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Annual Report

May 11, 2004 – May 10, 2005

University of Maryland, Baltimore County
Howard University
Hampton University
Caelum Research Corporation
Northrop-Grumman Corporation

UMBC
AN HONORS UNIVERSITY IN MARYLAND

GEST
GODDARD EARTH SCIENCES AND TECHNOLOGY CENTER

Goddard Earth Sciences and Technology Center (GEST)

Fifth Annual Report

10 May 2005

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INTRODUCTION

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INTRODUCTION

This annual report documents the completion of the fifth year of operation of the Goddard Earth Sciences and Technology (GEST) Center. Progress continues in establishing GEST as a prominent center for research and international collaboration in the Earth sciences and related information technologies. The organization grew more slowly during the fifth year of operation reaching a steady state of approximately 100 researchers. However, the breadth of research interests has continued to grow significantly. The organization continued with the eight research group structure accommodating the new research interests in related groups. Significant changes have been made in the administrative structure by combining related administrative functions of GEST with those of its "sister center" at UMBC, the Joint Center for Earth Systems Technology. This change has provided increased organizational efficiency and flexibility.

Research Accomplishments

Research by GEST faculty and staff has been recognized through significant publications in professional journals, invited presentations, and awards. The main body of this report contains brief discussions of the research focus and results for the faculty and staff who form GEST. The report consists of a total of 92 articles contributed by GEST's faculty researchers and visiting fellows. Also included in each report are the names of GSFC collaborators, accomplishments during the past year, and a plan for next year's work. Cumulative lists of publications in professional journals, conference proceedings papers, etc., are collected in appendices. During this year, there were 149 refereed scientific papers that were authored by GEST faculty and either accepted by or published in major journals. In addition, three GEST senior research faculty members served as lead editors for monographs published by the American Geophysical Union and John Wiley & Sons, Ltd.

Most of the research activities in this volume are funded through the program budgets of collaborating scientists at Goddard Space Flight Center (GSFC). However, an increasing number of GEST researchers have been successful in submitting proposals to NASA and other agencies, and have been awarded research grants. Reports of these grant-funded activities are also found in this report, organized by grant number within each research group. In most cases, GSFC scientists are listed as co-investigators with GEST PIs. GEST members were involved in submission of 182 proposals in the past year, of which 77 were funded; these are also listed in an appendix.

Goddard Visiting Fellows Program in the Earth Sciences

The Goddard Visiting Fellows Program in the Earth Sciences continued into its fifth year with 4 prominent international researchers participating in the program during the reporting period. This program provides the opportunity for selected Ph.D.-level scientists to pursue independent research in collaboration with scientists in the laboratories within the Earth Sciences Directorate either at GSFC or at the Goddard Institute for Space Studies. This report contains a more complete description of the program, the fellows selected, and some of their accomplishments.

Summer Educational Programs and Graduate Fellowships

The Summer 2004 Educational Programs continued into their fourth year under GEST management. Despite financial constraints, all programs were able to operate at full capacity and provided invaluable experiences to the students. The GEST Center organized and conducted the following three educational programs at GSFC:

- The *Visiting Student Enrichment Program (VSEP),* hosted 15 students in the physical sciences, mathematics, and computer science from high school through graduate school, who participated over a 10-week period in a wide variety of productive projects with GSFC-based mentors;

- The *High Performance Computing (HPC)* summer program hosted nine advanced graduate students who were guided through techniques for working with supercomputers on large, illustrative, computation-intensive problems;
- The *Graduate Student Summer Program (GSSP)* played host to nine students who worked with GSFC-based scientist mentors. The 2004 alumni project reports are available as PDF files at: http://gest.umbc.edu/student_opp/students.html. In association with the latter program, a series of four, half-day seminars, entitled, "Modern Themes in Earth Science", was conducted. A variety of Goddard and GEST scientists presented seminars on the most popular Earth science research occurring at GSFC. These seminars stimulated thought and discussion amongst the students, researchers, and other interested participants. The *Goddard Coastal Research Fellowship Program*, initiated two years previously, was absorbed into GSSP, enabling students to be placed at any of the three Goddard institutions: Goddard Space Flight Center, Goddard Institute for Space Studies, and the Wallops Flight Facility.

The educational aspect of GEST activities also included the appointment of a GEST graduate fellow in UMBC's Department of Computer Science and Electrical Engineering.

Short-Term Visiting Scientist Program and International Workshops

As part of our cooperative research program with the Earth Sciences Directorate, 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. 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. Over 50 visitors participated in this program from U.S. universities and international federal laboratories and universities.

Global Energy and Water Experiment

A significant focus of GEST Center research and programmatic involvement concerns understanding the cyclical processes linking water and energy in the Earth's environment. 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. Scientists from over 30 countries participate in major projects aimed at determining the hydrologic cycle and energy fluxes by means of global measurements of atmospheric and surface properties; modeling the global water cycle and its effects on the atmosphere, oceans, and land surfaces; 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 deal with land-atmosphere coupling processes and models, cloud system modeling, global data set development, water resource applications, and the effective use of Earth Observations in climate science.

GEST continues to provide leadership of the International GEWEX Project Office (IGPO) through coordination of international research programs in this area, sponsoring symposia and publication. The IGPO is responsible for international coordination of all aspects of GEWEX with the worldwide scientific community and the space agencies. Details about GEWEX may be found on its website: http://www.gewex.org. The IGPO has also been active in establishing the programmatic structure, and organizing resources and people for the Fifth International GEWEX Conference held in Orange County, California in June 2005.

Involvement of Consortium Members

The contributions of our four consortium partners continue to be significant. Most of the collaborative researchers in GEST were faculty of UMBC. However, research collaboration continued at Hampton University, Howard University, and Caelum Research Corporation during this fifth year of GEST. As in previous years Northrop Grumman Corporation has provided invaluable advice and support through representation on the GEST Executive Board.

Acknowledgements

The quality and significance of the research conducted by GEST and its collaborators is extremely satisfying. We have been especially happy to witness the realization of goals that were imagined during the inception of GEST, having to do with educational programs, support to graduate students and post-doctoral investigators, providing opportunities for visiting fellows, focused-topic international workshops, and international program coordination. This progress has been acknowledged during the reporting period with the extension of the original 5-year cooperative agreement to a total period of performance of 10 years. With the extension those activities will grow in importance, as the GEST capabilities become more widely known in the Earth sciences community.

GEST's continued growth and contributions have been possible only because of the hard work and enthusiastic support of many people. As always, the real credit for the vitality of the organization goes to the GEST faculty and staff whose excellent work is represented within. I am also grateful to Drs. Ronald Errico, Susan Hoban, Peter Merheim-Kealy, Richard Judelson-Kelley, Oreste Reale, Chung-Lin Shie, Lin Tian, Nickolay Krotkov and Tom Low, whose innumerable contributions as research group leaders greatly contributed to the progress made in this fifth year. Recognition for the development of this and the previous year's annual reports is given to the leadership of Dr. Tom Low and his collaboration with all the research group leaders. His work on this report and that of the research groups' leaders is greatly appreciated. Recognition for the day-to-day operations of GEST is given to Ms. Danita Eichenlaub, the Associate Director of the newly organized GEST/JECT administrative staff. Her leadership and the organization she has developed have given us the positive basis to successfully complete this fifth year.

We would like to thank Glen Engel-Cox, who served as technical editor of this volume, for his careful editing, integrating, and formatting of the many pieces and contributions into a single consistent document. We also recognize the work of Ms. Marcianna Ptak Delaney for her work in organizing the complexities of formatting the bibliographic material.

I continue to be indebted to the UMBC administration—especially to Dean Scott Bass, for his support and guidance—and to the administration of the NASA Goddard Space Flight Center—especially Dr. Franco Einaudi, for his vision of GEST for which we continue to strive.

Robert J. Curran
Director

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EXECUTIVE SUMMARY

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Executive Summary

The fifth year of existence for the Goddard Earth Sciences and Technology (GEST) Center has seen the most significant changes in its organizational structure, and its scientific research accomplishments. Administratively, GEST's directorship and operational staff have been merged with those of its "sister center" at the University of Maryland, Baltimore County (UMBC), the Joint Center for Earth Systems Technology (JCET). This change has provided increased organizational functionality and efficiency in providing response to the needs of GEST, its faculty, UMBC, and NASA Goddard. The growth of the overall organization has slowed this past year compared to previous years; its faculty numbers have stabilized around 100 research scientists. However, the breadth of research interests has continued to grow significantly, and GEST has gained momentum in becoming recognized as a prominent center for research and international collaboration in the Earth sciences and related information technologies. 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. As in previous years, the fifth GEST partner, Northrop Grumman Corporation, provided invaluable advice and support through representation on the GEST Executive Board.

The GEST faculty structure continues to be organized into eight related groups that reflect common research interests. This annual report predominantly contains brief discussions of the research focus and results for the GEST faculty and staff, a total of 92 articles from GEST's 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 success of our faculty's endeavours has drawn recognition through significant publications in professional journals, invited presentations, and awards. 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 149 referreed scientific papers that were authored by GEST faculty and published in major journals, with 57 more submitted or in progress. Three GEST senior research faculty members served as lead editors for monographs published by the American Geophysical Union and John Wiley & Sons, Ltd.

While funding for most of the research activities was through the program budgets of collaborating scientists at the NASA Goddard Space Flight Center (GSFC), the number of successful proposals awarded to GEST researchers from NASA, NSF, and other agencies, has increased significantly both in number (77 out of 182 proposals) and dollar value. These grant-funded activities are also reported herein.

The fifth year of the Goddard Visiting Fellows Program in the Earth Sciences had 4 prominent international researchers participating in the program during the reporting period. The participating fellows are listed and the results of their collaboration while at Goddard are summarized.

In terms of educational contributions, GEST continued its management of three Goddard Educational Programs during the summer of 2004. The Visiting Student Enrichment Program (VSEP) hosted 15 students in the physical sciences, mathematics, and computer science from high school through graduate school; the High Performance Computing (HPC) summer program hosted nine advanced graduate students; and the Graduate Student Summer Program (GSSP) had nine students who worked with GSFC-based scientist mentors. Despite financial constraints, all programs were able to operate at full capacity and provided invaluable experiences to the students. At UMBC, GEST's educational activities included the appointment of a GEST graduate fellow in UMBC's Department of Computer Science.

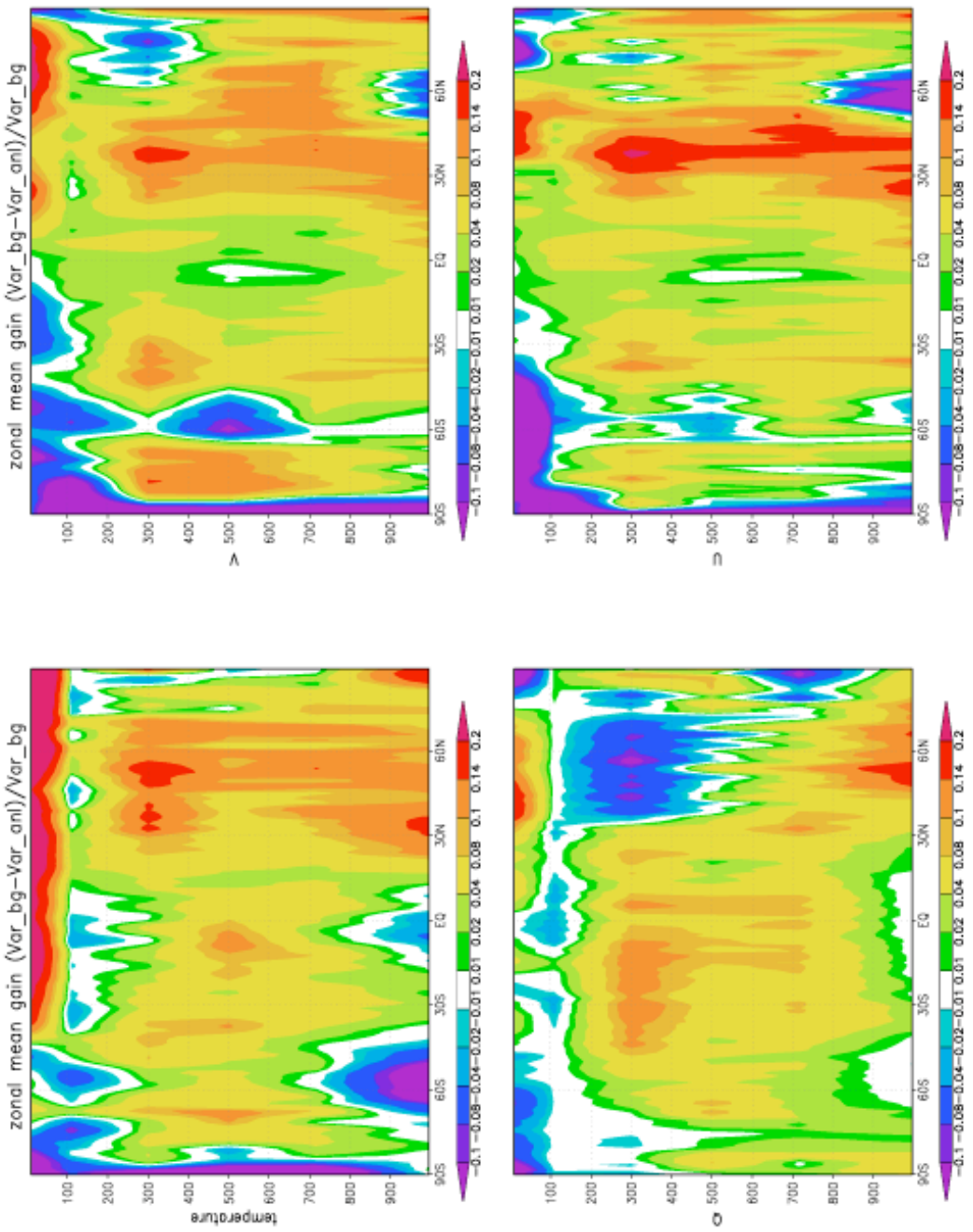
GEST continued to provide leadership of the International GEWEX Project Office (IGPO) in the pursuit of understanding coupled hydrologic and atmospheric processes on a global scale. The IGPO is

responsible for international coordination of all aspects of GEWEX with the worldwide scientific community and the space agencies. It has been active in sponsoring symposia and publications. In particular, it has been establishing the programmatic structure, and organizing resources and people for the Fifth International GEWEX Conference held in Orange County, California in June 2005.

If the results and accomplishments of this fifth year's efforts by GEST are an accurate indication, we can look forward to the future with much anticipation and expected accelerated growth once again.

Tom B. Low
Associate Director

Global Modeling and Assimilation Office
Research Group A



The zonal mean of the Kalman gain for temperature, northward and eastward wind components, and specific humidity computed from an OSSE using the present observation network. This can be interpreted as an estimate of the percentage reduction of the background error variance due to the consideration of new observations for each assimilation cycle. The variances from which the gain is computed are from 3 weeks of 6-hourly data. This work is a collaborative effort between Ronald Errico (GEST), Runhua Yang (GMAO), and Michiko Masutani and Jack Woollen (NCEP).

Global Modeling and Assimilation Office Research Group A

The Global Modeling and Assimilation Office Research Group A (GMAO-A) collaborates with other GMAO personnel in its main tasks of developing and investigating techniques for data assimilation (including chemical species), model forecasting (for various purposes on a range of time scales), and seasonal to interannual prediction. The three primary contributions by the GMAO-A group concern precipitation assimilation, ozone assimilation, and advanced diagnostic capabilities. Some personnel are currently occupied by the Office's major development activities. Others are more involved in experimentation and diagnosis using existing tools and datasets.

Four tasks are concerned with different but related aspects of the hydrological cycle. Julio Bacmeister is developing and integrating parameterization schemes for the new GEOS-5 model. Of particular concern are its precipitation processes, including the diurnal cycle and geographic distributions, along with their effects on the ITCZ and stationary planetary waves. Myong-In Lee is investigating difficulties of simulating the diurnal cycle of warm season rainfall over the continental United States by determining the similarities and differences of responses produced by different models. The relationship between difficult-to-simulate low-frequency phenomena, such as ENSO and the MJO, and the probability of extreme precipitation events in the Western U. S. is being investigated by Yehui Chang. The hydrological relationships between the land and atmosphere as simulated by the new catchment land surface model are being examined by Sarith Mahanama as part of its validation and an effort to quantify soil moisture "memory."

Three tasks are concerned wholly or partly with atmospheric chemistry. David Lary continues to be on the forefront of the application of neural network techniques for parameterizing the covariance modeling of chemical constituents. One of his models was used by Hiroo Hayashi, who has been comparing it with other methods for the assimilation of tropospheric ozone. Ronald Errico has been working on ameliorating the non-physical excitation of stratospheric and mesospheric gravity waves during data assimilation procedures by applying the technique of nonlinear normal mode initialization.

Most of these tasks are critical contributions to the new GEOS-5 modeling and data assimilation systems which are expected to be operational shortly after this report is completed. Besides those already mentioned, Ronald Errico has been contributing to the development of the adjoint modeling capability of the GMAO dynamic model and data assimilation systems. Also, he has developed and applied new diagnostic procedures to the OSSEs, in order to both assist in their validation and to provide a more complete characterization of analysis uncertainty.

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

Collaborators 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

Development and implementation of parameterized physics for the new GMAO atmospheric general circulation model, the GEOS-5 AGCM, was completed. The aim 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.

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

The principal accomplishment of this project during this year was to complete the initial development of the GEOS-5 AGCM. The GEOS-5AGCM was constructed from components derived from the NSIPP and DAO AGCMs. The dynamical core of the model is the finite volume core developed for the DAO by S. J. Lin. The model moist physics uses a prognostic cloud scheme developed by Bacmeister, coupled to a relaxed Arakawa-Schubert convection scheme. An important feature of the GMAO AGCM is its overall architecture which relies on the Earth System Modeling Framework (ESMF) for component-to-component coupling. The decision to use ESMF meant paying a substantial price, initially, in-terms of software development. However, now that the ESMF architecture is in place, subsequent model development, including parameterization "swapping," is relatively straightforward. Largely as a result of the modular ESMF architecture of GEOS-5, it was possible to develop a single-column model (SCM) that is precisely identical to the full GEOS-5 AGCM up to runtime initialization. The SCM has proved a valuable tool for full implementation and initial testing of model physics routines. As of February 2005, the complete GEOS-5 AGCM has been run for over 150 simulation experiments of one-year or longer. These results have been used in an effort to optimize model "tuning." Development of the first version of GEOS-5 is scheduled to be complete by April 2005.

In addition to the GMAO model development described above, work continued on understanding the physical causes of the so-called "double ITCZ bias" in climate models. The double ITCZ bias refers to a tendency for

AGCMs to form two narrow, parallel bands (Inter-tropical convergence zones or "ITCZs") of intense rain along 10S and 10N, which extend much of the way across the Pacific. The double ITCZ bias is present to varying degrees in almost all current AGCMs, and unfortunately, in coupled simulations, double ITCZs tend to be self-reinforcing, because of the strong surface wind stress divergence that is induced along the Equator by the paired convergence zones on either side. A series of intensive, short (2-year), forced-SST simulations was analyzed to isolate mechanisms responsible for the formation and/or suppression of the double ITCZ was completed. The final conclusion of this study is that low-altitude cooling from re-evaporation reduces boundary layer convergence forced by convective events, which in turn suppresses formation of the spurious southern ITCZs. Moisture from for the northern ITCZ appears to be fed by a steady or longer period convergence pattern that relies less on high-frequency forcing from convection [Bacmeister *et al.* 2004].

Another widespread AGCM defect is the inability to correctly simulate the diurnal cycle of precipitation over warm continents. Typically, AGCMs form precipitation maxima too early, in the early afternoon, rather than in the late afternoon or evening. The causes of this bias are not well known. In close collaboration with GEST researcher M-I Lee, sensitivity experiments and analysis were conducted which suggest that this bias may be related to the assumed coupling between the planetary boundary layer and convection in AGCMs.

Objectives for the Coming Year

In the coming year the GEOS-5 AGCM will be delivered to the GMAO for inclusion in its assimilation and forecasting systems. Free running multi year simulations will be performed, for diagnostic purposes, as well for inclusion in NSF's Tropical Cloud Climate Process Team modeling component. 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.

Task: 910-14-123 **The Impact of ENSO on Extreme Winter Weather of the Continental United States**

GEST Investigator: Yehui Chang

Collaborator: Siegfried Schubert (GSFC), Max Suarez (GSFC)

Abstract

The ENSO/weather connection clearly depends on a number of different process that include the large-scale seasonal mean response of the atmospheric to tropical Pacific SST anomalies, and potential attendant changes in various subseasonal low frequency variations such as the Madden-Julian Oscillation (MJO), PNA and blocking. These linkages are complicated by potential nonlinearities that result in the interactions between the various time and space scales. This research has led to better understanding of the ENSO and MJO effects on climate variability in the western U.S., including the occurrence of extreme weather (precipitation) events. Most current atmospheric general circulation models do poorly in simulating the MJO so that their potential for forecasting variability associated with the MJO is limited. The study has forced the NSIPP-1 AGCM with idealized MJO-like heating to examine the link between the MJO and extreme precipitation events over the western United States. Results from the simulations are compared with observations that are composited according to the different phases of ENSO and the MJO.

Accomplishments during the Reporting Period

ENSO, MJO and weather relationships involve three different time scales consisting of the seasonal mean, low frequency subseasonal transients (time scales of approximately 10-90 days), and weather or high frequency transients

(time scales of approximately 2-10 days). Understanding how ENSO affects weather is central to understanding and predicting ENSO's impact on the climate of United States. The robustness of the ENSO/weather connection clearly depends on a number of different process that include the large-scale seasonal mean response of the atmospheric to tropical Pacific SST anomalies, and potential attendant changes in various subseasonal low frequency variations such as the PNA and blocking. These linkages are complicated by potential nonlinearities that result in the interactions between the various time and space scales.

The NSIPP-1 AGCM was integrated at 2x2.5 resolution. A 100 year control run was made with climate SST boundary condition set. Two 10 year runs were made with climate SST and forced with idealized MJO-like heating. The second run has the heating extended further to the east to mimic the eastward extension of MJO variability during El Nino events. The validation data sets for the above analyses include the NCEP/NCAR global reanalyses, NOAA daily precipitation observations [Higgins *et al.* 1996] over the United States for the period 1949-2003, and OLR for the period 1974-2003 to help evaluate the model's ENSO and MJO response.

The most extreme precipitation events over Southern California tend to occur during EL Nino winters. The above result is quantified in terms of the PDFs of daily precipitation maxima. The PDFs clearly distinguish EL Nino winters from neutral and La Nina winters. The difference in the PDFs of daily precipitation maxima between La Nina and neutral winters is not significant. In addition to the link to EL Nino, there is also a strong relationship between the extreme precipitation events over Southern California and tropical Pacific convection on intraseasonal timescales that appears to be linked to the MJO. The NSIPP-1 AGCM with idealized MJO-like heating reproduces the basic structures of the precipitation over Southern California and its phase relationship with the MJO, particularly for the case when the MJO heating extends further eastward across the dateline as is often observed during El Nino events.

Objectives for the Coming Year

In the coming year, the linkage between ENSO and extreme precipitation events over the United States will be examined. In addition to the link to EL Nino, we will also quantify the impact of other subseasonal modes of variability including the PNA and AO on extreme weather throughout the continent. We will also seek to advance the practices of seasonal climate prediction. The specific aims are to estimate the causes for seasonal climate anomalies, to assess their predictability, and to determine the upper limit of US seasonal climate predictability.

Task 910-31-115: **Goddard Earth Observing System Data Assimilation System**

GEST Investigator: Ronald Errico

Collaborators: Ronald Gelaro (PI, GSFC), Nathan Winslow (DSTI), Ricardo Todling (SAIC), Runhua Yang (SSAI), Michiko Masutani (NCEP), Carolyn Reynolds (NRL), Martin Ehrendorfer (UIBK)

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 spectral and normal-mode analysis techniques and software for application on the GMAO GCM grid, and development of adjoint-based analysis tools for ranking the importance of observation types. He has also been examining the basis and progress of ensemble Kalman filter data assimilation as a possible foundation for a future GMAO DAS and has been estimating the fundamental limits of atmospheric predictability by using ensemble

forecasts. He was the chief organizer of the 6th International Workshop on Adjoint Model Applications in Dynamic Meteorology, held in Southern Italy during May 2004.

Description of Research

Many research and development activities require the estimation of sensitivities of measures of output data with respect to uncertainties of input data. Adjoint models are powerful tools for efficiently determining such sensitivity when the number of output measures is very small but the input data set is very large. The GMAO is interested in using such tools for assisting in determining the sources of errors in data assimilation systems. Adjoint models also reveal fundamental relationships in the atmosphere that should be properly considered when developing future data assimilation systems. These and other tools, such as nonlinear normal-mode initialization software, require development, testing, and application to the GMAO data assimilation/forecast system.

Accomplishments during the Reporting Period

An algorithm and modular software has been developed for performing exact spherical harmonic transforms on the GMAO model's computational D-grid. The staggering of fields and treatment of the poles precluded use of standard software packages and required substantial innovation. This tool provides new model diagnostic capabilities that will be required for several planned investigations. One application already implemented is the development of normal mode transform software required for investigating and ameliorating dynamic stratospheric noise generated during the FVGCM data assimilation procedure. A nonlinear normal mode initialization scheme is currently undergoing testing. Without it or an equivalent technique, the stratospheric noise renders the analysis almost useless there.

Development of an adjoint version of the GMAO modeling system continues. Required model physics continues to be added, the latest requirement being a numerically stable horizontal diffusion. Algorithms and software for preparation of adjoint model initial conditions (gradient fields) and post-processing diagnostics have been completed. The adjoint system is expected to be operational this summer, after almost three years of development.

Due to the difficulty of estimating them by direct means, many characteristics of analysis uncertainty remain unknown. Errico, with the assistance of Runhus Yang (SSAI) and Michiko Masutani (NCEP), has therefore employed an indirect means by examining results produced by the NCEP Observation System Simulation Experiments. Rather than conducting the usual OSSE analysis, which is fraught with validity and signal-to-noise ratio issues, he has used them as a proxy for an atmospheric analysis. His diagnostics have been used to add validity to the OSSEs, but also revealed some deficiencies. Surprisingly, the background errors are reduced by only 20% on the average at 12 or 00 UTC (less so at 06 or 18 UTC) and the vertical and horizontal spectra are only slightly whitened.

In anticipation of the completion of an adjoint of the GMAO DAS, two proposed measures (one from NRL, the other from Meteo-France) of adjoint-derived observation importance were compared. It was shown that both measures are actually non-linear, a property that potentially clouds their interpretations. The NRL measure is in fact 3rd order in observation innovations. A manuscript presenting these results has been prepared and is undergoing internal review.

A quasi-geostrophic model has been developed with the collaboration of Martin Ehrendorfer at the University of Innsbruck. It provides a model capable of resolving the primary atmospheric instabilities but also with few enough degrees of freedom to allow explicit computation of a Kalman gain matrix. The intention is to use this as an intermediate model for investigating fundamental properties of atmospheric DAS. A manuscript describing the new model and its dynamical stability properties is being prepared.

Objectives for the Coming Year

Three sets of activities are planned for the coming year. The first concerns applications and demonstrations of the utility of the GMAO adjoint model, including its combination with

the adjoint of the DAS. The second concerns continuing examination of the NCEP OSSEs and the development of a complimentary GMAO OSSE capability. The third is development and application of DAS software for the QG model, including a Kalman filter and both 3-D and 4-D variational techniques. These developments will be used to monitor the present GMAO DAS and to help guide future innovations.

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

GEST Investigator: Hiroo Hayashi

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

Abstract

Since it was revealed that ozone assimilation systems are beneficial to studies, especially those concerning distributions of tropospheric ozone, they have been continuously developed and modified. The first version of an online ozone assimilation system at GSFC was completed and has begun to provide support products for some field missions. While the ozone assimilation system is being evaluated by many experiments and comparisons with independent observations, further development is underway for the EOS-Aura validations and other future field missions.

Description of Research

Tropospheric ozone is environmentally important because it acts as a strong oxidant to control the concentrations of many reduced gases, such as methane, carbon monoxide, etc. Its radiative forcing plays a significant role in the greenhouse effect. The main goal of this research is to provide better tropospheric ozone distributions through the assimilation of satellite ozone measurements. For this purpose, online ozone assimilation systems have been developed and evaluated by comparisons with independent observations. Future studies based on the assimilation systems would lead to better understanding of the mechanisms that determine the ozone distribution in the real atmosphere.

Accomplishments during the Reporting Period

The first online ozone assimilation system (based on the GEOS-4.0.2 meteorological assimilation system) was completed. Hayashi contributed to this mainly by incorporating parameterized ozone chemistry into the system. The products of the assimilation system were provided to support the pre-Aura Validation Experiments (January-February 2004).

The ozone assimilation system has been continuously modified. Most important was modification of its parameterized heterogeneous chemistry to better reproduce significant ozone depletion in the polar stratosphere in the early spring. Based on the original code for this chemistry provided by David Lary (GSFC/GEST), Hayashi worked with him to develop it through many experiments and comparisons with observations.

Various experiments for the year 1998 with different conditions have been performed to evaluate the online ozone assimilation system. The results of the runs, in which ozone data from SBUV was assimilated, were compared to one another and to independent ozonesonde and satellite observations. These results will be published in the near future.

Since the GMAO meteorological analyses are currently produced by the GEOS-4.0.3 system, our ozone assimilation system had to reconstruct the meteorological system. This is necessary to implement ozone assimilation experiments for 2004 and 2005, and important especially to support planned field missions for the EOS-Aura validation. Hayashi has been working on integrating the ozone assimilation and parameterized chemistry schemes on the GEOS-4.0.3 meteorological assimilation system.

Objectives for the Coming Year

The next generation of the GMAO meteorological assimilation system (GEOS-5) is being developed, and will be officially operational this year. The online ozone assimilation system must be moved to this new system as well. At the same time, the incorporation of a more complicated (realistic) chemistry model instead of the current simple parameterizations will be considered. Most of the forthcoming year will be devoted to development of new ozone assimilation systems. In the meantime, the current system will be utilized, with additional modifications, to support field missions for EOS-Aura validations and other observational/numerical studies. Hayashi will contribute to such projects by providing analysis and forecast data from the ozone assimilation systems.

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

GEST Investigator: David Lary

Collaborator: Mark Schoeberl (GSFC), Anne Douglass (GSFC), Eric Nielsen (GSFC), Lynn Sparling (UMBC), Richard Stolarski (GSFC), Mian Chen (GSFC), Joe Waters (NASA JPL), Nathaniel Livesey (NASA JPL), Gloria Manney (NASA JPL), William Read (NASA JPL), Michelle Santee (NASA JPL), John Gille (NCAR), Alyn Lambert (NCAR), Doug Kinisson (NCAR), Doug Allen (Naval Research Laboratory), Steve Eckermann (Naval Research Laboratory), John Sienfeld (Caltech)

Abstract

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. 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 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

David Lary has been involved in three areas of research in the Global Modeling and Assimilation Office. The first area is multi-constituent chemical data assimilation, with particular emphasis in preparation for EOS/Aura. The second area is the use of neural networks to parameterize and accelerate various aspects of atmospheric chemical simulation. The third area is 3D global chemical simulation.

Accomplishments During the Reporting Period

An assimilation system has been prepared for satellite evaluation. Satellite instrument validation is obviously necessary but sampling issues often make practical application problematic. This research aims to aid 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 analysis can 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. Chemical data assimilation can ingest observations from platforms such as ACE, HALOE, and POAM to prepare global stratospheric multiconstituent analyses. These analyses can then be 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 may be present in the Aura observations. Aura measurements could be processed similarly to the validating observations to produce global stratospheric analyses which are then intercompared with the same tools. Additionally, chemical data assimilation can add 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), PK Bhartia (GSFC), Doug Kinisson (NCAR), and Joe Waters (JPL).

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 CH4-N2O correlation can be well described using a neural network trained with the latitude, pressure, time of year, and CH4 volume mixing ratio. A neural network using Quickprop learning and one hidden layer with eight nodes was able to reproduce the CH4-N2O 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 CH4 (but not N2O) from 1991 till the present. Work is now underway to use the neural networks to learn the behavior of ODEs and assist in their solution. This represents a strong collaboration between the GMAO and 916, in particular Anne Douglass (GSFC), Richard Stolarski (GSFC), and Mian Chen (GSFC), with whom bi-weekly meetings are held.

