bian (GEST)	Funded
An NACP Thematic Data Center for Modeling and Synthesis	NASA	Ranson (NASA)	Eastman (GEST), Tian (GEST), Morisette (NASA), Hall (NASA), Masek (NASA), Buonoua (NASA), Collatz (NASA), Wolfe (NASA)	Pending
Observing System Experiments (OSE and OSSE) to Evaluate and Enhance the Impact of Current and Future Satellite Observations	NASA	Reale (GEST)	Jusem (GEST)	Funded
Observing System Experiments (OSE and OSSE) to Evaluate and Enhance the Impact of Current and Future Satellite Observations	NASA	Reale (GEST)	Jusem (GEST)	Funded
Assimilation of AMSR-E data and application to the initialization of soil moisture reservoirs in a seasonal forecasting system	NASA	Reichle (GEST)	Koster (GSFC), Zhan (USDA), Bacmeister (GEST), Houser (GMU)	Funded
Enabling improved prediction of the global water and energy cycle through assimilation of land surface hydrological observations from NASA satellites into the NASA GMAO seasonal forecasting and weather prediction system	NASA	Reichle (GEST)	Bosilovich (GSFC), Kelly (Univ. of Waterloo, Canada), Koster (GSFC), Sun (GEST), Todling (SAIC)	Not Awarded
Land data assimilation development and implementation for NASA Water and Energy Cycle Studies	NASA	Reichle (GEST)		Pending
Improving NOAA/NWS River Forecast Center decision support with NASA satellite and Land Information System products	NASA	Restrepo (NOAA)	Peters-Lidard (GSFC), Cosgrove (SAIC), Houser (GMU), Koren (NOAA-NWS Office of Hydrologic Development), Garcia (GEST), Kumar (GEST), Rodell (GSFC), Seo (NOAA), Michael Smith (NOAA), Toll (GSFC)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Improving NOAA/NWS River Forecast Center Decision Support with NASA Satellite and Land Information System Products	NASA	Restrepo (NOAA), Peters-Lidard (GSFC)	Cosgrove (SAIC), Garcia (GEST), Kumar (GEST), Houser (GMU), Koren (NOAA/NWS), Rodell (NASA), Seo (UCAR NOAA/NWS), Michael Smith (NOAA/NWS), Toll (NASA)	Funded
Chemistry-Climate Studies Using General Circulation Models	NASA	Stolarski (GSFC)	Bacmeister (GEST), Douglass (GSFC), Gupta (FAA), Hollandsworth-Frith (SSAI), Kawa (GSFC), Newman (GSFC), Nielsen (SSAI), Olsen (GEST), Pawson (GSFC), Perlwitz (Columbia Univ.), Waugh (Johns Hopkins Univ.)	Funded
Satellite data in modeling and prediction of seasonal-to-interannual climate variability	NASA	Rienecker (GSFC)	Reichle (GEST) et al.	Funded
Global Modeling and Assimilation – Systems and Data Synthesis to Advance NASA's Exploration and Prediction of Earth's Environment	NASA	Rienecker (GSFC)	Reichle (GEST; Collaborator), Suarez (GSFC), Schubert (GSFC), Koster (GSFC), Keppenne (SAIC), Reichle (GEST), Adamec (GSFC), Yee (GSFC), Pan (NOAA), Behringer (NOAA), Higgins (NOAA), Rosati (GFDL)	Funded
Evaluation of Soil Moisture Ocean Salinity (SMOS) Satellite Retrievals of Soil Moisture Using In Situ Soil Moisture Observations from the Ukraine, Mongolia, China, and the United States	NASA	Robock (Rutgers)	Li (Rutgers), Reichle (GEST; Unfunded Collaborator)	Pending
Assimilation of GRACE Derived Terrestrial Water Storage Variations	NASA	Rodell (GSFC)	Reichle (GEST), Lemoine (GSFC)	Funded
Optimal Merging of AMSR-E Snow Water Equivalent and MODIS Snow Cover Observations Through Data Assimilation	NASA	Rodell (GSFC)	Reichle (GEST), Dong (GEST), Kelly (Univ. of Waterloo, Canada), Sun (GEST)	Not Awarded
Measurements, Modeling and Analyses in Support of Aura and Other NASA Satellite Observations of the Earth's Atmosphere	NASA	S. Carn (JCET)	Krotkov (GEST), Krueger (JCET), Schaefer (JCET), Bluth (Michigan Tech. Univ.), A. J. Prata (Independent Consultant)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Characterization of Volcanic Clouds from Top to Bottom with the A – Train	NASA	S. Carn (JCET)	Krotkov (GEST), Krueger (JCET)	Pending
Pathways to predictability on sub-seasonal timescales: Assessing the role of tropical forcing and land surface conditions	NASA	Schubert (GSFC)	Hou (GSFC), Koster (GSFC), Reichle (GEST), Suarez (GSFC), Wu (GSFC)	Funded
Application of Artificial Neural Networks to Integrate Remote Sensing Data into the National Fire Danger Rating System	NASA	Scott Goodrick (USDA)	Lary (GEST)	Pending
SENsor Web System for EarthQuake Early Warning, "SENEQA"	NASA	Shahid Habib (GSFC)	D. Ozounov (GSFC), S. Pulinets (GSFC), G. Cervone (GSFC), Lary (GEST), P. Taylor (GSFC), F. Policelli (GSFC), S. Talabac (GSFC)	Pending
Chemistry-Climate Studies Using General Circulation Models	NASA	Stolarski (GSFC)	Bacmeister (GEST)	Funded
The Global Modeling Initiative: Coordinated activities to reduce uncertainties in chemistry climate models	NASA	Strahan (GEST)	A.R. Douglass (GSFC)	Funded
Electrostatic Transport of Dust in the Lunar Environment	NASA	Stubbs (GEST)	Farrell, Halekas, Hesse, Lowman, Vondrak, Delory	Not Awarded
Ion Injection and Transport in the High-latitude Magnetosphere	NASA	Stubbs (GEST)	Sibeck, Fok, Boardsen, Trattner, Moore	Not Awarded
Ion Injection and Transport in the Earth's Magnetosphere	NASA	Stubbs (GEST)	Sibeck, Fok, Boardsen, Trattner, Moore	Pending
Applications, Evaluation and Improvement of a Coupled, Global and Cloud-Resolving Modeling System	NASA	Tao (GSFC)	Bacmeister (GEST)	Funded
Use of a coupled, global cloud-scale and land surface modeling system to study the impact of land surface processes on energy and water cycles	NASA	Tao (GSFC)	Atlas (NOAA), Peters-Lidard (GSFC), Chern (GEST), W. Lau (GSFC)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Applications, evaluation and improvement of a coupled, global and cloud-resolving modeling system	NASA	Tao (GSFC)	Atlas (NOAA), Chern (GEST), Henry Jin, M. Zhang, Bacmeister (GEST), A. Hou, W. Lau, A. Negri, W. Olson, D. Wang, Z. Wang	Funded
Global multi-sensor active and passive microwave retrieval of snow parameters	NASA	Tedesco (GEST)	Ed Kim, Richard Kelly, Glenn Liston	Pending
Multi-scale Modeling Studies of Tropical Cloud Systems-Aerosol-Chemistry Interactions for TCSP	NASA	W.-K. Tao, J. Simpson, D. Starr	Xiaowen Li (GEST), Chung-Lin Shie (GEST)	Not Awarded
Spectral Signatures of AEROSOLS from Satellite Data	NASA	Weaver (GEST)		Funded
Obtaining a 30 year aerosol record from satellite radiances	NASA	Weaver (GEST)		Pending
An A-train cloud retrieval that accounts for aerosol properties	NASA	Weaver (GEST)		Pending
Automating Electron Density Determinations from Magnetospheric Dynamic Spectra	NASA	Webb (GEST)	Benson, Green	Pending
The use of observational data and a 3D cloud-resolving model to improve the representation of cloud processes in General Circulation Models and to enhance the performance of rainfall and latent heating retrieval algorithms for Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Mission (GPM)	NASA	Wei-Kuo Tao, Henry Jin (Ames Research Center), Joanne Simpson, Peters-Lidard (GSFC)	Chung-Lin Shie (GEST), Steve Lang (SSAI)	Funded
Multi-wavelength Raman Lidar Measurements for Studies of the Aerosol Indirect Effect and AERONET Algorithm Development	NASA	Whiteman (GSFC)	Vesolovskii (GEST)	Funded
Detecting Aerosol-Cloud-Precipitation Interactions in Mixed-Phase Cloud Systems from the Space: A Modeling Guided Data Analysis	NASA	X. Li (GEST)		Pending
Measuring and modeling bi-directional exchanges of ammonia between the atmosphere and biosphere in the south eastern U.S.	NASA	Y. Wu (GEST)	John Walker (EPA), Robarge (NCSU), Warner (JCET), Peters-Lidard (GSFC), Donna Schwede (EPA), Drew Pilant (EPA)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Using GLAS/ICESat Measurements of Aerosol and Cloud Profiles to Constrain the Assessment of Aerosol Radiative Forcing and Influences on Tropospheric Chemistry	NASA	Yu (GEST)	Bian (GEST)	Pending
Using GLAS/ICESat Measurements of Aerosol and Cloud Profiles to Constrain the Assessment of Aerosol Radiative Forcing and Influences on Tropospheric Chemistry	NASA	Yu (GEST)	Bian (GEST), Chin (GSFC), Diehl (GEST), Duncan (GEST), Palm (SSAI)	Pending
Using GLAS/ICESat Measurements of Aerosol and Cloud Profiles to Constrain the Assessments of Aerosol Radiative Forcing and Influences on Tropospheric Chemistry	NASA	Yu (GEST)	Bian (GEST), Mian Chin, Bryan Duncan (GEST), Thomas Diehl (GEST), Steve Palm	Pending
Using satellite measurements to improve the modeling of low and middle clouds and their climate feedbacks	NASA	Zhang (SUNY/Stonybrook)	Bacmeister (GEST)	Funded
The development of tropospheric ozone data products from Aura OMI/MLS and their scientific evaluation	NASA	Ziemke (GEST)	Chandra (GEST)	Funded
The North American Monsoon onset and maintenance sensitivity to land and ocean surface conditions	NOAA	Bosilovich (GSFC)	K. Arsenault (GEST), J.Chern, P.Houser (GMU)	Funded
Improved Water Demand Forecasting for Water Resources Managers	NOAA	D. Matthews (USBR-retired), Richard Stodt (USBR)	K. R. Arsenault (GEST), P. Houser (GMU)	Funded
Subseasonal and synoptic variability in the tropical eastern Atlantic and its neighboring continent	NOAA	Gu (GEST)		Funded
Report on Evaluation of Upper Ocean Mixing Parameterizations	NOAA	Jacob (GEST)		Funded
NCEP Component of the NOAA Core Project for GAPP (GEWEX Americas Prediction Project)	NOAA	Kenneth Mitchell	J. Meng (GEST), H. Wei, R. Yang, C. Marshall, Y. Xia	Funded
Aerosol Algorithm Development Support for GOES-R	NOAA	Lyapustin (GEST)	Y. Wang (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
AERONET-based Surface Reflectance Validation Network (ASRVN): Centralized Support of the Government's Calibration-Validation Plan for the VIIRS Instrument	NOAA	Lyapustin (GEST)	Y. Wang (GEST)	Pending
An Intercomparison of LDAS Evapotranspiration and Soil Moisture Estimates with the Regional Reanalysis Data	NOAA	Toll (GSFC)	Houser (GMU), Arsenault (GEST), A.Pinheiro (NRC)	Funded
Assimilation of MODIS and AMSR-E Land Products into the Noah LSM	NOAA/NASA	Houser (GMU)	X. Zhan (USDA), K. Arsenault (GEST), B. Cosgrove (SAIC)	Funded
Multi-scale Analysis of Vegetation Dynamics and Land Cover Land Use Change Patterns in the Mt. Kilimanjaro Region Using Satellite Data (1970s - 2000s)	NSF	Anyamba (GEST)	Youngsinn (UMBC)	Pending
Climate Process Team for Tropical Clouds	NSF	Bretherton (Univ. of Washington)	Bacmeister (GEST)	Funded
Advanced Laser Fluorometer (ALF) for in vivo Characterization of Phytoplankton Pigments, Physiology and Community Structure	NSF	Chekalyuk (Hampton/GEST)	Mitchell (Scripps Institute of Oceanography, University of California San Diego, CA)	Not Awarded
Determination of the Effects of Non-Modality on the Data Assimilation and Numerical Weather Prediction Problems	NSF	Errico (GEST)		Funded
Patagonian Dust Deposition and Biological Productivity in the South Atlantic Ocean: Implications for the Present-day and Future Regional Carbon Cycle	NSF	Gassó (GEST)	Nicholas Meskhidze (Georgia Tech. Inst.), A. Nenes (Georgia Tech. Inst.)	Pending
Ground-based Measurements of Trace Gases Using MAXDOAS in Clean and Polluted Environments in Support of Aura Satellite Observations	NSF	George Mount	S. Janz, Bhartia (GSFC), Bucsela (GEST), Levelt, D. Swart	Pending
A Coupled Atmosphere and Groundwater System for Assessing a Tropical Island Water Budget	NSF	Harmsen	Eastman (GEST), Ramirez, Gonzalez	Not Awarded
A global water cycle observatory cyberinfrastructure demonstration	NSF	Houser (GMU)	B. Doty (COLA), P. Cornillon (URI), S.V. Kumar (GEST)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Collaborative Research: Mesoscale Variability during EPIC 2001	NSF	Shay (Univ. of Miami)	Jacob (GEST)	Not Awarded
Ion Injection and Transport in the High-latitude Magnetosphere	NSF	Stubbs (GEST)	Sibeck, Fok, Boardsen, Trattner, Moore	Pending
Development of a combined model to estimate falling snow and snow on the ground	NSF	Tedesco (GEST)	Min-Jeong Kim (GEST), Daqing Yang (University of Alaska)	Pending
Development and validation of a combined algorithm for falling snow and snow on the ground	NSF	Tedesco (GEST)	M.-J. Kim (GEST), Daqing Yang	Pending
Marine Synechococcus: Photophysiology: A Pigment Approach	NSF	Trees (Center for Hydro-Optics and Remote Sensing, San Diego State University, CA)	Chekalyuk (Hampton/GEST), Colyer (Department of Chemistry, Wake Forest University, Winston-Salem, NC), Mueller (Center for Hydro-Optics and Remote Sensing, San Diego State University, CA)	Not Awarded
Upgrade of Urban Pollution Emission Sources in the Navy Aerosol Analysis and Prediction System	Office of Naval Research	Gassó (GEST)	Douglas Westphal (NRL), Jeffrey Reid (NRL)	Funded
Proposal to ONR to Fund Research at GEST on the Development and Applications of Adjoint Models and Ensemble Techniques	ONR	Errico (GEST)		Funded
Tropospheric Ozone Pollution Project (TOPP): Investigating Air Quality Through Additional Ozonesonde Launches in Houston, Beaumont, and East Texas	Texas Commission on Environmental Quality	Morris (GEST)	Fraser (Rice Univ.), Few (Rice Univ.)	Funded
Measurement and modeling of net exchange fluxes and in-canopy source/sink characteristics of ammonia in forest and agricultural landscapes	USDA	Robarge (NCSU)	Y. Wu (GEST)	Funded
Biophysical Interactions in Ocean Margin Ecosystems (BIOME)	Virginia's Center for Innovative Technology (CIT)	Russ (GEST)		Pending