Working with Eric Nielsen, the AutoChem chemistry scheme has been installed in GEOS 4 and is currently being installed into GEOS 5.

Objectives for the Coming Year

The coming year will be dominated by two major new activities. The first major activity will be to prepare multi-constituent chemical analyses for NASA's EOS-Aura. The second major activity will be to develop generic neural networks for a variety of applications in Earth Science.

Task 971-00-002: **Moist Physics Studies for the NASA's Seasonal-to-Interannual Prediction Project Atmospheric General Circulation Model**

GEST Investigator: Myong-In Lee

Collaborator: Siegfried Schubert (GSFC, 610.1), Max Suarez (GSFC, 610.1), Julio Bacmeister (GEST), Phil Pegion (SAIC), Isaac Held (GFDL), Arun Kumar (NCEP)

Abstract

In efforts to improve the moist physical parameterizations in the NASA's Seasonal-to-Interannual Prediction Project (NSIPP) atmospheric model, the diurnal cycle of warm season rainfall over the continental United States and northern Mexico was analyzed in three AGCMs from NCEP, GFDL, and NASA/GMAO. All three models employ deep convection schemes that assume fundamentally the same mass flux closure based on simplified versions of the Arakawa-Schubert scheme. Nevertheless, there are substantially differences between the models in the diurnal cycle of the convection schemes, highlighting the importance of the differences in implementation, including trigger functions and the interactions with boundary layer and cloud schemes.

Description of Research

The diurnal cycle of rainfall is a difficult test for atmospheric general circulation models (AGCMs). A number of studies have examined the diurnal cycle produced in regional and global atmospheric general circulation models (*e.g.*, Dai *et al.* 1999; Lin *et al.* 2000; and Yang and Slingo 2001), in which the simulation of diurnal convection appeared to be common problems to many AGCMs. These include difficulties in getting the nocturnal rainfall maximum over the Great Plains (despite simulating a reasonable GPLLJ), too frequent precipitation and too much drizzle, too large of an amplitude in the diurnal cycle of precipitation over the central and eastern United States, excessive afternoon precipitation over the western slopes of the Sierra Madre Occidental, and a poorly resolved GCLLJ. Many of these problems appear to be linked to the models' convective parameterizations and how the schemes interact with the land surface, the boundary layer, and clouds. The current study is a coordinated effort to evaluate and understand the warm season continental diurnal cycle of the United States and northern Mexico in three different AGCMs run at a typical climate model resolution.

Accomplishments in FY 04-05

Based on the initial set of 5-member ensemble experiments forced by climatological SST at the current production resolution (approximately 2 degrees lat./lon.), the diurnal cycle of warm season rainfall over the continental United States and northern Mexico was analyzed in three global atmospheric general circulation models from NCEP, GFDL, and NASA/GMAO. The analysis includes a comparison of the basic warm-season climatology, and an in-depth evaluation of the processes and phenomena governing the diurnal cycle, with a particular focus on the convection schemes.

Although the overall patterns of time-mean (summer) rainfall and low-level wind are reasonably well simulated, all three models exhibit substantial regional deficiencies that appear to be related to problems with the diurnal cycle. Especially prominent are the discrepancies in the diurnal cycle of precipitation over the eastern slopes of the Rocky Mountains and adjacent Great Plains, including the failure to adequately capture the observed nocturnal peak. Moreover, the observed late afternoon-early evening eastward propagation of convection from the mountains into the Great Plains is not adequately simulated, contributing to the overall dry bias and the deficiencies in the diurnal cycle in the Great Plains. In the southeast U.S., the models show a general tendency to rain in the early afternoon—several hours earlier than observed. Over the southwest and northern Mexico (the North

American monsoon region), the phase of the large-scale diurnal cycle appears to be reasonably well simulated, though the coarse resolution of the runs precludes the simulation of key regional phenomena.

All three models employ deep convection schemes that assume fundamentally the same mass flux closure based on simplified versions of the Arakawa-Schubert scheme [Arakawa and Schubert 1974]. Nevertheless, there are substantially differences between the models in the diurnal cycle of the convection schemes, highlighting the importance of the differences in implementation, including various trigger/inhibition functions, and the interactions with boundary layer and cloud schemes. An analysis of local diurnal variations of convective available potential energy (CAPE) shows an overall tendency for an afternoon peak—a feature well-simulated by the models. The simulated diurnal cycle of rainfall is in phase with the local CAPE variation over the southeast U.S., although the peak phases of the rainfall differ in each model from early afternoon to evening. On the other hand, the simulated diurnal cycle in precipitation tends to be too strongly tied to CAPE over the Great Plains, where the observed CAPE and precipitation are out of phase, implying that boundary layer and free atmospheric large-scale forcing plays a more important role than surface heat fluxes in initiating or inhibiting convection.

The obtained results suggest that making substantial improvements to our models will require a better understanding of the relative contributions of local processes and large-scale influences in controlling the diurnal cycle. In certain regions and under specific conditions, the diurnal variation of precipitation is not simply tied to local convective instability as measured by the CAPE and the diurnal variation of large-scale forcing—e.g., low-level moisture flux [Schubert *et al.* 1998] or wave propagation [Yang and Slingo 2001]—can regulate convective intensity and the timing of diurnal convection.

Objectives for FY 05-06

A follow-on study will test the sensitivity of the diurnal cycle simulation to the modification of deep convection and PBL schemes in the NSIPP AGCM. In particular, some parameters and the triggering functions will be tested to focus on the local and non-local regulations of diurnal convection. It will also address the issue of the gains that are possible with higher resolution experiments by increasing horizontal resolution up to 0.5 degrees.

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

GEST Investigator: Sarith P.P. Mahanama

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

Abstract

Performance of the Catchment Land Surface Model (LSM) was evaluated along with other LSMs from most of the climate modeling centers around the world in the ongoing Global Soil Wetness Project – Phase 2 (GSWP-2). In a separate study, impact of Atmospheric General Circulation Model (AGCM) biases on the simulated soil moisture memory and land-atmosphere feedback of the Mosaic LSM was investigated. On the model development front, the earth's land surface was resolved into hydrologic catchments and the Catchment LSM soil and vegetation parameters were computed for each land element. Version 2 of the unified LSM of GMAO was tested globally off-line for 10 years and its results compared with those of the Catchment LSM.

Description of Research

The primary goal of land surface modeling in the GMAO is the development and validation of

the catchment LSM. This requires, in part, continuous validation of the catchment LSM by participating in inter-institutional efforts of intercomparison of land surface parameterization schemes. The LSM parameters are continuously updated using new satellite-based global data sets. Also, incorporation of additional parameterizations such as vegetation phenology and dynamics, and land carbon and chemistry processes are essential parts in the model development.

Accomplishments during the Reporting Period

Because precipitation and net radiation in an AGCM are typically biased relative to observations, the simulated evaporative regime of a region may be biased, with consequent negative effects on the AGCM's ability to translate an initialized soil moisture anomaly into an improved seasonal prediction. These potential problems were investigated through extensive offline analyses with the Mosaic LSM. We first forced the LSM globally with a 15-year observations-based dataset. We then repeated the simulation after imposing a representative set of GCM climate biases onto the forcings. The AGCM's climate biases lead to significant biases in evaporative regime in certain regions, with the expected impacts on soil moisture memory timescales. Furthermore, the offline simulations suggest that the biased forcing in the AGCM should contribute to overestimated feedback in certain parts of North America—parts already identified in previous studies as having excessive feedback. The present study thus supports the notion that the reduction of climate biases in the AGCM will lead to more appropriate translations of soil moisture initialization into seasonal prediction skill.

Global Soil Wetness Project – Phase 2 (GSWP–2) provided a unique platform for the land surface modelers to evaluate their LSMs globally, off-line, for a period of 10 years (1986-1995) on a 1x1-degree grid. This past year, meteorological forcing was provided by the ECMWF ERA-40 analysis. More than 10 sensitivity experiments have been planned and executed to isolate the impact of various forcing components and other vegetation data sets. At the end, the GSWP-2 should be able to produce the best estimate of the global land surface hydrological fluxes. Intercomparison of the baseline simulations showed that the Catchment LSM produces an excellent match to the annual and monthly mean runoff in the Mississippi basin.

The earth's land surface was resolved into hydrologic catchments. For easy communication with the boundary layer grid of the GEOS-5 AGCM, the GEOS-5 grid systems were overlaid on the global catchment map. The catchments which lie across grid lines (or share 2 or more AGCM cells) were sub-divided into two or more catchment-tiles. Six different global catchment-tile maps were created for 3 different grid resolutions (2ox2.5o, 1ox1.25o, and 0.5ox0.67o) with 2 different origins for the grid systems (one with the dateline as the western boundary, and the other with the dateline lie at the center of cell centers of the western-most column). The Catchment LSM specific parameters for each catchment-tile (for the 6 versions separately) were computed using the HYDRO1k topography data and the soil texture classification from the USGS (5'x5'). For the 6 versions of catchment-tiles separately, leaf area index (LAI), greenness fraction (using a1982-1998, 1-degree, global dataset based on AVHRR NDVIs) and snow-free albedo (using global 1'x1', bimonthly MODIS data for 2001-2002) were computed for each tile. A software utility was also developed to debug the catchment LSM offline which uses the AGCM forcing and enables users to identify problems associated with the LSM easily.

The catchment LSM is participating in the PILPS-2g (San Pedro – Sevilleta Experiment) in which the performance of the participating LSMs will be evaluated in semi-arid areas. The first (of a series of experiments) experiment was completed and the project is still underway.

Version 2 of the unified LSM of GMAO (by merging the Simple Biosophere Model, SiB canopy temperature parameterization to the catchment LSM) was tested globally off-line for 10 years using the GSWP-2 baseline forcing. Its comparison with the catchment LSM simulations showed a reduction in

evapotranspiration, particularly over the Amazon and Congo rain forests.

Objectives for FY 05-06

We may have to do a few more sensitivity GSWP-2 experiments once the organizers prepare the forcing datasets. The PILPS-2g is also underway. In addition, we have started studying the impact of land surface enthalpy on seasonal forecast of the AGCM.

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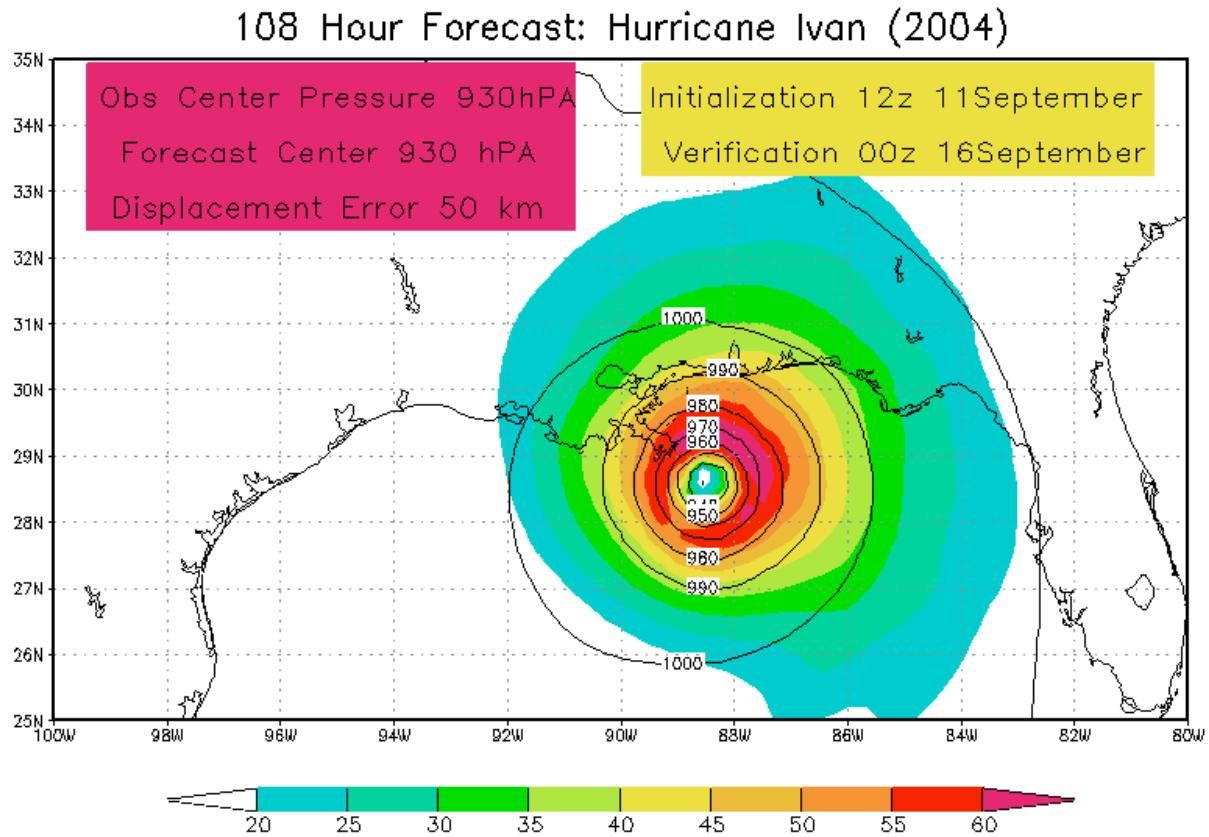
Global Modeling and Assimilation Office
Research Group B



From 2004, near real-time and real-time global forecasts have been performed at NASA Goddard and NASA Ames centers using the high resolution (quarter of a degree) finite-volume General Circulation Model.

In the figure a 108-hour forecast for center pressure (hPa, solid line), relative to hurricane Ivan (2004) at 00z 16 September 2004, shortly before landfall, is shown. The model is initialized at 12z 11 September with NCEP initial conditions and produces after 4 days a center of about 930 hPa, like the observed, without any bogusing or additional data assimilation. The displacement error is only of about 50km. The 850 hPa wind speed (m/s) is also over-imposed. A clear representation of an eye-like feature can be inferred, and the values above 60m/s to the northeast of the center are consistent with observations.

The high resolution NASA fvGCM has been the first General Circulation Model being run in real-time and producing realistic hurricane structure, intensity and scale. Other results from this effort have been published on Geophysical Research Letters (Atlas et al., 2005).

Global Modeling and Assimilation Office Research Group B

The work performed by the members of the Global Modeling and Assimilation Office Research Group B (GMAO-B) is focused on climate research; land, atmospheric, and oceanic data assimilation on a global scale, development of next generation global atmospheric models, and hurricane studies. The group originally was composed of eleven scientists: nine supported by GMAO, and two by the Laboratory for Atmospheres. However, four individuals, all belonging to GMAO, have left GEST during this time-frame: Steven Pawson, who became a civil servant at NASA; Augustin Vintzileos, who joined NOAA; Sonia Seneviratne, who successfully ended her visiting appointment and returned to her home Institution in Switzerland; and Rosana Nieto Ferreira, who left for family reasons. In spite of this, the group has produced a remarkable amount of scientific results, testified by 21 co-authored articles in peer-reviewed journals (four more than the past year).

Among the scientists who left, Steven Pawson was primarily focused on coupling chemistry modules into the GEOS-4 GCM. He was also involved in stratospheric research, ozone modeling and trace species, data analysis, modeling, assimilation, and validation. His truly exceptional scientific productivity is made manifest in the eleven articles he co-authored during the past year. Augustin Vintzileos and Rosana Nieto Ferreira were involved in climate predictability studies. In particular, Vintzileos has examined the seasonal-to-interannual time-scale, with emphasis on the El Niño/Southern Oscillation (ENSO) phenomenon, while Nieto Ferreira has investigated longer, decadal-to-multidecadal time scales, examining precipitation over the Americas and Africa. Sonia Seneviratne has worked on large-scale water balance estimates of changes in terrestrial water storage as part of an atmospheric GCM intercomparison project.

The scientists still in the group predominantly focus on different aspects of data assimilation. In particular, Xin Lin and Peter Norris are involved in rainfall and cloud assimilation studies. Lin has been evaluating his previously developed variational framework for assimilating satellite-derived surface rain rate and total precipitable water in the Goddard Earth Observing System (GEOS) data assimilation system (DAS), while Norris has been developing a cloud parameter estimation scheme to assimilate satellite inferred clouds into the GMAO DAS. Rolf Reichle is involved primarily in land surface studies and/or land surface data assimilation. Reichle has been leading the operational implementation of the previously developed land assimilation for seasonal forecasting, and promoting the development of an advanced land data assimilation system that makes also use of satellite land surface conditions. Lars Peter Riishojgaard leads the satellite data analysis group within the GMAO. The role of this group is to ensure that current and future satellite data from both research and operational satellites are assimilated as efficiently as possible. Chaojiao Sun has been working primarily in ocean data assimilation in a global ocean circulation model. Her current reseach is focused on the evaluation and validation of the GMAO and GFDL data assimilation systems.

Oreste Reale and Kao-San Yeh are not part of the GMAO but are sponsored by the GSFC Laboratory for Atmospheres, in the Data Impact and Modeling Team. 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). Oreste Reale is involved primarily with synoptic and dynamic evaluations of the fvGCM and with studies of the impact of increased resolution on the simulation of structure and track of tropical cyclones.

With such a diverse range of expertise and activities, it is difficult to assess relationships between the results. However, it can be stated that 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. None of the scientists is working on individual, "pure" scientific projects, but all are part of a complex, multitasking, multidisciplinary team effort that can be evaluated only in its entirety and over several years of activity. In particular, the modeling effort is the one from which most researchers benefit over the long term, although it is the least spectacular when measured by timeliness of results and publications. Similarly, designing and developing complex data assimilation code is extremely beneficial for a broad user community, but such work generally does not produce many publications. Finally, work related to testing the impact of newly developed models and methodologies on forecast skill, for example, is generally very time consuming and to some extent not always rewarding, since not all the code changes produce immediate and clearly favorable results, and improvements are obtained only after long trial-and-error procedures. In spite of all these intrinsic limitations—typical of any scientific team effort—the group produced 21 publications that were either accepted or published in major peer-reviewed journals during the reporting period, four more than the previous year.

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

Oreste Reale

Task 910-14-124: **Rainfall and Cloud Assimilation**

Gest Investigator: Xin Lin

Collaborators: Arthur Hou (PI, GSFC)

Abstract
A variational framework for assimilating the SSMI-derived surface rain rate and total precipitable water (TPW) has been developed, and its impact on the Goddard Earth Observing System (GEOS) Data Assimilation System (DAS) have been examined over the Tropics. This research is trying to apply the same methodology to midlatitude weather systems and evaluate its impact on analyses and forecastings of midlatitude winter storms. Algorithms to assimilate cloud data will be developed.

Description of Research
Rainfall data retrieved from satellites can be used to directly constrain systematic errors in model physics. A procedure for assimilating 6-h average surface rainfall and TPW estimates derived from SSMI has been developed and the global analysis produced by the GEOS DAS shows a significant improvement in the Tropics after assimilating the rainfall and TPW data [Hou *et al.* 2000, Hou *et al.* 2001].

Global Precipitation Measurement Mission plans to have a multiple-satellite constellation to achieve 3-hourly sampling at any given point on the globe 90% of the time or better. To serve as a pilot study for GPM, we plan to assimilate AMSR rainfall data from TERRA and AQUA, and examine their impacts on analyses and forecasts of weather systems in midlatitudes. At a later stage when the new prognostic cloud scheme is implemented in the GMAO Assimilation System, we will try to develop algorithms to assimilate cloud data from MODIS and Cloud-Sat in order to better constrain physical errors from model cloud misrophysics.

Accomplishments During the Reporting Period
GEOS DAS3 has been modified so that varying large-scale forcings, which is more realistic for midlatitude baroclinic frontal systems, can be used to drive the column model. Several sensitivity experiments have been performed to evaluate the impacts of different data assimilations. Pixel-size CERES data has been extensively analyzed and examined at 6-hourly intervals. When AMSR data are officially released, they will be assimilated into GEOS DAS3, along with SSMI and TRMM TMI. Heating profile assimilation has been intensively tested and evaluated. The preliminary results shows very positive improvements. By combining it with the precipitation assimilation scheme, a much greater improvement in the assimilation system can be expected.

Objectives for the coming year
The objectives for FY 05-06 are to evaluate the impact of GEOS DAS3 after assimilating AMSR rainfall and heating profile data, and develop algothrims to assimilate satellite cloud data. We will also start to develop preliminary methodologies to assimilate cloud data into cloud system models.

Task 971-00-002: **Interdecadal Variability and Predictability of Precipitation**

GEST Investigator: Rosana Nieto-Ferreira

Collaborators: Max Suarez (PI, GSFC), Siegfrid Schubert (GSFC)

Abstract
This task ended on 6 August 2004. The investigator concluded the research previously started on decadal-to-multidecadal variability and predictability of precipitation in the Americas and Africa, using the NSIPP-1 GCM. Several regions in the Americas and Africa have decadal-to-multidecadal precipitation variability that is tied to sea surface temperature variability. In this study various patterns of SST variability were shown to play a role in the observed decadal-to-multidecadal variability of precipitation.

Description of Research
This project focused on the decadal-to-multidecadal variability and predictability of climate in the Americas and Africa using results from the NSIPP-1 GCM (NASA Seasonal-to-Interannual Prediction Project General Circulation Model). The NCEP (National Center for Environmental Prediction) Reanalysis and GHCN (Global Climatological Precipitation Network) precipitation datasets (1900-present) were used to validate model results.

Accomplishments during the Reporting Period
Regions of good decadal-to-multidecadal precipitation predictability in the Americas and Africa were determined using ensembles of NSIPP-1 simulations. Various slow modes of SST variability have been shown to have a significant influence in the decadal-to-multidecadal precipitation in these regions, namely the trend, Pacific Decadal, and North Atlantic modes.

The predictability of various precipitation indices was assessed using tier-2 ensembles of NSIPP-1 land-atmosphere model simulations. In these simulations sea-surface temperature (SST) is prescribed, and therefore the ocean model is not involved. This study is based on a 14-member ensemble of 70-year long simulations that use prescribed monthly mean Hadley Center SSTs. The degree to which the temporal variability of these indices is reproducible in the ensemble simulations indicates how important SSTs are in determining the observed precipitation variability and is a measure of the degree of predictability of the decadal-to-multidecadal variability of precipitation in these regions.

It has been found that there is significant correlation between observed and modeled precipitation indices in various regions of the Americas and Africa, such as Northeast Brazil, subtropical South America, and parts of the Amazon region, as well as in the so-called North American Monsoon region and southern Great Plains of the US and in the African Sahel and forested areas to its south. The conclusions of this task indicates that the decadal-to-multidecadal variability in these areas is tied to the SST variability and therefore has some degree of predictability.

Task 910-01-009: **Cloud Assimilation**

GEST Investigator: Peter M. Norris

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

Abstract

A cloud parameter estimation system was previously developed by Norris and da Silva to assimilate satellite cloud data into the NASA Global Modeling and Assimilation Office (GMAO) GEOS-4 DAS and was highly successful in improving the realism of the cloud and cloud radiative forcing fields in analysis mode. Further quantification of the performance of this system has been carried out, with particular emphasis on the geographical distribution of estimated cloud parameters and their connection with relative humidity errors in the analysis and on the performance of the analysis-tuned cloud parameterization in climate mode. Assimilation of MODIS Level-II cloud data has begun and initial results are promising. The work has already led to identification of some problems in the MODIS Cloud Optical Properties product that will be improved upon in the upcoming Collection-5 reprocessing. Adaptation of the cloud assimilation system to GMAO's new GEOS-5 system is underway, including the necessary changes to permit its inclusion within the Earth System Modeling Framework. Also, as Principal Investigator of a submission to the recent NASA MAP solicitation, Norris collaborated with a number of UMBC and GSFC scientists in a proposal for a major upgrade to the capability of GEOS-5 cloud and radiation parameterizations, designed especially with the goal of allowing much improved assimilation of the high information content available in EOS cloud observations. Norris also contributed to a project by Raytheon Synergy V and the Goddard DAAC to improve access to EOS satellite data.

Description of Research

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.

Accomplishments for FY 04-05

At the end of the previous reporting period, a new cloud parameter estimation system (CPES) had been developed, in collaboration with Dr. Arlindo da Silva, to assimilate ISCCP, SSM/I, and MODIS cloud data using a variational parameter estimation method and had 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 two-paper write-up of this work is now in near final draft form and should be submitted shortly. Material added recently includes the non-equivalence of estimated cloud parameters in analysis and climate modes, since the underlying relative humidity fields between the two cases is significantly different. In an effort to explain some of the geographic variation in estimated parameters, a comparison of the relative humidity fields between the GMAO and ECMWF analyses is also under way.

The work on assimilating MODIS cloud data was preliminary at last reporting and has made

significant advances during this past year. In working with the MODIS cloud data, special care was taken to average the cloud optical thickness in a radiatively consistent manner (using the delta-Eddington approximation) rather than using a simple but inaccurate linear or logarithmic average. We decided to use the high-resolution Level-2 MODIS granules since the alternative daily average product merges higher latitude overlapping swaths rather than preserving the three to six hour temporal resolution we require. We maintained a close association with the MODIS Cloud Optical Properties Team (M. King, S. Platnick, *et al.*) during this process and were able to provide some very useful feedback to that team. Specifically, our analysis of the two different types of cloud fraction available from MODIS ("Cloud Mask" versus "Optical Retrieval Success") brought to light a significant difference between those fractions in MODIS Collection 4. The difference seems to be related to a relatively large number of failed optical retrievals in certain circumstances (most likely near cloud edges and in sub-pixel cloud fields). This finding was discussed with the Cloud Optical Properties Team and recent changes in the optical properties processing path for the upcoming Collection 5 are producing much fewer failed retrievals [Mike King, personal communication]. Norris was also invited by Dr. Steve Platnick to present the cloud assimilation work at the Aqua Science Working Group Meeting at GSFC last October, summarized in the Nov/Dec 2004 issue of Earth Observer. The presentation generated significant interest among attendees and readers. A seminar will also be given in March to the Joint Center for Satellite Data Assimilation.

We have begun the process of implementing the existing CPES cloud assimilation system into the new GEOS-5 model and assimilation system. The initial focus of this work has been to decide on the best method of integrating the new model and the variational estimation used by CPES within the new Earth System Modeling Framework. The review of the new GEOS-5 model code during this the process has already led to the discovery of several important bugs, which have been communicated back to the GMAO modeling team. Norris has also participated in a collaborative project between Raytheon Synergy V and the Goddard DAAC to facilitate improved access to DAAC satellite data archives. He has submitted his MODIS cloud pre-processing code to the project for testing of their system. The speed and utility of access to MODIS cloud data is expected to be significantly improved as a result of this project.

Another major achievement this year was the submission of a NASA MAP proposal in November titled "Improving the representation of cloud processes in GEOS-5: Advanced cloud parameterizations and data assimilation of EOS satellite observations," for which Norris was PI. The proposal involves some major advances in the treatment of clouds and their interaction with radiation in GMAO's GEOS-5 DAS, specifically, the use of statistical cloud schemes and cloud generators for the radiative transfer. It also describes a new method of assimilating the information content of high-resolution MODIS Level-II pixel cloud properties into the proposed statistical cloud parameterization. The project will lead to significant advances in cloud modeling and assimilation at the GMAO if funded. The budget is $1.5M over 3 years, and provides funds for Norris and one other GEST investigator, one JCET investigator, three NASA/GSFC civil servants, and a scientific programmer to be hired. The outcome of that proposal will be known shortly. Finally, Norris is also a GMAO representative on a team that will propose a sub-millimeter cloud ice water path instrument to the upcoming ESSP AO.

Objectives for the Coming Year

The two-part cloud data assimilation paper will be submitted shortly, after finishing analysis of relative humidity differences between the GMAO and ECMWF analyses. Work will continue with the assimilation of MODIS data, including water path and cloud effective radius, as part of the Cloud-Radiation Modeling and Assimilation IDS. ISCCP, SSM/I and MODIS Collection 5 cloud data will be inter-compared in an effort to assign error bounds on different retrieved cloud properties. The cloud assimilation system will be integrated into GMAO's new GEOS-5 DAS currently in

development and testing. This will involve assessing the quality of the GEOS-5 cloud properties and determining those parameters to which the cloud-radiation system is most sensitive, within their realistic ranges of variation. The parameter estimation approaches of Arthur Hou and Sara Zhang for convective precipitation and of da Silva and Norris for large-scale cloud properties will be studied in combination in an effort to produce a merged system. If the MAP proposal is funded a state-of-the-art statistical cloud parameterization will be implemented in GEOS-5 coupled to a parameter estimation system that will permit the assimilation of the high statistical information content present in MODIS Level-II cloud fields. Norris will also collaborate with Arthur Hou, Arlindo daSilva, and Lazaros Oreopoulus in the submission of several CloudSat proposals and with Dave Starr and Steve Ackerman on the assimilation component of an ESSP sub-millimeter cloud ice water path proposal.

Task 910-01-008: **Treatment of Atmospheric Trace Constituents in the Finite-Volume Data Assimilation System**

GEST Investigator: Steven Pawson

Collaborator: Michele Rienecker (GSFC), Anne Douglass (GSFC), S. Randolph Kawa (GSFC), Richard S. Stolarski (GSFC), Mohan Gupta (GEST), Hiroo Hayashi (GEST), Shuhua Li (GEST), Andrew Tangborn (JCET), L.-P. Chang (SAIC), J. Eric Nielsen (SAIC), Ivanka Štajner (SAIC), Wei Tan (SAIC), David Crisp (JPL), Gloria Manney (JPL), Daniel Jacob (Harvard University)

Abstract

Substantial advances were made in coupling chemistry modules into the GEOS-4 GCM. In collaboration with GEST and other staff, simulations of middle atmospheric ozone and other gases have been performed, with studies related to how ozone has evolved over the past decades. Parameterized tropospheric chemistry modules were used in GEOS-4 in order to provide pollution forecasts to NASA's Intex-NA field mission; these were used in the field to guide aircraft flight paths. Layers of pollution on the East coast of the U.S. were found to have different origins, with CO from Asian pollution lying over sources from forest fires in the western U.S., which itself was above a layer from more local fossil-fuel emissions. Substantial progress was made in assimilating trace gas observations, especially ozone from the MIPAS instrument.

Description of Research

This research is geared towards building a comprehensive capability to model and assimilate trace gases in the troposphere and stratosphere, in conjunction with the meteorological work in the GMAO. Specific foci in this year included assessing the dynamics and transport capabilities in the middle atmosphere of GEOS-4. Implementation of middle atmospheric chemistry codes was performed in collaboration with scientists in the GMAO and the Atmospheric Chemistry and Dynamics Group. This model was used for numerous studies and it is being adapted for long-term simulations of chemistry and climate, as well as for interface with meteorological analyses. A parameterized version of the Harvard tropospheric chemistry code is being used for tropospheric trace gas simulation and assimilation; one application of this is to support NASA's field missions and satellite data validation. Similarly, a comprehensive set of modules for the carbon cycle is being implemented.

Accomplishments during the Reporting Period

Stratospheric dynamics studies were undertaken in collaboration with colleagues at NASA GSFC and members of the EOS-Aura science team, in particular Dr. Gloria Manney at JPL. These involved comprehensive evaluation of the

GEOS-4 assimilation system, in order to thoroughly document this for public release and for the EOS-Aura mission. Comparison of GEOS-4 with other datasets revealed the strengths of the new assimilation, with generally favorable comparisons with ECMWF data. Using time-mean fields in GEOS-4, rather than snapshots, results in much more accurate transport properties.

Long-term stratospheric change is an important question, but interpretation is difficult because of large year-to-year variations in the circulation that appear without changes in external forcing. One study of recent warm stratospheric winters was completed, which updates a previous study of cold winters that was published some years ago! The GEOS GCM was updated to include the full stratospheric chemistry scheme developed at NASA and initial simulations, collaboratively with numerous colleagues, have begun. Those completed serve to justify use of this model for climate-change studies and colleagues are now working on aspects of coupling radiation code in the GCM with the predicted ozone, in order to thoroughly examine ozone-climate interactions.

Ozone assimilation has focused on the MIPAS instrument and on the beneficial impacts these data bring to the representation of ozone in the lower stratosphere. Transport studies have been performed, with demonstrable impacts of on-line transport, as long as time filtering is used in the winds from GEOS-4. The ozone assimilation is being adapted to carbon species, notably carbon monoxide and carbon dioxide.

Tropospheric trace gases have been implemented in the GCM. Simulations through July and August of 2004 were performed in near-real time to support the Intex-NA mission. Ten tracers, including tagged regional emissions of CO, were implemented in a collaborative study with Harvard University. The real-time analyses were used to produce five-day forecasts, in which pollution layers were predicted; NASA's aircraft then aimed to fly through these layers, which were often well predicted, despite discrepancies in the altitude of the predicted and forecast layers. Interesting events include layers of pollution from different sources, with local emissions near the boundary layer and pollutants with remote sources above: in one case air polluted by forest fires in the Southwest U.S. was sandwiched between local pollution and Asian contaminants at higher levels.

Objectives for the Coming Year

Steven Pawson left GEST in October 2004, in order to take up a civil-service position at NASA GSFC.

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, GSFC, Code 613)

Abstract

This task focuses primarily on the synoptic and dynamic evaluation of various aspects of the finite volume atmospheric model developed at the NASA Goddard Space Flight Center. The research has been performed within the `Data Impact and Modeling Team' in the Laboratory for Atmospheres at the NASA Goddard Space Flight Center, under Dr. Robert Atlas's guidance. The goal of this particular task aims to investigate and improve the representation of individual high-impact weather systems in the finite-volume General Circulation Model (fvGCM), through a deeper understanding of their dynamics and of the physical mechanisms involved. During the past year, research was performed mostly on Atlantic tropical cyclones. The research performed under this task has produced co-authorship on four peer-reviewed

articles and the 2004 NASA Laboratory for Atmospheres Outstanding Performance Award.

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, like for example tropical cyclones (because of their relatively small size) or fast-developing mid-latitude cyclones. The research 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 major accomplishment was obtained by another member of the Team (Dr. Bo-Wen Shen, SAIC) by bringing the fvGCM to the resolution of a quarter of a degree. It has been the main achievement of this particular task to find, demonstrate and quantify the impact of the increased resolution, with particular emphasis on the Atlantic hurricane season. In the past, general circulation models were not capable of accurately resolving tropical cyclones because of the intrinsically small scale. The research performed by this task has demonstrated that the increase in resolution represents a major breaktrough in atmospheric sciences, for the improved representation of hurricanes, which have allowed the fvGCM to be the first GCM in the world that can be run for real-time weather forecast and produces extremely realistic representation of tropical cyclones. The major accomplishment of this task has been to understand, demonstrate and explain how the increased resolution has represented a major improvement in the fvGCM capabilities. An article submitted to *Geophysical Research Letters* [Atlas *et al.* 2005], in which the investigator was the second author, was written in collaboration with eight other scientists from NASA and NOAA Geophysical Fluid Dynamics Laboratory (GFDL). The article was accepted and selected to be a highlight of the month for the journal. Beyond the previously described research, this particular task is more generally devoted to analyze the performance of the fvGCM and/or the impact of new data with respect to extreme events. Therefore, not only tropical cyclones, but also midlatitude floods are examples of extreme events on which research has been performed under this task. Research started in 2002 in collaboration with two other scientists at GMAO to evaluate the impact of a precipitation assimilation technique previously developed by Dr. A. Hou (GSFC) in the dynamic and synoptic representation of tropical cyclones has finally produced this year an article on *Monthly Weather Review* [Hou *et al.* 2004]. Collaborative research with two Italian scientists on another type of extreme event (Mediterranean floods), has also produced another peer reviewed article in the *Journal of Hydrometeorology* [Turato *et al.* 2004]. Finally, another work, completely performed during 2004, aiming to investigate the impact of QuikSCAT data on hurricane simulation, has been accepted [Atlas *et al.* 2005] and is now in press at the *Journal of Photogrammetry and Remote Sensing*.

Objectives for the Coming Year

The main goal of this task will continue to be the evaluation of the potential of the fvGCM in simulating weather events at spatial and temporal scales near the limits imposed by model resolution. The research will also continue to explore the impact of different data types, (*e.g.*, satellite-derived wind data, rainfall data, etc.) in synoptic situations which can represent a challenge for the fvGCM.

Since the National Hurricane Center has manifested interest in the fvGCM forecast, one important goal will be the creation of Model User Guidance for the next hurricane season. A model guidance requires an extensive analysis of how the model has performed with respect to every individual hurricane of the past seasons. So far the team has produced three years of simulations, and the PI of this task is investigating the performance of the fvGCM during the associated hurricane seasons. The anticipated result will be an understanding of how the model performs under different conditions, and a selection of circumstances under which the forecast can *a priori* be expected to be more or less successful. Alongside this main goal, research will be

conducted to investigate any new, fundamental, aspect pertaining to synoptic and dynamic meteorology, which might arise during the evaluation of the fvGCM, with particular emphasis on hurricanes.

Task 971-00-002: **Land Data Assimilation at the NASA Global Modeling and Assimilation Office**

GEST Investigator: Rolf H Reichle

Collaborators: Michele Rienecker (PI, GSFC), Randal Koster (GSFC), Matt Rodell (GSFC), Max Suarez (GSFC), Dara Entekhabi (MIT)

Abstract

During the past year, we demonstrated a long assumed (but rarely proven) property of global soil moisture fields derived from data assimilation: that the assimilation product is superior to either satellite data or model data alone [Reichle and Koster 2005]. This success followed a thorough investigation of the biases between satellite, *in situ*, and model soil moisture data [Reichle *et al.* 2004] and the subsequent development of a bias reduction method for the optimal use of short-term satellite records of soil moisture retrievals [Reichle and Koster 2004]. We also completed one of the first statistically complete demonstrations of actual skill in sub-seasonal precipitation forecasts that is associated with land initialization [Koster et al., 2004] and implemented a new scheme for the initialization of the GMAO operational seasonal forecasts.

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

In April of 2004, we completed the operational implementation of a new scheme for the initialization of the GMAO operational seasonal forecasts. The new scheme was developed in close cooperation with scientists at the NASA Hydrological Sciences Branch and utilizes the highest quality precipitation and radiation observations available for land initialization. Moreover, we have pressed on with the development of an advanced land data assimilation system that also makes use of satellite observations of land surface states (in addition to precipitation and radiation observations) for operational forecast initialization. Key science issues addressed during the report period were the transferability of soil moisture data between different satellite platforms and models, the global assimilation of a retrospective soil moisture data set, and the assessment of climate predictability associated with land surface initialization.

First, we demonstrated that global surface soil moisture retrievals from the historic Scanning Multichannel Microwave Radiometer (SMMR) agree with model-derived soil moisture conditions (based on antecedent surface meteorological data from observations) in the global patterns of wet and dry regions [Reichle *et al.* 2004]. Moreover, the time series of

satellite and model soil moisture are well correlated in the transition regions between wet and dry climates where land initialization may be important for seasonal climate prediction. However, absolute soil moisture values from the satellite and the model are very different, and neither agrees better with ground data, implying that the correct soil moisture climatology cannot be identified with confidence from the available global data. The biases between satellite and model soil moisture pose a severe obstacle to exploiting the useful information contained in satellite retrievals through data assimilation. A simple method of bias removal is to match the cumulative distribution functions (cdf) of the satellite and model data. However, accurate cdf estimation typically requires a long record of satellite data. We were able to demonstrate that through ergodic substitution of variability in space for variability in time we can obtain local statistics based on a one-year satellite record that are a good approximation to those that would be derived from a much longer time series [Reichle and Koster 2004]. This result increases the usefulness of relatively short satellite data records, such as from the currently operational Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E).

Next, we assimilated global retrievals of surface soil moisture from SMMR after applying bias-reducing scaling techniques [Reichle and Koster 2005]. Validation against ground-based measurements in Eurasia and North America from the Global Soil Moisture Data Bank demonstrated a long assumed (but rarely proven) property of soil moisture fields derived from data assimilation: that the assimilation product is superior to either satellite data or model data alone. Finally, we completed one of the first statistically complete demonstrations of actual skill in sub-seasonal precipitation forecasts that is associated with land initialization [Koster *et al.* 2004]—skill that is based on the integration of antecedent surface meteorological conditions and that is independent of that from atmospheric initialization. As satellite observations of soil moisture are included in the data assimilation system, knowledge of land surface hydrological conditions are bound to improve, and seasonal forecast skill should increase further.

Objectives for the Coming Year

Our main objective for the coming year is to incorporate AMSR-E surface soil moisture retrievals into the quasi-operational GMAO seasonal climate prediction system. This involves the application of the bias correction method of Reichle and Koster [2004] to the AMSR-E data, and the tuning of the existing land assimilation system for optimal operational performance, based on our experience with the historic SMMR data. We will also begin development and testing of the snow component in the GMAO land assimilation system to assimilate AMSR-E snow water equivalent retrievals and MODIS snow cover data. Moreover, we plan to advance the land surface temperature assimilation in the new GMAO operational atmospheric data assimilation system. 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 910-01-010: **Leadership of the GMAO Satellite Data Group**

GEST Investigator: Lars Peter Riishojgaard

Collaborator: Michelle Rienecker (PI, GSFC)

Abstract

The main activity 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 Goddard and the agency for atmospheric modeling and assimilation of satellite data in particular. After some attrition and internal reallocation among tasks, the satellite data group now consists of

about 10 individuals and is expanding. 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.

A new activity initiated by the investigator this past year was the preparatory work on the proposal for a new space mission, the Molniya Orbit Imager, targeted for the upcoming Announcement of Opportunity of NASA's Earth System Science Pathfinder (ESSP) program. This effort is rooted in the work on assimilation of the MODIS winds pioneered in the DAO by the investigator since 2001.

The investigator is also the NASA Deputy Director of the NASA/NOAA Joint Center for Satellite Data Assimilation. In collaboration with the JCSDA Director, the responsibility of the Deputy Director is to 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.

Description of Research

The work in the satellite data group falls in four main categories: (i) supervising the routine assimilation of satellite data and troubleshooting, (ii) conducting data impact experiments to verify and where possible improve the usefulness of satellite data on GMAO systems, (iii) devise new methodologies appropriate for satellite data, and (iv) test candidate new satellite data in GMAO systems.

Accomplishments in the Reporting Period

During the past year, most of the emphasis has been in the area of supervising routine assimilation of data. The reason for this is the fact that the GMAO is in the process of transitioning to a new analysis system, namely the Grid-point Statistical Interpolation (GSI) developed jointly by the GMAO and NOAA/NCEP. A substantial amount of effort has gone into transitioning the observational datastream to this new context and ensuring that the GMAO will be able to meet its obligations in after having switched to a system closer coupled to the NCEP operational system. This is of special concern for datatypes that have no immediate operational interest to NCEP. Some experimentation has also taken place, primarily aimed at testing the impacts of AIRS and MODIS observations in various test versions of the new GSI-based data assimilation system. It was found that AIRS has a substantial positive effect on the forecast skill over all verification regions and that the MODIS winds from Aqua and Terra are of comparable quality with a good positive impact especially on forecasts with lower than average skill. In addition, a new initiative has been launched concerning implementation of an advanced quality control package for satellite winds. This is expected to substantially improve the data selection of the winds so that extensive experimentation can be performed with the so-called deep-layer water vapor winds. These winds have long been regarded as potentially interesting but difficult to assess with traditional quality control methods.

Early in 2004, the investigator put forward a proposal 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. The work with the MODIS winds has demonstrated the value of high-latitude water vapor winds, but the operational follow-on to MODIS—the VIIRS imager on NPOESS—does not include a water vapor channel and will in any case not be able to provide wind observations for latitudes lower than roughly 67 degrees. The Molniya Orbit Imager initiative was first reviewed and approved by the former Code 900 (now Code 610), and is now being supported at the level of the Center Director. Goddard is investing substantial resources in studying the concept in detail and in preparing what is hoped to be a strong competitive proposal. Over the course of the last year, the investigator has given on the order of 25 briefings to a wide range of organizations but nationally and internationally in order to provide information to and receive feedback to potentially interested collaboration partners. As expected, support for the mission has proven to be very strong in the

meteorological community, and discussions concerning actual partnerships are ongoing.

The Joint Center for Satellite Data Assimilation 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 hosted a workshop at Goddard in June 2003 for ocean-related studies sponsored by JCSDA through its first AO, and in the fall of 2003 letters of intents and proposals for the second AO were reviewed and decisions made.

Other activities by the investigator include: chaired Global Numerical Weather Prediction session at WMO-sponsored workshop on Impact of the Global Observing System in Alpbach, March 2003; chaired Global NWP session at the 7th International Winds Workshop in Helsinki in June 2003; participated in Mission Advisory Group meeting for ESA's Atmospheric Dynamics Mission in October 2004. The PI of this task is also Associate Editor for the *Quarterly Journal of the Royal Meteorological Society*.

Goals for 2005

A key goal for the GMAO satellite data group in 2005 will be to quickly establish a baseline set of Observing System Experiments (OSEs) in which all major components of the Global Observing System are tested both together and individually in the upcoming GSI-based GEOS-5 system. This activity will serve both as part of the system validation and as a future reference for the assessment of the incremental impact of any new datatypes on this system.

Concerning the Molniya Orbit Imager, the goal is simple: submission of a high-quality and hopefully successful proposal to NASA for this new mission.

Task 971-00-002: **Global Land Atmosphere Coupling and Water Balance Studies**

GEST Investigator: Sonia I. Seneviratne (Visiting Research Associate, Oct. 2003- Dec. 2004)

Collaborators: Randal D. Koster (GSFC), Rolf H. Reichle (GEST), Matt Rodell (GSFC), Paul A. Dirmeyer (Center for Ocean-Land-Atmosphere Studies, Calverton, MD), Zhichang Guo (COLA, Calverton, MD), Martin Hirschi (ETH Zurich, Switzerland), Christoph Schär (ETH Zurich, Switzerland), Jacques Hinderer (GEST), Pedro Viterbo (ECMWF, Reading, UK)

Abstract

Research conducted in 2004 during this visit included the analysis of soil moisture memory from eight atmospheric general circulation models (AGCMs) participating to the Global Land-Atmosphere Coupling Experiment (GLACE), the comparison of basin-scale water-balance estimates of changes in terrestrial water storage with satellite estimates from the Gravity Recovery and Climate Experiment (GRACE), as well as the initiation of a data assimilation project for the assimilation of basin-scale estimates of terrestrial water storage variations in a catchment-based land surface model.

Description of Research

Work under this task focuses on two main areas of research. The first deals with the investigation and understanding of the mechanisms controlling soil moisture memory in AGCMs [Seneviratne *et al.* 2005]. These mechanisms constitute key aspects of land-atmosphere interactions and their understanding is of major implications for seasonal forecasting. The second area of research deals with the derivation and use of basin-scale estimates of changes in terrestrial water storage using a new approach based on water-balance considerations [Seneviratne *et al.* 2004a, Hirschi *et al.* 2005]. The obtained data has large potential for hydrological and climate research given the

dearth of observations of terrestrial water storage and its components.

Accomplishments during the Reporting Period

The first project completed during this period dealt with the analysis of soil moisture memory in present AGCMs [Seneviratne *et al.* 2005]. What is understood by "soil moisture memory" is the fact that the soil can "remember" a wet or dry anomaly long after the conditions responsible for the anomaly are "forgotten" by the atmosphere. This is a key aspect of land-atmosphere interactions and has significant implications for seasonal forecasting. This study was conducted in collaboration with Randal Koster (NASA/GSFC), Zhichang Guo and Paul Dirmeyer (COLA), and well as several participants of the Global Land-Atmosphere Coupling Experiment (GLACE). The completed study investigates the soil moisture memory characteristics of AGCM integrations from the GLACE project, using an equation that relates the autocorrelation of soil moisture in climate models to four terms: seasonality in the statistics of the atmospheric forcing; the variation of evaporation with soil moisture; the variation of runoff with soil moisture; and the correlation between the atmospheric forcing and antecedent soil moisture. The results demonstrate that soil moisture memory is mostly controlled by the variation of evaporation with soil moisture in dry cases and by the variation of runoff with soil moisture in wet cases, and that both are strongly constrained by water-holding capacity. Overall, most models present similar global patterns of soil moisture memory. Outliers are generally characterized by either anomalous water-holding capacity, biases in atmospheric forcing (mostly radiation), or exaggerated land surface sensitivity due to extreme dry conditions. Comparisons with observations demonstrate that the models' average soil moisture memory is generally close to the available observed values.

The second project dealt with the derivation and use of basin-scale estimates of changes in terrestrial water storage [Seneviratne *et al.* 2004a, Hirschi *et al.* 2005]. During the reporting period, final updates were brought to the study by Hirschi *et al.* [2005]. Moreover, there were contributions to two short studies comparing this approach with satellite measurements from the GRACE mission [Rodell *et al.* 2004, Andersen *et al.* 2005). Finally, a pilot assimilation framework for assimilating these estimates in a catchment-based land surface model was developed in collaboration with Rolf Reichle (NASA/GSFC and GEST) and Randy Koster (NASA/GSFC). The framework uses an Ensemble Kalman filter technique for the weighing between the relative uncertainty of the model and that of the assimilated data. The model uncertainty is estimated using ensemble simulations driven with perturbed forcing. Results for the Volga river basin demonstrate that the tested approach is successful for the assimilation of soil moisture in this region and that the combined product has a higher quality than either the model or the diagnostic estimates. A publication on this study is currently in preparation at ETH (see also Seneviratne *et al.* [2004b] for some preliminary results).

Objectives for the Coming Year

This project was completed in December 2004.

Task 971-00-002: **Ocean Data Assimilation in a Global Ocean Circulation Model**

GEST Investigator: Chaojiao Sun

Collaborators: Michele Rienecker (PI, GSFC), Michael Ghil (UCLA/Ecole Normale Supérieure), Tony Rosati (GFDL), James Foster (GSFC).

Abstract

This task focuses on the research in ocean data assimilation at GMAO. The major achievements are the undertaking of the evaluation and validation of GMAO and GFDL ocean data assimilation systems by performing experiments using identical forcing and observations. Extensive and diverse observational data sets

were used. Some general questions related to different ocean assimilation systems have been answered. Salinity treatment is found to be important to correct model bias in salinity and provide a more realistic current structure. This also leads to the assessment of observational impact on seasonal forecasting by different coupled models initialized with ocean states produced from different ocean data assimilation schemes and the comparison of ocean assimilation diagnostics. This work in snow data assimilation has led to the publication of two peer-reviewed papers.

Description of Research

One of the goals of this research is to develop 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 which consist of thousands of floats that 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.

Accomplishments in FY 04-05

There were two major accomplishments during this reporting period. One is in the ocean data assimilation research, which has resulted in a manuscript that will be submitted to a major journal in a couple of months [Sun *et al.* 2005]. The other is related to snow data assimilation, which led to the publication of a peer-reviewed paper in the journal *Remote Sensing of the Environment* [Foster *et al.* 2005]. This paper is complementary to the paper by Sun *et al.* [2004], which focuses on the modeling of observation errors from passive microwave observations of snow mass from the space.

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 have been used in intercomparison experiments as part of the CEDP Consortium for Ocean Data Assimilation Consortium for Seasonal-to-Interannual Prediction (ODASI). In these experiments, the same observations (temperature only) and same forcing are used by all assimilation systems. We sought to address some of the most basic questions with regards to evaluation of different systems: How do different assimilation procedures affect the analyses, including those fields that are not directly assimilated (due to lack of observations) such as salinity and currents? Do temporal and spatial variabilities 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 extensively 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 variabilities of temperature, current and salinity, but different schemes have different effects on the field details. The treatment of salinity impacts the salinity and current structures. Schemes that adjust salinity based on climatology while assimilating temperature are able to correct model bias quite successfully, and have the smallest error as compared to observed currents. Work is under way to assimilate newly available Argo temperature and salinity data to improve salinity analyses using *in situ* salinity data which were extremely sparse before the Argo era.

The continuing effort in snow assimilation related work has resulted in two papers published during the reporting period: Sun *et al.* [2004] and Foster *et al.* [2005]. These papers concluded active involvement in snow

assimilation work, and future involvement will depend on funding.

Objectives for the coming year

The main objectives are to continue to develop diagnostic tools to evaluate different ocean data assimilation systems; evaluate the impact on coupled forecast using different ocean general circulation models (OGCMs) and different assimilation systems, particularly on seasonal forecasts; improve current ocean assimilation schemes to achieve practical and near-optimal implementation; and lead the efforts in the ECCO-GODAE project which incorporates the partitioned Kalman filter into the ocean models used at GMAO, which greatly reduces computational costs and promises a more efficient and practical assimilation tool.

Task 971-00-002: **NASA Seasonal-to-Interannual Prediction Project: Study of predictability and forecast of the ENSO phenomenon**

GEST Investigator: Augustin Vintzileos

Collaborators: Michele Rienecker (GSFC), Max Suarez (GSFC), Siegfried Schubert (GSFC), Christian Keppene (SAIC), Chaojiao Sun (GEST)

Abstract

This task ended on 30 June 2005. It has been focused on one key aspect for a successful Seasonal-to-Interannual prediction system, which is its ability to forecast the ENSO phenomenon up to 12 months in advance. Successful ENSO prediction depends on two major elements: adequate modeling of the processes governing this phenomenon and initialization of this model close to the observed state. Analysis of existing ENSO forecast in order to understand reasons for successes and failures is then necessary, allowing for not only the improvement of the system but also for understanding the physics and predictability of the most important variability mode of earth's climate.

Description of Research

Vintzileos leads two efforts in the Seasonal-to-Interannual Prediction effort at the GMAO. The first is the analysis of the ENSO forecast conducted quasi-operationally in order to understand reasons for successes and failures. The latter can be attributed to (a) inadequacies of the model, (b) incorrect initialization and (c) ENSO predictability issues. The second effort is the validation of simulated tropical variability with the GMAO coupled ocean – atmosphere model. Several sets of atmospheric and oceanic observations are used for this reason. Upon detection of drawbacks in the simulated climate the effort focuses in understanding and eventually correcting formulation inadequacies.

Accomplishments During the Reporting Period

There were two major accomplishments regarding this research on the validation of tropical variability simulated by the GMAO coupled model. First, the narrow meridional extend of the spatial structure of ENSO, a systematic bias that plagues most coupled models since the beginning of coupled modeling was attributed to stronger than observed trades to the north and south of the equator during warm ENSO events. This systematic bias which tends to decrease sea surface temperature and thus narrows the meridional extend of ENSO was also found in simulations with the forced atmospheric model. Currently, experiments are designed in order to assess the impact of cumulus friction on this systematic bias. This research effort was described in a paper in *CLIVAR – Exchanges*. The second major accomplishment came from the investigation of variability simulated by the GMAO coupled model in the Indian Ocean. This research was conducted for the graduate thesis of a student from the Ecole Polytechnique in Paris, France under the direction of Vintzileos for which he received an award for Outstanding Mentoring

from GEST. The conclusion of this research was that stronger than observed mean annual convection in the eastern tropical Indian Ocean is responsible for a shallower than observed mean thermocline which facilitates coupled interactions and thus explains stronger and more frequent than observed variability.

The first major accomplishment regarding research on ENSO predictability and prediction came from the analysis of quasi-operational forecast of ENSO with the GMAO system for the period from 2000 to 2003. While forecasts with this system from 1993 to 2000 present a very good skill—*i.e.*, anomaly correlation at lead times of 9 months is 0.6—this skill drops significantly for forecasts after 2000. Analysis of these forecasts indicates that poor skill is due to ENSO predictability issues ranging from decadal variations of its characteristics to high frequency events such as the Maiden-Julian Oscillation and Westerly Wind Bursts. The second major finding of this research came from the analysis of forecasts from 1993 to 2000. It was found that the so-called "spring predictability barrier" should not exist, at least during major ENSO events like in 1997-98. This result was presented at the AMS meeting in Seattle in January 2004. One paper on this work was published in *Geophysical Research Letters*.

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, GSFC)

Abstract
This task significantly supported the writing of the major proposal entitled "Development of a High-Resolution Earth System Model for Satellite Data Assimilation, Weather and Climate Applications." In addition, the manuscript on the second-order transport schemes of the newly developed Streamline Subgrid Integration (SSI) method was revised, and new formulations for the extension of the SSI method to the third-order accuracy were derived and tested. Yeh co-authored a paper on hurricane forecasting with the high-resolution NASA fvGCM, which is highlighted in *Geophysical Research Letters*.

Description of Research
The goal of this project is to develop a next-generation dynamical core 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.

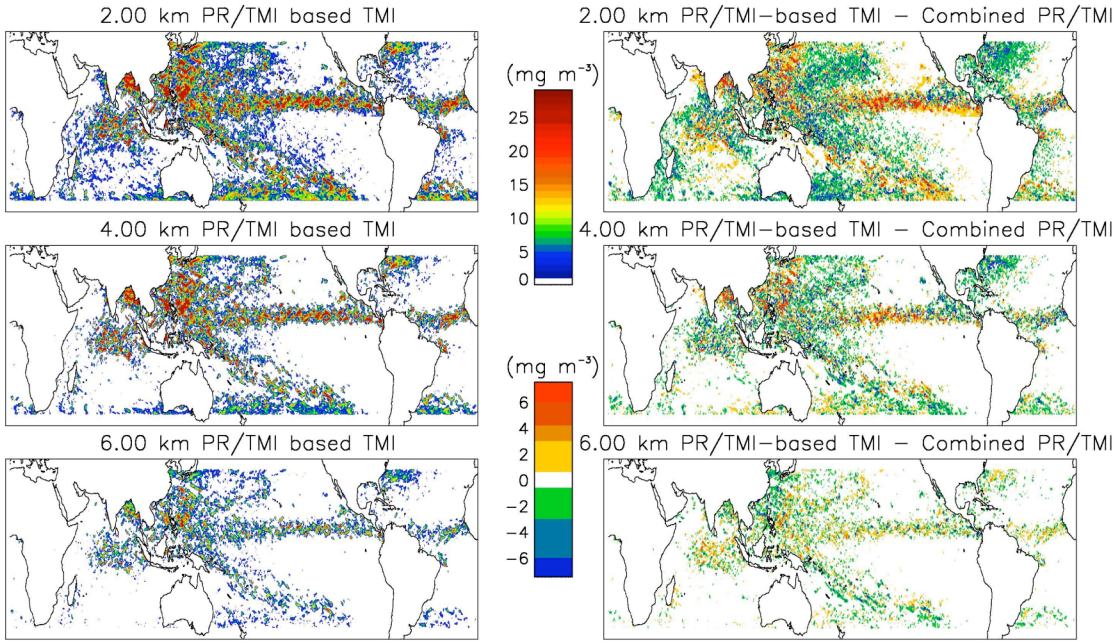
Accomplishments during the Reporting Period
The investigator supported the creation of a major proposal entitled "Development of a High-Resolution Earth System Model for Satellite Data Assimilation, Weather and Climate Applications" (PI: Robert Atlas), including writing original technical parts for atmospheric dynamics, and participating in the organization and revision of the entire proposal. He also revised the manuscript on the second-order transport schemes of the newly developed Streamline Subgrid Integration (SSI) method, which has been designed for accurate and efficient modeling of atmospheric dynamics with globally high resolution on icosahedral geodesic grids. Yeh investigated several

formulations for extending the accuracy of the SSI method from the second to the third order. Further research is required to determine an optimal formulation for the third-order schemes. He co-authored a paper on "Hurricane forecasting with the high-resolution NASA Finite-Volume General Circulation Model (February 2005)." This paper is highlighted in the *Geophysical Research Letters*. Yeh was awarded a NASA GMAO/SRT Outstanding Performance Award (December 2004), for outstanding support of the strategic planning for the NASA fvGCM.

Objectives for the Coming Year

The investigator will optimize the third-order formulation for the SSI method on icosahedral geodesic grids. He will also design and test the formulation for atmospheric dynamics on icosahedral geodesic grids.

Cloud Modeling Research Group



The Combined PR/TMI algorithm of Grecu et al. (2004) is applied to a month-long record of TRMM observations to create a database, or look-up table, relating TMI radiances to retrieved vertical precipitation profiles. This database supports a new Bayesian method for estimating precipitation profiles from TMI observations alone. Monthly rain estimates from the newly derived algorithm for July 2000 are shown in the left hand side panels of the figure. The algorithm errors are presented in the right hand side panels. These errors are significantly smaller than those (not shown) from the current TRMM TMI facility algorithm especially at upper levels.

Cloud Modeling Research Group

The GEST Cloud Modeling Group (CMG) scientists seek to understand the different cloud systems and their link to environment conditions, climate variability, and weather forecasting. The research is conducted through modeling and observations with studies ranging from cloud physical and dynamic properties, structure, and evolution and its climate variability to the remote sensing of precipitation.

Research on interaction between cloud system and its environment continues to be one of the major elements within the group. Several of CMG scientists have maintained/developed the Goddard Cumulus Ensemble (GCE) model (a cloud-resolving model), as well as used it as a tool to understand the physical process of the convection. An explicit bin micophysical scheme was used in GCE to study the impact of increased aerosol concentration on mesoscale convective systems (X. Li). Simulations of convective activity over tropical and mid-latitude environments have been conducted to characterize the relationship between the environment temperature and water vapor. (C.-L. Shie). Model performance has been scientifically improved by a new representation of moist thermodynamics (X. Zeng), as well as been sped up by a parallel computation method: MPI (X. Zeng and C.-L. Shie). Successful effort has been made to use cloud resolving model in a global model to study the interaction between small-scale cloud and cloud system (J.-D. Chern). Three different cases studies were conducted using 1D and 2D cirrus models to understand the role of cirrus in global climate (R.-F. Lin).

Several scientists in the group have conducted observational and numerical studies to understand the interaction between the cloud system (occurring in hurricane, tropical cyclone, or convective system) and its large-scale environment. The specific topics include studies on the climate variability in different regions of the world, such as West African Monsoon and the tropical Atlantic basin (G. Gu) and numerical studies on the tropical cyclogenesis and the potential impacts of global warming on the tropical cyclone motion (L. Wu).

Another major component in the CMG is the remote sensing of clouds and precipitation. Several scientists in the group retrieved a variety of cloud properties using both active and passive instruments. Studies using active instruments include calibrating the 94 GHz cloud radar using surface return and developing a new X-band radar for an Unmanned Aerial Vehicle (L. Li); evaluating the performance of the NASA polarimetric ground-based radar (J. J. Wang); developing dual-wavelength algorithms to estimate drop size distribution and attenuation (L. Tian). Retrievals based on observations from both passive and active instruments include a study that used the TRMM satellite data (*i.e.*, including the radar and multi-frequency radiometer observations) to estimate vertical profile of precipitation (M. Grecu). To support future Global Precipitation Measurement (GPM) missions, effort has been made to develop an advanced three-dimensional physical radiative transfer (PRT) model that incorporates realistic hydrometeor information (K.-S. Kuo).

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

Lin Tian and Chung-Lin Shie

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

GEST Investigator: Jiun-Dar Chern

Collaborators: Wei-Kuo Tao (PI, GSFC)

Abstract

The highest science priority identified in the Global Change Research Program (GCRP) is the role of clouds in climate and hydrological systems, identified as being the most problematic issues facing global change studies. Clouds and cloud systems are tightly coupled with many physical processes (*i.e.*, radiation, turbulence, and surface processes) over a wide range of scales, from microphysical scales to mesoscale and synoptic scale. This makes the representation of convective clouds and cloud systems one of the most complex scientific problems in earth system modeling. To break the cloud parameterization deadlock in global models, a new modeling approach, the Multi-Scale Modeling Framework (MMF) or superparameterization, was developed [Grabowski and Smolarkiewicz 1999; Grabowski 2001; Khairoutdinov and Randall 2001, Randall *et al.* 2003]. 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). The MMF has been successfully ported and tested on the Columbia supercomputer. Currently, two yearly MMF experiments are running on Columbia. The PI will assess the performance and explore the capabilities of this system. The superparameterizaion can also provide global simulations of the statistics of clouds 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 Goddard, a MMF based on the two-dimensional GCE and the fvGCM is being developed with production runs scheduled for the beginning of 2005. 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 and performance of moist processes in climate models and to improve our understandings 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

In this fiscal year, the PI has devoted his major effort in developing a Goddard MMF based on the fvGCM global model and the 2D GCE cloud-resolving model. The fvGCM has been constructed with the unique finite-volume dynamic core developed at Goddard [Lin and Rood 1996, 1997; Lin 2004] and the physics

package from the NCAR Community Climate Model CCM3 [Kiehl *et al.* 1998]. The GCE model has been developed and improved at Goddard over the past two decades [Tao *et al.* 2003; Tao 2003; Juang *et al.* 2005]. The GCE includes comprehensive cloud microphysics, radiative transfer processes, sub-grid turbulent processes, and land surface processes. The prototype Goddard MMF includes the fvGCM run at 2.5o x 2o horizontal resolution with 32 vertical layers from the surface to 0.4 hPa and a two-dimensional GCE at each fvGCM grid point using 64 x 28 grid points with 4 km horizontal resolution and cyclic lateral boundaries. Globally, there are a total of 13,104 2D GCEs running at the same time. The time step for the 2D GCE is 10 seconds, and the fvGCM-GCE coupling frequency is 30 minutes (*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. Because the vertical coordinate of the fvGCM (a terrain-following floating Lagrangian coordinate) is different from that of the GCE (a z coordinate), vertical interpolations between the two coordinates are needed. The PI has successfully developed a coupler between the fvGCM and GCE models to ensure that the mass, momentum, and total energy are conserved. The computation of large-scale forcings and the interpolation between two vertical coordinates are closely followed the finite-volume concept.