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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 and DoD-GEIS Programs.

Ms. Kristi R. Arsenault received a Bachelor's of Science degree in geography and climatology from Arizona State University in May of 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 The Ohio State University in Columbus, Ohio, where she pursued a Master's 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 of 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 Reclamation. In conjunction with her work at GSFC, she is pursuing her Ph.D. degree in Climate Dynamics at George Mason University in Fairfax, VA.

Dr. Julio T. Bacmeister received his Ph.D. in Geophysical Fluid Dynamics from Princeton University in 1987 where his research concentrated on numerical simulation of stratified flow around obstacles. From 1987 until 1992 he worked as a post-doctoral fellow in the Atmospheric Chemistry and Dynamics Branch at NASA's Goddard Space Flight Center. He joined the Middle Atmospheric Chemistry and Dynamics Branch at the Naval Research Laboratory in Washington DC in 1992 where he led the development of a two-dimensional chemical transport model, as well as establishing a research effort in Atmospheric Gravity Wave Dynamics. In 1998, Dr. Bacmeister joined the NASA Seasonal-to-Interannual Prediction Project as a Visiting Scientist, where he led efforts in atmospheric model development. In 2003, Dr. Bacmeister joined the Global Modeling and Assimilation Office (GMAO) at Goddard Space Flight Center, where he leads physics parameterization development for the GMAO's global atmospheric model. His current interests include cloud and convection parameterization, as well as parameterization of orographic effects for tropospheric climate models. He has published over 35 refereed papers in the fields of gravity wave dynamics, atmospheric transport, and parameterization development for climate models.

Mr. Larry Belcher received his MS in Atmospheric Science (2000) from Colorado State University, Fort Collins, CO, and a BS in Physics from Colorado State University (1997). His MS thesis is on the intercomparison of radar, profiler, and disdrometer observations of tropical convection during the NASA TRMM-LBA field program. He worked at NASA/GSFC for Science Systems and Applications Inc. (SSAI) for two years as a research scientist. He worked as a research associate at the North Carolina State University investigating airborne radar observations of mixed-phase altocumulus clouds. He then rejoined SSAI in 2004 at NASA/GSFC continuing his work on tropical precipitation processes. In 2005, he joined the Goddard Earth Sciences Technology Center at the University of Maryland, Baltimore County as a

member of the scientific research staff. His current work continues to investigate tropical cloud systems and precipitation processes with an emphasis on airborne radar observations.

Mr. Timothy Berkoff is a Research Engineer with the University of Maryland's Goddard Earth Science and Technology Center. He has more than 15 years of experience in optical instrumentation and measurement analysis, and currently serves at 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 at the 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 the 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. Oliver Botta received his Ph.D. in organic chemistry from the University of Basel, Switzerland, in 1999. He then moved to the Scripps Institution of Oceanography at the University of California, San Diego, as an NASA Specialized Center for Research and Training (NSCORT) fellow, where, under supervision of Prof. Jeffrey L. Bada, he learned the techniques to analyze organic compounds a trace levels in terrestrial and extraterrestrial samples. One of the results from this work was the first analysis of the amino acids in CI carbonaceous meteorites. In 2002, he moved to the Leiden Institute of Chemistry at the University of Leiden, the Netherlands, as an ESA Postdoctoral Fellow. Working in the group of Prof. Pascale Ehrenfreund, he established a laboratory for the organic analysis of meteorites, involving liquid extraction and HPLC-UVF techniques. During that time, he also performed radio-astronomical observations of carbon-rich giant stars that are thought to be the main producers of PAHs in space. He also was a member of the field team during the 2003/04 ANSMET season, which was deployed to the LaPaz ice field in Antarctica. In spring 2004, he moved to the International Space Science Institute (ISSI) in Bern, Switzerland, first as a post-doc and then as the Astrobiology Discipline Scientist. He organized the first Forum to be held at ISSI, bringing together world-renown scientists to discuss the prospects of ISSI's involvement in this interdisciplinary field.

Dr. Eric Bucsela received a B.S. in physics from Emory University in 1983, a M.S. in electrical science from the Department of Electrical Engineering at the University of Michigan in 1986 and a Ph.D. in physics from the University of Michigan in 1994. At Michigan, he conducted research in aeronomy of the dayglow and developed instrumentation for *in situ* measurements and remote sensing of the atmosphere. He completed a postdoctoral fellowship at the Naval Research Laboratory in 1997. At NRL he developed models to investigate atomic and molecular excitation processes in the thermosphere. He also participated in the Defense Missile Satellite Program by playing a pivotal role in the calibration of the far-ultraviolet SSULI spectrometer. Additional research and publications have involved studies of thunderstorm electrification processes. Such processes create sprites and other visible emissions above thunderstorms. In addition to his work at NRL, Dr. Bucsela has been active in research at GSFC through affiliations with Raytheon, SSAI and most recently, GEST. His work at NASA has led to key insights about how observations of Raman scattering in the atmosphere can be used to infer cloud-top heights from space. Current research involves retrievals of critical trace-gas constituents from satellite measurements and the

development of algorithms to extract total column and profile information for air pollutants. These algorithms are now being used to retrieve NO_2 amounts from the Ozone Monitoring Instrument (OMI) on board the EOS-AURA satellite. OMI is part of an international venture between NASA and the Royal Dutch Meteorological Institute (KNMI).

Dr. Sushil Chandra is a Visiting Senior Research Scientist in GEST. Prior to the GEST appointment, he was a senior scientist at GSFC where he conducted research in the fields of aeronomy, ionosphere, and many other aspects of atmospheric science. During his tenure at GSFC (1966-2003), Chandra worked at the NASA Headquarters in the Upper Atmosphere Research Program (1980-1983) and as a Project Scientist for SPARC (1992-93) in France. Chandra has over 100 publications, most of which are in refereed journals and most of those as first author. Chandra was involved in the development of the first interactive ionosphere-atmosphere model. This coupled model played a major role in the interpretation of data obtained from several NASA satellites including OGO-4, OGO-6, Explorer 31, ISIS, AE, AEROS-A and AEROS-B. As a principal investigator for the RPA (Retarding Potential Analyzer) on OGO-4, Chandra initiated several correlative studies using ionospheric and airglow data from a number of instruments on OGO-4. As a member of the AEROS Science Team, he initiated several collaborative studies of the thermospheric density and temperature involving US and German scientists. Later, Chandra 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 periods to long term trends. Currently, Chandra is involved in developing new methods for deriving tropospheric ozone from satellite data. This work has produced a unique ~25-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. Chandra is PI and Co-I for several NASA funded proposals. He was a Co-I for the WINDII (Wind Imaging Interferometer) experiment on the UARS and was a member of the UARS Science Team from the very beginning of the UARS program. Chandra is currently an active science team member for both TOMS and 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, 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 and the impact of ENSO on extratropical low frequency noise in seasonal forecasts. Dr. Chang joined GEST in September 2001, as Associate Research Scientist at UMBC.

Dr. Alexander M. Chekalyuk is a GEST Investigator (NASA/GSFC, Wallops Flight Facility, Code 972) and Research Associate Professor (Hampton University, VA). Dr. Chekalyuk received a B.S. in physics, from Moscow State University (MSU), in 1977, and a Ph.D. in physics, from MSU, in 1982. He conducted laboratory research on new technologies for phytoplankton taxonomic analysis (2001-present, NASA/GSFC Wallops Flight Facility), airborne LIDAR technique for remote monitoring of aquatic photosynthesis (1998 – present, NASA/GSFC Wallops Flight Facility), submersible multispectral camera with laser illumination for small-scale structure studies (1997, Scripps Institution of Oceanography, CA), pump-during-probe technique and instrumentation for measurement of photosynthetic characteristics of phytoplankton cells with micro-fluorometry and flow cytometry (1994-97, Woods Hole Oceanographic Institution, MA), pump-and-probe LIDAR prototype for remote monitoring of photosynthetic activity of

phytoplankton and terrestrial vegetation (1990-93, MSU), pulsed saturation fluorometry for retrieving quantitative characteristics of complex organic molecules in liquid media (1975-89, MSU), nonlinear laser spectrometer and its application for quantitative measurements in two-component liquid media (1979-81, MSU), LIDAR applications in biological oceanography and environmental monitoring in the sea (1977-91, MSU), shipboard LIDAR system for remote monitoring of phytoplankton and dissolved organic matter in the sea water (1976-89, MSU), new technique and instrumentation for measurement of concentration of fluorescent organic substances in liquid Raman-active solutions (1975-76, MSU). Dr. Chekalyuk served as research scientist at the Department of Physics, MSU, in 1977-94. He was a visiting scientist at Woods Hole Oceanographic Institution, MA, in 1994-1997. He served as a project scientist at Scripps Institution of Oceanography in 1997-1998. He was a National Research Council Senior Research Associate with NASA/GSFC/WFF in 1998-2001.

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 model. 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 cloud modeling group at Mesoscale Atmospheric Processes Branch to develop the Multi-scale Modeling Framework or superparameterization based on the fvGCM and 2D GCE models.

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 2008. 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 for two years, and is currently teaching 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 area is improving education for blind students and minority students through the use of advanced technologies. She will be presenting her most current research, "Looking inside urban mathematics and science classrooms" at this year's NARST convention in April.

Dr. Robert J. Curran has served as senior staff scientist in the Climate Change Science Program Office in Washington, DC since August 2005 through an Intergovernmental Personnel Act (IPA) agreement with UMBC funded by NASA Headquarters. In that position his responsibilities include developing and drafting *Our Changing Planet*, which is the CCSP annual report to Congress as required by statute, and providing support for the Atmospheric Composition interagency working group. Prior to joining the CCSPO, Dr. Curran was Director of GEST at UMBC. He was the initial director of this center, which was started in 2000 through the award of a cooperative agreement with GSFC. In his previous position he was responsible for GEST's development into a multidisciplinary Earth science center performing collaborative research with scientists at GSFC. 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 at GSFC. His main research interests are in understanding the radiation properties of clouds and aerosols and their role in climate. In addition to his experience within NASA, Dr. Curran has 6 years of 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. He received

a B.S. in Physics from Creighton University and an M.S. and Ph.D. in Physics, with a specialization in Atmospheric Physics, 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 work includes electromagnetic modeling of vegetation, and microwave active and passive remote sensing, and he is part of the Science Algorithms team of the AQUARIUS instrument.

Dr. Marci P. Delaney is a Research Associate at GEST. Marci received her BS in Marine Biology with a concentration in Physics at the University of North Carolina in Wilmington in 1994. She earned her MSc and PhD 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 also continues to consult as a science content specialist to companies that produce educational materials for grades K-12. Dr. Delaney is currently the project coordinator for the NASA Exploring Space Challenges (NASA ESC). This project is a new initiative from NASA Education bringing together new and traditional academic competitions for students in grades K-12. The NASA ESC covers all disciplines, from science and math to language and creative arts. As a member of the GEST Information Science and Educational Technology faculty group, Dr. Delaney assists in the creation and publication of the NESNews, a monthly newsletter for the NASA Explorer Schools, and contributes to the Goddard Digital Learning Network.

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. Jiarui Dong received a B.S. in meteorology from Beijing Institute of Meteorology in 1989, a M.S. in computational mathematics in 1992 from Chinese Academy of Sciences, and a Ph.D. in atmospheric sciences in 1997 from CAS, where he developed a coupled model for simulating drought and regional flood disasters. In addition, he earned another Ph.D. in remote sensing in 2002 from Boston University. Dr. Dong's major accomplishments include remote sensing estimates of northern boreal and temperate

forest woody biomass: carbon pools, sinks and sources, improving the precision of simulated hydrologic fluxes in land surface models, developing and analyzing vegetation data sets from NOAA global data, and evaluating the utility of satellite-based vegetation parameters for climate simulation. Dr. Dong joined the GEST center at the Hydrological Science Branch at GSFC in 2002, working on assimilating global land surface remote sensing products into land surface models to generate optimal global land products and improving the capability of land data assimilation system.

Dr. Bryan Duncan received a B.S. in Chemistry in 1991 and a Ph.D. in Earth and Atmospheric Sciences in 1997 from the Georgia Institute of Technology. He was a postdoctoral fellow and research assistant from 1997 to 2001 in the Department of Earth and Planetary Sciences at Harvard University where he helped to develop the GEOS-CHEM 3-D model of transport and chemistry and conducted a model study of the seasonal and interannual variations of carbon monoxide. He then spent two years at the Swiss Federal Institute of Technology as a research scientist performing model studies of the export of pollution from Europe and from wildfires in Indonesia. Now as an Associate Research Scientist, he contributes to the model development and validation for the NASA Global Modeling Initiative (GMI).

Dr. Joseph L. Eastman received a Ph.D. in ecology/atmospheric science from Colorado State University, Ft. Collins, CO. in 1999. Prior to that, he received a B.A. in physics from the University of Minnesota in 1987 and a M.S. in atmospheric science focusing on the development of a Lagrangian Particle Dispersion model. He was the first to couple a carbon and stomatal control model to mesoscale atmospheric model leading to a dissertation detailing the effects of carbon dioxide and land use change on regional scale climate. His post-doctoral appointment in 1999 was under the guidance of Dr. Robert Waide, national director of the Long Term Ecological Research program and examined the implementation of high performance computing in ecological and atmospheric models. He served as a research associate from 2001-2002, working with Dr. Roger Pielke Sr. researching regional climate using coupled ecological and atmospheric models. He joined the Goddard Earth Science Technology Center at the University of Maryland, Baltimore County, in 2002 as a member of the research faculty. His research interests include mesoscale meteorological modeling, tropical cyclone modeling, regional climate change, dispersion modeling, and coupled earth system process models.

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 be began work at Goddard Space Flight Center (GSFC) and has continued working at GSFC (in association with the Biospheric Sciences Branch, Code 614.4) for more than 24 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. Currently he carries 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 80 refereed papers with recent emphasis on studies of the optical properties of atmospheric aerosols, especially from biomass burning and fossil fuel combustion, 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 11 international workshops, including 6 of the7 International Workshops on the Application of Adjoint Models in Dynamic Meteorology and 6 on various aspects of data assimilation. 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.

Dr. Francesco Fedele received a Ph.D. in Civil and Environmental Engineering (2004) from the University of Vermont, Burlington, VT, and a Laurea (magna cum laude) in Ocean Engineering (1998) from the University Mediterranea of Reggio Calabria, Italy. His Ph.D. thesis is on new numerical techniques to solve various problems in engineering science such as optical tomography by the use of the Boundary element method, sensitivities computation in the context of inverse problems by adjoint techniques, hydrodynamic stability of Poiseuille flows by means of Galerkin methods, contamination plume modeling in porous media using Hermite collocation methods. His interests span ocean engineering, fluid mechanics, structural analysis, applied mathematics and biomedical engineering. Since at GEST, he started to be interest in data assimilation techniques in meteorology. His publications include papers on linear and nonlinear ocean waves, numerical methods, adjoint techniques and inverse problems for optical tomography.

Dr. Hui Feng joined GEST in November 2002 as a Research Associate through Hampton University. He received a B.S. degree in radio physics from the East China Normal University, Shanghai, China in 1983 and a M.S. degree and Ph.D. in oceanography from the University of New Hampshire in 1996, 2004, respectively. Prior to joining GEST, he spent three years as a software development engineer with an industrial company. Dr. Feng has various experience in applied mathematics and statistics, physical and bio-optical oceanography, ocean remote sensing and software development. His specific research interests are in the field of ocean color remote sensing, hydro bio-optics and radiative transfer in optically-complex waters. His research interests include the development of ocean color inversion algorithms to retrieve in-water optically-active bio-optical properties, and the evaluation of ocean color atmosphere correction performance in coastal regions using in-situ atmospheric and aquatic optical measurements. A recent research focus involves the sea state bias modeling for altimeter range correction by using global ocean surface wave model and scatterometer data. Dr. Feng's work with GEST has been focusing upon the refinement of the altimeter sea state bias correction algorithm by using altimeter, scatterometer wind and global ocean wave modeling data.

Mr. Matthew Garcia has achieved a basic degree in Physics and Geosciences (Montclair State University, 1996) and advanced degrees in Atmospheric Science (Colorado State University, 1999) and Civil Engineering (Colorado State University, 2003). In the combination of these fields, Mr. Garcia works at the interface of weather and land, where precipitation turns into runoff and streamflow. In his position through UMBC-GEST at the NASA-GSFC Hydrological Sciences Branch, Mr. Garcia's efforts are oriented principally on full LIS-based land-surface hydrologic capability for the purposes of research investigations on, and applications to, remote sensing, floods and flash floods, and water resources management problems. Outside of work, Mr. Garcia delights in the pleasures of reading science and history, yard work, biking, doting on his wife, and watching his pre-school daughter paint, draw, kick a soccer ball, swing a bat, play with the family dog, and lecture us on how to use the home computer and other electronic devices.

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 Ph.D. thesis work, 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 Radition Branch at GSFC under the supervision of Dr. Si-Chee Tsay on the development of a radiative transfer module for the Navy Aerosol Analysis Prediction Systems (NAAPS) aerosol transport model. Since 2004, Dr. Gassó is working on the transport of aerosols into the South Atlantic (in particular dust) and its possible influences on phytoplankton. In addition, he is a member of the NPOESS Preparatory Project (NPP) science team and he is working on the development and testing of the aerosol retrieval algorithm with Dr. Torres (JCET) and Dr. Gleason (NASA).

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 Witwatersrand, South Africa, in 1999. He holds the position of Lecturer in the Institute of Nuclear Science, University of Nairobi, where he teaches courses on air pollution using nuclear related techniques. He came to NASA Goddard Space Flight Center in 1999 as a Resident Research Associate of the Universities Space Research Association (USRA). He is currently an atmospheric scientist in the Goddard Earth Science and Technology Center, University of Maryland Baltimore County, and is on leave from his faculty position in Kenya. His 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 statistical and trajectory methods. He has been involved in International Atomic Energy Agency (IAEA) coordinated research project on air pollution using nuclear related analytic techniques and in 1994/95 was a member of the United Nations Environmental Programme (UNEP)/World Health Organization (WHO), Global Environmental Monitoring System (GEMS)/Air team of experts. Dr. Gatebe has been involved with modification of NASA's Cloud Absorption Radiometer to have modern data acquisition system and UV optical channels suitable for remote sensing of aerosol. He has participated in several field campaigns and most recently participated in the SAFARI-2000 field experiment in southern Africa, which took place from August-September, 2000 and also CLAMS 2001, USA eastern coast, July–August 2001. In both experiments he made measurements using NASA's Cloud Absorption Radiometer aboard the University of Washington Plane, CV–580. Currently, he is interested in remote sensing of aerosols and bidirectional reflectance distributions functions to better understand their role in global change. Dr Gatebe was recognized for his work as a fellow of Global Change System for Analysis, Research and Training (START) during the 5th International Geosphere Biosphere Programme (IGBP)-Scientific Advisory Committee meeting in Nairobi, Kenya, 1998, and is the winner of the 2000 World Meteorological Organization Young Scientist Award.

Dr. Luis R. Gaya-Piqué got his PhD (2004) and a MS (2000) in Geophysics from the Universitat Ramon Llull, Spain, and his BS in Physics (1996) from the Universitat of Barcelona, Spain. His PhD thesis is on the development of a regional geomagnetic reference model for Antarctica. He worked for four years at Ebro Geophysical Observatory, Spain, and for other four years at the National Institute for Geophysics and Volcanology, Italy. He spent six months in 2005 at the Ohio State University as a Visiting Scholar. In October 2005 he joined 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 the development of magnetic field models and the analysis of satellite magnetic data. He has participated in several ground and airborne magnetic surveys, in Spain, Italy, New Zealand, and Antarctica. He has participated in five Antarctic expeditions since 1998. He has been selected three times as Spanish delegate in the framework of training courses organized by the United Nations Comprehensive Nuclear-Test-Ban Treaty Organization.

Dr. Yolanda Gayol is a Visiting Scientist at GEST. She received a BS in educational psychology from the National Autonomous University of Mexico (UNAM, Mexico) in 1979. She was awarded a MS in educational research at the Center for Research and Advanced Studies at the National Polytechnic Institute CINVESTAV/IPN (Mexico) in 1994 and a DEd in adult/distance education at the Pennsylvania State University. She has conducted research education and distance education at the Pennsylvania State University and the University of Maryland University College. Dr. Gayol served as Program Director at the Master of Distance Education at the University of Maryland University College (UMUC) in 2002-2003. Previously, she was distance education specialist at the World Bank and the Inter-American Development Bank (1999-2001). She has been Task Force Leader for USAID/ICMA on e-Learning for municipal management and citizen training in Latin America and the Caribbean. Since 1994, she works on knowledge dissemination on distance education through a specialized newspaper in Mexico with nationwide distribution, U2000: Chronicle of Higher Education. Currently, Dr. Gayol is developing an evaluation instrument for educational technologies for the NASA Learning Technologies Project.

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 a variational estimation framework.

Dr. Guojun Gu received a B.S. in atmospheric physics from Nanjing University in 1986, and a Ph.D. in meteorology and physical oceanography from University of Miami in 2001. Prior to joining the UMBC/GEST center, he was a postdoctoral research scientist at Columbia University. Dr. Gu's research is primarily in the field of tropical meteorology which covers tropical convection and waves/oscillations, tropical atmospheric dynamics and circulation, and air-sea-land interaction. He is currently involved in the Tropical Rainfall Measuring Mission (TRMM) at the Mesoscale Atmospheric Processes Branch of NASA GSFC.

Dr. Bruce Guenther completed his doctorate at the University of Pittsburgh in 1974. He became a member of the research staff at GSFC, and worked there for over 15 years as project scientist on the Earth Observing System (EOS)-AM Project, responsible for calibration and data product validation.
Dr. Guenther developed the Moderate Resolution Imaging Spectroradiometer (MODIS) Characterization Support Team, and was responsible for the first publicly available EOS data sets. He then became a systems engineering fellow at Lockheed Martin Missiles Space Operations, working on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) system. Dr. Guenther returned to GSFC under the auspices of GEST as leader of the NPOESS Preparatory Project sensor calibration and data product validation effort. He has published extensively in the peer-reviewed literature, and has made presentations at many scientific meetings.

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 associated with the trowal and warm front 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. Hiroo Hayashi completed his education at Hokkaido University in Sapporo, Japan. His doctorate was awarded in 2001 for a thesis about inertial instabilities in the tropical atmosphere, detected using space-based and in-situ data. After graduation, he was a postdoctoral fellow at the National Institute for Environmental Studies in Tsukuba, Japan, where he worked on descending motion in the polar vortex using trace-gas data from the ILAS satellite instrument. Dr. Hayashi joined GEST in April 2002 and has been working on developing satellite ozone assimilation systems at the NASA Global Modeling and Assimilation Office.

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 its contract in 2000 as Acting Director. Dr. Hoban is currently a Senior Research Scientist in the UMBC Goddard Earth Science and Technology Center, spokesperson for the Information Science and Educational Technology Faculty group. Her interests include scientific information systems, digital library technologies and information technologies for science, technology, engineering and mathematics (STEM) education. Dr. Hoban has a particular interest in contributing to the STEM foundation of our nation's K-12 educators.

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. In May 2005, he was transferred to Instrumentation Sciences Branch. As a member of Aquarius science team, Daniel conducts research on the effects of surface forcing and ocean mixing on sea surface salinity and also leads an effort to identify an appropriate mixing scheme for use in coupled predictive models of hurricane intensity.

Dr. Juan Carlos Jusem started his meteorological activity in January 1957 as an aerological observer in the Meteorological Service of Argentina. In 1959, received his diploma of forecaster and in 1961 obtained the title of "Licenciado" in Meteorology at the University of Buenos Aires Argentina. Until 1966, Dr. Jusem worked simultaneously at the University as instructor and at the Meteorological Service as an analyst and forecaster. From 1966 to 1969, Dr. Jusem performed as an investigator at the University of Chile and since 1969 collaborated with the WMO until 1976, in two countries: Costa Rica and El Salvador; in the former, as a GARP consultant in charge of the Tropical Center of the BDSP and as teacher at the University of Costa Rica. From 1974 to 1976; while in the latter, Dr. Jusem co-operated

with the Meteorological Service as WMO expert. Since 1976 until 1984, Dr. Jusem studied at FSU, where he received the degrees of Master in 1979 and of PhD in 1984. From July 1984 up to the present time, Dr. Jusem has worked at the Laboratory of Atmospheres in GSFC/NASA.