The second cloud-modeling workshop took place at Goddard on 14-15 September 2004. The workshop focused on the issues related to the development of MMFs, the use of NASA satellite data, capabilities and future improvements of MMFs (*i.e.*, microphysics, cloud-radiation interaction, surface processes, and different framework configurations) and selection of cases for MMF models inter-comparison. It was decided by the participants that a total of 8 numerical experiments (including sensitivity tests by changing the physical processes) would be conducted in FY05 and FY06. These experiments are yearly integrations for 1998, 1999 and 2000. The years 1998 and 1999 were chosen as they were El Nino and La Nina years, respectively, and satellite data is available from Terra for the year 2000. The PI has developed utilities to produce the MMF initial conditions for these experiments. The dynamic initial condition is interpolated horizontally and vertically from 1o x 1.25o GEOS4 CERES analysis. The initial states for physics and land surface model come from the fvGCM 2o x 2.5o AMIP run. The utilities also produce the initial file for the MMF. Currently, two yearly MMF experiments (one starts at Nov. 1, 1997 and the other starts at Nov. 1, 1998) are running on Columbia. The PI will analyze the results of these two experiments and compare them with the results from fvGCM AMIP run, NCEP or ECMWF reanalysis, and satellite observations to see if the MMF improves the systematic biases of climate models.

The MMF requires a substantial amount of computing resources, two-to-three orders of magnitude more expensive than current climate models [Khairoutdinov and Randall 2001]. Only supercomputers with thousands of processors, such as the Columbia computer at NASA/AMES, are able to achieve results in a timely fashion. The Goddard MMF has been successfully ported and tested on the Columbia supercomputer. The MMF 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. To improve performance and scalability, two-dimensional horizontal domain decomposition is needed for the MMF. The PI and Dr. Tao visited Dr. Haoqiang H. Jin at NASA Ames in Dec. 2004 to discuss how to improve the MMF scalability and performance on the Columbia supercomputer. The goal is to scale the MMF to at least hundreds of processors if not thousands of processors.

Objectives for the Coming Year

The MMF can provide global simulations of the statistics of clouds that can be compared with NASA's new satellite platforms. More complete

online cloud statistic diagnostics will be added to the MMF. The cloud information obtained from the International Satellite Climate Climatology Project (ISCCP) is a very valuable source of information that has not been extensively used as part of standard model evaluation exercises due to problems in relating the model clouds diagnosed to those observed by the satellites. The ISCCP cloud simulator [Klein and Jakob 1999; Webb *et al.* 2001] can produce clouds that are consistent with the satellite algorithms. The ISCCP cloud simulator will be implemented in the MMF. With "ISCCP clouds" available from the model, it will be possible to compare the behavior of various types of model clouds with satellite observations under differing climate regimes. It was decided by the participants that a total of 8 numerical experiments (including sensitivity tests by changing the physical processes) would be conducted.

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

GEST Investigator: Mircea Grecu

Collaborator: Robert F. Adler (PI, GSFC)

Abstract

From the standpoint of limiting random error and potential biases in satellite estimates of precipitation and latent heating, the use of coincident spaceborne radar and passive microwave radiometer observations leads to estimates that are credible and superior to those derived from either sensor alone. Unfortunately, spaceborne radars are narrow-swath instruments that currently do not provide sufficient sampling for many applications. Microwave radiometers, on the other hand, are relatively wide-swath instruments that operate on several low-earth orbiting platforms. Microwave radiometer estimates of precipitation and latent heating are compromised, however, by significant ambiguity in the interpretation of the radiance observations that can only be resolved if the algorithm training (or "calibration") data properly represent the environmental conditions and storm morphology where the algorithm is applied. In this research, a database of coincident precipitation profiles and associated radiances 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 radiances are the TRMM TMI observed radiances. However, the observed radiances are consistent with the radiances derived by a model during the combined retrievals. Therefore, the coincident precipitation-radiances database is physically consistent.

Description of Research

The combined radar-radiometer precipitation estimation method of Grecu *et al.* [2004] is applied to several months of TRMM PR and TMI data to construct different training databases that relate precipitation/latent heating vertical profiles to observed TMI radiances. Over a typical month, ~500,000 profile-radiance combinations are obtained using the PR-TMI data in the tropics and subtropics over ocean backgrounds. Those profiles are clustered based on the sea surface temperature, an estimate of the cloud top height from the radiometer data, and brightness temperatures into a total number of about 10,000 classes. However, for each pair of sea surface temperature and cloud top height, the number of classes does not exceed 300. For each class, the average radiance features, precipitation profile, and probability of occurrence are determined. The radiometer-only algorithm is based on a Bayesian estimation framework. In the Bayesian framework, the precipitation estimates are weighted averages of the precipitation values corresponding to the classes in the database, and the weights are determined based on the similarity between the observed radiance features and the radiance

features of those classes. Because the classes are stratified by the sea surface temperature and a cloud top height estimator, the number of classes that are considered for a retrieval is significantly smaller than the total number of classes, which makes the algorithm efficient.

Accomplishments during the Reporting Period

The PR-TMI trained radiometer algorithm was compared to an earlier radiometer algorithm that was trained using a suite of cloud-resolving model simulations. In applications of the algorithms to TMI observations over the tropical and subtropical oceans, both algorithms yielded monthly-mean surface rain rate distributions that are very similar to combined PR-TMI derived distributions. Aloft, however, the cloud model trained algorithm produced estimates of precipitation water content with significant high biases, while estimates from the PR-TMI trained algorithm were consistent with the combined PR-TMI estimates. The high-biases of estimates from the earlier algorithm are attributed to similar high-biases in cloud model simulated water contents in the algorithm training data. Although monthly zonal-mean precipitation distributions from the PR-TMI trained radiometer algorithm are in very good agreement with those from the combined PR-TMI algorithm, offsets between algorithm estimates at regional/seasonal scale are still evident. This suggests that a monthly, globally-based training set for the radiometer algorithm may not be representative for specific regions/seasons; *i.e.*, that the *a priori* probabilities of precipitation profiles in the training database may vary regionally/seasonally. In the current research we examine the space- and time-variations of these *a priori* probabilities and determine how the training data can be augmented and/or restructured to reduce space- and time-dependent biases of algorithm estimates.

Objectives for the Coming Year

This year, the work will focus on the analysis of the sensitivity of the precipitation estimates to seasonal and regional differences in the databases. Also, the precipitation estimation component will be augmented with a procedure to estimate the hydrometeor latent heating directly from passive microwave observations. This can be achieved by creating a general look-up table, or database, relating latent heating vertical structure to observed microwave radiances, based upon combined radar-radiometer estimates of latent heating and incorporating the latent heating database into a Bayesian method for estimating latent heating vertical structure from microwave radiances and radiance horizontal texture. The procedure will be evaluated using coincident high-resolution combined PR-TMI estimates of heating. A knowledge of global latent heating distributions would be valuable not only from the standpoint of understanding the earth's water and energy cycles, but also for climate and numerical weather prediction applications.

Task 912-21-145: **TRMM Project Science**

GEST Investigator: Guojun Gu

Collaborators: Robert F. Adler (GSFC), George J. Huffman (SSAI), Scott Curtis (JCET and East Carolina University), and Adam H. Sobel (Columbia University)

Abstract

During FY04-05, the PI has primarily been focusing research on the West African Monsoon, interannual to interdecadal variability in the tropical Atlantic basin, and the mean state and variations of the ITCZ in the tropical eastern Pacific. Analyses of the recently archived TRMM (rainfall and SST) and long-recorded (25-year) Global Precipitation Climatology Project (GPCP) products are key means in current research.

Accomplishments during the Reporting Period

Major mean rainfall over West Africa tends to be concentrated in two regions and is observed in two distinct seasons, manifesting an abrupt shift of the mean rainfall zone during June-July. Near the Gulf of Guinea (about 5oN), intense convection and rainfall are seen during April-June and roughly follow the seasonality of SST in the tropical eastern Atlantic. Then, along the latitudes of about 10°N over the interior West African continent, a second intense rain belt begins to develop from July and remains there during the later summer season. This belt appears with a northward-moved African Easterly Jet (AEJ) and its accompanying horizontal and vertical shear zones, the appearance and intensification of an upper tropospheric Tropical Easterly Jet (TEJ), and a strong low-level westerly flow. Westward-propagating wave signals dominate the synoptic-scale variability during July-September, in contrast to the evident eastward-propagating signals during May-June. The abrupt shift of the mean rainfall zone thus turns out to be a combination of two distinct physical processes: (i) evident seasonal cycles in the tropical eastern Atlantic ocean which modulate convection and rainfall in the Gulf of Guinea by means of SST-related forcing; (ii) the interaction among the AEJ, TEJ, low-level westerly flow, moist convection and waves during July-September which modulates rainfall variability in the interior West Africa, primarily within the ITCZ rain band.

Interannual-interdecadal climate variability in the tropical Atlantic sector is a very important topic which is directly associated with how to improve climate forecasts and diagnoses in the Atlantic basin and neighboring continents. Detailed physical patterns behind this variability, particularly rainfall variability have been quantified using the GPCP rainfall product, TRMM and other satellite observations. Current research focused on the impact of Pacific El Niño on the Atlantic basin.

The 6-year (1998-2003) TRMM rainfall is also used to quantify the Intertropical Convergence Zone (ITCZ) in the eastern Pacific (defined by longitudinal averages over 90°W-130°W) during boreal spring (March-April). The double ITCZ phenomenon, represented by the occurrence of two maxima with respect to latitude in monthly mean rainfall, is observed in most but not all of the years studied. The relative spatial locations of maxima in sea surface temperature (SST), rainfall, and surface pressure are examined. Interannual and weekly variability are characterized in SST, rainfall, surface convergence, total column water vapor, and cloud water. There appears to be a competition for rainfall between the two hemispheres during this season. When one of the two rainfall maxima is particularly strong, the other tends to be weak, with the total rainfall integrated over the two varying less than does the difference between the rainfall integrated over each separately. There is some evidence for a similar competition between the SST maxima in the two hemispheres, but this is more ambiguous, and there is evidence that some variations in the relative strengths of the two rainfall maxima may be independent of SST. Using a 25-year (1979-2003) GPCP rainfall data set, four distinct ITCZ types during March-April are defined, based on the relative strengths of rainfall peaks north and south of, and right over the equator. Composite meridional profiles and spatial distributions of rainfall and SST are documented for each type. Consistent with previous studies, an equatorial cold tongue is essential to the existence of the double ITCZs. However, too strong a cold tongue may dampen either the southern or northern rainfall maximum, depending on the magnitude of SST north of the equator.

Objectives for the Coming Year

Interannual to interdecadal variability in the global hydrological (water) cycle is an essential part of global change. How to quantify and correctly estimate this variability is a critical, very first step to answer whether there is a corresponding acceleration of hydrological (water) cycle given a relatively confident belief of global warming. During the forthcoming year, studies will primarily focus on exploring whether there is a coherent trend or interdecadal variability in various environmental components, *e.g.*, atmospheric water vapor content, surface evaporation rate, river run-off,

etc., with a specific focus on surface precipitation, and on examining how confident we might be to the possible answers. Analyses of the GPCP rainfall product and other remotely-sensed satellite measurements, such as the Special Sensor Microwave Imager (SSM/I) derived data sets, and the recently archived TRMM (rainfall and SST) products, will be key means in the research.

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 at furthering our understanding of the global water cycle. The mission requires quantitative error characterization and algorithm validation to ensure its success. An advanced three-dimensional physical radiative transfer (PRT) model that incorporates realistic hydrometeor information is an important and integral part of the validation effort. Furthermore, it is desirable for this PRT model to carry a solution for time-dependent point sources in order to simulate illumination by a spaceborne radar.

Description of Research
The physical radiative transfer model will take as input hydrometeor profile measured by a Doppler profiler, temperature/humidity profile measured by radiosonde, and surface emissivity measured by a downward-pointing multi-spectral radiometer. The hydrometeor profiles will be adjusted within the Doppler profiler's error range to determine the closest match between the model-simulated radiances and those measured by a downward-looking radiometer and radar from a space platform. The resultant mismatch between simulation and measurement will characterize the background bias uncertainty. The difference between any retrieval algorithm's hydrometeor solution and the error model solution will define the current retrieval bias.

Accomplishments in the Reporting Period
The design and implementation of the Satellite Simulator Model (SSM) based on a three-dimensional formulation of the radiative transfer equation has achieved initial success. The model compares well, in scalar mode, with existing models. It also compares well with a plane-parallel vector radiative transfer model. Further verification of the model is still needed.

Analysis of the retrieved liquid water path (LWP) from the MODIS cloud products reveals that, while the LWP distribution in cloudy fields is accurately described by a gamma distribution, the distribution of LWP anomaly ratio (LAR), defined as the ratio of LWP departure from mean to its standard deviation, is best captured by a general beta distribution. The parameter, LAR, is directly related to saturation excess which is used in many of the sub-grid cloud parameterization schemes for dynamical models [Sommeria and Deardorff 1977]. Therefore this study has important application in the sub-grid cloud parameterization of dynamical models.

An innovative method was invented to extract and combine spatial statistics from radar reflectivity data alone to be used as surrogates for polarimetric radar parameters in the absence of polarimetric functionalities. A research publication is in preparation to report this innovation.

Further analysis of TRMM version 6 products was carried out. The analysis provided insights

into the discrepancies between different rain rate retrieval algorithms which included 2A12, 2A25 and 2B32. These insights would in turn provide improvements to these algorithms. Although the statistics are different from our preliminary analysis performed last year the general conclusion remains valid (*i.e.*, only less than 10% of the pixels compared shows large discrepancy). These will be the focus of algorithm improvements.

A peer-reviewed paper, Kuo *et al.* [2004], describing a new mathematical-physical framework for the retrieval of raindrop size distributions using a dual-frequency (Ku-Ka-band) precipitation radar was published in *Journal of the Atmospheric Sciences*.

Objectives for FY 04-05

Further testing of the SSM will be performed to extend improvements and validation activities,. The SSM will be applied to find optimal frequencies for Ground Validation radiometer and radar.

Task 912-19-131: **Cloud Radar Calibration, Data Analysis and Instrument Development for Hurricane Genesis Study**

GEST Investigator: Lihua Li

Collaborator: Gerry Heymsfield (PI, GSFC), Lin Tian (GEST)

Abstract

Ocean surface has been widely used as a calibration reference for airborne and spaceborne microwave radar radiometers. However, at millimeter-wave frequencies, the ocean surface backscattering mechanism is still not well understood, in part, due to the lack of experimental measurements. Through the analyses on Cloud Radar System (CRS) ocean surface return obtained from the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE), a conclusion has been reached that the ocean surface is proper to be used as a calibration reference for airborne and spaceborne millimeter-wave cloud radars. Other research contributions include the analysis of radar data and retrieval of precipitation/cloud microphysical properties, including particle size and water content. Moreover, a new X-band radar/radiometer is under development for flying on an Unmanned Aerial Vehicle (UAV) in support of the study of hurricane genesis.

Description of Research

Microwave and millimeter-wave radars have been proved as essential tools for atmospheric remote sensing. During the past decade, NASA GSFC has developed the 9.6 GHz ER-2 Doppler Radar (EDOP) for cloud/precipitation measurements and the CRS for cloud detection, especially for ice phase cloud studies. By combining radar data with measurements made by other sensors, such as lidar, radiometer and *in situ* instruments, microphysical properties of precipitation/clouds can be retrieved. To ensure the accuracy of the retrieval, instrument calibration is crucial. However, since it is not trivial to achieve radar calibration, different approaches have been explored including using the ocean surface as a reference. In hurricane research, current hurricane forecasting models greatly need environmental and interior storm measurements (surface winds, temperature, profiled winds, temperature and moisture, etc) over the open ocean where manned aircraft are unable to fly and satellite measurements are inadequate. Long-duration, high-altitude UAVs are capable to provide this greatly needed information. A new X-band is under development for flying in UAV payloads to study hurricanes.

Accomplishments during the Past Year

Research efforts during the past year have led to five papers submitted to peer-reviewed journals where the PI was author or co-author, as well as four conference presentations. The researcher is

also PI or Co-PI for seven research proposals. CRS data was analyzed and data products were provided to other research groups. The research lead a group of engineers and technicians in the development of a new X-band radar/radiometer. Due to his significant contribution, Dr. Li was honored with the Outstanding Performance in Technical Support/Instrumentation Award by the Laboratory for Atmospheres, NASA GSFC, in 2004 and the NASA Group Achievement Award to GSFC ER-2 Crystal-Face Research Team in August 2004.

As the leading author, Dr. Li's effort contributed to the publication of a journal paper on CRS instrumental merits and preliminary data. CRS is a new instrument in the research community. It has a number of unique features compared to the other ground-based and airborne millimeter-wave cloud radars. The design of the CRS involved a compromise in order to address the scientific requirements that demand high sensitivity and high spatial and temporal resolution, and hardware limitations imposed by the size, power, and weight constraints of the ER-2 platform. Special issues, such as a low pressure and low temperature environment, have been carefully considered during the development of the instruments. Most of CRS data processing code was developed after the CRYSTA-FACE experiment. The nature of backscattering and propagation of 94 GHz signal is significantly different from the lower frequency radar signals. Special effort has to be made to post averaging of the data and noise subtraction to improve the radar sensitivity to atmospheric attenuation and navigation correction.

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. During the CRYSTAL-FACE, measurements of ocean surface scattering have been made using CRS. The relationship between the normalized ocean surface cross section and the incidence angle at different wind conditions was obtained. Analysis of the radar measurements shows very good agreement with quasi-specular models. This unprecedented dataset enhances our knowledge about the ocean surface scattering mechanism at 94 GHz and it provides 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. Dr. Li led these analyses and the results have been included in a journal paper, which is in press.

During the past year, Dr. Li has worked closely with other scientists on data analysis and the retrieval of cloud microphysical properties using radar, lidar and radiometer measurements. One of six aircrafts operated during the CRYSTAL-FACE, the ER-2 carried a full suite of sensors, including Cloud Physics Lidar (CPL), the 9.6 GHz ER-2 Doppler Radar (EDOP), Conical Scanning Sub-millimeter wave Imaging Radiometer (CoSSIR), Dropsonde, and Modis Airborne Simulator (MAS). The remote sensing data collected by this ensemble of instruments is unprecedented and enables the study of cloud microphysical properties from different approaches. To this end, CRS data has been completely processed and widely shared by the research community, including scientists from different universities and government research institutes. Efforts on this task have contributed to collaborative research studies, leading to the publication/submission of a number of peer-reviewed journal papers and conference presentations.

In addition, task effort has contributed to the development of a low-cost, miniaturized, light-weight, X-band (9.3 GHz) for flying on a UAV. During the Atlantic hurricane season, about one-tenth of the waves that frequently come off the African continent develop into hurricanes that eventually may threaten the coastal U.S. area. 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 but it will be necessary to miniaturize and reduce the cost of current aircraft radars and radiometers to maximize efficiency.

Objectives for the Coming Year

In the coming year, research will concentrate on the development of the UAV X-band radar/radiometer instrument. As the leading system engineer, Dr. Li will oversee the design, fabrication and testing of the new instrument, including the radar RF front end, data system, and possible integration on the aircraft and test flight. In addition, a CRS hardware upgrade is planned, including using a larger size antenna to improve the sensitivity. Dr. Li will continue analyzing the data on cloud particle and water content retrieval using radar and lidar measurements. A CRS field deployment in support of the NASA GSFC code 975 research program ("Improvement to the Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)") is planned. If funded, Dr. Li will prepare CRS, EDOP and new UAV radar for field deployment in support of the NASA TCSP program, which aims at gaining an 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. Also if funded, the CRS will be prepared for installation on the NASA WB-57 aircraft in support of the NASA Aura validation and the Tropical Composition, Cloud and Climate Coupling (TC4) program.

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), with an explicit bin micophysical scheme (from HUCM) has been used to study the impact of increasing aerosol concentration on cloud structures, their radiation properties and precipitation systems. The second-indirect effect of aerosol (increasing the aerosol concentration leads to the delay of rain formation and reduction of the surface rainfall) only occurs to short-lived convections, or the initial half-hour of a complex mesoscale convective system. The impact of aerosol on storm strength and surface precipitation varies significantly with the environment in which the storm forms. These case studies suggest the complexity of the aerosol-cloud-precipitation interactions in the global hydrological system.

Description of Research

Aerosols pose the biggest 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. Much progress has been achieved 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. The investigator's current research focuses on the impact of aerosol concentration on mesoscale convective systems, which are responsible for the majority of the rainfall in tropics and summer time mid-latitudes.

Accomplishments during the Reporting Period

The investigator has been involved in testing and improving of the GCE bin spectra model in the past year. The ice falling velocity has been added to the GCE model with bulk microphysics to improve the model performance. In addition to a midlatitude squall line (PRE-STROM) and a tropical oceanic squall line (TOGA-COARE) cases that have been simulated over the past two years on the study of the aerosol impact on storm structure, a sea-breeze type convection with shorter lift-time (CRYSTAL-FACE) has been successfully simulated using both the bulk and the bin spectra scheme. In the dry, less stable mid-latitude continental case, increasing aerosol concentration increases the total rainfall only slightly. The stratiform rain portion in the convective systems increases considerably with increasing aerosol concentration, therefore produces a larger anvil and more light rain. In the wet, more stable tropical maritime case, increasing the environmental aerosol concentration leads to significantly more vigorous convections and enhanced surface rainfall. For an isolated, short-lived convection, more aerosols reduce the total surface rainfall, similar to the prediction by the theory of the aerosol indirect effect. These results show the complexity of the aerosol-cloud-precipitation interaction and the necessity of further modeling study and observations.

Comparisons of the model simulations using the bulk and bin microphysical schemes are important for both the validation of the newly implemented bin scheme and the improvement of the bulk scheme. The PRE-STROM case study shows many detailed differences in storm dynamics in different microphysical schemes, which indicates the importance of the interactions between cloud microphysics and dynamics. The artificially enhanced rain evaporation simulated by the bulk microphysical schemes is the key factor that determines different storm structures in the simulations. The precipitable ice particle's falling velocities also play an important role in shaping the stratiform region of a mesoscale convective system in the midlatitude. A paper based on this study has been accepted by the *Journal of Atmospheric Sciences*. A follow-on to this paper has also been submitted to the same journal.

Observational evidences of the impact of aerosol concentration in surface precipitation intensity are needed to validate the modeling results. The investigator has analyzed the TRMM 3G68 daily radar surface rainfall data to detect possible signals produced by the anthropogenic aerosols, in support of the findings by Dr. Tom Bell in GSFC. A weak weekly cycle has been found in both radar and microwave observations.

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. More detailed analysis—for example, offline heat and water vapor budget, particle trajectory analysis, tracer analysis—will be performed in the coming FY. The bin spectral model will be implemented into 3-D framework and MPI version of the GCE model to allow for faster and more realistic cloud system studies. Further improvement of the bin microphysics will include implementing detailed aerosol dynamics and chemistry into the GCE model in order to study the aerosol impact on cloud systems more realistically. The impact of increasing ice nuclei on cloud formation and dynamics will also be studied. As always, adequate comparisons of the model results with the observations will be an important part of this study.

Task 912-02-036: **Physics of cirrus clouds and their role in global climate**

GEST Investigator: Ruei-Fong Lin

Collaborators: D. O'C. Starr (PI, GSFC)

Abstract

The formation and evolution of cirrostratus, which is formed by large or mesoscale forcing, and cirrus outflow of thunderstorms are investigated by in-house 1-D or 2-D cirrus models with explicit microphysics, in which the aerosol and ice crystal size distributions are fully resolved. Three case studies are performed: (1) a long-lived cirrostratus measured by the GKSS lidar in the wintertime of Sweden, (2) a long-lived mid-latitude cirrus anvil measured by the NASA Scanning Raman Lidar on June 19-20, 2002 during the International H2O Project (IHOP), (3) subtropical cirrus anvils observed on July 23, 2002 in the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL-FACE).

Description of Research

With the explicit microphysical schemes incorporated into a 1-D model of very fine vertical-resolution (grid spacing from 1 to 100m), the nucleation regions in the long-lived arctic cirrostratus are revealed. The effect of nucleation modes (homogeneous freezing versus heterogeneous nucleation) on the cloud bulk microphysical and optical properties is significant. Our study shows that, when heterogeneous nucleation in the dominant nucleation process, the complex structure of cirrostratus may result solely from the episodic nature of nucleation, particle growth and sedimentation in the absence of turbulence and cloud-scale dynamical processes. The study also suggests that the depth of nucleation zones, usually un-resolvable by the vertical grid spacing of GCM, should be considered in parametric treatments of ice cloud generation.

Turbulence and cloud-scale circulation could play a significant role in the evolution of cirrus anvil. Furthermore, gravity waves induced by the associated storm could also affect the cloud development. Therefore, we use a 2-D cirrus model of spatial resolution of 100-m to simulate the interested cirrus anvils. The overall cloud height and depth (about 1.5 to 2 km) of the persistent cirrus anvil observed on June 19-20, 2002 did not change much for 7 hours. However, the optical and microphysical properties became two-layered. The top layer featured higher depolarization ratio, larger ice water content, and smaller ice crystals, while the lower layer featured the opposite. Furthermore, the upper level seems to correspond to a layer of neutral instability. This prompts the question if the layering was associated with a cirrus outflow layer which was decreasing its depth with time. The composite of NASA Cloud Radar System (CRS) and Cloud Physics Lidar (CPL) rendered a rather complex structure of the subtropical anvil systems of July 23, 2002 [McGill *et al.* 2004]. MM5 simulated cloud field is compared with the measurements, *i.e.*, NEXRAD, CRS and CPL composite, and MODIS airborne simulator. We also extracted vertical wind field from the MM5 simulation and compared it with *in situ* wind measurements by the aircraft WB-57, which flew flight legs of altitude 11-15 km into the cloud system. Vertical wind derived from MM5 is then used to drive the 2-D cirrus model to study the impact of gravity waves on the cirrus anvil.

Accomplishments During the Reporting Period

Numerous new components have been developed for the in-house cirrus model during the past year. The 1-D model is now able to be coupled with large-scale forcing data such as the ARM forcing data [Zhang and Lin 1997]. The model is able to treat multiple ice crystal species now. The direct effect of radiation on ice crystal growth was added to the microphysical module. Furthermore, the scattering and absorption properties database for nonspherical ice particles in the infrared spectral region [Yang *et al.* 2005] was implemented. These additions enhance the model flexibility and reduce model uncertainty.

The 1-D study of the arctic cirrostratus is complete [Lin *et al.* 2005]. The new 1-D model is used to study high ice supersaturation in cirrus observed in the ARM Southern Great Plain site [Comstock *et al.* 2004]. Preliminary studies of the IHOP and CRYSTAL-FACE cases were reported in conference papers. Numerical simulations of the IHOP case indicate that our hypothesis of a cirrus outflow evolving into a mixed layer with a decreasing depth and a debris layer of larger crystals is possible. Numerical simulation of the CRYSTAL-FACE case highlights that the stratiform cloud beneath the cirrus anvil tends to reduce the radiative destabilization in the cirrus anvil.

Objectives for FY 05-06

The studies of the IHOP June 19-20, 2002 case and the CRYSTAL-FACE July 23, 2002 case continue to be the research foci in the coming year. The new 1-D model will be used for a series of simulations of cirrus cloud observed in the ARM Southern Great Plain site. The statistics of the model results will be assessed and compared with observations with an aim to develop a new cirrus parameterization scheme or strategy for the use of general circulation models.

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)

Abstract

Research tasks performed during this past Fiscal Year consist of three major studies. Two of them 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, while the third 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 Tropics, mid- and high-latitudes. The second study extended the investigation of domain-averaged Q-T relationship to the tropical Pacific, Atlantic and Indian Oceans using the GEOS-3 monthly data. The third study aimed to simulate various marine and continental cloud systems using the GCE model (a cloud resolving model, or CRM) driven by either observed or GEOS-3 large-scale forcing fields.

Description of Research

The primary objective of this research, which involves a series of numerical simulations using the GCE model, aims to better understand the role cloud systems play 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. The fast growing usage of a 3-D CRM instead of a 2-D CRM has become a popular trend among the cloud modeling community due mainly to the fact that the former provides a numerical tool with an overall more realistic physical structure than the latter does. In a NASA Interdisciplinary Science project (collaborating with Dr. A. Hou at GSFC), the 3-D GCE/MPI model was proposed to be used 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 by applying the GEOS-3 reanalysis data from different geographic locations. This long-term task of performing extensive model simulations, including a production of upward/downward radiation

fluxes at both top and bottom boundaries, has been started recently.

Accomplishments During the Reporting Period

For research Subject 1, an ideal and simple formulation was successfully derived that well represented a quasi-linear relationship found between the domain-averaged water vapor and temperature fields obtained from a series of quasi-equilibrium simulations for the Tropics using a 2-D GCE model. Earlier model work showed that the forced maintenance of two different wind profiles in the Tropics led to two different equilibrium states. Examining this finding required investigation of the slope of the Q-T relations, which turns out to be linear in the Tropics. 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 then found in this study. Such a genuine finding clarified that the dynamics were crucial to the climate (shown in an earlier work) but the thermodynamics adjust [Shie *et al.* 2005a].

For research Subject 2, as a continuation of research Subject 1, the investigation of the domain-averaged Q-T relationship was extended from the Tropics to the Pacific, Atlantic and Indian Oceans using the GEOS-3 global reanalysis monthly products. 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 embedded in a global, curvilinear Q-T relationship. Q, however, increased faster with T over oceans than over the Tropics. A positive correlation was also found between T and sea surface temperature (SST), which seemingly implied that air mass might have tended to obtain more heat from open oceans during the warmer season as compared to the colder season. Q and SST were also found to be positively correlated in a manner that quantitatively resembles an earlier result found by Stevens [1990]. Relative humidity (RH) exhibited similar behaviors for oceanic and tropical regions, respectively. RH increased with increasing SST and T over oceans and increased with increasing T in the Tropics [Shie *et al.* 2005b]. The similar features found between oceanic and tropical regions seemed to imply that oceans occupy most of the Tropics and so play a key role in determining the tropical climates.

For research Subject 3, one of the major tasks for this NASA IDS project was to simulate the targeted cloud systems at different geographic locations (tropics and subtropics; marine and continental) by implementing the GEOS-3 or observed forcing data to the 3-D GCE/MPI model. Preliminary 2-D pilot results using GEOS-3 data showed good agreement with the numerical results using observations from field experiments [Shie *et al.* 2004b]. The 3-D modeled rainfall results were also found consistently corresponding to a properly correlated large-scale T and Q forcing (*i.e.*, a cold and moist concurrent environment) [Shie *et al.* 2005c]. The task of performing extensive model simulations has been started recently. Ten episodes of long-term (ranging from 5-15 days) simulations for the TRMM field experiments (*i.e.*, KWAJEX and SCSMEX) were completed so far using either the GEOS-3 or observed forcing data. The GEST Investigator also has collaborations with Columbia University, University of Virginia, Texas A&M University, as well as NASDA in Japan. His contributions include being the co-author on a handful of publications [Perez *et al.* 2004, 2005, Juang *et al.* 2004, O'Halloran *et al.* 2004, Shige *et al.* 2004].

Objectives for the Coming Year

The projects detailed above are ongoing and will require much of the investigator's attention in the next FY, including focusing on a project that will be based on Subject 3. In such a project, a 3-D GCE 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 Water Vapor Attenuation**

GEST Investigator: Lin Tian

Collaborator: Gerry Heymsfield (PI, GSFC)

Abstract

A method is developed for estimating rainfall rate and other parameters in light stratiform rain using airborne Doppler radar observations at 94 and 10 GHz. The method uses the difference of return power as well as Doppler velocity measured at the two frequencies to estimate rainfall rate, vertical air velocity, and water vapor attenuation that is nearly proportional to the water vapor content. The method is applied to observations near 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.

Description of Research

Measuring global rainfall property by satellite such as the Tropical Rain Measuring Mission (TRMM) is important for understanding weather and how to improve weather prediction. Rain has been very difficult to measure accurately over a wide range of intensities because there is generally insufficient information about the rain properties. A dual-wavelength radar, such as the one proposed for the Global Precipitation Measurement (GPM) can improve the accuracy of rainfall estimation. However, the 14 and 35 GHZ frequencies proposed for the GPM radar may not resolve the raindrop size distribution in light rain due to the small difference of the reflectivity at the two frequencies. By using a combination of 94 GHz and 10 GHz reflectivity and Doppler information that is not available on GPM, it has been found in this work that light rain can be estimated more accurately.

Accomplishments during the Reporting Period

The investigator has developed two techniques for retrieving the slope and intercept parameters of an assumed exponential 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 and W-band). In both techniques, the slope parameter of the RSD and the vertical air velocity are retrieved using only the mean Doppler velocities at the two wavelengths. In the first method, 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. In the second technique, it is assumed that the longer wavelength suffers attenuation only in the melting band. Then, assuming a distribution of water vapor, the melting band attenuation at both wavelengths and the rain attenuation at the shorter wavelength are retrieved.

The techniques were applied to a light stratifom rain near Florida. Retrieved raindrop size distribution showed 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 attribute to a large error in estimating 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.

Objectives for the Coming Year

The GEST investigator will extend the new method described above to the ice region above the melting band and continue to improve the algorithms with a more-realistic drop size distribution, concentrating on the physical interpretation of the estimated DSD and vertical air velocity, and estimating attenuation in the melting band.

Grant CV526574: **The Evaluation and Application of N-POL Data in TRMM/GPM GV program**

GEST Investigator: Jian-Jian Wang

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

Abstract

The NASA Polarimetric Radar (NPOL) is NASA's only portable polarimetric precipitation research radar and one of the very few polarimetric weather radars in the world. 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. Our main effort is to evaluate the performance of this new advanced radar, and provide suggestions for the future improvement of this polarimetric weather radar.

Description of Research

Our central research effort is to assess the NPOL polarimetric performance relative to that of established polarimetric radars (*e.g.*, CSU-CHILL, NCAR SPOL, and BMRC CPOL). To do this, a rain gauge and distrometer network has been created within 150 km radius to NPOL radar, which is currently located at Oyster, Virginia. Key technical and scientific issues that have been developed and studied, include: a) the standardized procedure and methodology to process and analyze the polarimetric radar 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 and drop diameters derived from polarimetric radar with the observations by rain gauges and distrometer.

Accomplishments in FY 04-05

The research in the reporting year has focused on the evaluation of the performance of the NASA NPOL radar. We have collected more than ten cases during the period of June to September 2004. Detailed case studies are performed to examine the NPOL data quality and compare NPOL results to the results from other radars.

We start with the estimation of differential reflectivity (Zdr) bias by examining the histogram of Zdr in anvil echo. We choose data 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). We found that Zdr had a positive bias of +0.5-1.0 dB. We next compared the NPOL reflectivity data with Wakefield NEXRAD radar and S-band SPANDAR radar, which are 102 km southwest and 82 km northeast to the NPOL, respectively. The slope of the linear interpolation for two S-band radars, NPOL and SPANDAR, in general was close to the perfect correlation (1:1) line. The NPOL reflectivity data are about 0.7 dBZ, higher than the SPANDAR reflectivity data. The correlation between NPOL and NEXRAD was about equally good. However, the NPOL had reflectivities about 1.7 dBZ higher than NEXRAD. In general, the match of reflectivity data among all three radars we examined is reasonably good, thus giving us confidence that the NPOL reflectivity data are very reliable.

To compare NPOL with other established polarimetric radars, we take samples representing drizzles, which should be characterized approximately by specific differential phase, Kdp ≈ 0° km-1, Zdr ≈ 0 dB, and correlation coefficient, ρHV ≈ 0.99. Our results demonstrate that polarimetric data quality for the relatively new NPOL radar is not yet up to the standards of other established research polarimetric radars in the international community (*e.g.*, CSU-CHILL, NCAR SPOL, and BMRC CPOL). For example, the random measurement error in the measured differential phase (Ψdp) is about 7° compared to more typical values of 1.4° to 2.5° for the other radars. In drizzle, Kdp should be zero. Any deviation from zero is associated with measurement error. The NPOL Kdp distribution has a significant fraction of |Kdp| beyond 1 ° km-1. 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. The distributions of Zdr are highly peaked about zero as expected for the other radars while the NPOL Zdr distribution has significant contributions for |Zdr| > 0.5 dB. These NPOL measurement errors above are consistent with depressed values of the NPOL correlation coefficient (ρHV) in the "drizzle" data. The NPOL's ρHV distribution in drizzle has a broad peak from 0.94 to 0.98 and a lot values below 0.9.

The implications of these errors are significant. Along with reflectivity, Zdr and Kdp are key parameters for the estimation of rain rate and other DSD parameters and the identification of hydrometeor types. The Zdr and especially Kdp are also very important for data processing and quality control (*e.g.*, power calibration, attenuation correction, and the removal of clutter, clear air and anomalous propagation). An increase in the measurement errors of these polarimetric radar parameters directly amplifies the error in the estimated rain rate or other DSD parameters (*e.g.*, Bringi and Chandrasekar [2001]). These measurement errors also decrease the effectiveness of algorithms for hydrometeor identification and data processing and quality control.

Also, the NPOL radar suffered a serious reflectivity attenuation problem when the antenna was wet. It is our interest to use the case studies to quantify the influence of wet antennae. The time series of reflectivity differences between NPOL and NEXRAD radars show that the NPOL was generally 1.5-2 dBZ higher than NEXRAD before the antenna gets wet. After the rain started, the NPOL reflectivities were about 9 dBZ lower than NEXRAD reflectivities throughout the heavy rain period. After the rain ended, it took about 40-50 min for the antenna to return back to its normal status. It is also noted that the negative reflectivity bias is not constant during the passage of a typical rainband but varies with rain rate and hence likely "wetness" of the antenna.

Objectives for FY 05-06

In the coming year, we will continue our effort regarding the evaluation of dual polarimetric radar data collected by the new NASA NPOL radar. We will process the rain gauge and distrometer data collected during the same period of NPOL operation. Then, we will compare the total rainfall derived from all three instruments for every NPOL cases we have analyzed. This comparison will provide further information about the NPOL performance. After the NPOL radar is improved, especially in the areas of noisy data and wet antenna, we will perform a series of new case studies with the similar procedures described above. The

untimate goal is, with the collaboration with engineers, we will make the NPOL radar a high quality research radar.

GEST 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, where he is advancing our understanding of tropical cyclone activities. This work mainly involved research into the environmental influence on tropical cyclogenesis and potential impacts of global warming on the tropical cyclone motion, especially in the western North Pacific basin and vertical alignment of hurricane vortices under the influence of environmental vertical wind shear and tropical cyclone intensity change. Preliminary findings include the significant shifts of the prevailing typhoon tracks over the past four decades, the gyroscopic effect in the tilted hurricanes, and strong environmental control on the Atlantic tropical cyclogenesis.

Description of Research
Hurricanes, as a key component of the global climate system, can be significantly affected by the global climate change and 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. During the past year, particular foci have been placed on the interaction between large-scale environment and tropical cyclone activity, primarily through numerical experiments using MM5.

Accomplishments in FY 04-05
During the past year, we investigated the environmental controls on tropical cyclogenesis and intensity change to examine the possibility of extended numerical predictions of tropical cyclogenesis. More extended simulations for 2003 and 2004 hurricane seasons were conducted using the state-of-the-art MM5 model by feeding the coarse-resolution NECP re-analysis as initial and lateral boundary conditions. These experiments can capture the primary features of the hurricane activity. It was found that the simulated tropical cyclone activity can be significantly improved by nudging the AIRS/Aqua air temperature profiles. The observed cyclones are reasonably simulated in terms of the formation location and time. The simulated tracks are also comparable to the observed.

The study on the tropical cyclone intensity was conducted by numerical modeling with a 2D version of TCM3. It was found that the vertical wind shear significantly reduced Erin's intensity by inducing wavenumber-1 components in the vicinity of the radius of maximum wind, which can weaken the radial circulation, the tangential wind, and the convective activities of the eye wall. In addition, the Erin case was simulated again with very high-resolutions (2 km) to reveal the convective processes in the core region.

Numerical model studies have suggested that the ongoing global warming will likely affect tropical cyclone activity. But, so far, little observed evidence has been detected to support the projected future changes. Using satellite-supported best-track data from 1965 to 2003, we showed for the first time that the prevailing typhoon tracks over the western North Pacific (WNP) have significantly changed over the past four decades. The typhoon activity over South China Sea has decreased and the prevailing typhoon tracks have shifted westward in the WNP. East Asia has experienced increasing typhoon influence. Our trajectory model simulation indicates that the long-term shifts in the typhoon tracks result primarily from the westward expansion and strengthening of the WNP subtropical high, which leads to changes

in the large-scale steering flow and thereby in the mean translation velocity of typhoons.

Objectives for FY 04-05

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.

Task 912-29-152: **Development of the Second-Generation of GCE Model**

GEST Investigator: Xiping Zeng

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

Abstract

A cloud-resolving model with the domain size of 103 km can represent explicitly both clouds and synoptic large-scale circulations, and will become a useful tool in exploring clouds in weather and climate change. The Goddard Cumulus Ensemble (GCE) model is one of the best cloud-resolving models in the world. It has been widely applied to studying precipitation processes associated with convective systems from different geographic locations. This model is being upgraded to its second generation for better performance, especially in the future exploration of clouds in weather and climate change. As the first step, the "exact" representation of moist thermodynamics has been explored with moist entropy as a prognostic thermodynamic variable. Future work will address the connection of moist thermodynamics to atmospheric dynamics and cloud microphysics in cloud-resolving modeling.

Description of Research

Clouds play a central role in weather and climate change. They connect atmospheric aerosol, radiation and circulations to each other. Due to the scale difference of aerosol, clouds and synoptic large-scale circulations, numerical simulation is important in exploring the nonlinear relations between clouds and other factors. Thus, an interesting topic is how to represent clouds properly in the numerical simulation. Current numerical weather and climate models use large spatial grid size, and represent clouds implicitly with cumulus parameterization. However, the cumulus parameterization is far from a satisfactory model, especially in the Tropics.

In contrast to the numerical weather and climate models, cloud-resolving models use fine spatial resolution so that they represent clouds explicitly, avoiding the cumulus parameterization. With the aid of massive parallel computation, they may expand their domain size to thousands of kilometers in the following years. Since they represent clouds explicitly and introduce cloud microphysics properly with parameterization, they provide an ideal framework to study the interaction between clouds and other factors (*e.g.*, aerosol, radiation and synoptic large-scale circulations).

Accomplishments During the Reporting Period

Current cloud-resolving models usually use a domain size on the order of 101-102 km and cannot accommodate synoptic large-scale circulations. With the aid of massive parallel computation, the models may expand their domain size to 103-104 km in the following years for the explicit representation of clouds and the large-scale circulations. In response to this computational development, the three-dimensional Goddard Cumulus Ensemble (GCE) model was improved during the past year for massive parallel computation, in cooperation with the scientists in NOAA and NASA. The parallel computation code was tested successfully, and its introduction is ready for publication.

Due to the complexity of cloud microphysics, a key consideration is how to represent moist

thermodynamics properly in cloud-resolving model for long-term (*e.g.*, months) integration. To minimize computational errors, it is proposed to return to the primitive form of moist thermodynamics, in which prediction is made in terms of conservative properties such as mass and entropy. In other words, moist entropy is used as a prognostic variable in cloud-resolving modeling, and other thermodynamic variables (*e.g.*, temperature) are diagnosed from that and other prognostic variables. Previous work on warm-cloud modeling has shown the possibility and advantage of this approach. During the past year, the theoretical work on moist thermodynamics was done, providing the theoretical base for moist entropy as a prognostic variable in the modeling of cold clouds. Meanwhile, a new efficient method for sound wave was developed for the proper connection between moist thermodynamics and dynamics. Papers on that work have been submitted to *Journal of Atmospheric Sciences* for publication.

Objectives for the Coming Year

In the coming year, the work on moist thermodynamics will continue with the scientists in NASA, focusing on the connection of moist thermodynamics to cloud microphysics. The code package for moist thermodynamics will be developed for the second generation GCE model.

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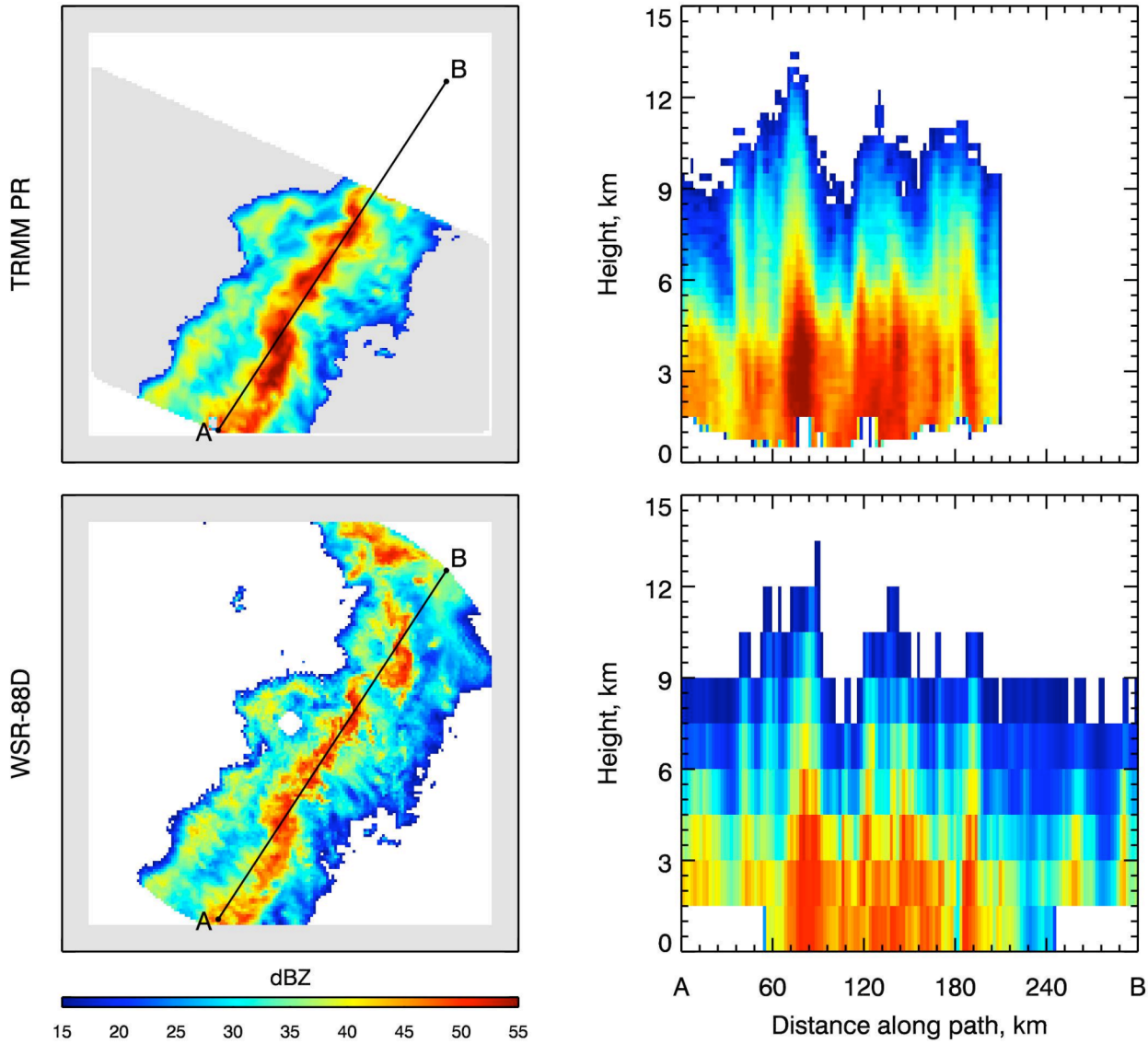
Cloud Analysis Research Group



Measurements of the TRMM Precipitation Radar (top) with attenuation correction and WSR-88D ground-based radar (bottom) reflectivities (dBZ) for the March 9, 1998 satellite overpass in Melborne of Florida. Left: CAPPI display at a height of 3 km; right: RHI display along the path AB.

Cloud Analysis Research Group

Faculty members of the Cloud Analysis Research Group had number of different projects dealing with both the development of instrumentation used to conduct remote measurements, and the subsequent analysis which follows the collection of such data.

Tim Berkoff's work was in the area of deployment and operational improvement of the lidar instrumentation/data retrievals in the Micro-Pulse Lidar NETwork (MPLNET) continued this past year. This included efforts in the commercialization of a lidar system specifically tailored for MPLNET, further development and demonstration of overlap calibration techniques, and investigation of satellite data in relation to MPLNET ground-based measurements. There was research activity on further development of methods to calibrate and model the MPL overlap function, and development of an analytical model to provide thermal correction to it. MPL systems contain a commercial grade telescope that is sensitive to environmental changes which, in turn, influence the geometrical overlap calibration. To reduce data errors and improve operational temperature range of the instrument, a model, based on geometrical and paraxial descriptions of the telescope focus response, was used to predict the expected changes in overlap calibration as a function of temperature. Comparisons of corrected versus non-corrected data for two different thermal cases demonstrated a significant reduction in thermally induced bias errors.

Continuing along the theme of utilizing satellite instrumentation, Redgie Lancaster conducted an engineering study of an advanced cloud aerosol lidar for the upcoming Earth Science System Pathfinder mission. This lidar was to be coupled with a hyper spectral radiometer for ocean color measurements, and detection of subsurface ocean properties as they relate to biomaterial. Additionally, a study was performed that examined the ocean surface reflectance using backscatter returns from the Geoscience Laser Altimeter System. It was found that the ocean reflectance at a wavelength of 1 um can be predicted very accurately using global measurements of surface wind speed made with the SeaWinds microwave scatterometer aboard Quikscat. The surface winds drive the surface roughness of the ocean and modify the angular distribution of the backscatter reflectance. A proposal to build an engineering model of this advanced lidar was also prepared and submitted to the NASA Instrument Incubator Program using injection seeded lasers, narrowband solar etalon filters and photon counting detector capabilities. He also examined the use of a multi-angle infrared imaging radiometer to fly along side a sub-mm conical scanning radiometer, together to measure cloud water content. The measurements at multiple angles provides for a stereo view from which cloud heights and motions (for tropospheric winds) can be derived.

Liang Liao's research was on a variety of topics related to microwave radar applications in estimating microphysical properties of hydrometeors. His studies included: 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 effective dielectric constant of mixed-phase particle.

Ash Mahesh used observations from GLAS, beginning in February 2003, to both study the atmosphere of the polar regions, and to validate other studies made using passive observations. His interest was in the layering of Antarctic clouds, their frequency of occurrence, and their typical thickness to develop a complete climatology of clouds over the entire high plateau. The broad purpose of these studies is to characterize polar clouds and climate more accurately for inclusion in general circulation models (GCMs) and to determine the impacts of clouds, snow and ice particles on the radiation balance between the surface and the atmosphere in the high latitudes. Using multi-year observations of clouds by lidar at South Pole station, a climatology of cloud base heights was constructed.

Multiwavelength Raman lidar technique in combination with sophisticated inversion algorithms has been recognized as a new tool to derive information about microphysical properties of atmospheric aerosols. Igor Veselovskii used the results of eigenvalue analysis to study the information content of multiwavelength lidar data with respect to microphysical particle properties. Such an analysis provided, on a rather mathematical base, more insight on the limitations of these inversion algorithms regarding the accuracy of the retrieved parameters. It was shown that the effective radius may be retrieved to 50% accuracy, and the real and imaginary part of the complex refractive index to +- 0.05 and +-0.005i, if the imaginary part is < 0.02i. These results are in accordance with the classic approach of simulations studies with synthetic particle size distributions. Eigenvalue analysis also shows that the accuracy of the derived parameters degrades if the imaginary part is > 0.02i, and the importance of the simultaneous use of backscatter and extinction coefficients for the retrieval of microphysical parameters.

Hailan Wang's work has been in two areas. Her NSIPP project studied the role of extratropical air-sea interaction in contributing to predictability of warm season precipitation anomalies over the U.S. By coupling a Mixed Layer Ocean model (MLO) of variable depth to the NASA NSIPP 1 AGCM, it was found that the interannual variations of extratropical Sea Surface Temperature (SST) and overlying dynamical and physical fields are strongly coupled to one another, so that the entire extratropical atmosphere-ocean system is fairly well self-sustained. Her second area of research was in the CMEP project, which studiee and evaluated tropical hydrological cycles in IPCC AR4 20th century coupled climate simulations by 14 new generation coupled GCMs. The goal was to document and understand the changes in tropical hydrological cycle simulated by the coupled models. All the coupled models consistently well simulated the observed warming trend in the 20th century, but significant diversity is seen among the models in simulating trends and variability of cloudiness and tropical rain processes. Clouds still remain the main source of uncertainty.

Zhien Wang's research had three main components. The first is to study the influence of thin cirrus clouds on the retrievals of water vapor using IR sensors such as AIRS and GOES and provide reliable observations of upper tropospheric water vapor for AIRS validation. The second was to develop algorithms for two CloudSat standard products: radar-only and combined lidar-radar cloud scenario classifications. The third was to develop new ground-based algorithms to study mixed-phase and ice cloud microphysical properties and cloud type based on ARM ACRF sites observations. A new retrieval algorithm for mixed-phase clouds was applied to long-term observations at the NSA site and a new cloud ice water content measurement method with Raman lidar was demonstrated with NASA/GSFC scanning Raman lidar measurements. With this new method, cirrus microphysical and radiative properties can be measured remotely and simultaneously during the night

Guoyong Wen focused his research on the quantification of the 3D radiative effects of clouds on the aerosol retrieval. This study is conducted on a fair-weather cumulus in biomass burning region in Brazil through a combination of EOS observations and 3D radiative transfer modeling efforts. Clouds were found to be effective to enhance reflected sunlight in clear patches in cumulus cloud fields over dark surfaces. 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. Dr. Wen also studied the variations of the solar energy. Results from analyses of spectral solar irradiance (SSI) from SIM (Spectral Irradiance Monitor) on SORCE (Solar Radiation and Climate Experiment) satellite show that SSI at different wavelengths does not vary uniformly with time as assumed before. 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.

Yaping Zhou also had two different studies, one dealing with a new concept of using physical models in onboard data compression and processing in response to ever increasing spatial and spectral resolution in

satellite remote sensing. Hyperspectral imagers, in particular, have a very high data rate generation rate which will easily saturate all existent space-to-ground RF communication bandwidth. Physical models have been evaluated in onboard lossless data compression and lossy compression in two different studies. The conclusion was that as long as the requirement of lossless compression is maintained, the gains from using a physical-based model are significant (up to 50% improvement) but not dramatic except in highly idealized noiseless situation; in actual situations, these gains can only become dramatic when lossy compression (which however retains the actual information content of the data) is allowed. Next generation remote sensing scientists will have to make transition from raw bits to information content as a result of sheer data volume. His second project was to conduct observational studies on cloud-radiation-precipitation processes from satellite (mainly TRMM and MODIS) measurements and compares the results with cloud resolving model as well as global climate models in an effort to improve physical parameterizations in the global system.

Tom B. Low (Acting)

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

GEST Investigator: Timothy Berkoff

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

Abstract

During this reporting period instrumentation management and technical oversight was provided to ensure the successful deployment and operational performance of lidar systems in the Micro-Pulse Lidar NETwork (MPLNET). This included continued efforts in the commercialization of a lidar system specifically tailored for MPLNET, further development and demonstration of overlap calibration techniques, and investigation of satellite data in relation to MPLNET ground-based measurements. 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 GSFC.

Description of Research

MPLNET is a network of lidars systems 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 in FY 04-05

General management for MPLNET instrumentation matters were carried out throughout the reporting period to enable MPLNET participation in a number of field campaigns and establishment of new sites in the network. In the last reporting period, a new prototype version of the MPL—called "Type 4"—was developed and field tested. Technical information, alignment methods, and training were provided to a commercial vendor to enable the construction and delivery of these systems to MPLNET partners. This commercialization activity continued into this reporting period and, for the first time, "Type 4" lidars have been commercially sold directly to research groups interested in joining MPLNET. Systems purchased by network partners were evaluated for alignment quality, performance, and calibration prior to operation at MPLNET sites. Technical feedback was provided to correct deficiencies observed in the first commercial units, and consulting with the vendor continues to investigate and address technical issues.

Research activity this reporting period led to further development of methods to calibrate and model the MPL overlap function. The overlap function is a non-linear optical loss in the lidar near-range signal and must be accurately characterized to enable quality-assured MPLNET data retrievals. Traditional methods employed by GSFC to obtain this calibration require horizontal atmospheric measurements to be obtained in a homogeneous optical path. In earlier work, an alternative method was proposed using a secondary wide-field receiver to recover the instrument overlap function from nighttime vertical measurements. For the first time this reporting period, automated MPLNET processing routines used results from this technique to generate advanced data products

such as extinction retrievals and aerosol optical depths for a set of trial measurements at GSFC. Data obtained from these retrievals produced extinction-to-backscatter values within expected range, further demonstrating the potential of this approach. In related work, further development of an analytical model to provide thermal correction of the MPL overlap function was accomplished. MPL systems contain a commercial grade telescope that is sensitive to environmental changes which, in turn, influence the geometrical overlap calibration. To reduce data errors and improve operational temperature range of the instrument, a model, based on geometrical and paraxial descriptions of the telescope focus response, was used to predict the expected changes in overlap calibration as a function of temperature. Results were then applied to MPL data collected during the 2004 United Arab Emirates Unified Aerosol Experiment. Comparisons of corrected versus non-corrected data for two different thermal cases demonstrated a significant reduction in thermally induced bias errors.

One of the key motivations for lidar networks, such as MPLNET, is the contribution towards the calibration and validation of satellite data. However, direct correspondence between MPLNET and satellite measurements are complicated by the spatiotemporal differences between measurements. Satellite lidars such as ICESAT/GLAS and CALIPSO pass over ground sites at ~ 7 km per second while ground-based MPLNET sites obtain measurements from a stationary vertically-pointing laser beam. A method using wind velocity information was investigated to improve the spatiotemporal relationship between surface and satellite data. Spatial constant lidar profiles were generated from ground-based measurements by adjusting the temporal average in each range bin to maintain a constant advection path length, as determined by wind data from radiosonde profiles. Initial results comparing ground-based MPL spatial-constant profiles to coincident ICESAT/GLAS February 26, 2004 overpass data were examined. For conditions where advection is the dominant source of atmospheric motion, this approach is expected to improve sample representation, and in certain conditions allow for extended signal averaging intervals.

Objectives for FT 04-05

The main objective for the upcoming year is to enable further expansion of MPLNET by continuing to provide management of instrumentation matters for the network, and investigation of technology and calibration improvements.

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

GEST Investigator: Reginald S. Lancaster

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

Abstract

Developing advanced electro-optic instrumentation for satellite remote sensing is critical to understanding the processes that govern changes in the Earth and its atmosphere. Among the complement of instruments used in satellite remote sensing are infrared imaging radiometers and atmospheric 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

Advances in detector technology are among the most important that have occurred in both lidar and infrared remote sensing. Infrared detectors are now available in large format arrays and do not require cooling below room temperature. Single photon counting capabilities are presently available for lidar systems operating at visible wavelengths and are forthcoming for those operating at a wavelength of 1 um. The present research centers upon developing lidar and imaging systems that take full advantage of these technological advances to enable new measurement capabilities. Specifically, the uncooled infrared focal plane array is being advanced as an enabling technology for stereo measurements of global cloud height from space. Advances in lidar technology are being directed toward applications centering upon global cloud and aerosol measurements.

Accomplishments

An engineering study of an advanced cloud aerosol lidar was conducted in preparation for the announcement of the Earth Science System Pathfinder mission. This lidar was to be coupled with a hyper spectral radiometer for ocean color measurements. The aerosol measurements of the atmosphere over the ocean are critical to the proper retrieval of color as the absorptive properties of the atmosphere affect the ocean color. Also included as part of this study were the requirements for subsurface ocean properties as they relate to biomaterial. Additionally, a study was performed that examined the ocean surface reflectance using backscatter returns from the Geoscience Laser Altimeter System. It was found that the ocean reflectance at a wavelenth of 1 um can be predicted very accurately using global measurements of surface wind speed made with the SeaWinds microwave scatterometer aboard Quikscat. The surface winds drive the surface roughness of the ocean and modify the angular distribution of the backscatter reflectance. A proposal to build an engineering model of this advanced lidar was also prepared and submitted to the NASA Instrument Incubator Program. The proposed instrument would utilized injection seeded lasers, narrowband solar etalon filters and photon counting detector capabilities. A manuscript was prepared for submission to *Applied Optics* detailing the engineering work for the narrowband solar filter of GLAS reported upon previously. Additionally, a manuscript detailing the ocean pulse reflectance at 1 um as measured with the GLAS instrument has been prepared for submission to a GLAS special issue of *Geophysical Research Letters*.

An engineering study was also performed for a multi-angle infrared imaging radiometer in preparation for the ESSP mission announcement. This instrument is to fly along with a submm conical scanning radiometer, which together will measure cloud water content. This infrared imaging radiometer makes use of uncooled microbolometer array detectors that are now available in formats of 640x480 pixels. The measurements at multiple angles provides for a stereo view from which cloud height can be gleaned. Also, they allow for the detection of cloud motions thereby simultaneously providing a measurement of tropospheric wind. A proposal for a multi-angle, infrared cloud track radiometer was submitted to the Instrument Incubator Program. Additionally, algorithm development was accomplished to advance the retrieval of cloud height from infrared imagery obtained during a shuttle flight in 1997 using a radiometer developed around this technology. This algorithm development takes advantage of the height information contained within the radiometric measurement of thermal brightness temperature to improve the accuracy of the height retrievals beyond that obtained at visible wavelengths. This infrared approach extends the measure of cloud heights and winds to nighttime conditions. A manuscript was prepared for this work and will be submitted to an IEEE journal shortly.

Objectives for Next Year

In the next year design and development of the infrared and visible imaging radiometers will continue with an emphasis on meeting the mission goals of various large and small space programs. Particular programs include those mentioned previously but also include the possibility of other smaller missions of opportunity and unmanned aerial vehicles. In the realm of lidar remote sensing, future space

missions will likely be even more aggressive in their intent and thus further technological advances are imperative. In the case of atmospheric lidar these advances can be measured in terms of increasing sensitivity to the faint return signals typical of probing an optically thin target such as the atmosphere. This challenge must be addressed, in part, through spectral filtering without which a diurnal variation is necessarily introduced into the measurement precision. Research activities for the upcoming year will be directed toward advancing the capabilities of the solar filters beyond that used with the GLAS payload and for use with the next generation of space lidar systems.