Dr. Hyung Rae Kim received a B.Sc. in Department of Geology from Yonsei University, Seoul, South Korea in 1993, a Masters degree majoring in Geophysics in Department of Earth and Atmospheric Sciences from Purdue University, Indiana in 1997. His Masters thesis examined aspects of the external geomagnetic field in the POGO satellite data. Satellite magnetic data measured the signals due to the electromagnetic current systems occurring especially around the dip equator (called Equatorial Electrojet) in the daytime. He investigated the nature of Equatorial Electrojet in terms of local time and longitude. He continued studying the geomagnetic field of the Earth in the Department of Geological Sciences at The Ohio State University under Dr. R. von Frese's direction and earned a PhD in June of 2002. His PhD thesis investigated the lithospheric magnetic anomalies from Ørsted magnetometer satellite and near-surface (i.e., ground, shipborne and airborne) data in Antarctic. After he finished his PhD degree, he spent one year as a postdoctoral researcher at the Ohio State University working for ADMAP and preparation for Mars Data Analysis Program. While he stayed in Columbus, he also prepared several pending proposals for the Antarctic research, Mars magnetic field study, geopotential analysis of North America (e.g., Earthscope) and so forth. In 2003, Dr. Kim has received a GEST visiting scholarship and since then he has conducted research as a postdoctoral research associate at GEST, where his research activity has focused on developing the advanced model of Antarctic magnetic field anomaly as an active member of ADMAP in cooperation with other international geophysical community.

Dr. Min-Jeong Kim was born in Busan, Korea. She received the B.S. degree in Atmospheric Sciences with a minor in Physics from the Busan National University and M.S. degree in Atmospheric Sciences from the Seoul National University in 1995 and 1997, respectively. Her work focused on numerical model simulations of airflow and cloud microphysics. Since September 1998, Min-Jeong has attended graduate school. She has worked on radiative transfer processes and microwave remote sensing of precipitation over the ocean to support the Tropical Rainfall Measurement Mission (TRMM) satellite projects. Since 2002, she has been studying the electromagnetic characteristics of frozen hydrometeors and received her doctoral degree in Atmospheric Sciences in 2004. Since March 2005, she has been working on millimeter and submillimeter-wave remote sensing for ice crystals at the NASA Goddard Space Flight Center. She has been collaborating on several projects related to high frequency microwave remote sensing of cloud with many other scientists in the U.S. Her research interests include passive microwave and radar remote sensing of atmosphere, ice physics, light scattering by nonspherical particles, radiative transfer process, and interactions of cloud, aerosols, radiation, and climate.

Dr. Anuradha Koratkar is an Associate Research Scientist at GEST. She graduated with a B. Sc in Mathematics, Physics and Chemistry from the Osmania University (1981) in India, a Masters degree in Astronomy from State University of New York (1989) and A Ph. D. in Astronomy from University of Michigan (1990). Her thesis examined the dynamics and kinematics of the Broad Line Region in Active Galactic Nuclei. She was a research scientist at the Space Telescope Science Institute for 10 years where she was involved in many aspects of science operations for the Hubble Space Telescope mission. She has also been a scientific lead on IT projects that will optimize science operations and maximize scientific returns. She has been awarded a number of awards for her activities related to the Hubble Space Telescope. Her innovative ideas have also received recognition via the NASA Software of the Year Award, Honorable Mention for 2001. In 2003 she came to GEST as a visiting research associate. Anuradha has published over 50 original refereed journal publications and 20 contributed papers in the field of Active Galactic Nuclei (AGN) physics. Her science community activities involve serving on several peer review committees, working groups and organizing scientific and technical meetings. Recently Anuradha was appointed to the board of the Fulbright Commission's Luso-American Board.

Dr. Nickolay A. Krotkov received a B.S. from Moscow Institute of Physics and Technology in Physics in 1983, M.S. (with honors) in Remote Sensing in 1985 and a Ph.D. in oceanography (physics and mathematics) in 1990 from the P.P. Shirshov Institute of Oceanology Russian Academy of Sciences where his major research was using polarization properties of light in the oceanic remote sensing. Since 1993 he has worked in close collaboration with NASA/TOMS scientists to study volcanic clouds, surface and underwater ultraviolet radiation and aerosols. Dr. Krotkov has over 20 years experience in UV radiative transfer modeling, satellite and ground based UV data analysis. He has published over 40 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.

Dr. Sujay V. Kumar received a Ph.D. in computer aided engineering from North Carolina State University, Raleigh, NC. in 2002. Prior to that, he received a Bachelor of Technology in civil engineering from the Indian Institute of Technology, Bombay in 1996 and a Master of Science in environmental engineering from North Carolina State University in 1998. His Ph.D. thesis is on the development of a generic, high resolution, distributed computing framework for engineering decision support systems. In 2002, he joined the Goddard Earth Science Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. His research interests include land surface hydrology, mesoscale meteorological modeling, data assimilation systems, hydrological applications, mathematical optimization and decision support systems.

Dr. Kwo-Sen Kuo received his BS in Atmospheric Science in 1983 from National Taiwan University, Taiwan, Republic of China, his MS in Meteorology in 1987 form South Dakota School of Mines and Technology, and his Ph.D. in Atmospheric Science in 1995 from Colorado State University. Although his main interest of research is in atmospheric radiative transfer and its applications in remote sensing, he also has expertise in image processing and interpretation using both conventional methods and artificial intelligence. He developed a three-dimensional radiative transfer model as his dissertation research. He joined his alumni mater, South Dakota School of Mines and Technology (SDSM&T), as a Research Scientist in 1994 continuing his research in radiative transfer modeling and cloud-field property analyses. His position at SDSM&T changed to Research Assistant Professor in 1995 and to Assistant Professor in 1996 while engaging in a variety of research topics including retrievals of cloud and aerosol properties using satellite data, investigation of cloud three-dimensional effects on retrievals, cloud mask development for ASTER and CERES, and classification of objects within satellite images. Dr. Kuo moved in July 1997 to University of Alabama in Huntsville to take a Research Scientist position and continued his areas of research. In late 1999 he started investigating improvements to precipitation retrievals using spaceborne radar. Dr. Kuo took a leave-of-absence from November 2000 to January 2002. He started his position as an Associate Research Scientist with Caelum Research Corporation in the Goddard Earth Science and Technology (GEST) Program in January 2002, working to create a more realistic physical radiative transfer model for the Global Precipitation Measurement mission.

Dr. Redgie Lancaster received a B.S. in physics from Bethel University in 1990 and a Ph.D. in Astronomy in 1997 from Boston University where his major research interest was in atmospheric remote sensing. He has developed a variety of imaging systems and spectrometers and has carried out experimental research focusing on several atmospheric regions of the Earth ranging from the troposphere to the exosphere. After beginning his career studying atomic oxygen and hydrogen in the tenuous upper atmosphere he joined the University of Michigan in 1997 where the focus of his research shifted to that of remotely measuring ozone in the lower atmosphere. In 1999 he began work as an atmospheric scientist onsite at the NASA Goddard Space Flight Center. He is presently daddy to his precious little girl and conducts research in the fields of cloud and ocean remote sensing.

Dr. David Lary completed his education in the United Kingdom. He received a First Class Double Honors B.Sc. in Physics and Chemistry from King's College London (1987) with the Sambrooke

Exhibition Prize in Natural Science, and a Ph.D. in Atmospheric Chemistry from the University of Cambridge, Churchill College (1991). His thesis described the first chemical scheme for the ECMWF numerical weather prediction model. Lary then held post-doctoral research assistant and associate positions at Cambridge University until receiving a Royal Society University Research Fellowship in 1996 (also at Cambridge). A Royal Society University Fellowship is one of the most prestigious awards for young scientists in the U.K. The Royal Society is the world's oldest scientific academy in continuous existence, and has been at the forefront of enquiry and discovery since its foundation in 1660. From 1998 to 200, Lary held a joint position at Cambridge and the University of Tel-Aviv as a senior lecturer and Alon fellow. An Alon Fellow is the highest award Israel can give a young scientist. In 2000 the chief scientific adviser to the British Prime Minister and Head of the British Office of Science and Technology, Professor Sir David King, recommended Lary to be appointed as a Cambridge University lecturer in Chemical Informatics. In 2001, Lary joined UMBC/GEST as the first distinguished Goddard fellow in earth science at the invitation of Richard Rood. His automatic code generation software, AutoChem, has won four NASA awards. In 2006, Lary joined the Atmospheric Chemistry and Dynamics Branch at GSFC.

Dr. Daniel Laughlin is an Assistant Research Scientist at GEST. He received his Ph.D. in Education from American University in 2001. His area of focus was information technology in education and he did research in cognitive science experimenting with methods to explicitly teach critical and scientific thinking skills. Before coming to GEST, 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 teaching. Dr. Laughlin joined GEST in 2002. He is currently the NASA Learning Technologies Project coordinator and leads the games research effort for NASA's Education Office. Laughlin's interests include information technology management, cognitive science, educational technologies and the use of computer and video games as educational tools.

Mr. Rick Lawford has served as the Director of the International GEWEX Project Office (IGPO) for the past two and a half years. Previously he worked for more than eight years for the University Corporation of Atmospheric Research (UCAR) with NOAA as the program manager for the GEWEX Americas Prediction Project, one of the GEWEX CSEs. In this position he managed 40 to 50 projects and a peer review grant selection process, organized science meetings, and developed planning documentation, reports, synthesis presentations and publications. His current scientific interests include water cycle science and the contributions of remote sensing, droughts (all aspects) and the effective incorporation of water science into water policy and management. Prior to joining UCAR, Rick spent many years working in the fields of hydrology and meteorology with the Canadian government. There he served as Division Chief for a research group in hydrometeorology at the National Hydrology Research Center in Saskatoon. He has also worked in the fields of science policy development (Ministry of State for Science and Technology), program planning, evaluation and environmental policy development (Environment Canada) in Ottawa. Early in his career, he worked as a weather forecaster, research meteorologist and an instructor in the government's professional training program in meteorology. He has served as the regional chief of a Scientific Service Division, supervising a group of meteorologists working in applied climatology in Toronto, Ontario. He has served as an adjunct professor (Geography) at the University of Saskatchewan and a lecturer in Physics (Carleton University in Ottawa). Rick Lawford received his undergraduate degree in Physics at the University of Manitoba (Brandon College) and undertook graduate studies in meteorology at the University of Alberta and McGill University. He is a member of the American Geophysical Union, the American Meteorological Society and the Canadian Meteorological and Oceanographic Society. He has published on a broad range of topics, frequently gives invited conference presentations, and has been listed in the "International Who's Who."

Dr. Myong-In Lee received his degrees of B.Sc. and M.Sc. in Atmospheric Sciences, both from the Seoul National University, Korea in 1994 and 1996, respectively. In 2001, he received a Ph.D. degree at the

same university by investigating the cumulus parameterizations in the climate model for the tropical Madden-Julian Oscillation simulation, for which he was awarded a prize by the Korean Meteorological Society. Dr. Lee started his career of post-doc in the Climate and Environment System Research Center (CES), Korea, where he was dedicated to develop the systems for the dynamical seasonal and sub-seasonal prediction. He also got a lectureship in climate modeling class at Seoul National University in 2002. Dr. Lee joined GEST in 2003 and currently works at the Global Modeling and Assimilation Office at NASA/GSFC for the atmospheric modeling and climate studies. His interests are in the examinations of moist convective parameterizations in the NSIPP atmospheric general circulation model and the warm season diurnal cycle simulations over the North American region.

Dr. Lihua Li received a B.S. in electrical engineering from Tsinghua University, China in 1988, a M. S. in high energy physics from Chinese Academy of Sciences in 1991 and a Ph.D in electrical engineering from the University of Massachusetts at Amherst in 2000. Before joining GEST, he was a research engineer in the Microwave Remote Sensing Laboratory (MIRSL), University of Massachusetts. At NASA GSFC/GEST, Dr. Lihua Li's research efforts involve remote sensing radar development, instrument calibration and data analysis for atmospheric research. As a lead system engineer, Dr. Li has made substantial contribution to the development the NASA GSFC 94 GHz cloud Radar System (CRS), field deployment and data analysis. Currently, Dr. Li is leading a group of engineer on the development of a new X-band UAV Radar (URAD) and a NASA IIP funded High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP). Both radars will fly on NASA high altitude research aircrafts, such as WB57 or Global Hawk for study of tropical cloud and storm systems. Dr. Li also works closely with other scientists on data analysis and the retrieval of cloud microphysical properties using radar, lidar and radiometer measurements.

Dr. Xiaowen Li received her B.S. degree in atmospheric sciences from Beijing University, China. She worked as an associate researcher in Chinese Academy of Meteorological Sciences for two years after she received her M.S. degree in 1994. 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. 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. 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 a Senior Scientist at the Goddard Earth Sciences and Technology Center/Caelum Research Corp.

Dr. Ruei-Fong Lin is currently an assistant research scientist in the GEST Center. Dr. Lin received her B. S. degree in atmospheric Sciences from National Taiwan University (NTU), Taiwan in 1990, and M. S. and Ph. D. in meteorology from Pennsylvania State University in 1993 and 1997. Before joining GEST Center, she spent 8 months in NTU working as a post-doctoral research scientist followed by 2 years in Universities Space Research Association as a visiting scientist. Dr. Lin's expertise and research interests are numerical modeling of cirrus, cloud physics and radiative transfer. She participates in the GCSS (Global Energy and Water Cycle Experiment Cloud Systems Studies) Working Group on Cirrus Cloud

Systems (WG2). She, together with Dr. David O'C Starr of NASA/GSFC and Dr. Paul DeMott of Colorado State University, leads the Cirrus Parcel Model Comparison Project of the GCSS WG2.