Task **Application of Air/Space-Borne Radar to Atmospheric Remote Sensing**

GEST Investigator: Liang Liao

Collaborator: Robert Meneghini

Abstract

We conduct research on a variety of topics related to microwave radar applications in estimating microphysical properties of hydrometeors. Radar simulations are found to be a very useful means to improve the accuracy for the retrieval of meteorological parameters. They can also be used to test the radar theory and its various techniques, and can be effectively used for an assessment of uncertainties or errors of various radar algorithms. Among one of the fundamental problems in the radar simulation is the electric field scattering and its attenuation from hydrometeors that appear in the different phases and habits. While we employ a versatile numerical scheme to study general scattering characteristics of different types of hydrometeors, our focus is on the computation of scattering properties of melting hydrometeors (mixed-phased particles). 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

Our research includes: 1) Simulations of dual-wavelength radar profiles in stratiform rain; 2) Assessment of the radar techniques used to retrieve the microphysical properties of hydrometeors; 3) Validation of radar measurements and 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 effective dielectric constant of mixed-phase particle.

Accomplishments in FY 04-05

The correction for TRMM PR attenuation, while propagating in hydrometeors, is a crucial procedure in order to accurately estimate rain rate. Validating the TRMM PR measurements and estimates and examining some of TRMM standard algorithms requires comparisons with well-calibrated non-attenuated ground-based radar measurements. The relative calibration accuracy of the radars has been evaluated by checking the reflectivities at the storm top, where the PR attenuation is negligible. Near the surface, where the PR attenuation effects can be significant, the data are used to assess the performance of the PR attenuation correction algorithm. In this study the ground-based measurements are taken from the S-band WSR-88D radar during TRMM's first 5-year mission for the more than 100 overpasses of the TRMM satellite over the Melbourne, Florida site during times when significant precipitation was present in the overlap region of the PR and WSR-88D. Resampling the PR and WSR-88D data sets to a common high-resolution grid provides a means by which the radar reflectivity factor can be compared at different heights and for different rain types over ocean and land. The comparisons

are also made for the surface rain, area-averaged rain and classification of storm types. The statistical parameters of mean and standard deviation have been given for the evaluation of the PR products.

We study a framework that employs air/space-borne dual-wavelength radar for the estimation of characteristic parameters of hydrometeors. The focus of our study is on the Global Precipitation Measurements (GPM) precipitation radar, a dual-wavelength radar that operates at Ku (13.8 GHz) and Ka (35 GHz) bands. As the droplet size distributions (DSD) of rain are expressed as the Gamma function, a method is investigated to derive the median volume diameter (D0) and particle number concentration (NT) of rain. The correspondences of an important quantity of dual-wavelength radar, defined as deferential frequency ratio (DFR), to the D0 in the melting region are given as a function of the distance from the 00C isotherm. A self-consistent iterative algorithm that shows promise to account for rain attenuation of radar and infer the DSD without use of surface reference technique (SRT) is being examined by applying it to the apparent radar reflectivity profiles simulated from the DSD model and then comparing the estimates with the model (true) results. To further examine the dual-wavelength techniques, the self-consistent algorithm, along with forward and backward rain profiling algorithms, has been applied to the measurements taken from the 2nd generation Precipitation Radar (PR-2) built by Jet Propulsion Laboratory. It was found that rain profiles estimated from the forward and backward approaches are not sensitive to shape factor of DSD Gamma distribution.

A dual-wavelength algorithm has been developed to estimate the characteristic parameters of the snow size distributions. An analysis of the computational results, made at X and Ka bands (T-39 airborne radar) and at S and X bands (CP-2 ground-based radar), indicates that valid estimates of the median volume diameter of snow particles, D0, should be possible if one of the two wavelengths of the radar operates in the non-Rayleigh scattering region. To examine the validity and accuracy of the dual-wavelength radar algorithms, the algorithms have been applied to the data taken from the Convective and Precipitation-Electrification Experiment (CaPE) in 1991. Good agreement was found between the radar-derived snow parameters and *in situ* particle measurements.

To simulate the radar bright band, a scattering model of melting snow was proposed in which the fractional water content is prescribed as a function of the radius of a spherical mixed-phase particle consisting of air, ice and water. The model is based on the observation that melting starts at the surface of the particle and then gradually develops towards the center. To compute the scattering parameters of a non-uniform melting particle, the particle is modeled as a sphere represented by a collection of 643 cubic cells of identical size where the probability of water at any cell is prescribed as a function of the radius. With use of this heterogeneously melting model, the simulated radar bright-band profiles were shown to compare well with measurements from the Precipitation Radar (PR) aboard the Tropical Rainfall Measuring Mission (TRMM) satellite and a dual-wavelength airborne radar. The results suggest that the proposed model of a melting snow particle may be useful in studying the characteristics of the bright-band in particular and mixed-phase hydrometeors in general.

Objectives for FY 04-05

Continue research on a variety of topics associated with airborne and spaceborne weather radar analysis generally and the TRMM Precipitation Radar (PR) specifically. The work includes single- and dual-wavelength radar analysis of the melting layer, development of the theory and application of the effective dielectric constants of the mixed-phase hydrometeors, retrievals of the microphysical properties and characteristic parameters of drop size distribution using data from a dual-wavelength airborne weather radar, and the validation of the TRMM PR derived rain rates using ground-based radar data.

Task **Information Content of Multiwavelength Lidar Data With Respect to Microphysical Particle Properties Derived From Eigenvalue Analysis**

GEST Investigator: Igor Veselovskii

Collaborator: David N.Whiteman (GSFC)

Abstract

Multiwavelength Raman lidar technique in combination with sophisticated inversion algorithms has been recognized as a new tool to derive information about microphysical properties of atmospheric aerosols. The report presents results of eigenvalue analysis, which has been used to study the information content of multiwavelength lidar data with respect to microphysical particle properties. Such an analysis provides us, on a rather mathematical base, more insight on the limitations of these inversion algorithms regarding the accuracy of the retrieved parameters. We show that the effective radius may be retrieved to 50% accuracy, and the real and imaginary part of the complex refractive index to +- 0.05 and +- 0.005i, if the imaginary part is < 0.02i. These results are in accordance with the classic approach of simulations studies with synthetic particle size distributions. Major difficulties are found for particle effective radius <0.15 µm. In that case the complex refractive index may not be derived with sufficient accuracy. Eigenvalue analysis also shows that the accuracy of the derived parameters degrades if the imaginary part is > 0.02i. It furthermore shows the importance of the simultaneous use of backscatter and extinction coefficients for the retrieval of microphysical parameters.

Description of Research

In recent years the multiwavelength Raman lidar technique has become a powerful tool to obtain information about microphysical parameters of atmospheric particles. Despite the achieved progress there are still some fundamental questions concerning the method accuracy, the limit of applicability of this method, and the optimum number of laser wavelengths. One way of assessing the performance is achieved through extensive numerical simulations for numerous particle size distributions and refractive indices, but which sometimes makes the modeling unmanageable. Another possible approach is to consider the information content of lidar data, or rather that of the underlying kernel functions using eigenvalues analysis. Such an approach offers the possibility to draw more general conclusions on the limits of the used algorithms, and in fact such results can be generalized towards other methods that solve the inverse problem.

Accomplishments in FY 04-05

The essence of the multiwavelength lidar technique is the measurement of spectrum of aerosol backscattering $\beta(\lambda)$ and extinction $\alpha(\lambda)$ coefficients. Changes of particles parameters, such as size or *m* lead to variations of $\beta(\lambda)$ and $\alpha(\lambda)$. If this spectrum is unique, i.e. the functions $\beta_i(\lambda)$ or $\alpha_i(\lambda)$ are linearly independent, the identification of the underlying aerosol parameters becomes possible.

A detailed description of the concept of eigenvalue analysis for linear independence study is given by Twomey. If $\beta_i(\lambda)$ are measured with error δ, the condition $l^{\beta}_{min}>\delta^2$ has to be fulfilled in order to obtain linear independence of $\beta_i(\lambda)$, where l^{β}_{min} is minimum eigenvalue of corresponding covariance matrix. The same holds, if extinction is considered. We should also keep in mind that $\alpha(\lambda)$ and $\beta(\lambda)$ are two independent parameters, so the criterion of independence has to be fulfilled at least for one of these parameters. Moreover, the combination of $\alpha(\lambda)$ and $\beta(\lambda)$ allows the retrieval even for the case, when each of these sets is linear dependent. It can be shown, that this case we should consider the matrix ($\boldsymbol{C}^{\beta}+\boldsymbol{C}^{\alpha}$), and for linear independence the condition $q_{\min} = l^{\alpha+\beta}_{\min}$ should be fulfilled.

A test of linear independence was done for a set of $\beta_i(\lambda)$, which correspond to different values of refractive indices m (m_R, m_I), and aerosol distribution modal radius r_0. In a first step we assume a log-normal aerosol size distribution, and the complex refractive index is kept size- and wavelength independent. If we do not consider a mixture of particles with different m, the set $\beta_{ij}=\beta(\lambda, m_i, r_{0j})$ is tested for linear independence of each of its elements. For M values of m_i and N values of r_{0j}, the number of such pairs is $\sum_{i=1}^{M\times N-1}(M\times N-i)$. For each pair we form the covariance matrix, which is 2×2 in size, and find the corresponding eigenvalue l^{β}_{min}. If the smallest l_{min} for all pairs fulfills the requirement $l^{\beta}_{min}>\delta^2$ the β_i of the respective data set are linearly independent. The same analysis is performed for α_{ij}, and for the case of the combined use of extinction and backscattering coefficients. In that case the eigenvalues of the sum matrix are calculated, and the constraint $l^{\beta+\alpha}_{min}>\delta^2$ is tested.

In the following the main results from the study are summarized and put in comparison to our results from previous simulation studies carried out with the inversion algorithm for synthetic data sets.

1. Eigenvalue analysis confirmed the importance of combining particle backscatter and extinction coefficients.
2. Present analysis demonstrates that the accuracy of r and m estimation depends on range of m_I variations. Hence the presence of strongly absorbing particles may increase the method uncertainties. The accuracy of m_R estimation in the middle of the considered particle size interval (r_0~0.7 μm) is about ±0.05. The realistic accuracy of estimation of the imaginary part m_I is ±0.01.
3. Simulation studies showed that the maximal mean particle size (for $\ln\sigma$=0.4) which may be estimated with an accuracy better than 50% is < 1 μm. The current analysis shows that the limit is ~1.5 μm for mean particle size. These results are again in rather good agreement.
4. Current eigenvalue analysis has shown that the information content of the spectra of particle backscatter and extinction coefficients is limited. As a result, the sensitivities of $3\beta+2\alpha$ and $6\beta+2\alpha$ data sets are similar for the investigated particle parameters (effective adius, complex refractive index), if 10% measurement error are considered.

We should also point out, that the current analysis gives us just rough estimations, so the comparison with results from simulation studies should be done with care. The main advantage of this approach is the possibility to obtain a more general picture and thus to understand the way, how different parameters influence each other.

Objectives FY 05-06

The algorithm for retrieval of cloud particles size will be developed basing on the measurements of lidar with variable field of view. Contribution of multiple scattering to lidar signal depends on particles size and on lidar field of view. So solving the corresponding inverse problem it is possible to estimate the particles size distribution. In retrieval both polarized and depolarized lidar signals will be considered.

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**

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

GEST Investigator: Hailan Wang

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

Abstract

The NSIPP project studies the role of extratropical air-sea interaction in contributing to predictability of warm season precipitation anomalies over the U.S. By coupling a Mixed Layer Ocean model (MLO) of variable depth to the NASA NSIPP 1 AGCM, we find that the interannual variations of extratropical Sea Surface Temperature (SST) and overlying dynamical and physical fields are strongly coupled to one another, so that the entire extratropical atmosphere-ocean system is fairly well self-sustained. The CMEP project studies and evaluates tropical hydrological cycles in IPCC AR4 20th century coupled climate simulations by new generation coupled GCMs. All the coupled models consistently well simulate the observed warming trend in the 20th century, but significant diversity is seen among the models in simulating trends and variability of cloudiness and tropical rain processes. Clouds still remain the main source of uncertainty.

Description of Research

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 focuses on the identification of boreal summer teleconnection patterns and associated extratropical SST variability and how they relate to tropical SST, *i.e.*, El Niño. The research effort involves climate diagnosis of various physical and dynamical fields in observations as well as simulations of coupled and un-coupled GCM experiments. The CMEP project aims 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 projecting future climate. The goal is to document and understand the changes in tropical hydrological cycle simulated by the coupled models, and to provide inputs to the 4th IPCC Assessment Report.

Accomplishments during the Reporting Period

In the past one year, after the GSFC MLO was coupled to the NASA NSIPP 1 AGCM, efforts were spent on modulating the coupled framework so as to minimize the model biases in simulating the observed climatology and interannual variations in oceanic low boundary conditions. After the coupled model framework was frozen, a global fully coupled run (referred to as globally coupled run) of 60 years was performed, in which the NSIPP 1 AGCM was coupled to the MLO for each grid point over the whole global oceanic domain. The coupled model has been shown to simulate the observed climatological SST fairly well. The model simulated climatology in various physical and dynamical fields exhibit striking similarity to those in NSIPP 1 AGCM AMIP runs, suggesting the main deficiencies present in the coupled model simulated climatology originate from the NSIPP 1 AGCM, not from the coupling processes at the air-sea interface. Since tropical ENSO is not present in the globally coupled model simulation, the maintenance of dominant SST modes in extratropics that are independent of ENSO, and its linkage to North American climate variation during boreal summer, were examined using the outputs of the globally coupled run. Consistent with observations, the coupled model simulated summertime extratropical air-sea interaction was dominated

by local processes. 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, were strongly coupled to one another, so that the entire extratropical atmosphere-ocean system is fairly well self-sustained.

With the NSIPP 1 AGCM and the GSFC MLO, a series of long standard experiments were completed. These experiments differ from one another in the configuration of oceanic low boundary conditions. Each of the experiments contained 9 members, integrating from year 1901 to year 2000. The outputs of the above experiments along with existing outputs of NSIPP AMIP type experiments provided by the NSIPP group were analyzed using various statistical techniques and a diagnostic stationary wave modeling approach. The comparison between different model simulations shed light on the physical and dynamical mechanisms through which the air-sea interaction in extratropics affects interannual variation of U.S. climate. The outputs of the above model experiments also provided valuable data sets for other various scientific investigations.

Starting in October 2004, we also were involved in a CMEP project, "Hydrological Cycles in the Tropics." In this study, we analyzed, and compared with available observations, the late 19th - 20th century simulations carried out by 14 new-generation coupled GCMs. The goal is to document and understand the changes in the tropical hydrological cycle simulated by the coupled models. Observations from various data sources, especially those from the satellite era, *e.g.*, TRMM, GPCP, TOVS and ISCCP, were used. Given the broad perspectives associated with the atmospheric hydrological cycle, our work focused on two aspects that built upon our prior researches. The first part of the work is on the trends and variability of precipitation and atmospheric temperature over the tropical land and oceans. The second part of our study focuses on the warm rain processes over the tropical ocean. It has been shown that, when driven by the sum of historical external forcings corresponding to the 20th century, including changes in greenhouse gases, sulfate aerosols, volcanic eruptions and solar irradiance, all the coupled models consistently well simulate the observed warming trend in 20th century. This enhances our confidence in the ability of the models in projecting future climate change. However, significant diversity is seen among the coupled models in simulating trends and variability of cloudiness and precipitation, as well as changes in warm rain process in the tropics. Clouds still remain the source of uncertainty although significant improvement of coupled model physics has been made.

Objectives for the Coming Year

Upcoming work will include investigating the impact of global warming on tropical warm rain and cold rain processes as well as regional climate extremes in IPCC AR4 coupled climate model simulations. Another major research effort will be on the effect of aerosol on regional monsoon climate.

Task 924-21-142: **Water Vapor and Cloud Detection Validation for Aqua Using Raman Lidars and AERI; Using Radar, Lidar, and Radiometer Measurements to Classify Cloud Type and Study Middle-level Cloud Properties; and CloudSat Level 2 Combined Radar and Lidar Cloud Scenario Classification Standard Product Development**

GEST Investigator: Zhien Wang

Collaborators: David Whiteman (PI, GSFC), Belay Demoz (GSFC), Kenneth Sassen (University of Alaska)

Abstract

To estimate possible effect of thin cirrus clouds on the retrievals of water vapor using IR sensors such as AIRS and GOES, we analyzed sub-tropical cirrus properties measured during the CAMEX 3 experiment by the GSFC Scanning Raman Lidar (SRL). As part of the CloudSat standard product algorithm developing team, I delivered the Vision 4 cloud scenario classification code to the CloudSat data analysis center at Colorado State University. A combined lidar and radar cloud classification algorithm using CloudSat and CALPISO measurements was developed, and vision 1 code was delivered. Mixed-phase clouds are important in the earth climate system, but they are poorly understood. A new retrieval algorithm for mixed-phase clouds is being applied to long-term observations at the NSA site providing a rich dataset to study arctic mixed-phase clouds. A new cloud ice water content measurement method with Raman lidar was demonstrated with NASA/GSFC scanning Raman lidar measurements. With this new method, we can remotely sense cirrus microphysical and radiative properties simultaneously during the night.

Description of Research

This research, jointly funded by NASA and the DOE ARM program, entails three main components. The first is to study the influence of thin cirrus clouds on the retrievals of water vapor using IR sensors such as AIRS and GOES and provide reliable observations of upper tropospheric water vapor for AIRS validation. The second is to develop algorithms for two CloudSat standard products: radar-only and combined lidar-radar cloud scenario classifications. The CloudSat will be launched in 2005, and will provide essential measurements of clouds globally. The third is to develop new ground-based algorithms to study mixed-phase and ice cloud microphysical properties and cloud type based on ARM ACRF sites observations. The ultimate goal of these researches is to better understand the cloud-radiative feedback and the atmospheric water cycle.

Accomplishments during the reporting period

Cirrus clouds affect earth radiation budget strongly through both albedo and greenhouse effects, and its high occurrence, especially in the tropical region, results in some challenges to retrieve water vapor profile in the presence of thin cirrus clouds using IR sensors. To evaluate the possible effect of thin cirrus clouds, radiative properties of sub-tropical cirrus derived from ~150 hrs SRL measurements during CAMEX 3 were analyzed and compared with its midlatitude counter part. This dataset is one of largest cirrus measurements in tropical and subtropical region from a high quality Raman lidar measurements. We found there are noticeable differences in the temperature dependencies of extinction-to-backscattering ratio between hurricane generated cirrus clouds and the other cirrus clouds. Another important application of these analyses is to improve satellite-based lidar cirrus cloud measurements [Whiteman *et al.* 2004].

Cloud scenario identification is an important step to apply remote sensing algorithms for cloud property retrieval because of different microphysical and radiative properties of water, ice and mixed phase clouds. Vision 4 radar-

only cloud scenario classification algorithm was delivered to the CloudSat data analysis center at the Colorado State University, and was improved using different test data sets. Combined lidar and radar cloud classification algorithm using CloudSat radar and CALIPSO lidar measurements was funded. We simulated CloudSat radar measurements based CALIPSO lidar test data set. The vision 1 lidar-radar code based on this simulated test data was developed and was delivered to the CloudSat data analysis center.

There are two main achievements for the DOE ARM funded research. First, we developed a new approach to study the simplest mixed-phase cloud: supercooled water dominated generating cloud layer with ice virga or precipitation [Wang *et al.* 2004a]. Although the simple structure of this type of mixed-phase cloud, it is the main mixed-phase cloud type observed in the Arctic. The algorithm is capable of retrieving ice and water microphysical properties by combining lidar, radar and radiometer measurements. This mixed-phase cloud algorithm is being applied to long-term observations at the NSA site. So far, we have analyzed 150 days single-layer mixed-phase cloud cases starting from January 1999 to August 2003. These retrievals provide a rich dataset to study arctic mixed-phase clouds. The initial statistical results indicate that the colder the mixed-phase cloud is, the larger the contribution of ice to the total optical depth is. It is also clear that the mean liquid water path and effective radius of supercooled water increase with the increase of cloud temperature. However, large standard deviations of the means reflect that many other factors control the microphysical properties of arctic mixed-phase clouds. Although these simple statistic results provide useful information for model validations, better understanding of these mixed-phase clouds is needed to improve their representations in GCMs. We will use this dataset to better understand arctic mixed-phase cloud process.

Second, we developed a new cloud ice water content (IWC) measurement method with Raman lidar. Cloud IWC measurement is an extremely challenging task for both in situ sampling and remote sensing. A new IWC measurement method by using ice Raman scattering signal was demonstrated with NASA/GSFC scanning Raman lidar measurements obtained during an ARM Intensive Observation Period (IOP) at the SGP site [Wang *et al.* 2004b]. Since the intensity of Raman scattering is fundamentally proportional to the number of molecules involved, this method provides a more direct way of measuring cloud IWC compared with other schemes. The approach was recommended as a high priority for ARM instrument upgrade during the 2004 ARM cloud property working group meeting. The upgrade of ARM Raman lidar with this capability is planned for next year. With this unique capability, we will be able to better study cirrus clouds at the SGP site.

Objectives for the Coming Year

This task has been completed.

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

GEST Investigator: Guoyong Wen

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

Abstract

A quantification of the 3D radiative effects of clouds on the aerosol retrieval was conducted on a fair-weather cumulus in a biomass burning region in Brazil. With a combination of EOS observations and 3D radiative transfer modeling efforts, we have quantified 3D radiative effects of clouds on the reflected sunlight in clear

patches in a realistic cumulus cloud field, and the associated errors in ambient aerosol retrievals. Clouds are found to be effective to enhance reflected sunlight in clear patches in cumulus cloud fields over dark surfaces. The additional reflected sunlight could be translated to additional aerosol amounts in 1D retrieval, leading to a incorrect relation between the cloud properties and aerosol amounts. This study is the first step towards understanding the effects of aerosol on cloud properties. Our second research focus area is on the variations of solar energy. Results from analyses of spectral solar irradiance (SSI) from SIM (Spectral Irradiance Monitor) on 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 of the variations of spectral and total solar irradiance is important in climate research.

Description of Research

Aerosol quantity is an important parameter in studying the effects of aerosol on cloud properties. However, it is difficult to retrieve aerosol optical depth in a 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 an incorrect relation between the cloud properties and aerosol amounts. We researched the quantification of 3D radiative effects on radiation fields and aerosol retrievals.

We also undertook efforts to advance 3-dimensional radiative transfer modeling capabilities. This project is called I3RC (International Intercomparison of 3D Radiations Codes) 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. We are constructing the 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. Our objective 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 a cumulus cloud field of ASTER image. The cloud optical depth field from MODIS is used in the simulation. The results were presented in the Fall AGU Meeting [Wen *et al.* 2004a]. A paper summarizing the results was submitted to a refereed journal [Wen *et al.* 2004b]. From the analysis of ASTER images in biomass region in Brazil, a simple method was proposed to estimate aerosol amount embedded in typical cumulus cloud fields. The method and results were presented in the International Radiation Symposium 2004 [Wen and Cahalan 2004c].

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 was 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

(International Intercomparison of 3D Radiation Codes) project supported by NASA and DoE's ARM Program. The project has been carried out smoothly through phases I and II. A co-authered paper that summarizes the major results is under review for publication in a peer reviewed journal.

Objectives for the Coming Year

The main objective for the coming year is to continue investigating clear sky atmospheric radiative transfer with emphasis on retrieval of aerosol and cloud properties in complex atmospheric conditions. To accomplish this, we 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 will be to look at MODIS, ASTER, and MISR images in Amazon and other regions in the world. With different spatial resolutions and angular capability, we expect to have some interesting results for cloud and aerosol studies. We will also continue to investigate the SOLSTICE time series in the finer spectral resolution. In particular, SORCE launched in January 2003 will provide accurate observation of both total and spectral solar irradiance.

Task 913-13-120: **Unified Onboard Processing and Spectromery**

GEST Investigator: Yaping Zhou

Collaborator: Si-Chee Tsay (PI, GSFC), Warren Wiscombe (GSFC), Pen-Shu Yeh (GSFC)

Abstract

A new concept of using physical models in onboard data compression and processing in response to ever increasing spatial and spectral resolution in satellite remote sensing is explored. Hyperspectral imagers, in particular, are increasingly the wave of the future in process-oriented research as well as monitoring of the atmosphere and surface. The data rate generated by hyperspectral imagers will easily saturate all existent space-to-ground RF communication bandwidth. Dealing with this data rate requires revolutionary new approaches, including onboard processing and compression. Physical models have been evaluated in onboard lossless data compression and lossy compression in two different studies. Our conclusion is that as long as the requirement of lossless compression is maintained, the gains from using a physical-based model are significant (up to 50% improvement) but not dramatic except in highly idealized noiseless situation; in actual situations, these gains can only become dramatic when lossy compression (which however retains the actual information content of the data) is allowed. Next generation remote sensing scientists will have to make transition from raw bits to information content as a result of sheer data volume.

Description of Research

Information theory tells us that lossless compression is limited by the entropy of the data. In reality, the entropy of data is statistically estimated therefore real entropy of the data is not known for many complicated nonlinear systems. Our first goal is to assess whether physical models can be used in lossless data compression of remote sensing data to break the statistical entropy limitation and outperform the statistically-based algorithm. The idea is to use radiative transfer models to remove the known component of the observed spectra from various scenes of the earth, leaving a remainder that is much more compressible than the original spectra. The more input variables put into the radiative transfer model, the smaller the residual will be. The interplay of input and residual will reach an optimal point where maximum compression ratio can be achieved. The second goal of the research is to propose a "lossy compression" which will be acceptable to scientists; that is, with specific physical application in mind, data can be processed in lossy way that only useful

information and information beyond instrument noise, calibration noise and other sources of irreducible uncertainty will be retained.

Accomplishments during the Reporting Period
A cloud retrieving algorithm was selected to demonstrate the performance and feasibility of physical models in data compression. The scheme uses two key parameters, *i.e.*, cloud optical thickness and effective radius to predict the major signals in the visible and NIR regions of the cloud spectrum [1]. We first verified the scheme using extensive model simulations of cloud scenes. Then we applied the method to MODIS observational data. The improvement gained by using models for the compression of 5-channel simulation data ranges from 9-40% and much higher for 52-channel simulation data. Applying the same scheme to MODIS observational data (5 channels) did not produce worthwhile gains as compared to the simulation data because physical models are simplified and are unable to fully capture all the signal variations in the observed spectra. Furthermore, physical models are devoid of predicting instrument noises embedded in the observed data that reflect as additional error in the retrieval-prediction. On the basis of the results of this study we conclude that lossless compression, even with the help of physical model, will not be able to meet the data reduction requirements in the future. Compression that yields much higher data ratios—for example, lossy compression—will eventually be invoked in future missions.

Objectives for the Coming Year
Conduct scientific research to develop quantitative metrics based on satellite and ground observations to evaluate the performance of the cloud-resolving Goddard Cumulus Ensemble (GCE) model and GEOS global modeling and data assimilation systems.

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
We conducted observational studies on cloud-radiation-precipitation processes from satellite (mainly TRMM and MODIS) measurements and compared the results with a cloud resolving model as well as global climate models in an effort to improve physical parameterizations in the global system.

Description of Research
By using observations and GCE model simulations we seek to improve the representation of cloud/radiative/convective processes in the fvDAS through comparisons of different parameterization as implemented in DAO system and by ultimately providing a better performing "merged" parameterization that captures the desirable features of the different schemes.

Accomplishments during the Reporting Period
A simplified cloud mask algorithm suitable for present-day onboard processing was developed based on the operational MODIS cloud mask algorithm. Clear sky data compression was tested using our simplified cloud mask followed by application of the CCSDS lossless compression algorithm. For most channels, compressing the cloud-masked MODIS L1B data can reduce the data volume by about 40% compared with compression without using a cloud mask. The cloud mask was also applied to L1A data with comparable or even better data reduction performance depending on local data

filling schemes. This study demonstrates that physical models and physical understanding can be used in onboard data processing and compression to intelligently retrieve only the needed information [Zhou *et al.* 2003].

Objectives for the Coming Year

Investigate systematic dependence of cloud-radiation-precipitation relationship with SST and other large-scale forcing.

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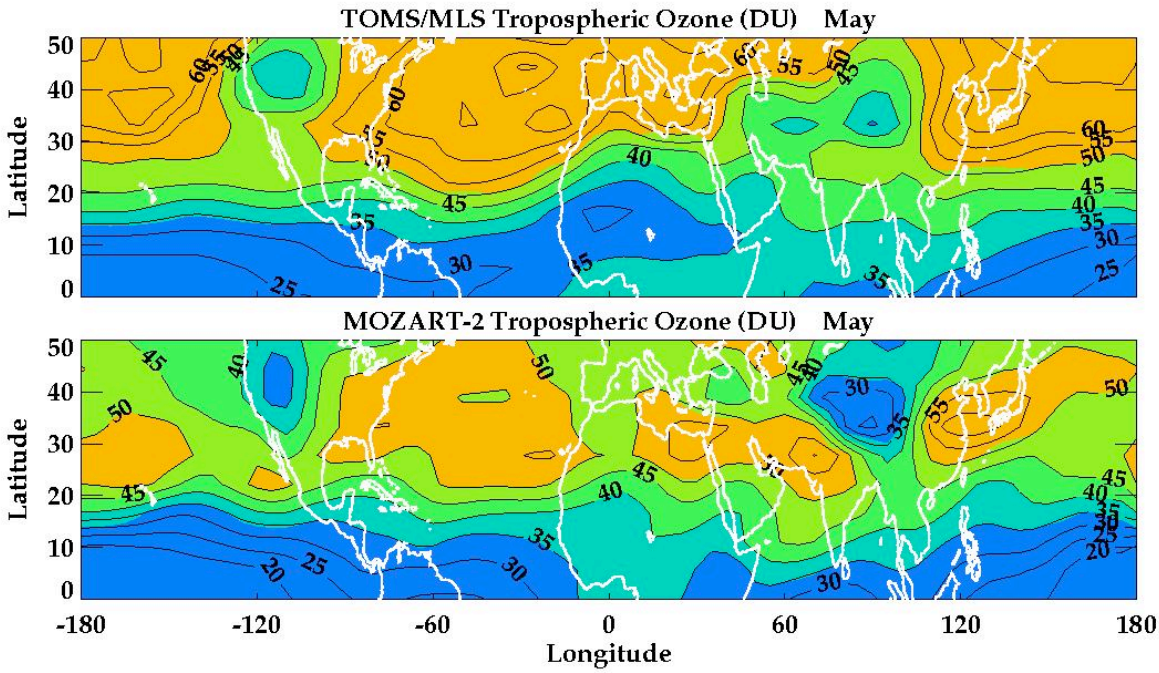
Atmospheric Chemistry and Dynamics Research Group



Tropospheric column ozone (TCO, in Dobson Units) in the northern hemisphere for late spring (May, 1997). Top: TCO derived from differencing Total Ozone Mapping Spectrometer (TOMS) total column ozone and Microwave Limb Sounder (MLS) stratospheric column ozone. Bottom: Similar TCO for May 1997 derived from the MOZART-2 global chemical transport model. This study [Chandra et al., Geophys. Res. Lett., 31, L23102, 2004] is the first to quantify TCO distributions in the mid-latitudes between satellite observations and model. The figure shows for both observations and model, elevated ozone over the oceans despite most pollution in the lower atmosphere occurring over land. The model suggests that around 30-35 percent of TCO over the oceans is caused by land surface NOx emission. The remaining TCO enhancements over the oceans in the model are attributed primarily to stratosphere-troposphere exchange of ozone and ozone generated by cloud lightning NOx. Figure provided by Drs. Sushil Chandra and Jerry Ziemke.

Atmospheric Chemistry and Dynamics Research Group

Members of the Atmospheric Chemistry and Dynamics Research Group investigate atmospheric distributions of trace gases and aerosols, and examine the spectral and geographical distributions of the UV radiation fields and their impacts on photochemistry and climate. Activities of group members span measurement and retrieval processes, satellite, ozonezonde and ground based data analysis, assimilation and modeling. These studies play an important role in NASA Earth Science Enterprise's (ESE) goal of "assessing the quality of air we breathe," and provide important input for the study of "climate variability and change."

Modeling studies

One of the major goals of the atmospheric modeling at NASA 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.

The Global Modeling Initiative (GMI) was initiated under the auspices of the Atmospheric Effects of Aircraft Program (AEAP) in 1995. The goal of GMI (http://gmi.gsfc.nasa.gov) is to develop and maintain a state-of-the-art modular 3-D chemistry and transport model (CTM, an offline chemical transport model that uses wind fields from another meteorological model), that can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry and serve as a testbed for model improvements. The GMI modular code is currently implemented at GSFC (the "core" institution) under the direction of Susan Strahan. Her work has been focused on managing the development and evaluation of four versions of the NASA GMI CTM. All versions have a global domain extending to the mesosphere, but each has a different chemical mechanism: tropospheric, stratospheric, tropospheric aerosol, and a combined troposphere-stratosphere mechanism, which is currently being tested and is expected to replace the purely tropospheric mechanism as a 'workhorse' model for GMI.