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. Tom Low is the associate director of GEST. He received his B.A.Sc. in engineering science and a Ph.D. in physics from the University of Toronto. His specializations in cloud physics and precipitation formation have included laboratory studies, field measurements, and numerical modeling of the evolution of precipitation processes. His work in IR and microwave remote sensing has led to the development of surface boundary layer models for both marine and land surfaces. Dr. Low has been a research scientist and program manager in the private sector in the international community for over 20 years. He is also a trained weather forecaster, and has been named a Certified Consultant Meteorologist by the American Meteorological Society.

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 on the 3D radiative transfer over anisotropic non-homogeneous surfaces, developing the method of spherical harmonics. At present, he develops algorithms of the aerosol retrieval and atmospheric correction of the Landsat ETM+, EOS MODIS, and future NPOESS VIIRS instrument based on the new theory. Since 2004, his group 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. Dr. Lyapustin has delivered a series of lectures on atmospheric correction on invitations from Boston University, UMBC and George Maison University. A. Lyapustin has been an associate member of VIIRS Operational Algorithm Team (VOAT) since 2000. Dr. Lyapustin is a science team member of MODIS and NPP Science Teams (since 2004), and GOES-R Algorithm Working Group since 2005.

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. Jesse Meng received a Ph.D. (2001) and a M.S. (1997) in meteorology from the University of Maryland, College Park, Maryland, and a B.S. (1991) in atmospheric sciences from National Taiwan University, Taipei, Taiwan. His research at the University of Maryland mainly focused on the development and implementation of methods to estimate, monitor, and evaluate the Earth's land surface radiation and energy budgets from satellite observations. He joined UMBC/GEST in March 2001 as a member of research faculty, spending half time at NASA/GSFC, Hydrologic Sciences Branch (Code 614.3), and half time at NOAA/NCEP Environmental Modeling Center, working on the NASA/NOAA joint project of GLDAS and LIS. His primary duty in GLDAS and LIS includes: 1) generate near real

time global land surface shortwave and longwave radiation fields, based on satellite observations, to support the land surface modeling, and evaluate the impact on the land simulation corresponding to the alternative radiation forcing; 2) implement a parallel GLDAS/LIS at NOAA/NCEP to support the NCEP operational GFS and CFS and other land and hydrological research; and 3) evaluate land surface radiation and energy components over a wide range of products including operational and experimental NWP prediction, data assimilation, satellite retrieval, and surface observations.

Ms. Stefanie Misztal is a media specialist in the Information Science and Educational Technology faculty group. In 2004, she received a B.S. in environmental studies with an emphasis in biology from the University of Southern California, and is currently pursuing a Master's of Fine Arts in science and natural history filmmaking from Montana State University. As a Master's student she has produced an educational video for the Grizzly and Wolf Discovery Center in West Yellowstone, and is currently finishing a film about whirling disease, slated for release on PBS in the summer of 2006. She began employment at GEST in October 2005, and has since been working on producing various environmental and solar science media products for GSFC.

Dr. Gary A. Morris is an Assistant Professor in the Department of Physics & Astronomy at Valparaiso University with joint appointments as an Adjunct Assistant Professor in the Department of Physics & Astronomy at Rice University and as an Intermittent Assistant Research Scientist through GEST at UMBC. He earned his M.S. and Ph.D. degrees in Space Physics & Astronomy from Rice University in 1992 and 1995 respectively. His research focuses on studies of ozone, both stratospheric loss and tropospheric pollution. He has developed and employed numerous models of atmospheric chemistry and dynamics, including trajectory mapping. During the Summer of 2004, he established an ozonesonde station at Rice University in Houston, TX and participated in NASA's IONS mission. Since the establishment of this station, the Rice University site has employed 6 undergraduate students and launched over 90 ozonesondes. Morris continues to supervise ozonesonde launches from Rice University and will be a funded participant in MILAGRO, INTEX-B, and TexAQS 2005 – 2006, launching ozonesondes from sites in Houston, Beaumont, and East Texas. In his spare time, he enjoys ballroom dancing and serves as the faculty advisor for Valparaiso University's Dance Etc., a student ballroom dance organization.

Dr. Lars Nerger received a M.S. in physics in 2000 and a Ph.D. in mathematics in 2004, both from the University of Bremen, Germany. His master's thesis work at the Max Planck Insitute for Graviational Physics in Golm, Germany was in the field of general relativity on the numerical simulation of collisions of black holes. He performed research work for his Ph.D. thesis on parallel filter algorithms for data assimilation in oceanography at the Alfred Wegener Instute for Polar and Marine Research (AWI), Bremerhaven, Germany. Subsequently, he worked at the AWI as a postdoctoral fellow, where he continued and expanded his work on the application and characterization of sequential data assimilation algorithms based on the Kalman filter with regard to their application on parallel computers. This work led to the development of the Parallel Data Assimilation Framework (PDAF), which simplifies the implementation of data assimilation systems with existing numerical models on parallel computers. Dr. Nerger joined GEST in August 2005 and is working on the assimilation of satellite ocean color data into the NASA Ocean Biogeochemical Model.

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. Together with Dr. Arlindo da Silva, also of the GMAO, Norris implemented one of the first cloud assimilation systems, using a variational parameter estimation technique, with very successful results. He has also participated in numerous atmospheric field experiments, including the FIRE Cirrus II, Kansas, 1991, FIRE ASTEX, Azores, 1992, TOGA-COARE, Solomon Islands, 1993, and CRYSTAL-FACE, Florida, 2002, 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 from 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. Olsen became a research associate at GEST in December 2002 and later appointed assistant research scientist in December 2004. With GEST, Olsen has continued to concentrate on many facets of upper-troposphere/lower-stratosphere structure and dynamics, including cross-tropopause transport.

Dr. Kevin Olson is an Associate Research Scientist at GEST. He received his Ph.D. from the University of Massachusetts in 1990. For his novel use of a supercomputer of that time he received first place in the IBM 3090 supercomputing competition sponsored by the IBM corporation. After receiving his Ph.D. he began work at Goddard Space Flight Center as part of the in-house team of scientists for the High Performance Computing Project. During this time his researched focused on developing numerical algorithms for scientific purposes using high-performance parallel computers. One of the main achievements during this time was to participate in the development of a software package known as PARAMESH. PARAMESH was developed to allow a user to more easily add dynamic adaptive mesh refinement to an existing application and also make use of parallel computer architectures. He has also worked at the University of Chicago as part of the Department of Energy's Advanced Strategic Computing Initiative (ASCI). The code that was developed using the PARAMESH software at the University of Chicago recently won a Gordon Bell Prize for performance. Dr. Olson continues to work on developing and extending PARAMESH and collaborating with people in different scientific communities to develop codes which use PARAMESH.

Dr. Judit M. Pap received her PhD in astrophysics in 1986, from Eötvös University, Budapest, Hungary, where she worked as a research associate until 1988. In 1988 she was a visiting scientist at the Institute for Solar Physics at Freiburg, Germany. She was appointed as a research associate at the University of Colorado at Boulder in 1989. She was a staff member of the California Institute of Technology Jet Propulsion Laboratory between 1991 and 1997, and Research Astronomer at the Department of Physics and Astronomy at UCLA until the end of November 2001. Dr. Pap has been a senior research scientist at GEST since June 2001. She conducts research on solar irradiance variations and their effect on the Earth's atmosphere and climate using ground- and space-based measurements. She is a NASA-funded co-investigator on the ESA/NASA SOHO/VIRGO and MDI experiments, was guest investigator of the UARS mission, and co-investigator on the French PICARD experiment, and Associated Scientist on HMI/SDO. She is principal investigator on various grants from NASA's Office of Space Science. Dr. Pap is involved in a wide range of collaborations with scientists from JPL, UCLA, NRL, the University of Alabama, NCAR/HAO, NOAA/SEC, C.N.R.S, (Paris, France), PMOD/WRC (Davos, Switzerland), and the Heliospheric Observatory (Debrecen, Hungary). She is member of the Editorial Board "Weather", a journal of the Hungarian Meteorlogical Service. Dr. Pap has organized several international meetings on solar irradiance variations, she chaired the last workshop of Working Group 1 of the International Solar Cycle Studies, working under the auspices of the Scientific Committee on Solar-Terrestrial Physics

(SCOSTEP). She is the chair of Working Group 1 “Solar Variability” of Theme 4 “Space Climatology” of the newly implemented program of SCOSTEP: “Climate And Weather of the Sun-Earth System” (CAWSES). CAWSES performs in collaboration with the International Living With a Star (ILWS) program, which will play a major role in solar-terrestrial physics in the next decade or beyond. Since July 2004 she has been serving as US National Disciplinary Sciensc Representative for the SCOSTEP Bureau on sun-climate connections. She was the chief editor of the AGU Monograph Series, No. 141: *Solar Variability and Its Effect on Earth's Climate*, published in March 2004.

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 Ph.D. in meteorology in 1996. Upon completing his doctorate, from 1996 to 1999 Dr. Reale worked as a visiting scientist at the International Center for Theoretical Physics (ICTP), Physics of Weather and Climate Section, Trieste. He also consulted for a weather forecasting operational center (CMIRL, Genoa, Italy), as an invited lecturer on synoptic-dynamic meteorology and he was co-advisor on three theses on synoptic meteorology at the University of Trieste. From 1999 to 2001 Dr. Reale moved to the Center for Ocean-Land-Atmosphere Studies, Institute for Global Environment and Society (COLA-IGES), Maryland, where he worked 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. Dr. Reale's current research focus is on the synoptic and dynamic meteorology of extreme events. In particular, he investigates the sensitivity of extreme events, such as tropical cyclones and extratropical sub-synoptic scale cyclones, to model improvement, different data types and different data assimilation procedures. Dr. Reale received the Outstanding Performance Award from the Data Assimilation Office in the Laboratory for Atmospheres at GSFC in December 2002, and the Outstanding Performance Award from the GMAO/SRT at GSFC in December 2004 and the Outstanding Performance Award from the Laboratory for Atmosphere in July 2005. He is PI of a funded NASA proposal on Observing System Simulation Experiments.

Dr. Rolf H. Reichle received a Ph.D. in Environmental Engineering (2000) from the Massachusetts Institute of Technology (MIT), Cambridge, MA, and a MS in Physics (1996) and a BS in Mathematics (1992) from the University of Heidelberg, Germany. His Ph.D. thesis is on the optimal assimilation of remote sensing data for land surface hydrology applications. He worked for one year as a Postdoctoral Research Associate at the Ralph M. Parsons Laboratory at MIT where he continued and expanded his work on land data assimilation. In 2001 he joined the Goddard Earth Sciences and Technology (GEST) Center at the University of Maryland, Baltimore County, as a member of the research faculty and began working in close collaboration with researchers at the NASA Goddard Space Flight Center. Dr. Reichle received the Outstanding Performance Award of the NASA Global Modeling and Assimilation Office (GMAO) in 2004 for his leadership in developing, organizing, and coordinating the land assimilation activities within the GMAO and with collaborators at Goddard, and again in 2005 for his ground-breaking research on soil moisture data assimilation. In 2005, Dr. Reichle was promoted to the rank of Associate Research Scientist and was selected as Faculty Group Leader for the GEST Hydrological Sciences faculty group. His main research interest is land data assimilation development and the application of land data assimilation to seasonal climate and weather forecasting. His publications include papers on global soil moisture data, land data assimilation, seasonal climate predictability, and on groundwater contaminant transport.

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. 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. Dr. Riishojgaard has been with GEST since September 2000.

Dr. Mary Elizabeth Russ received her Ph.D. in Environmental Geosciences from Michigan State University in 2003, and her B.S. in Biology/Ecology from the University of Maryland at College Park in 1997. Her dissertation research encompassed the use of stable isotopes of dissolved oxygen to determine the trophic status (respiration to photosynthesis ratio) of Lake Superior and the subtropical and tropical North Pacific Ocean. Dr. Russ is a seasoned oceanographer and limnologist, with participation in over twenty research cruises during her graduate and post-graduate careers, in both oceanic and freshwater ecosystems. The extent of her publication topics include both the development of a method to analyze the stable isotopes of oxygen, as well as, the application, of pre-established stable isotope methods for oxygen and nitrogen, to physical and biological studies in Lake Superior and the North Pacific Ocean. Upon completion of her degree in 2003, she participated in the Oak Ridge Institute for Science and Education (ORISE) Visiting Research Scientist Program, as a post-doctoral research scientist at the FBI Academy in Quantico, VA. While at the Academy, she was involved in the formulation and installation of a stable isotope ratio mass spectrometry laboratory for the application of stable isotope analysis to forensic science. In January of 2005, she was an invited speaker at the 17th Sanibel Conference for Mass Spectrometry in Forensic Science and Counter-Terrorism, in Clearwater, Florida. She joined the Goddard Earth Sciences and Technology Center (GEST) at the University of Maryland, Baltimore County in March of 2005, and is part of the NASA New Investigator Program project, where she is involved in evaluating the degradation of DOC via microbial mineralization, and the potential production of labile DOC from the photochemical decomposition of CDOM.

Dr. Robert Schiffer is the chief scientist for GEST. Dr. Schiffer received his Ph.D. in 1971 from the University of California at Los Angeles in meteorology. He has over 27 years of program management experience at NASA HQ, including positions as deputy director of the Research Division, chief of the Atmospheric Science Branch, chief of the Climate and Hydrologic Systems Branch, and manager of NASA's Climate Research Program and Global Atmospheric Research Program. He has chaired or cochaired numerous national and international research panels in the areas of climate studies. These activities included directorship of the WMO's World Climate Research Program - Radiation Project Office, and directorship of the U.S. Secretariat for International Global Observing Systems Programs. Dr. Schiffer also worked for 11 years at the Jet Propulsion Labs as a research engineer/scientist, involved in NASA's Planetary Exploration Program. His most recent accolade was the award of the NASA Distinguished Service Medal after he retired last year from GSFC.

Dr. Chung-Lin Shie, originally from Taiwan, R.O.C., received a B.S. in atmospheric sciences from National Taiwan University in 1977. He was curious about snowy weather and ended up with a M.S. in meteorology from Pennsylvania State University in 1985. Missing the sunshine, led him to Florida State University where he received his Ph.D. in meteorology in 1995. Then, he returned to the cold D.C. Metropolitan area and became a research meteorologist at NASA/GSFC affiliated first with SSAI (till March 2001), and then an associate research scientist with UMBC/GEST (since April 2001) ever since. During his early career (from February 1993 to March 1997), he had 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 (Special Sensor Microwave Imager) precipitable water data. He later produced a global (2x2.5 grid) daily air-sea surface flux product for a 7.5-year period (from July 1987 to December 1994), which was archived and distributed by the Goddard DAAC. Since April 1997, he joined his current research project involving numerical simulations using 2- and 3-dimensional Goddard Cumulus Ensemble (GCE) models, and scientific analysis to study radiative-convective systems and their interactions with large-scale environment. He recently won a "Meritorious Service Award" from COAA (Chinese American Oceanic and Atmospheric Association) for his genuine performance serving as one of the COAA Board Directors during 2003-2004. He also won an "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. While working as a full-time researcher in science, he however considers himself a 50% research meteorologist (cloud modeling, air-sea interaction, remote sensing, and atmospheric dynamics), 20% arts-lover, 20% philosophy-seeker, and 10% math-hobbyist. He had moonlighted as an amateur Chinese Calligraphy teacher during his leisure time at weekends for several years (from 1995 to 2001).

Dr. Alexander Smirnov received a M.S. in physics, from St.Petersburg State University, St.Petersburg, Russia in 1980 and a Ph.D. in Oceanology (Physics and Mathematics) in 1988 from Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia, where his major research interest was atmospheric aerosol optical properties over the oceans. From 1980 to 1991, Dr. Smirnov served as a Scientist and Senior Scientist at St.Petersburg Hydrometeorological Institute, developing aerosol models, and participating in marine and coastal expeditions. From 1993 to 1996 he was a Postdoctoral Fellow and Project Scientist at the Université de Sherbrooke, Sherbrooke, Québec, Canada, where he successfully studied the effect of various synoptic air masses on the atmospheric optical parameters. In June of 1996, Dr. Smirnov joined Science Systems and Applications, Inc., and started working on the AERONET Project. He has led an effort and contributed to the design and implementation of the operational cloud screening and quality control algorithm for the AERONET database. His current research interests include ship-borne and ground based studies of atmospheric aerosols, remote sensing instrumentation, and data analysis. Dr. Smirnov has been with the GEST Center since October 2001. He has over 70 peer-reviewed papers in the leading geophysical journals. He is presently one of three Co-Investigators of the AERONET Project.

Ms. Silvia Stoyanova is a media specialist in the Information Science and Educational Technology faculty group. She received a B.S. degree in computer studies from the University of Maryland University College in 2004. Currently, she is finishing a Master's in Film program at American University in Washington, DC. Her professional experience includes the Library of Congress and the US Agency for International Development. In 2005, she traveled to Ghana and South Africa where she produced two short documentaries on HIV/AIDS education for USAID, aired on Ghana National Television and distributed to a number of government officials and schools in Africa. Stoyanova was employed by GEST in August 2005 and her work has included variety of multimedia projects including web development, graphics and animations for the NASA Web Portal as well as video production.

Dr. Susan Strahan received a B.S. in chemistry from Stanford University in 1980 and a Ph.D. in chemistry from the University of California, Berkeley in 1986. She was an NRC postdoc at NASA Ames Research Center, where 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 stratospheric circulation of 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, overseeing model evaluation and coordinating production of new model simulations. She contributes to the evaluation of the Goddard Chemistry and Transport Model and the NASA GMI models.

Dr. Tim Stubbs obtained his PhD in space physics from Imperial College, London in 2002, under the supervision of Peter Cargill and Mike Lockwood (at the Rutherford Appleton Lab). His thesis included statistical studies of ion injection and transport in the high-latitude magnetosphere, as well as multi-instrument cusp studies. Shortly thereafter he joined the Laboratory for Extraterrestrial Physics at NASA/GSFC as an NRC Research Associate and worked with Rich Vondrak on simultaneous spacecraft observations of the entire auroral oval in both hemisphere, as well as dust dynamics in the lunar electrostatic environment. He recently joined the University of Maryland, Baltimore County GEST program and continues to work at Goddard with Rob Pfaff on cusp electrodynamics, Bill Farrell on electrostatic dust transport, and Mel Goldstein on multipoint magnetospheric observations from Cluster.

Dr. Chaojiao Sun received a BS from the University of Science and Technology of China (USTC) and a PHD in oceanography from Oregon State University, where her major research interest was internal waves and turbulent mixing in the upper equatorial oceans. In 1998, she joined UCLA at the Department of Atmospheric Sciences and the Institute of Geophysics and Planetary Physics. She carried out research on data assimilation with an intermediate coupled ocean-atmosphere model for the study of El Nino Southern Oscillation (ENSO), using a sequential estimator— the extended Kalman filter. She joined UMBC GEST in November 2000, and has been working on snow data assimilation with land surface models and ocean data assimilation with general ocean circulation models. Her major research interests are ocean data assimilation, coupled model data assimilation, ENSO, tropical oceanography, and snow data assimilation.

Dr. Marco Tedesco received his 'Laurea' degree in Electronic Engineering from the University of Napoli 'Federico II' (Italy) in May 1999. In October 1999 he joined the Microwave Remote Sensing Group of the Institute of Applied Physics 'Carrara' of the Italian National Research Council (CNR), Firenze, Italy with a one year appointment (scholarship) for the development and validation of techniques for microwave remote sensing of natural surfaces. In 2000, he was visiting scientist of the Chinese Academy of Science (CAS) in Beijing (Prof. Chao Wang) and of the Fudan University (Prof. Ya-Qiu Jin), Shanghai. In February 2004 he obtained his Ph.D. in Methods and Techniques for Environment Engineering (February 2004) from the Institute of Applied Physics 'Carrara' with the thesis titled 'Microwave Remote Sensing of Snow'. In 2002, he was invited student at the Space Laboratory of the Helsinki University of Technology, and in 2001 he attended the School on Hydrological Model Forecasting (Massachusetts Institute of Technology, MIT). He also collaborated with the Group of Interaction between Electromagnetic Fields and Matter of the Institute of Research on Electromagnetic Waves (IROE) of the Italian National Research Council (CNR). In June 2004, he joined the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. In August 2005 he was the recipient of a NASA Outstanding PostDoc/Research Associate Peer Award and on October of the same year Dr. Tedesco received the Young Scientist URSI Award during the URSI International Conference in New Delhi 24-28 Oct. 2005. Dr. Tedesco is Member of IEEE Geoscience and Remote Sensing Society, of the American Geophysical Union Society, of the Technical Committee of Frequency Allocation in Remote Sensing (FARS) of the GRSS and he serves as reviewer for the IEEE TGARS and GRSL, Remote Sensing of Environment, Hydrological Processes, Geophysical Research Letters and the Journal of Scanning Microscopies.

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 2000, she joined the Goddard Earth Science and Technology Center. She conducted research in the areas related to the remote

sensing of precipitation and understanding of storm structures and microphysical characteristics of precipitation using observations from the ER-2 airborne Doppler radars. 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. Most recently, she used dual-wavelength airborne Doppler radar observation to retrieve raindrop size distribution, vertical velocity and attenuations. 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. Yudong Tian received a Ph.D. in Atmospheric Sciences in 1999 from UCLA, where his conducted research in climate dynamics and geophysical fluid dynamics. He was also one of the developers at UCLA for the popular advanced spectral analysis SSA-MTM Toolkit. Prior to joining GEST, he had been working in the Internet industry, holding positions as systems manager and chief technology officer. In addition to his atmospheric research background, he has extensive professional experience in network architecture, software engineering, database design and system and network security. He has been working on GSFC's Land Information System since early 2002, a high-performance computing platform for real-time land surface simulation, which won NASA's 2005 Software of the Year Award.

Mr. Jonathan M. Triggs is a Research Coordinator for GEST. He is affiliated with the Hydrological Sciences Branch at GSFC, working primarily with the NASA Applied Sciences Program. Mr. Triggs studied meteorology and climatology in the Department of Geography at Arizona State University, obtaining a B.S. in Geography in 1998 and a M.A. in Geography in 2002. After receiving his B.S. he worked as a Research Assistant for the University of Arizona Maricopa Agricultural Center at the U.S. Water Conservation Lab (USWCL, USDA/Agricultural Research Service). At the USWCL, he worked with a team of researchers studying the effects of increased carbon dioxide on agricultural crops. His research focused on evapotranspiration and water resources. Mr. Triggs' research today focuses on the continued pursuit of understanding land-atmosphere interactions, particularly with respect to water resource management. He is primarily interested in applying NASA data to real-world applications with other federal agencies. Recently, Mr. Triggs was designated as the North American Contact and Regional Coordinator for the UNESCO Hydrology for the Environment, Life, and Policy (HELP) Programme.

Dr. Sushel Unninayar is a Senior Research Scientist at GEST. Education: Ph.D (Meteorology) in 1978 from the Institute of Geophysics, U. Hawaii; M.S: Electrical Engineering in 1971 (U. Hawaii); B.Technology (Honors) IIT, and E.E (I.E.E, London), in 1968. Selected past experience/positions held: He has been with NASA-HQ/ESE in various "Senior Scientist" capacities since about 1991. He directed the NASA-HQ Greenhouse Effect Detection project in 19991-93. Was seconded by NASA-HQ to the UN Institute for Training and Research in 1993-94 as Director of International Projects for addressing global change and climate change research. Was Director of the US Vice-Presidential initiative of the GLOBE Project at UCAR/NCAR in 1994-95. Was program Director at NSF (Global Change Research Planning) in 1988-91. Was Senior Scientific Advisor to UNEP, seconded by NASA-HQ, to the UN Environment Program (UNEP) in 1987-88. Was Division Head, World Climate Program (WCP), World Meteorological Organization, in 1981-87. Was Deputy Director, International GARP programs and interdisciplinary, international field campaigns/projects (MONEX (International Monsoon Experiment) and ALPEX (International Alpine Mountain Experiment)), in 1978-81. He has been directly involved and instrumental, from inception, in the planning and implementation of the World Climate Research program, the US Global Change Research program, and the US Climate Change Science program.

Dr. Igor Veselovskii graduated from the faculty of Theoretical and Experimental Physics of Moscow Engineering Physical Institute in 1982. In 1987 he received Ph.D from the same Institute for the studies in photoacoustics. Since 1988 he is with Physics Instrumentation Center of General Physics Institute. During

1988-1994 he was involved in the development of excimer lasers and in nonlinear optics studies, such as phase conjugation, Raman conversion and Brillouin compression of UV laser pulses. In 1995 he becomes the head of lidar program. As a visiting researcher he spent one year in South Korea (KAERI) and one year in Brazil (INPE). Since 2001 he works with NASA GSFC. His current scientific interests include development of lidars for tropospheric ozone monitoring, Raman lidars for the water vapor and liquid water study and multywavelength lidars for aerosol size distribution retrieval.

Dr. Hailan Wang received a B.S. in Marine Meteorology from Ocean University of Qingdao in People's Republic of China. She then pursued her graduate study in University of Illinois at Urbana-Champaign, and obtained her M.S. and Ph.D in Atmospheric Sciences in 1997 and 2000 respectively. In fall 2000, she moved to Princeton NJ and worked in the Climate Diagnostic Group in Geophysical Fluid Dynamics Lab (GFDL) as a postdoctoral visiting scientist. In December 2002, she joined the Climate and Radiation Branch of GSFC/NASA. One of her past major research efforts has been on understanding global and regional climate and their variations from stationary wave perspective, using diagnostic linear and nonlinear stationary wave modeling approaches. She has also been engaged in a number of other topics including the impact of air-sea interaction, *e.g.*, ENSO, on climate variation in local and remote regions, and the response of tropical climate to global warming in coupled model simulations. During her stay in GEST, she is investigating the potential importance of extra-tropical air-sea interaction in predictability of U.S. summer time precipitation variations. Recently, she has been engaged in the Climate Model Evaluation Project, whose goal is to assess the new generation model predictions and a better quantification of uncertainty in projecting future climate, to provide inputs for the 4th IPCC Assessment Report.

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, mesoscale meteorology, 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, rawinsonde soundings, Portable Automated Mesonet (PAM) stations, as well as aircraft and satellite 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 has been an Assistant Research Scientist in JCET at the University of Maryland Baltimore County since February 1999. Between 1997 and 1999, he was a postdoctoral Research Associate with the University of Illinois and NCAR. His research during that period 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 has also held positions as a Research Assistant at the University of Hawaii (1990-1995) and Peking University (1987-1990).