Bryan Duncan contributed to the development and evaluation of the NASA GMI 3-D CTM. His research focused on implementing code to simulate the radiative and heterogeneous chemical impact of aerosols on trace gas photochemistry; incorporating new meteorological fields that drive transport in the CTM; and evaluating model output. He and the GMI science team participated in a model inter-comparison of the Intergovernmental Panel on Climate Change (IPCC).

Huisheng Bian continued developing a unified CTM system (UCTM) that couples stratospheric and tropospheric photochemical processes. She has conducted an extensive evaluation of the UCTM dynamical processes. The model has been used to simulate atmospheric CO_2 and CO and model results have been compared with various measurements from surface, aircraft, and satellite. In addition, the correlations between atmospheric CO and aerosols from Goddard Chemistry Aerosol Radiation and Transport (GOCART) have also been investigated to reveal the general features of atmospheric pollutant loading.

The exchange of air and chemical species across the tropopause has implications to many atmospheric chemistry and climate problems. Mark Olsen has examined the relationship between ozone and mass transport across the tropopause and in the upper troposphere/ lower-stratosphere (UT/LS) region using global atmospheric datasets and Goddard 3-D CTM model output. Science issues addressed include ozone trends in the UT/LS; seasonal and interannual trends in Stratosphere-Troposphere Exchange (STE) of total mass and ozone mass; and the importance of STE to climate change.

The emphasis of Mohan Gupta's research was on the detailed stratospheric chemistry with adequate representation of mesospheric photochemistry. A coupled chemistry-climate model (GEOS-CCM) has been developed that links GMAO GEOS general circulation model with the GSFC stratospheric chemistry through ozone. Various aspects of the coupled model have been thoroughly examined and validated. Modeling tools developed are being used to examine the important scientific issues such as future recovery of stratospheric ozone and atmospheric chemistry-climate interactions. His second study involved analysis of meteorological dependence of intercontinental transport of the inert tracer radon (Rn).

Satellite ozone data analysis and comparison with models

Creation of long-term data records necessary for global change studies—*i.e.*, satellite Climate data records (CDR)—requires a multi year effort by a dedicated team of calibration, validation and algorithm scientists working in collaboration with scientists who use the data. Understanding the distribution and long-term changes in ozone is the basis for many of the research studies performed by members of this research group. These studies are based on NASA's long-term measurements of column ozone and ozone vertical distribution from 2 types of satellite UV instruments. The Total Ozone Mapping Spectrometer (TOMS) instrument was first launched on NASA's Nimbus-7 satellite in October 1978 and lasted 13.5 years. Four additional TOMS instruments have been launched in the past years on Russian, Japanese and commercial satellites, but only one of these (EP-TOMS), launched on July 4, 1996, is currently operating. The TOMS data record, 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 knows as the "ozone hole." The NASA Solar Backscatter Ultraviolet (SBUV) program started in April 1970 to monitor upper stratospheric as well as column ozone, but has lower spatial and temporal resolution than TOMS. It flew jointly with TOMS on the Nimbus-7 satellite and has continued to this day on a series of NOAA polar orbiting satellite series as SBUV/2. By combining measurements of total ozone, clouds, 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 UVB data are scarce and typically available only from mid 90s, TOMS-generated record of surface UVA and UVB is the only long-term record (since 1978) available for the evaluation of environmental and health effects of UV radiation on a global scale. These datasets form an essential component of NASA Earth Science Enterprise's (ESE) stated goal of "capturing and documenting the dynamics of the Earth's ozone layer, and in developing an understanding of the effects of its depletion on exposure to UV radiation at the Earth's surface."

Current research efforts with ozone CDRs are focused on data re-analysis, merging data from different satellite instruments and comparing with global models. Joan Rosenfield applied statistical time-series analysis to the new Version 8 merged SBUV data set of ozone profiles for the years 1979-2003. Linear trends for the 1979-1997 time period were determined and compared to trends computed using ozone profiles from the GSFC zonally averaged coupled model. Research by Joan Rosenfield has shown that both observed and modeled annual trends generally agreed within statistical uncertainties, reaching maximal values in the higher latitudes of the upper stratosphere in winter, with southern hemisphere (SH) trends greater than northern hemisphere (NH) trends.

Jerry Ziemke and Sushil Chandra continued their derivations of tropospheric column ozone (TCO) and stratospheric column ozone (SCO) from TOMS total ozone data using the Convective Cloud Differential (CCD) method. Two important new algorithms developed are the Cloud Slicing (a generalization of the CCD method) and cross-calibration residual methods. Combining data from TOMS and SBUV measurements a new ozone data products were developed covering low-to-high latitudes for 1979-present: (1) tropospheric ozone, (2) upper stratospheric ozone, and (3) lower stratospheric ozone. In addition to developing public-domain data products for NASA, this research, combining measurements

and photochemical transport models (*e.g.*, MOZART-2, GEOS-CHEM, GMI), has led to substantial new understanding of the dynamics and sources/sinks of global tropospheric and stratospheric ozone.

Nickolay Krotkov has helped to perform radiative transfer modeling study to illustrate how Mie scattering from cloud particles interacts with Rayleigh scattering in the atmosphere to produce a complex wavelength-dependence in the top-of-the-atmosphere (TOA) reflectances measured by satellite instruments that operate in the ultraviolet (UV) part of the spectrum. The plane parallel cloud (PPC) model was used to quantify how clouds can perturb tropospheric ozone absorption in complex ways that cannot be explained by models that treat them as reflecting surfaces rather than as volume scatterers.

New satellite data sets

Year 2004 saw the launch of NASA EOS-AURA satellite with 4 instruments designated to most comprehensive measurements of atmospheric chemistry: Microwave Limb sounder (MLS), Tropospheric Emission Sounder (TES), Ozone Monitoring Instrument (OMI) and High Resolution Dynamic Limb Sounder (HIRDLS) (http://aura.gsfc.nasa.gov). The TOMS capabilities are now fully duplicated by the new Ozone Monitoring Instrument (OMI, provided to NASA by Netherlands Space Agency) that has superior ground resolution and hyperspectral capabilities. Many group members are currently involved with analyzing "fresh" data from the AURA satellite.

An algorithm to infer troposheric and stratospheric column nitrogen dioxide (NO_2) distribution has been developed by Eric Bucsela for OMI. When the actual OMI data became available during the Fall of 2004, the first daily high-resolution maps of global NO_2 fields were produced. All work is being carried out at NASA as part of a joint venture with Netherlands Meteorological Institute (KNMI). Several calibration issues in provisional OMI data have been identified and analyzed. Since many of these problems have origins in the spectral radiance and wavelength calibration,"soft" calibration techniques were employed to overcome these temporal difficulties. Daily NO_2 images over North America were of critical value in supporting the NASA's Polar Aura Validation Experiment (PAVE) campaign during January and February 2005.

Using similar "soft calibration" techniques, Jerry Ziemke and Sushil Chandra first assessed both TCO and SCO measurements from the provisional OMI data. They also combined OMI total ozone measurements with Aura MLS stratospheric ozone profile data to develop the first comprehensive record of global daily tropospheric ozone maps.

Atmospheric Transport of Trace Gases and Aerosols

Gary Morris combined results from GSFC trajectory model with data from multiple ozonesondes to derive chemical component of ozone loss rates in the lower Arctic stratosphere using modified Match technique. The technique "matched" ozonesonde measurements linked by computing trajectories for the air masses in which the measurements were made. His study uses better trajectory mapping that accounts for realistic uncertainties associated with this Match method. The smaller ozone loss rates found in his study are more consistent with current understanding of polar stratospheric chemistry.

Clark Weaver developed an off-line system for the assimilation of visible and near infrared radiances measured by the MODIS instrument on NASA EOS satellite platforms (TERRA and AQUA) using GSFC Global aerosol Chemistry-Aerosol Radiation-Transport (GOCART) CTM model, which provides *a priori* 3-D spatial distributions of main aerosol components. Improved aerosol distributions were computed by minimizing residuals between simulated (using forward radiative transfer model) and measured radiances. The assimilated aerosol distributions were validated against sun-photometer measurements from NASA global AERONET network. In a separate study he investigated interfering effects of mineral aerosol absorption on infrared operational satellite temperature and moisture retrievals

by National Center for Environmental Prediction (NCEP) satellite instruments (TOVS) and feasibility of using a Fabry-Perot Interferometer to obtain CO_2 vertical profile information.

Ground UV and aerosol measurements for satellite validation

Ground instruments have always been critical for checking the long-term calibration of the satellite-derived data records and have helped inter-calibrate satellite data across data gaps. This synergy between ground and space-based assets has been a major factor in making ozone as one of the best-monitored environmental variables. Similar synergy has been recently developed for the purpose of surface UV irradiance monitoring.

Nickolay Krotkov continued providing TOMS UV data for comparisons with ground-based UV data from WMO, US and European UV networks. He suggested several improvements to ground measurements in order to explain originally high biases between satellite and ground UV data. One of the most important improvements was cosine corrections applied to Canadian-WMO network of Brewer UV spectrometers. As a result of these improvements the bias was reduced by half, but still is statistically significant in summer conditions for many locations in Canada, USA and Europe, except for clean locations (New Zealand, Canadian West Coast, North Finland). Using radiative transfer modeling, Nickolay Krotkov parameterized the bias as function of aerosol absorption optical thickness, AAOT (optical thickness can be defined as logarithmic attenuation of direct solar beam and is the sum of absorption, AAOT, and scattering optical thickness) and suggested off-line corrections to the operational TOMS UV data.

Since no reliable measurements of AAOT were available to test this parameterization, he has developed a novel technique to calibrate commercial UV Multifilter Filter Rotating Shadowband Radiometers (UV-MFRSR) using a CIMEL sunphotometers located at Goddard. (The CIMELS have been deployed globally as part of the AERONET network for measurement of aerosol properties.) The technique now provides better than 2% accuracy in measuring global surface UVA radiation (at wavelengths longer than ~320 nm), which allows one to estimate (column) AAOT to better than 0.01 in absence of clouds. This dataset, only one of its kind, was used to confirm the theoretical parameterization and remove the bias of TOMS UV data. This work is currently undergoing, given its importance in monitoring changes in the surface radiation, particularly the UVA and photo-synthetically-active radiation (PAR). It should be noted that in the tropics, as well as over most of the inhabited land areas, aerosol absorption of shortwave solar radiation has arguably produced far greater effects on human health, agricultural productivity, environment, and air quality than ozone depletion.

Nickolay A. Krotkov

Task 916-39-176: **Implementation and Application of a Unified Chemistry and Transport Model (UCTM) for the Interactive Simulation of Stratospheric and Tropospheric Photochemical Systems**

GEST Investigator: Huisheng Bian

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

Abstract

The capability of studying both tropospheric and stratospheric photochemistry in a consistent way using broadly available Chemistry and Transport Models (CTMs) is critically needed to improve our understanding of atmospheric chemistry and the climate system. UCTM is being developed in Goddard's Atmospheric Chemistry and Dynamics Branch (code 916) to move the effort in this direction. An extensive evaluation of the model dynamical processes has been conducted by simulating atmospheric CO_2 and CO and comparing model results with various measurements from surface, aircraft, and satellite. The correlations between CO and CO_2 in the atmosphere and emissions have been investigated to elucidate the influence of atmospheric emission, transport, and transformation. The correlations between atmospheric CO and aerosols have also been investigated to reveal the general features of atmospheric pollutant loading.

Description of Research

The Atmospheric Chemistry and Dynamics Branch modeling group is developing a CTM system (UCTM) that couples stratospheric and tropospheric photochemical processes. This effort builds upon the understanding gained from satellite remote sensing of the stratosphere and is in response to the emergence of new satellite remote sensing measurements of the troposphere. We continued with model improvement, evaluation, and application with focus on the Aura validation support. Global CO_2 and CO have been simulated with UCTM. The model-observation comparisons are encouraging and allow for the combination of UCTM's CO_2 and CO simulations in carbon cycle research. UCTM has also been used to provide daily 5-day CO forecasts to direct airplane measurements in an integrated approach of Aura evaluation.

Accomplishments During the Reporting Period

This continuous model development activity is expected to provide a state-in-the-art model framework for future research focused on chemical/dynamical processes in the Earth's atmosphere. UCTM has been improved technically by implementing post-process code and by troubleshooting. UCTM has also been applied in scientific studies by providing global CO_2 and CO simulations in global carbon cycle research. Our model results are evaluated by comparing with various concurrent and long-term measurements coming from surface (CMDL), airplane (CMDL and MOZAIC), and satellite (MOPITT). The extensive model-measurement comparisons indicate that UCTM has a good ability to reproduce global CO_2 and CO fields. Analyzing CO_2 and CO fields by isolating their emission components and by attributing to their influence regions allows us to better understand the impact of emission, transport, and transformation to the atmospheric CO and CO_2 distributions. The findings will help to reduce uncertainty in the carbon cycle processes that create the so-called missing sink of atmospheric CO2. Since CO_2 and CO have a common source originated in anthropogenic emission, the research facilitates inversion estimates of CO_2 sources and sinks by simultaneously using satellite CO_2 and CO measurements. The successful model-measurement comparisons allow us to apply UCTM to direct field campaign. UCTM has been used in assisting Pre-Aura validation experiment (PAVE) aircraft measurement by supplying daily 5-day real time CO simulation during 10/18/2004-11/17/2004. The afterward model-measurement comparisons indicate

UCTM captures observed tropospheric CO vertical profile.

Other major efforts during this reporting period include simulating CO using GOCART and investigating the correlation between CO and fine mode aerosols. In the northern hemisphere (NH) continental, fossil fuel emission dominates both CO and aerosol magnitudes. In addition, both CO and aerosol variations reflect the atmospheric oxidant concentration which determines the primary sink of CO and the production of sulfate aerosol. As a consequence, the seasonal cycles of regional CO and aerosol are several months out of phase. Over the NH remote ocean, fossil fuel emission from land areas still controls CO change through transport. However, aerosol is dominated by local ocean sources because its lifetime is only on the order of days. This results in a different correlation of CO and aerosol in the NH oceanic regions than its continental counterpart.

On the other hand, the variations of CO and aerosol in the southern hemisphere are dominated by biomass burning. The majority of aerosols released from biomass burning is carbonaceous aerosol. Therefore, the timings of CO and aerosol variations in the SH have the best agreement. By investigating the correlation between CO and aerosol, we understand better about atmospheric oxidizing ability, atmospheric pollutant loading, and how atmospheric transport and chemistry influence on pollutant distributions.

Objectives for the Coming Year

In the coming year the simulated CO_2 and CO fields by the newly developed Chemistry and Transport Model (UCTM) will be analyzed. This scientific application of the UCTM will provide understanding and interpretation of satellite derived, high spatial resolution carbon dioxide measurements. Scientific findings will be delivered to public. The manuscript of correlations between CO and fine mode aerosols from GOCART will also be prepared. Based on an analysis of the results of these scientific applications, improvements will be made to the UCTM design. The radiative and microphysical properties of atmospheric aerosols will be implemented in the UCTM during the coming year. With the inclusion of interactive atmospheric aerosols UCTM will be used to investigate radiative forcing by black carbon aerosols. Previous studies have shown that black carbon is the only aerosol species with a significant positive radiative forcing in our atmosphere. Elucidation of the radiative forcing due to black carbon aerosols and their interaction with other atmospheric processes may make a significant contribution to our understanding of global climate change.

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

GEST Investigator: Eric Bucsela

Collaborators: James Gleason, Edward Celarier, Mark Wenig, PK Bhartia, Ernie Hilsenrath, Scott Janz, George Mount, Jochen Stutz.

Abstract

Fiscal year 2004-5 saw the launch of the EOS-AURA satellite and deployment of the Ozone Monitoring Instrument (OMI). Before launch, the initial phase of work on algorithm development was completed, using simulated data sets from stratospheric and tropospheric NO_2 models. A paper describing the development of the OMI NO_2 algorithm has been submitted to a refereed journal. The actual OMI data became available during the Fall of 2004, and we were able to produce the first high-resolution maps of global NO_2 fields. The NO_2 images were presented at the Fall AGU meeting, and were used in the PAVE campaign in January and February 2004. Several calibration issues in OMI have been identified and are being analyzed. While many of these problems have origins in the spectral radiance and wavelength calibration, we have temporarily

employed a "soft" calibration using zonal mean data fields. This calibration corrects for the apparent striping in the data fields due to an anomaly in the cross-track calibration. The soft calibration will be useful until the causes of the cross-track anomaly have been identified and corrected.

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-based validation programs. The goal was to build on feasibility studies from the previous year and to begin processing of the first data from the OMI, which was successfully deployed on the EOS AURA satellite in July 2004. It was hoped that the processing of early OMI data would demonstrate the ability of the instrument to provide daily global NO_2 measurements and help to identify any instrument calibration issues. Resolution of these issues is important in providing a data set that can be verified against several of the proposed aircraft and ground-based validation campaigns.

Accomplishments During the Reporting Period

During FY 04-05, the EOS AURA satellite was launched, and work during this period included final pre-launch refinements to the NO_2 retrieval algorithm, as well as examination and analysis of data returned by the Ozone Monitoring Instrument. The satellite with its suite of four instruments was successfully deployed in July 2004. All work is being carried out at NASA as part of a joint venture with KNMI in the Netherlands, and details are described below. Significant milestones for the year included completion and submission of the algorithm paper, processing of the initial data returned by the instrument, and its presentation at the "first-light" press conference.

Rigorous algorithm tests were possible during the current fiscal year due to the availability of model data for both stratospheric and tropospheric NO_2, which was combined to simulate actual geophysical data. Use of these data allowed for several improvements in the stratosphere/troposphere separation algorithm. One result was confirmation that the statistically most accurate retrieval is effected using an "unpolluted" profile containing stratospheric NO_2 and zero - rather than some small amount (~5%) of - tropospheric NO_2. It was also found that tropospheric AMF correction of the NO_2 field is optimally performed when the initial VCD field departs from the Fourier-modeled smooth field by any positive amount. In previous versions of the algorithm, a threshold value greater than zero was set for the AMF correction.

The primary focus of work during the latter part of the reporting period was the processing of initial data from OMI. Global NO_2 fields were presented at poster sessions and at the AURA "first-light" press conference at the Fall 2004 AGU meeting in San Francisco. Although no tropospheric AMF correction was applied to these initial results, the images clearly revealed NO_2 enhancements over polluted regions of North America, Europe and Asia. They also demonstrated OMI's ability to examine regional NO_2 fields in unprecedented detail at resolutions on the order of 20 km. Daily NO_2 images over North America were also produced and were of critical value in supporting the Polar Aura Validation Experiment (PAVE) campaign during January and February 2005. Results from this aircraft campaign are currently being analyzed and should yield valuable information about the vertical distribution of NO_2 over polluted regions in the wintertime. Some tropospheric NO_2 profile measurements from KNMI have already been made available. These profiles were used to apply tropospheric AMF corrections to initial NO_2 fields over Europe for January 24 2005. The tropospheric NO_2 VCDs derived from the measured profiles were compared with those obtained from the model profiles used in the OMI algorithm. Results showed differences as large as 1016 cm–2 in tropospheric VCD for the two types of profiles.

The utility of the early OMI data was limited by calibration uncertainties. The Operational Parameter File (OPF), which is used to apply calibration parameters to the level-0 OMI data, has evolved through version 7 during the first 6 months since launch. The most recent version

significantly reduces the orbital "striping" artifact seen when mapping OMI data. This artifact is due to a calibration anomaly dependent on the cross-track pixel number (1 through 60). The anomaly is seen as an additive effect in the NO_2 SCDs, as well as in the cloud-fraction and cloud-pressure fields. The investigator devised methods for reducing the magnitude of this artifact by applying a "soft" calibration to the OMI data. The calibration is calculated as a function of cross-track pixel number for each day of observation, based on the mean field in a given latitude band. Some day-to-day variations have been observed in the anomaly from November through February, but there is no evidence that the overall magnitude of the anomaly is increasing over time for any of the OMI data fields examined so far.

The investigator was also involved in proposals that were part of validation efforts using DOAS retrievals from spectrometers either on the ground or deployed from aircraft. The measurements made by these instruments will be compared with simultaneous satellite overpasses to validate local tropospheric NO2 amounts. An additional proposal is aimed at studying tropospheric NO_2 over clouds—particularly thunderstorms—using OMI data.

Objectives for the Coming Year:
During FY 05-06, work will continue on the characterization of the OMI instrument. Emphasis will be on the visible band of the spectrum, where NO_2 measurements are made. The calibration, in particular, will be an ongoing issue, and those at GSFC and KNMI involved in NO_2 retrievals will work closely with calibration team. Anomalies found in the geographic NO_2 fields have already provided clues about variations in instrument sensitivity across the satellite track. Results from the analysis will be fed back to those involved in OMI calibration to develop improved versions of the Operational Parameter File (OPF). NO_2 measurements will also be validated using ground-based studies as well as aircraft campaigns. The MAX-DOAS instrument should be ready for operation in the upcoming fiscal year. The investigator plans to continue to be involved in developing software for interpretation of the measurements from this ground-based instrument, as well as the processing of actual data after it is deployed. The aircraft version of this instrument (AMAX-DOAS) will involve similar efforts. We hope to receive support money for both of these validation efforts. Additional projects will be undertaken as funding permits.

Task : 916-54-206 **A Global Modeling Initiative (GMI) Study of the Sensitivity of Transport to Meteorological Fields: Model Development and Evaluation**

GEST Investigator: Bryan N. Duncan

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

Abstract
Research has concentrated on completing the development and evaluation of the Global Modeling Initiative's (GMI) 3-D tropospheric chemical tracer model (CTM). Our developmental activities included the implementation of 1) code to simulate the radiative and heterogeneous chemical impact of aerosols on trace gas photochemistry; 2) new meteorological fields that drive transport in the CTM; and 3) code to simulate the production of nitrogen oxides from lightning. As part of our continuing model evaluation effort, we participated in a model inter-comparison of the Intergovernmental Panel on Climate Change (IPCC); our model results fell in the "middle of the pack" as compared to the other participants.

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, we been involved in the development and evaluation of the GMI Tropospheric CTM with the GMI science team. We are presently analyzing model output for our first set of papers describing the GMI tropospheric CTM.

Accomplishments during the Reporting Period

We were involved in a number of development activities on the GMI tropospheric CTM during the reporting period. The discussion here covers the most important activities.

The chemical mechanism was updated with the latest chemical and photolytic rate information. The chemical mechanism includes a detailed description of tropospheric O_3-NOx-hydrocarbon and stratospheric chemistry [Bey *et al.* 2001]. It was updated with recent experimental data, such as the removal of $O_{(1D)}$ by several atmospheric molecules [Dunlea and Ravishankara 2004]. Photolysis frequencies are computed using the Fast-J radiative transfer algorithm [Wild *et al.* 2000], which considers Rayleigh scattering as well as Mie scattering by clouds and aerosol.

We implemented code in the CTM to simulate the radiative and heterogeneous chemical effects of sulfate, dust, sea-salt, organic carbon and black carbon aerosol on tropospheric photochemistry following Martin *et al.* [2003]. (Previously, only the heterogeneous chemical effect of sulfate aerosol was simulated.) The 3-D aerosol mass distributions were calculated off-line using the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model [Chin *et al.* 2002]. The net effect of aerosols on the tropospheric hydroxyl radical burden is small, but the changes for specific regions are quite dramatic.

We are implementing new meteorological fields that drive transport in the CTM: 1) GEOS-4-DAS fields [Goddard Earth Observing System (GEOS) data assimilation systems (DAS), version 4] from the Goddard Modeling and Assimilation Office (GMAO); 2) GEOS-4 DAS forecast fields (GEOS-4-Forecast); 3) Oslo/European Centre DAS forecast fields (Oslo/EC-Forecast) from Oslo University and U. California, Irvine; and 4) GEOS-4 Atmospheric global circulation model (GCM) fields (GEOS-4-AGCM).

We are implementing a new lightning emissions parameterization, which is a function of the meteorological fields [personal communication, D. Allen and K. Pickering, UMCP].

Our evaluation activities include the comparison of model output with observations from field campaigns, satellites (*e.g.*, GOME nitrogen dioxide, TOMS ozone, and MOPITT carbon monoxide), and surface sites. In addition, we participated in a model inter-comparison of the Intergovernmental Panel on Climate Change (IPCC); our model results fell in the "middle of the pack" as compared to the other participants, which is encouraging.

Objectives for the Coming Year

Work will be undertaken with other GMI science team members to evaluate the credibility of circulation produced by several meteorological fields that drive transport in the GMI CTM. We will assess the model's simulation of large-scale circulation, such as stratosphere-troposphere exchange (STE) and tropospheric inter-hemispheric exchange (IHE), as well as smaller scale motions, including convection and pollution plume transport. The GMI CTM is uniquely suited for this study as it can use meteorological input from various GCM and DAS. First, we will evaluate the performance of the GMI CTM with transport driven by meteorological fields from several sources: 1) GEOS-4-DAS, 2) GEOS-4-Forecast, 3) Oslo/EC-Forecast, and 4) GEOS-4-AGCM. We will perform a series of CTM simulations for January through April 2001, which include the time of the TRACE-P field campaign, evaluating the runs with measurements from the

campaign and observations taken from space. Second, we will assess the credibility of GMI CTM simulations using Oslo/EC-Forecast and GEOS-4-Forecast fields as applied to the impact of boreal forest fires in 2002 on United States air quality. To evaluate the fidelity of transport in the two simulations, we will compare CTM output with in situ observations, such as ground-level ozone from the AIRNow database, and remotely sensed data (*e.g.*, carbon monoxide from the MOPITT instrument).

Task 916-01-016: **Interactive Global Modeling of Stratospheric and Tropospheric Photochemical Systems Coupled with the Atmospheric General Circulation Model**

GEST Investigator: Mohan Gupta

Collaborators: Anne Douglass (PI, GSFC), Rich Stolarski (GSFC), Mark Schoeberl (GSFC), Paul Newman (GSFC), Steven Pawson (GSFC/GMAO), Eric Nielsen (SSAI/GMAO)

Abstract

Research efforts under this task relate to the study of changing atmospheric chemical composition and its interaction with the climate change. At the present, the emphasis is on the detailed stratospheric chemistry with adequate representation of mesospheric photochemistry and progressive plans to include tropospheric photochemistry. A coupled chemistry-climate model (GEOS-CCM) has been developed that links the GMAO GEOS general circulation model with the GSFC stratospheric chemistry through ozone. Various aspects of the coupled model have been thoroughly examined and validated. At present, one of the versions of GEOS-CCM model is in a freeze mode and is being used to simulate the steady state stratospheric chemical composition for the periods of pre-(1980) and post-(2000) ozone hole era. One of the prime objectives of these simulations is to examine the impacts of change in ozone concentration during these two periods on the atmospheric radiation and dynamics and their feedback to ozone changes.

Description of Research

One of the major goals is to study atmospheric radiative, dynamical, and chemical interactions in the single 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. There is an ongoing project to couple the atmospheric chemistry (of the region that extends from surface up to 80 km) with the GSFC GEOS general circulation model. Modeling tools developed under this task will be used to examine the important scientific issues such as future recovery of stratospheric ozone and atmospheric chemistry-climate interactions.

Accomplishments during the Reporting Period

Since the last reporting period, we have made progress on several fronts in the continued development of coupled chemistry-climate model (GEOS-CCM) which resulted in sensible model simulations and stable runtime performance. This coupled model extends from surface up to 80 km in the mesosphere. We have incorporated the mesospheric photochemistry of Ox and HOx families to properly account for magnitude of Ox species and its partitioning between ozone and oxygen atoms. An inert tracer representing the model runtime clock is added to determine the age of airmass. In addition, the changes have been made in the model so that stratospheric ozone in the troposphere can be relaxed to observed ozone climatology. Changes have also been made to properly account for oxidation of stratospheric methane to produce water vapor. Ongoing analysis indicates that the coupled model may have a bias towards the low temperature at the tropical tropopause which is resulting in lowering in stratospheric water vapor. The entering value of stratospheric water vapor at

380K is lower by about one ppm as compared to the corresponding value of 3.8 ppm derived from satellite data. Investigations are underway to improve the model for this discrepancy. Similar to our earlier analysis of chemical ozone before it was radiatively coupled in GEOS-CCM, there is also an ongoing effort to analyze the GEOS component of stratospheric water vapor with the chemically calculated water vapor. Conclusions drawn from this analysis will provide a basis for radiative coupling of chemically updated stratospheric water vapor. This additional linkage will make chemistry-climate coupling more robust in the GEOS-CCM because water vapor is not only a major component of stratospheric chemistry but it also plays an important role in radiative balance. More importantly, dynamical entry of water vapor in the stratosphere is controlled by the tropical tropopause temperature.

At this stage, one of the versions of GEOS-CCM is considered a freeze version and is being used to simulate the stratospheric chemistry-climate interactions for the pre- (1980) and post- (2000) ozone hole era. Before proceeding to full chemistry-coupled simulations for these periods, we performed 20-year GEOS simulations for each of these two periods by incorporating corresponding year GSFC CTM produced ozone fields in the radiation package. These simulations only accounted for ozone-induced changes in radiation and dynamics. We are analyzing these simulations to investigate the effects of ozone-induced changes of radiation and dynamics on the development and break-up of polar vortex and water vapor transport across 380K surface.

During the previous year, we concluded a study on sensitivity of distribution of atmospheric Rn on its surface emissions. Results of this study have been published in Tellus-B. Also, we have completed the analysis of meteorological dependence of intercontinental transport of regionally tagged Rn. Results of this study will be soon submitted to *JGR-Atmosphere*.

Objectives for the FY 05-06

Our research activities will continue to develop, test and validate the chemistry-climate coupled model using UARS and AURA measurements and address key scientific issues of chemistry-climate interaction. One of the key tasks would be to couple the water vapor fully interactive in chemistry, radiation and the GEOS model. Some of the scenarios of chemistry-climate interactions will be investigated in time-slice and time-dependent modes. One such scenario would address the chemistry-climate interactions during the pre- and post- ozone hole era. Based on the funding status of two submitted research proposals, additional research activities will also be carried out related to consistency analysis of water measurements by A-train instruments; and implementation of fully coupled tropospheric-stratospheric-mesospheric chemistry in the GEOS-CCM. This fully interactive chemistry-coupled model would be used for in-depth analysis of chemistry-climate interactions with the emphasis on investigation of anthropogenic activities on atmospheric chemical composition and its interaction with the climate change.

Task 916-04-074: **Surface UV irradiance and Aerosol UV Absorption Remote Sensing**

GEST Investigator: Nickolay Krotkov

Collaborator: Jay Herman (GFSC), P.K. Bhartia (GSFC)

Abstract

Support was provided for developing applications of satellite data, such as ozone and ultraviolet (UV) surface irradiance from the NASA Total Ozone Mapping Spectrometer (TOMS) and EOS/AURA missions. The focus was on understanding effect of clouds on ozone retrieval, validating satellite UV maps and measuring aerosol UV absorption using ground-based remote sensing techniques. Direct

measurements were conducted to quantify 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

Little is known about spatial and temporal distribution of boundary layer absorbing aerosols, especially in the photochemically important UV spectral region. It is likely that aerosol absorption of UV radiation is not properly accounted for in radiative transfer models used to predict the UV index in operational weather forecasting and satellite UV mapping. This may yield a 10-30% systematic difference between model-based UV index forecasts and real measurements or forecasts based on empirical relationships between UV and shortwave radiation measurements. Long-term changes and trends in aerosol absorbers may yield effects on UV that are comparable to, and even stronger than, those from ozone depletion. Research focused on TOMS UV and aerosol data validation and extension of ground-based passive measurements of column aerosol absorption into UV spectral region. The goals were (1) to validate TOMS and AURA/OMI aerosol absorption products; (2) to measure aerosol absorption consistently across UV-VIS wavelengths; (3) to distinguish between absorption by black carbon and other potential UV absorbers (organics, nitrated and aromatic aerosols and gases); and (4) to quantify aerosol effects on Photolysis Frequency rates and surface UV irradiance.