Dr. Yujie Wang received a BS and an MS in physics from Tsinghua University, Beijing, China in 1994 and 1998 respectively, and PhD in geography from Boston University, Boston, MA in 2002. In July of 2002, Dr. Wang joined GEST as a Research Associate. During his PhD study, Dr. Wang's research was mostly focused on the prototyping and validation of radiative transfer based EOS MODIS LAI/FPAR algorithm. At present, he is developing a new generic aerosol retrieval and atmospheric correction algorithm 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 Master's 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, Weaver 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 GSFC in 1991 and has worked there ever since. His current interests include stratospheric transport, data assimilation and remote sensing.

Dr. Phillip Webb is an Assistant Research Scientist with Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, which he joined in 2005, and is currently working at the Laboratory for Solar and Space Physics, NASA/GSFC. He obtained his BSc in 1993 and MSc (1st Class Hons.) in 1995 from The University of Auckland, New Zealand, and his PhD in 2001 from La Trobe University, Australia. His awards include an Australian National University Summer Scholarship, Australian National University (1992); Senior Prize in Physics, Department of Physics, The University of Auckland (1992); Dennis Brown Prize for Experimental Physics, Department of Physics, The University of Auckland (1992); Postgraduate Scholarship, La Trobe University, Australia (1995-1999); Cooperative Research Centre for Satellite Systems Supplementary Scholarship, La Trobe University, Australia (1998-2000); Young Scientist Award, URSI 1999 General Assembly in Toronto, Canada (1999); and a National Research Council Resident Research Associateship Award at NASA/GSFC, U.S.A (2001-2003). His PhD work produced a dynamic global model of the plasmaspheric plasma population that reproduced dynamic features observed by both in-situ electron density and total electron content (TEC) observations. At NASA/GSFC he is undertaking studies to interpret data collected by the Radio Plasma Imager (RPI) on NASA's IMAGE satellite. He has published or submitted 15 scientific publications dealing with ionospheric and plasmaspheric physics. He has also given 50 presentations at national and international scientific meetings as well as invited university seminars on these topics.

Dr. Guoyong Wen received a B.S. degree from Peking University in 1982, a M.S. in atmospheric sciences in 1987 from Purdue University, and a Ph.D. in atmospheric physics in 1992 from the University of Chicago. He did his postdoctoral work at Argonne National Laboratory. His research interests focus on atmospheric remote sensing, ozone, aerosols, clouds, and atmospheric radiative transfer, climate variations, solar variability. He joined GEST in 2003.

Dr. Mark Wenig received his Intermediate Diploma in physics from the University of Münster, Germany, in 1995, and his Diploma in physics from the Interdisciplinary Center for Scientific Computing at the University of Heidelberg, Germany, in 1998. In 2001 he received a Ph.D. in Physics at the Institute of Environmental Physics at the University of Heidelberg, for his work on Satellite measurement of long-term global tropospheric trace gas distributions and source strengths. He had been awarded a National Research Council scholarship from 2002 – 2005 to work at the NASA Goddard Space Flight Center, Atmospheric Chemistry and Dynamics Branch on atmospheric data assimilation. Since 2005 he has been affiliated with GEST to work at NASA GSFC on new techniques to combine multi-dimensional data sets coming from satellite measurements to analyze the impact of trace gases and aerosols on air quality.

Dr. Konrad Wessels received a BSc in Zoology in 1992 and MSc in Landscape Ecology and Conservation Planning from the University of Pretoria, South Africa in 1997. He received a PhD in Geography from University of Maryland in 2005. He specialized in monitoring vegetation function, land use and land cover using long-term remote sensing data. He is currently a research associate with GEST and working with the Hydrospheric and Biospheric Sciences Laboratory (GSFC) on modeling bird migration using climate and other remote sensing data.

Dr. Liguang Wu is an assistant research scientist at GEST. He received a B.S. in meteorology from Nanjing University, China, in 1984; a M.S. in meteorology from State Oceanic Administration (SOA), Beijing, China, in 1990; and a Ph.D. in meteorology from University of Hawaii in 1999. Dr. Wu served as an operational weather forecaster at SOA from 1984 to 1987 and from 1990 to 1994. From 1994 to 1999,

he worked as a research assistant at the University of Hawaii. He developed a coupled hurricane-ocean model system and proposed a new diagnostic approach to quantitatively assess contributions of various physical processes to tropical cyclone motion. From 2000 to 2001, as an AIRS data specialist, he developed the official AIRS data support web site and various tools for accessing Aqua AIRS data at DAAC/GSFC. His current research interest includes tropical cyclone genesis, structure, intensity, and motion; air-sea interaction; numerical modeling; analysis and application of remote sensing data, the relationship between climate changes and hurricane activities.

Dr. Yihua Wu received a Ph.D. in Atmospheric Sciences (1999) and a MS in Horticultural Sciences (1993) from North Carolina State University, Raleigh, North Carolina, and a BS in Agro-meteorology (1982) from Nanjing Institute of Meteorology, Nanjing, China. His Ph.D. thesis is on the investigation of scale interactions associated with the formation and the structure of low-level jets. He worked as an engineer at the State Meteorological Administration of China (SMA) from 1982 to 1991, and earned an academic award from SMA in 1991 for his distinct contributions in agro-meteoroogical research and service at the national level. He developed a multi-layer biochemical dry deposition model when he worked as a UCAR visiting scientist at US EPA from 2000 to 2002. In 2002 he joined 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 modeling the bi-directional exchanges of trace gases between the atmosphere and biosphere. His publications include papers on the formation and structure of low level jets, land use pattern effects on meso-scale circulations, dry deposition modeling, and watershed scale soil moisture simulations.

Dr. Kao-San Yeh, also known as Kevin Yeh, has been an Assistant Research Scientist at GEST since December 2001. He has developed a few numerical methods for modeling geophysical fluid dynamics since he joined the GEST center, including the Streamline Subgrid Integration method for applications on arbitrary grid systems. Dr. Yeh received a B.S. in physics from the National Taiwan University in 1987, an M.S. in mathematics from Purdue University in 1992 and a Ph.D. in meteorology also from Purdue University in 1997. He conducted the development of the non-hydrostatic version of the Canadian Global Environmental Multiscale Model as a post-doctor in the Meteorological Research Branch of Environment Canada in 1997-1999. During 1999-2001, Dr. Yeh generalized the NASA/NCAR finite-volume General Circulation Model from uniform to variable resolution as a Research Associate in the Earth System Science Interdisciplinary Center of the University of Maryland, College Park.

Dr. Hongbin Yu received his PhD 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. His Ph.D. thesis is on aerosol radiative effects on the environment. He also conducted data analysis and modeling on tropospheric O3-NOx chemistry during the early years of his PhD study. After his graduation in 2000, Dr. Yu then worked at Georgia Tech as a postdoctoral fellow through 2002, and as a research scientist from January 2003 to October 2004, focusing on aerosol-cloud-radiation-climate interactions. Before pursuing his PhD in the U.S., 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 in air pollution and atmospheric boundary layer. In October 2004, Dr. Yu joined Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County, as a member of the research faculty. His current task is to assess the measurement-based estimates of the aerosol climate forcing. Dr. Yu's publications cover topics of global aerosol assimilation and direct forcing, aerosol impacts on the evolution of the atmospheric boundary layer and crop yields, tropospheric ozone and nitrogen chemistry, and air pollution and boundary layer meteorology.

Dr. Boris Yurchak received a M.S. in Electronics from the 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. From 1969 to 1996 he conducted

studies in the field of radar methodology applications to cloud and precipitation measurements and atmospheric diffusion. From 1996 to 2001 he served as a senior research scientist and branch head at the Russia Federal Environmental Emergency Response Center (FEERC), Obninsk, Russia, where he developed a remote system for detecting clouds of pollutants at emergency situation and also used remote sensing capabilities to study environmental 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 he continued working on the NASA's Earth Science & Public Health Program. Dr. Yurchak has been with GEST since July 2002.

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. Yunhe Zhao received the B.S. degree in computational mathematics from Xiamen University, Xiamen, China in 1984, and both the M.S. and Ph.D. degrees in mathematics from North Dakota State University, Fargo, ND, in 1993 and 1997, respectively. He has been with Caelum Research Corporation, Rockville, MD, and worked on-site at the Oceans and Ice Branch, NASA Goddard Space Flight Center as a contractor since May 1997. He currently is a Senior Analyst and works in GEST program at Caelum Research Corporation, a GEST partner. During his graduate study, he did research on numerical solutions of boundary integral equations, numerical integrations of improper integrals, and wavelet analysis and its applications in the numerical solutions of integral equations. Since working at NASA/GSFC, he has worked on satellite ocean and sea ice remote sensing data analysis and image processing, especially on deriving sea ice motion and deformation in the Arctic using wavelet analysis method from SSM/I, NSCAT, QuikSCAT, SeaWinds, and AMSR-E data, using the derived data sets to study sea ice dynamics and interaction of sea ice motion and pressure field, and studying internal wave propagation in South China Sea by integrating and assimilating both SAR and mooring data into nonlinear internal wave models.

Dr. Yaping Zhou received a Ph.D. in Physical Oceanography and a M.S. in Computer Science from Stony Brook University, NY in 1999. For her Ph.D. work, she studied longwave radiative transfer in atmosphere and developed an algorithm for retrieving surface downwelling longwave radiation. After graduation, she worked at NASA Langley Research Center and National Environment Prediction Center for brief periods of time before 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. Her research interests include radiative transfer in the atmosphere and application; cloud-radiation-precipitation interaction and climate variability.

Dr. Jerry Ziemke came to NASA Goddard in 1994 as an NRC research postdoc (Ph.D. Physics, Iowa State University) specializing in atmospheric composition and dynamics. He has over 50 scientific publications, most all of which are in refereed journals and most of these as first author. His primary tasks since coming to Goddard in 1994 have been the measurement and analysis of atmospheric ozone, and since 1996 his main focus has been the satellite retrieval of tropospheric ozone. He is currently an active science team member for both TOMS and EOS Aura OMI, and he contributes to SPARC, WMO, and UNEP reports. In recent years he has contributed significantly to developing algorithm schemes for deriving tropospheric ozone from Cloud Slicing and residual methods using satellite measurements. Jerry Ziemke became an associate research scientist within GEST in March, 2002.

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Acronyms and Abbreviations

Acronym/ Abbreviation	Expansion/Definition
2-D	Two-dimensional
3-D	Three-dimensional
AAOT	Aerosol Absorption Optical thickness
AASE-2	Airborne Arctic Stratospheric Expedition 2
ACP	ammonia compensation point
AEROCOM	Aerosol Comparisons
AERONET	Aerosol Robotic Network
AFWA	Air Force Weather Agency
AGCM	Atmospheric General Circulation Model
AGU	American Geophysical Union
AIB	α-Aminoisobutyric Acid
ALF	Advanced laser fluorescence
AMF	Air Mass Factor
AMMA	African Monsoon Multidisciplinary Analysis
AMS	American Meteorological Society
AMSR-E	Advanced Microwave Scanning Radiometer for the Earth Observing System
AMSU-B:	The Advanced Microwave Sounding Unit-B
AO	Announcement of Opportunity
AO	Atlantic Oscillation
AOT	Aerosol Optical Thickness
ARMCI	Aggregate Remote Memory Copy Interface
ARMS	Army Remote Moisture System
ARS	Agricultural Research Service
ASRVN	AERONET-based Surface Reflectance Validation Network
ASTEX	Atlantic Stratocumulus Transition Experiment
AURA	NASA EOS satellite on polar sun synchronous afternoon orbit
AVHRR	Advanced Very High Resolution Radiometer
AWARDS	Agricultural WAter Resources Decision Support
B.S.	Bachelor of Science
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BDSP	Basic Data Set Project.
BRD	Band Residual Difference Algorithm for determining SO2 from OMI
CAF	Co-Array Fortran
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	The NASA Convection And Moisture Experiment
CAN	Cooperative Agreement Notice
CAPE	Convective Available Potential Energy
CB	Chesapeake Bay
CBP	Chesapeake Bay Plume
CBP	Chesapeake Bay Program
CCD	Convective Cloud Differential
CCRI	U.S. Climate Change Research Initiative
CCSP	U.S. Climate Change Science Program
CCSPO	U.S. Climate Change Science Program Office
CDOM	Chromophoric dissolved organic matter

CEOP	Coordinated Enhanced Observing Period
CERES	Clouds and the Earth's Radiant Energy System
CESDIS	Center for Excellence in Space Data and Information Science
CFS	Climate Forecast System
CLM	Community Land Model
CLM2	Community Land Model version 2
CLPX	Cold Land Processes Experiment
COAA	Chinese American Oceanic and Atmospheric Association
COAD	Coupled Ocean Atmospheric Data Set
COARE	Coupled Ocean-Atmosphere Response Experiment
COLA	Center for Ocean-Land-Atmosphere Studies
COMBO CTM	3-D Combined Stratosphere-Troposphere chemical tracer model
CONUS	Continental U.S.
CPES	Cloud Parameter Estimation System
CR-AVE	The NASA AURA Validation Experiment (Costa Rica)
CRM	Cloud-resolving model
CRS	The NASA Cloud Radar System
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers -Florida Area Cirrus Experiment
CTM	Chemistry and Transport Model
DAAC	Distributed Active Archive Center
dAMF	Differential (or Altitude-Dependent) Air Mass Factor
DAO	Data Assimilation Office
DAS	Data Assimilation System
DCF	Direct Climate Forcing (by anthropogenic aerosols only)
DDA	Discrete-Dipole Approximation
DESWAT	Destructive Waters Abatement program (Romania)
DMRT	Dense Medium Radiative Theory
DMSP	Defense Meteorological Satellite Program
DOAS	Differential Optical Absorption Spectroscopy
DOC	Dissolved organic carbon
DoD	Department of Defense
DODS	Distributed Oceanographic Data System
DOM	Dissolved organic matter
DRE:	Direct Radiative Effect (by natural and anthropogenic aerosols)
DROPPS	Distribution and Role of Particles in the Polar Summer Mesosphere
DSSs	Decision Support Systems
DST	Decision Support Tool
DU	Dobson Unit (2.69E20 molecules per square meter)
EC	Environment Canada
ECCO-GODAE	Estimating the Circulation and Climate of the Ocean – Global Ocean Data Assimilation Experiment
ECMWF	European Center for Medium Range Weather Forecasting
ECU	East Carolina University
EDOP	The NASA ER-2 Doppler Radar
EKF	Extended Kalman Filter
EnKF	Ensemble Kalman Filter
ENSO	El Niño Southern Oscillation
ENVISAT	ESA Environmental satellite
EOP	Enhanced Observation Period
EOS	NASA Earth Observing System

EP	Earth Probe
EPA	Environmental Protection Agency
ERS	European Remote Sensing Satellite
ERS-2	European Remote Sensing Satellite-2
ESA	European Space Agency
ESMF	Earth System Modeling Framework
ESSIC	Earth System Science Interdisciplinary Center
ESSP	Earth System Science Pathfinder
ESTEC	European Space Research and Technology Centre
ESTO	Earth Science and Technology Office
ET	Evapotranspiration
ETM+	Enhanced Thematic Mapper Plus
FAO	United Nations Food and Agriculture Organization
FAS	Foreign Agricultural Service
FEWSNET	Famine Earl Warning Systems Network
FIRE	First ISCCP Regional Experiment
FM	Flight Model
FSU	Florida State University
fvDAS	finite volume Data Assimilation System
fvGCM	finite-volume General Circulation Model
FVGSI	Finite-Volume Grid-point Statistical Interpolation
GAME	GEWEX Asian Monsoon Experiment
GAPP	GEWEX Americas Prediction Project
GARP	Global Atmospheric Research Program.
GC	Gas Chromatograph
GCE	Goddard Cumulus Ensemble
GCLLJ	Gulf of California Low Level Jet
GCM	General Circulation Model
GCRP	Global Change Research Program
GEIS	Global Emerging Infections System
GEMTM	General Energy and Mass Transfer Model
GEOS DAS	Goddard Earth Observing System Data Assimilation System
GEOS	Goddard Earth Observing System
GEOS-4	Goddard Earth Observing System, Version 4
GEOS-CCM	Global Earth Observing System - Chemistry Climate Model
GEOS-CHEM	Goddard Earth Observing System CHEMistry model
GEST	Goddard Earth Sciences and Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System
GLDAS	Global Land Data Assimilation System
GLRON	Great Lakes Region Ozonesonde Network
GMAO	NASA Goddard Model and Assimilation Office
GMI	NASA Global Modeling Initiative
GMU/IGES	George Mason University, Institute of Global Environment and Society
GOCART	Goddard Global Ozone Chemistry Aerosol Radiation and Transport
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GPLLJ	Great Plains Low Level Jet
GPM	Global precipitation measurement
GRACE	Gravity Recovery and Climate Experiment

GrADS	Graphical Analysis and Display System
GRL	Geophysical Research Letters
GSFC	Goddard Space Flight Center
GSWP	Global Soil Wetness Project
GSWP-2	Global Soil Wetness Project – Phase 2
HALOE	Halogen Occultation Experiment
HELP	Hydrology for the Environment, Life, and Policy
HPLC	High Performance Liquid Chromatography
HSB	Hydrological Sciences Branch
HSPF	Hydrological Simulation Program - Fortran
HYCOM:	Hybrid Coordinate Ocean Model
IABP	International Arctic Buoy Programme
IAI	Inter-American Institute
IDS	Interdisciplinary Science in the NASA Earth Science Enterprise
IGPB	International Geosphere Biosphere Program
IHE	Inter-hemispheric exchange
IHOP	International H2O Program
ILAS	Improved Limb Atmospheric Spectrometer
IMAGE	Imager for Magnetopause - to - Aurora Global Exploration
INTEX	Intercontinental Chemical Transport Experiment
INTEX-A	Intercontinental Transport Experiment A
INTEX-B	Intercontinental Transport Experiment B
Intex-NA	Intercontinental Transport Experiment – North America
IONS	INTEX Ozonesonde Network Study
IOP	Intensive Observation Period
IPA	Intergovernmental Personnel Act
IPCC	Intergovernmental Panel of Climate Change
ISCCP	International Satellite Cloud Climatology Project
ISIS	International Satellites for Ionospheric Studies
IT	Information Technology
ITCZ	Inter-Tropical Convergence Zone
JAS	Journal of the Atmospheric Sciences
JAXA	Japanese Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology
JGR	Journal of Geophysical Research
JHT	Joint Hurricane Testbed
JPL	Jet Propagation Laboratory
KF	Kalman Filter
KNMI	Royal Netherlands Meteorological Institute
LAI	Leaf area index
LAS	Live Access Server
LDAS	Land Data Assimilation System
LEAF-2	Land Ecosystem Atmospheric Feedback model version 2
LIDAR	LIght Detection And Ranging
LIS	Land Information System
LISGCE	Land Information System coupled to the Goddard Cumulus Ensemble model
LIS-R	Land Information System, with hydrologic and hydraulic Routing capability
LISWRF	Land Information System coupled to the Weather Research and Forecasting model
LSM	Land Surface Model
LSOS	Local Scale Observation Site

LTER	Long Term Ecological Research
LUT	Look Up Table
M.A.	Master of Arts
MAB	Mid-Atlantic Bight
MAP	Modeling, Analysis, and Prediction
MAX-DOAS	Multi-Angle Differential Optical Absorption Spectroscopy
MFRSR	Multifilter Rotating Shadowband Radiometer
MISR	Multi-angle Imaging SpectroRadiometer
MJO	Madden Julian Oscillation
MLS	Microwave Limb Sounder
MM5	The fifth generation of Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) Mesoscale Model
MMF	Multi-Scale Modeling Framework
MMS	Modular Modeling System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
MOZART	Model for OZone And Related chemical Tracers
MPI	Message-Passing Interface
MS	Mass Spectrometry/Spectrometer
MSFC	Marshall Space Flight Center
MSL	Mars Science Laboratory
MSU	Moscow State University
NAAPS	Navy Aerosol Assimilation Prediction System
NAME	North American Monsoon Experiment
NAO	North Atlantic Oscillation
NARR	North American Regional Reanalysis
NAS	NASA Ames Reserch Center
NASA	National Aeronautics and Space Administration
NASA/GSFC	National Aeronautics and Space Administration, Goddard Space Flight Center
NASA/HQ	National Aeronautics and Space Administration Headquarters
NCAR	National Center for Atmospheric Research
NCCS	NASA Center for Computational Science
NCEP	National Center for Environmental Prediction
NCFR	Narrow cold front rain band
NDVI	Normalized Difference Vegetation Index
Ne	Electron Density
NEWS	NASA Energy and Water Cycle Study
NLDAS	North American LDAS
NOAA	National Oceanic and Atmospheric Administrition
NOAH	National Centers for Environmental Prediction (NCEP)/Oregon State University/Air Force Hydrologic Research Laboratory
NOBM	NASA Ocean Biogeochemical Model
NRA	NASA Research Announcement
NRC	National Research Council
NSCAT	NASA Scatterometer
NSIPP	NASA seasonal to Interannual Prediction Project
NSSL	National Severe Storms Laboratory
NWP	Numerical Weather Prediction
NWS	National Weather Service
NWSRFS	NWS River Forecast System
ODAS	ocean data assimilation system

ODASI	Consortium for Ocean Data Assimilation Consortium for Seasonal-to-Interannual Prediction
OGCM	ocean general circulation model
OHD	Office of Hydrologic Development
OLR	Outgoing Long-wave Radiation
OMI	Ozone Monitoring Instrument
OPF	Operational Parameter File
OSSE	Observation System Simulation Experiment
PAHs	Polycyclic Aromatic Hydrocarbons
PAR	Photo-synthetically-active radiation
PAVE	Polar AURA Validation Experiment
PBL	Planetary Boundary Layer
PCA	Principal Component Analysis
PDAF	Parallel Data Assimilation Framework
PDE	Partial Differential Equation
PDF	Probability Density Function
PDR	Preliminary Design Review
PECAD	Production Estimation and Crop Assessment Division
PEST	Parameter Estimation Tool
PI	Principal Investigator
PID	Particle Impact Detector
PILPS-2g	Project for Intercomparison of Land surface Parameterization Schemes – Phase 2g
PM	Particulate Matter
PMM	Precipitation measurement missions
PNA	Pacific North America pattern
POAM	Polar Ozone and Aerosol Measurement
POLDER	Polarization and Directionality of the Earth's Reflectance
POM	Princeton Ocean Model
PR	Precipitation radar
PRMS	Precipitation Runoff Modeling System
PSU-NCAR	Penn State University – National Center for Atmospheric Research
PV	Potential Vorticity
QG	Quasi-Geostrophic
QMS	Quadrupole Mass Spectrometer
QPE	Quantitative Precipitation Estimation
QuikSCAT	Quick Scatterometer
RAMS	Regional Atmospheric Modeling System
RAS	Relaxed Arakawa-Schubert
ROSES	Research Opportunities in Space and Earth Sciences
RPI	Radio Plasma Imager
RRKF	Reduced-Rank Kalman Filter
RSS	Remote Sensing Systems, Inc.
SAC-SMA	Sacramento Soil Moisture Accounting model
SAGE III	Stratospheric Aerosol and Gas Experiment III
SAGE	Stratospheric Aerosol and Gas Experiment
SAIC	Science Applications International Corporation
SAM	Sample Analysis at Mars
SAR	Synthetic Aperture Radar
SBUV	Solar Backscatter UltraViolet radiometer
SCA	Snow cover area

SCAN	Soil Climate Analysis Network
SCD	Slant Column Density
SCIAMACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY, one of the payload instruments on board the ESA Envisat satellite
SCM	Single Column Model
SCO	Stratospheric Column Ozone
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEIK	Singular Evolutive Interpolated Kalman
SGT	Stinger Ghaffarian Technologies
SHADOZ	Southern Hemisphere Additional Ozonesonde
SHDOM	Spherical Harmonics Discrete Ordinate Method
SI	Standard Initialization
SIO	Scripps Institution of Oceanography
SIR	Shuttle Imaging Radar
SIRICE	Submillimeter and Infra-Red Ice Cloud Experiment
SIVO	Software Integration and Visualization Office
SMMR	Scanning Multichannel Microwave Radiometer
SNOTEL	SNOwpack TELemetry
SOLVE	SAGE III Ozone Loss and Validation Experiment
SPOT	Systeme Probatoire pour l'Observation de la Terre
SPRINTARS	Spectral Radiation-Transport Model for Aerosol Species
SRT	Sounder Research Team.
SRTM	Shuttle Radar Topography Mission
SSAI	Science Systems and Applications, Inc.
SSB	Sea state bias
SSI	Streamline Subgrid Integration
SSM/I	Special Sensor Microwave/Imager
SSS	Sea Surface Salinity
SST	Sea-Surface Tempeature
SST	Sea surface temperature
SSWSF	Snow Survey and Water Supply Forecast
ST-5	Space Technology 5
START	SysTem for Analysis, Research, and Training
STE	Stratosphere-Troposphere Exchange
STO	Stratospheric column ozone
SUMS	Segregation Using Multiple Sensors
SV	Singular Vector
SWE	Snow Water Equivalent
TCO	Tropospheric Column Ozone
TEC	Topographic Engineering Center
TEC	Total Electron Content
TLS	Tunable Laser Spectrometer
TMI	TRMM Microwave Imager
ToF	Time of Flight
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPEX	TOPography EXperiment for Ocean Circulation
TOPP	Tropospheric Ozone Pollution Project
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
UARS	Upper Atmosphere Research Satellite

UCLA	University of California, Los Angeles
UIBK	University of Innsbruck
UMB	University of Melbourne, Australia.
UMBC	University of Maryland, Baltimore County
UMCP	University of Maryland College Park
UNCCD	United Nations Convention to Combat Desertification (UNCCD)
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USACE	US Army Corps of Engineers
USAID	United States Agency for International Development
USAMC	United States Army Medical Component
USAMRU	United States Army Medical Research Unit
USBR	U.S. Bureau of Reclamation
USDA	United States Department of Agriculture
USDA/NRCS	United States Department of Agriculture Natural Resources Conservation Service
USGCRP	U. S. Global Change Research Program
USGS	United States Geologic Survey
USWCL	United States Water Conservation Laboratory
UT/LS	Upper-Troposphere/Lower-Stratosphere
UTC	Universal Time Coordinate
UV	Ultraviolet radiation
UVF	Ultraviolet Fluorescence
VCD	Vertical Column Density
VIC	Variable Infiltration Capacity Model
VIRSS	Visible/Infrared Imagery Radiometer Suite
WMO	World Meteorological Organization
WOUDC	World Ozone and Ultraviolet Radiation Data Center
WRAIR	Walter Reed Army Institute for Research (WRAIR)
WRF	Weather Research and Forecasting

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