Accomplishments in FY 04-05

Radiative transfer modeling study was conducted to quantify effect of clouds on measured UV backscattered radiances averaged over TOMS footprint as well as TOMS ozone retrieval [Ahmad *et al.* 2004]. Comparisons of the plane parallel cloud (PPC) model-derived spectral dependence of UV reflectances with the Total Ozone Mapping Spectrometer (TOMS) measurements have shown surprisingly good agreement over a wide range of observational conditions. The PPC model results also were compared with the results of two other cloud models: Lambert Equivalent Reflectivity (LER) and Modified Lambert Equivalent Reflectivity (MLER) that had been extensively used to analyze satellite data in the UV. These models assume that clouds are opaque Lambertian reflectors rather than Mie scattering particles. Although one of these models (MLER) agrees reasonably well with the TOMS data, the results from this model appear somewhat unphysical and may not be suitable for interpreting satellite data if one desires high accuracy. The study confirmed that currently used cloud lookup tables based on plane-parallel homogeneous cloud (PPC) model are adequate for describing average cloud reflectance of low resolution TOMS and OMI instruments and cloud spectral signature in UV. The PPC model was also used to illustrate how clouds can perturb tropospheric ozone absorption in complex ways that cannot be explained by models that treat them as reflecting surfaces rather than as volume scatterers.

TOMS surface UV irradiance database (1978 to 2003) has been expanded to include 5 new products (noon irradiance at 305, 310, 324, and 380 nm, and noon erythemal-weighted irradiance), in addition to the existing erythemal daily exposure [Krotkov *et al.* 2004]. UV index (erythemal-weighted noon irradiance) climatology over North America for the period 1980-1990 was calculated using satellite UV estimates from TOMS total ozone and reflectivity data and UV index values derived from ground-based global solar radiation, total ozone, snow and dew point temperature measurements [Fioletov *et al.* 2004]. UV index climatology from TOMS measurements for snow-free conditions in summer is 10-30% higher than those from pyranometer-based estimates. They are also higher than estimates from Brewer UV spectrometers measurements. It is likely that the bias between TOMS UV estimates and Brewer measurements is caused by boundary layer absorbing aerosols, whose effects are not accounted for by the TOMS algorithm [Krotkov *et al.* 2004, 2005b; Arola 2004]. The bias does not exist at sites with exceptionally clean local environments and/or at sites located above that absorbing aerosol layer.

A novel technique has been developed [Krotkov *et al.* 2005a] to calibrate commercial UV Multifilter Rotating Shadow Band Radiometers (UV-MFRSR) using a CIMEL sunphotometers located at GSFC. (The CIMELS have been deployed globally as part of the AERONET network for measurement of aerosol properties.) Our technique now provides better than 2% accuracy in measuring global surface UV radiation (at wavelengths longer than 320 nm), which allows one to estimate (column) aerosol absorption optical depth to better than 0.01 in absence of clouds [Krotkov *et al.* 2004, Krotkov *et al.* 2005b].

Data from UV-shadow-band radiometer and well-calibrated CIMEL sun-sky radiometer were analyzed to quantify the aerosol absorption bias at the GSFC site in Greenbelt, MD, which is representative of the mid-Atlantic suburban area. This work involves scientists from GSFC as well as U.S. Department of Agriculture UVB network. The additional absorbing aerosol correction based on new TOMS aerosol absorption data was developed and shown to improve TOMS UV comparisons with spectral ground UV measurements.

Wintertime bias was also found in the TOMS UV data due to inability to distinguish between snow and cloud cover using only TOMS UV reflectance data. This results in large errors in estimating surface UV using snow climatology [Fioletov *et al.* 2004]. A correction was suggested for the case when the regional snow albedo is known from an independent source.

Objectives for the Coming Year

Ground-based passive remote sensing of column aerosol absorption across UV-visible spectral range will continue at the GSFC site using a combination of direct sun, sky radiance and total and diffuse irradiance measurements. This dataset, the only one of its kind, will be invaluable for the validation of aerosol absorption product derived using TOMS-like UV instruments.

Based on the previous research, it is clear that TOMS-provided estimates of aerosol absorption have the potential to improve the quality of TOMS 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). It should be noted that in the tropics, as well as over most of the inhabited land areas, aerosol absorption of shortwave solar radiation has arguably produced far greater effects on human health, agricultural productivity, environment, and air quality than ozone depletion.

Task 916-01-017: **Investigation and Application of the Match Technique**

GEST Investigator: Gary A. Morris

Collaborators: P.K. Bhartia (GSFC), Mark Schoeberl (GSFC), Richard Stolarski (GSFC), Bojan Bojkov(GSFC), Leslie Lait (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 2 (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

Final versions of the figures for our paper and a final draft of the text were prepared for submission to the *Atmospheric Chemistry and Physics Discussions* journal. At this point, however, we are investigating a partitioning of loss between daylight and nighttime hours in our model. Rex *et al.* [1998] demonstrated through bi-variate regression that their model showed almost no loss during dark hours. We are currently in the process of evaluating the amount of loss that may or may not be occurring during the nighttime hours in our model. If we find such loses, we plan to rerun our model using the recently acquired ECMWF wind fields in place of the UKMO 24-hour analyses that we have used in our study.

Large ozone loss rates in the arctic remain troublingly inconsistent with our current understanding of polar stratospheric chemistry [*e.g.*, Becker *et al.* 2000]. The smaller ozone loss rates found in our version of Match and in the trajectory mapping approach are more consistent with currently accepted chemistry. Although the Match studies have produced an appealing and consistent picture of high ozone loss rates associated with large areas of cold temperatures that often lead to the development of polar stratospheric clouds, the picture may not be so clear when errors are more appropriately considered. While Match truly represents a powerful approach to studying ozone loss, it must be applied with great care to produce reliable, robust results.

Objectives for the Coming Year

Evaluate nighttime ozone losses and rerun our analysis using ECMWF wind fields in place of UKMO wind fields. The higher temporal resolution of these wind fields may lead to better results and may be related to the differences we have observed between our results and those of Rex *et al.* [2002]. The ECMWF analyses have just recently have become available on the science system in the Atmospheric Chemistry and Dynamics Branch and should prove interesting for our analysis
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Task 916-37-173: **Stratosphere-Troposphere Exchange**

GEST Investigator: Mark A. Olsen

Collaborators: Anne R. Douglass (GSFC), Mark R. Schoeberl (GSFC)

Abstract
The relationship between ozone and mass transport across the tropopause has been examined in great detail. The seasonal cycles and spatial distributions have been investigated for the adiabatic and diabatic fluxes of ozone and mass. The short- and long-term variability and trends of the transport are currently being examined from model output. The cross-tropopause transport and stratospheric structure are being evaluated for a study of chemistry and climate interactions. Ozone depletion in the Southern Hemisphere polar region has changed the radiative balance, which in turn has altered the dynamics of the region by blocking vertical wave propagation into the stratosphere. Finally, a study of the ozone-HCl correlation in the lowermost stratosphere has begun. This work aims to aid estimations of how much ozone in a measurement was produced in the stratosphere.

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 stratosphere-troposphere exchange (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 in FY 04-05
We focused on dynamics and transport of mass and trace gases in the upper-troposphere/lower-stratosphere (UT/LS). One study examined the model-based five-year climatology of stratosphere-troposphere exchange (STE) of mass and ozone [Olsen *et al.* 2004]. The diagnostic algorithm used allows an analysis of the net, adiabatic, and diabatic aspects of the transport. This work found that: (i) the seasonal cycle of the ozone mixing ratio in the lower-stratosphere is out of phase with the transport cycle producing a temporal offset of the mass and ozone STE on the order of a month; (ii) the downward net diabatic flux of mass and ozone occurs primarily at middle latitudes while the adiabatic mass flux is dominated by troposphere-to-stratosphere transport at higher latitudes; (iii) the Southern Hemisphere stratospheric vortex is more effective at blocking meridional transport, resulting in a phase difference of mean tropopause ozone mixing ratio in the higher SH latitudes with respect to the corresponding NH season and location; (iv) and the individual pathways of cross-tropopause transport are unlikely to be the result of simultaneous adiabatic and diabatic mechanisms.

Results from a fifty-year integration of the Goddard 3-D Chemistry and Transport Model (CTM) are being analyzed to determine the short- and long-timescale variability of extra-tropical mass and ozone STE. The long-term trends of the mass and ozone transport are also being evaluated. The effect that sea surface temperatures have on the STE of mass is included in this work. The same diagnostic algorithm as the previous STE work is being used to evaluate the trends and variability of the net, adiabatic, and diabatic STE.

The correlation of atmospheric ozone and HCl in the UT/LS is currently being investigated using CTM output. HCl is chemically similar to ozone in that it has a primary source in the stratosphere and has a very long lifetime in the lowermost stratosphere. Thus, ozone and HCl are strongly correlated in the UT/LS. It has been suggested that HCl can be used to estimate how much

ozone in a given air mass was produced in the stratosphere. The CTM output will be used to determine this relationship, including temporal and spatial variability.

The investigator is providing analysis of the UT/LS region and STE for a model investigation of the relation of chemistry and climate. Currently, two model integrations with different climatological ozone fields are in the process of being assessed. It was found that the differences in extra-tropical mass STE is likely insignificant. However, the structure of the UT/LS is significantly changed through the radiative balance. Furthermore, the different temperature structures significantly influence the dynamics of the troposphere through the stratosphere in the Southern Hemisphere polar region.

Objectives for FY 05-06

Several of the aforementioned research projects will be continued or completed. These include the STE trends and variability study, analysis of the ozone-HCl correlation and variability, and comparison of the UT/LS structure and STE differences for the chemistry-climate model study. The role of monsoon circulations in transporting water vapor from the troposphere to the stratosphere will also be examined in the upcoming year. This investigation will employ a mesoscale model to examine the physical processes and an adjoint model to determine the magnitude and spatial distribution of the flux.

Task 910-01-014: **Radiative Transfer Modeling and Zonally Symmetric Atmospheric Modeling**

GEST Investigator: Joan E. Rosenfield

Collaborators: Mark R. Schoeberl (PI, GSFC), Richard Stolarski (GSFC)

Abstract

A statistical time-series analysis was applied to the new Version 8 merged Solar Backscatter Ultraviolet (SBUV) data set of ozone profiles for the years 1979-2003. Linear trends for the 1979-1997 time period were determined and compared to trends computed using ozone profiles from the GSFC zonally averaged coupled model. Both observed and modeled annual trends were a maximum in the higher latitudes of the upper stratosphere, with southern hemisphere (SH) trends greater than northern hemisphere (NH) trends. Both observed and modeled trends are most negative in winter and least negative in summer, although the modeled seasonal difference is less than observed. Model trends are shown to be greatest in winter due to a repartitioning of chlorine species due to colder winter temperatures and the increasing abundance of chlorine with time. The observed and modeled trends generally agreed within statistical uncertainties. Model results illustrate the trend differences that can occur at 3 hPa depending on whether ozone profiles are in mixing ratio or number density coordinates and whether they are recorded on pressure or altitude levels.

Description of research

The radiative transfer model, developed by J. E. Rosenfield, is used to calculate global three dimensional stratospheric and tropospheric heating rates from analysed temperature fields. These heating rates are being used in calculations of diabatic parcel trajectories by scienists at GSFC and elsewhere in the community. The radiative transfer model also constitutes a module in the GSFC zonally symmetric interactive atmospheric model. This zonally symmetric model couples chemistry, radiation, and dynamics, and is being used to study the current and future state of the ozone layer. The task also includes adapting and/or developing improved parameterizations in the radiative transfer model.

Accomplishments During the Reporting Period

Very recently, the newly reprocessed Version 8 Solar Backscatter Ultraviolet (SBUV) combined data set of ozone profiles has become available.

A multiple linear regression statistical time-series analysis was used to compute the annual mean and seasonal trends of these ozone profiles between 1979 and 2003. The statistical analysis included seasonal, 11-year solar cycle, and quasi-biennial oscillation terms, as well as a term proportional to the calculated time dependence of chlorine and bromine in the upper stratosphere. For 1979 through 1997, the chlorine term is nearly linear with an increase of 1.2 ppbv/decade. Although the entire time series was fit to the regression model, linear trends derived from the 1979 through 1997 part of the chlorine fit were computed. The regression model was also applied to the ozone profile output of the GSFC zonally averaged interactive model. One model run used the entire suite of natural and anthropogenic source gas boundary conditions given by a World Meteorological Organization (WMO) scenario. Another run was the same except for carbon dioxide, which was fixed at 1979 values in order to examine the effect that greenhouse cooling of the stratosphere would have on ozone trends.

We found a general pattern of maximum negative annual trends in the higher latitude upper stratosphere, with minimum trends in the tropics, in agreement with previous results. Upper stratosphere trends were more negative in the southern hemisphere (SH) than in the northern hemisphere (NH) for both the observations and the chemical model output, although the modeled trends had less interhemispheric asymmetry than the observed trends. The modeled NH midlatitude annual trends agreed well with the observations, while the agreement in the SH was somewhat less good. In the model run with fixed carbon dioxide, the computed ozone trends were more negative than was the case for increasing carbon dioxide. This is expected as the stratospheric cooling due to increasing carbon dioxide results in a slowing of the ozone catalytic loss cycles, thus reducing the downward trend.

Four seasonal averages were constructed for both the SBUV and the model ozone profiles, and the corresponding trends computed. In the upper stratosphere, winter trends were most negative and summer trends least negative for both observed and modeled ozone. The model trends did not exhibit as great a seasonal variability as the observed trends. Overall, however, the agreement between observed and modeled upper stratospheric trends was within the statistical uncertainties. The more downward winter trends were shown to result from the increasing abundance of chlorine with time and the greater abundance of chlorine monoxide in winter due largely to the lower winter temperatures.

Both the SBUV and the model profiles were in the form of mixing ratios on pressure levels. We calculated trends for three other representations of the model ozone profiles; mixing ratios on geometric altitude, number density on pressure, and number density on geometric altitude. One can show that in the presence of a temperature trend, the various representations of the profiles will give different ozone trends due to the changing altitudes of pressure surfaces with time and the changing air density on pressure surfaces with time. In the upper stratosphere, computed trend differences were as large as 1-2 %/decade. This illustrates why care must be taken in comparing SBUV trends with ozone trends from instruments which use a different vertical coordinate, such as the SAGE instrument which records ozone profiles as number density on altitude. This work is in press in the *Journal of Geophysical Research*.

In other work, we have previously reported that our interactive chemical model predicts a post 1980 tropical ozone depletion in the lower stratosphere, which does not recover. A depletion of 2% relative to 1980 values remains out to the year 2050. The model run incorporates changing chlorofluorocarbons, methane, nitrous oxide, and carbon dioxide, as well as heterogeneous chemistry occurring on the surface of sulfate aerosols. We have analyzed the model output and have determined that this sustained depletion is caused by a complicated interplay between chemical production and dynamics. A paper was submitted to GRL entitled "Recovery of the Tropical Lower Stratospheric Ozone Layer" by Joan Rosenfield and Mark Schoeberl.

Objectives for FY 05-06
Joan Rosenfield plans on incorporating the newer version of the radiative heating code she developed into the zonally symmetric chemical model. She will also document her computer codes in preparation for her anticipated retirement this year.

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

GEST Investigator: Susan Strahan

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

Abstract
Chemistry and transport model (CTM) implementation studies testing sensitivity to horizontal and vertical resolution were completed. Results of these studies are being used to improve transport characteristics of the Goddard and the Global Modeling Initiative (GMI) CTMs. The major focus has been on managing the development and evaluation of several versions of the NASA GMI CTM. New, multi-decadal stratospheric simulations have been completed. The tropospheric version of the GMI model has matured to the point of being able to participate in an international model intercomparison. The GMI aerosol model is now successfully implemented and has produced useful results for GMI team members. A new version of the model that uses a combined tropospheric-stratospheric chemical mechanism is under development.

Description of Research
This research focuses on interpretation and analysis of stratospheric trace gas observations and the application of those analyses to three-dimensional atmospheric models. The goal of the data analysis is to better understand the balances between photochemistry and transport on stratospheric ozone and other constituents. The data analyses, scientifically important by themselves, are also used to evaluate the performance of models. Studies are also performed that examine the sensitivities of CTMs to horizontal and vertical resolution, and other aspects of model implementation. The models evaluated are the Goddard 3-dimensional Chemistry and Transport Model (3D-CTM) and the NASA Global Modeling Initiative (GMI) 3D-CTM. These models are used to investigate anthropogenic influences on the stratosphere and estimate possible future trends based on changes in surface emissions.

Accomplishments During the Reporting Period
Transport diagnostics have been applied to a series of CTM sensitivities studies to understand how model implementation affects constituent distributions. A CTM is an offline chemical transport model that uses wind fields from another meteorological model. The circulation, transport, and mixing processes in a CTM are not only a function of the input wind fields, but also of many aspects of its implementation such as horizontal and vertical resolution, height of the model domain, and whether or not the input winds have been interpolated in space or time. The CTM sensitivity studies systematically changed one implementation aspect at a time to understand the consequences of a single model change. Issues examined included horizontal resolution, height of the model lid, vertical resolution, and sensitivity of the advection scheme numerics to wind field resolution. Offline (CTM) vs. online (GCM) chemistry differences using identical meteorological field were also compared. A manuscript is in preparation that describes these results.

The main focus of work has been on managing the development and evaluation of four versions of the NASA GMI CTM. All versions have a global domain extending to the mesosphere, but each has a different chemical mechanism: tropospheric, stratospheric, tropospheric aerosol,

and a combined troposphere-stratosphere mechanism. As a result of the CTM sensitivity studies, the stratospheric version was tested at a higher resolution and then used for two 50-year simulations of past and projected future anthropogenic emissions (*e.g.*, of N_2O, CH_4, and halogenated species). The tropospheric model underwent major revision as a result of extensive evaluations that identified a number of bugs. The model is now able to produce credible distributions and behavior for a number of important tropospheric species, such as O_3 and CO. Because of these improvements, simulations were performed and submitted to an international tropospheric model intercomparison for the Intergovernmental Panel for Climate Change (IPCC).

In collaboration with GMI science team members at the University of Michigan, updates were made to the GMI aerosol model and new simulations were performed. The newest version of the GMI model uses a combined tropospheric-stratospheric chemical mechanism; it is being developed in collaboration with NASA Langley Research Center. This model is being tested and is expected to replace the purely tropospheric mechanism as a 'workhorse' model for GMI.

The GMI web page (http://gmi.gsfc.nasa.gov) has expanded. This website explains the purpose of GMI, provides documentation on the models and instructions on their use, lists recent experiment and science highlights, and provides links for software and other computational support for GMI team members.

Objectives for the Coming Year

The CTM sensitivity studies manuscript will be completed and published. The knowledge gained from these sensitivity studies will be used to improve the implementation of the Goddard and GMI CTMs.

Continued management of the GMI project will be the major focus of this investigation. The 50-year stratospheric experiments recently completed (the 'hindcast' runs) will be used to investigate past and projected future ozone trends and will be compared with long-term data records (*e.g.*, TOMS column O_3 and ground-based networks). New meteorological fields from GCMs and data assimilation systems will be processed, tested, then used in the GMI models for upcoming experiments. A new aerosol microphysical code will be implemented to improve our aerosol modeling capabilities in the troposphere. The combined chemical mechanism will be comprehensively evaluated. Once it has "passed the bar" for credible simulations, it will be used in experiments studying the chemical behavior of the tropopause region. The combined chemical mechanism will also be shared with the GMAO AGCM model development effort at GSFC.

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

GEST Investigator: Clark Weaver

Collaborators: Arlindo da Silva (GSFC), Mian Chin (GSFC), Loraine 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-retrieved aerosol optical depths 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. To initiate the calculations, the Global aerosol Chemistry-Aerosol Radiation-Transport (GOCART) model provides three dimensional aerosol spatial distributions. Using the multiple scattering radiation transfer model developed at the University of Arizona, *a priori* MODIS-like radiances are calculated for the aerosol species given in the GOCART model. These forward calculations are organized for tabular "look-up." A variational approach is used to produce aerosol distributions by modifying the GOCART aerosol concentrations to minimize the differences between the simulated radiances and those observed from MODIS. A version 2 MODIS assimilation system has been developed that inserts MODIS radiance information over ocean and land. The assimilated aerosol distributions are validated against AERONET observations. A manuscript is in preparation.

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. This study addresses the effect of mineral aerosol absorption in the Optical Path Transmittance Model (OPTRAN) which is used for satellite temperature and moisture retrievals by National Center for Environmental Prediction (NCEP). Additional analyses are in progress to determine whether TOVS radiances are being assimilated into the NCEP products in locations of low to moderate dust loading based on the TOMS aerosol index.

A final project is exploring the feasibility of using a Fabry-Perot Interferometer to obtain CO_2 vertical profile information A retrieval algorithm has been developed that specifies the signal to noise ratio that the instrument will need in order to sense vertical profile information.

Objectives for the Coming Year

In the coming year the MODIS aerosol assimilation system will be improved to assimilate radiances over land. The higher reflectance of most land surfaces make isolation of the aerosol effects more difficult than the lower reflectance ocean surface. Ultimately, the goal of this effort is to provide a system capable 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 916-21-144: **Tropospheric ozone derived from satellite measurements**

Task 916-43-181: **Tropospheric ozone derived from satellite measurements**

GEST Investigators: J.R. Ziemke and S. Chandra

Collaborator: P.K. Bhartia (GSFC)

Abstract

During FY 04 we continued to develop and maintain the NASA Code 613.3 satellite-derived data sets of tropospheric column ozone (TCO) and stratospheric column ozone (SCO) for 1979-present. These ozone data products are obtained from Total Ozone Mapping Spectrometer (TOMS) ozone measurements using the Convective Cloud Differential (CCD) method. Two important new algorithms we developed are the Cloud Slicing (a generalization of the CCD method) and cross-calibration residual methods. Cloud Slicing derives tropospheric ozone profile information, and the cross-calibration residual method (which uses CCD SCO) provides global measurements of TCO. From TOMS and SBUV measurements, we have developed in year 2004 a new comprehensive ozone data product covering low-to-high latitudes for 1979-present for (1) tropospheric ozone, (2) upper stratospheric ozone, and (3) lower stratospheric ozone. This task now includes assessment of both TCO and SCO measurements from the new Aura OMI instrument. Aside from our role in developing public-domain data products for NASA, our research, combining both measurements and photochemical transport models, has led to substantial new understanding of the dynamics and sources/sinks of global tropospheric and stratospheric ozone.

Description of Research

The primary purpose of this task is to derive tropospheric ozone data products from satellite-based ozone measurements from TOMS and OMI. In addition to developing tropospheric ozone data products for NASA, we conduct a significant amount of scientific research in an effort to understand the nature of these observations. This includes the use of photochemical transport models (*e.g.*, MOZART-2, GEOS-CHEM, GMI) to quantify the various factors contributing to the observed ozone characteristics. This involves developing scientific retrieval algorithms, validating the derived data products with ground-based ozonesonde measurements, and conducting scientific research of the ozone data including model comparisons. Our work is devoted primarily to using existing TOMS and the new OMI ozone data for developing tropospheric ozone algorithms and data.

Accomplishments During the Reporting Period

We developed a long record (1979-present time) of tropospheric and stratospheric ozone from TOMS satellite measurements extending from the tropics to the high latitudes in both hemispheres. In a recently submitted paper to JGR, this dataset was used to determine long-term changes in ozone in both the troposphere and stratosphere. The paper discusses the important issues of stratospheric ozone recovery and long-term increases in tropospheric ozone related to increases in industrial pollution. The satellite data are currently being used to study the efficacy of 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.

The satellite measurements of tropospheric ozone were also used to characterize the ozone pollution in the northern hemisphere [Chandra *et al.,* 2004]. This study indicated that ozone values over surface emission-free regions of the Atlantic and Pacific Oceans are relatively high (50-60 DU) and are comparable to industrial regions of North America, Europe, and Asia where surface emissions of NOx from industrial sources are significantly high. These zonal features of tropospheric ozone are well

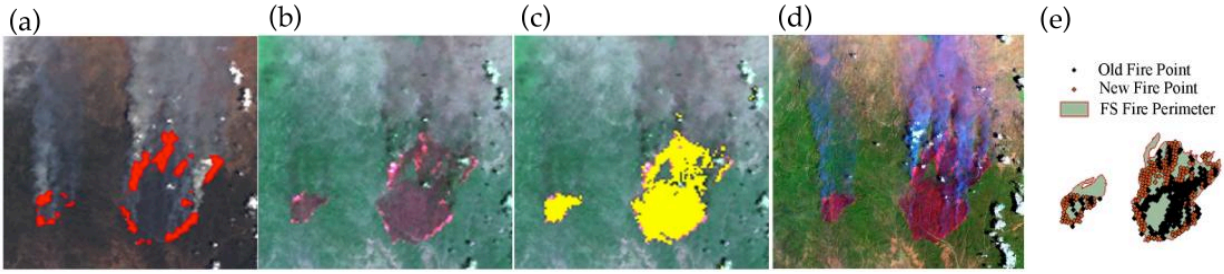
simulated by MOZART-2 model which is based on a 3D global model of atmospheric chemistry and transport. The success of MOZART-2 model to simulate the observed changes in tropospheric ozone from satellite measurements is a significant step in our understanding of the role of global pollution and to delineate the various processes which affect the tropospheric ozone on a global scale.

A major component to our tasks was to develop tropospheric ozone data products from the new Aura satellite (launched July 2004). From Aura OMI measurements we are developing daily measurements of stratospheric and tropospheric ozone data sets in the tropics. We are also combining Aura OMI ozone measurements with Aura MLS stratospheric ozone profile data to develop the first comprehensive record of global daily ozone maps. These ozone data products from Aura are currently in the development stage.

Objectives for the Coming Year

We will continue updating our Cloud Slicing TCO and SCO public domain data products and validate with SHADOZ and WOUDC ozonesondes. We will also continue evaluation of OMI measurements of TCO and SCO and incorporate with the long data record from TOMS. Combining Aura MLS and OMI measurements will enable us to establish a data record of daily global tropospheric column ozone. Tropospheric ozone from TOMS and OMI will be evaluated to characterize pollution events and to study intra-seasonal oscillations such as the 1-2 month Madden-Julian Oscillation. We will continue cross-analysis of the MOZART-2 model.

Terrestrial Physics Research Group



Sample results from MODIS data, Landsat TM data, and ground measurement in Arizona on June 21, 2002 are shown. (a) – A true color MODIS image acquired over areas near Rodeo and Chediski of Arizona in western U.S. on June 21, 2002; (b) – a false color MODIS image (red: 2.13 µm; green: 1.24 µm; blue: 1.64 µm) of the same scene; (c) – the same as (b), but with the burned areas masked in a yellow color; (d) - a Landsat 7 image (30 m spatial resolution) over the same areas as (a); and (e) - aircraft mapped fire perimeters that were obtained by researchers from the USDA Forest Services. Figure provided by Dr. Rong-Rong Li.

Terrestrial Physics Research Group

The GEST Terrestrial Physics Research Group consists of eighteen researchers whose interests integrate geospheric, atmospheric and biospheric aspects of the remote sensing of the Earth. The group not only studies a wide variety of science processes, but also spans the entire development and implementation lifecycle of remote sensing technologies. One subgroup is interested in optimizing the sensor and algorithm capabilities of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP), which is a mission to bridge the gap from Earth Observing System (EOS)-era missions to future capabilities. A second subgroup is developing the Aerosol Robotic Network (AERONET) capability to provide ground-based validation assets and to develop new algorithms for various climatic, weather forecasting, and tactical applications. The work performed in this group can feed back into developmental processes for the next generation of Earth observation technologies, and lay the foundation for long-term, consistent data sets that are the basis of climate research applications. A third subgroup of GEST researchers is investigating a diverse set of physical processes linked to climate change research, using years of data over wide geographical areas. Through close collaboration with NASA and other research and operational agencies, the process of interpretation, modeling, and assimilation will lead to improved system-wide science understanding and improved remote sensing technologies that provide the foundation on which the science activities are built.

The NPOESS is the next generation of remote sensing platforms, designed to replace and combine the present military Defense Meteorological Satellite Program (DMSP) and the National Oceanic and Atmospheric Administration (NOAA) polar system. The NPP will span the temporal gap between the end of the EOS missions and the start of NPOESS operations. Several researchers are addressing sensor and system development within the NPP and NPOESS framework. Dr. Guenther is chiefly concerned with calibration and validation of the four NPP sensors, while Dr. Kealy works on algorithm design and implementation into the real-time operational system. Drs. Lyapustin, and Wang are exploring algorithm improvements with potential for insertion into the program. This algorithm will provide surface temperature and internally consistent aerosol retrievals and atmospheric correction. The algorithm is based on a recently developed theory that rigorously describes 3-D radiation effects and gaseous absorption in the atmosphere. The atmospheric correction algorithm is currently being validated with data from AERONET.

The AERONET efforts cover research by Drs. Dubovik, Eck, Gatebe, and Smirnov. These efforts focus on the deployment, validation, and analysis of measurements made by automatic sun-sky scanning radiometers. Additional AERONET sites were deployed and algorithm improvements derived in several areas. Advances were made in developing and validating an algorithm for the spectral separation of coarse- and fine-mode contributions to aerosol optical depth. The effects of variation in the angular distribution of light, its polarization characteristics, and algorithm performance in maritime and smoky environments also led to improvements in understanding aerosols and their effect on climate. This year saw the execution of the United Arab Emirates Unified Aerosol Experiment (UAE2) major field campaign that will advance our knowledge in a geophysically complex region.

The AERONET activities form a basis for validation of several MODIS products. Several members of the group, Drs Gasso, Li, Yu, and Wei are concerned with developing improvements to the aerosol and related products from MODIS. Specifically these activities include advancing our understanding of the aerosol Fine Mode Fraction, aerosol retrieval over bright surfaces, and global statistics on aerosol radiative forcing estimates that will support Government decision making. Dr. Zubko is working on improved 3-d cloud physics as part of the atmospheric algorithm development activities of the group.

The processes of algorithm development and validation merge into large-scale data analysis over global and continental scales. The African continent is the major focus of Dr. Anyamba, who is studying the El Niño/Southern Oscillation (ENSO) effect on vegetation and fire patterns using data from the NOAA Advanced Very High Resolution Radiometer (AVHRR). Dr Defourny's research focuses on the combined use of several remote sensing technologies for forest and crop monitoring. A further regional study, conducted by Dr. Yurchak, investigates the combination of remote sensing technologies, geographic information systems (GIS), and local, ground-based knowledge to manage information that addresses the reindeer population of Arctic regions.

In addition to the meteorological and biophysical aspects of terrestrial applications, this group also studies regional and global gravity and magnetic affects. These studies link ground measurements to satellite missions. Dr. Kim is concerned with magnetic anomalies, particularly in the Antarctic. Many of the gravity and magnetic techniques used here are being applied to Martian studies. Dr Freund is investigating how tectonic stress within the Earth's crust may be manifested at the Earth's surface as electro-magnetic effects that may cast new light on ionospheric perturbations and may be precursor indicators of impending major earthquakes.

This summary and this year's impressive publication and presentation record this year show the group's research interests, which cover not only a variety of high-level terrestrial physics applications, but which also span the full development cycle of remote sensing technologies.

Peter Merheim-Kealy

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/GSFC), Edwin Pak (SSAI/GSFC), Doorn Bradley (USDA/FAS), Curt Reynolds (USDA/FAS), LT. Jean-Paul Chretien (DoD/WRAIR-GEIS), Sheryl Bedno (USAMRU & GEIS-Kenya), Kenneth Linthicum (USDA-Center for Medical, Agricultural & Veterinary Entomology)

Abstract

This research focuses on the land surface patterns of interannual variability using time series vegetation index data derived from measurements made by National Oceanic and Atmospheric Administration (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, 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 work in environmental analyses for famine early warning, as well as the agricultural monitoring activities of the United States Agency for International Development (USAID) and United States Department of Agriculture /Foreign Agricultural Service (USDA/FAS). Additionally it impacts analysis of disease outbreak patterns of NASA's initiative on Environment and Human 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 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 we have identified two periods of differing anomaly pattern. Firstly, 1982-1993 marked by below average NDVI and persistence of drought with a signature large scale drought during the 1982-1985 period. Secondly, 1994-2003, marked by a trend towards "wetter" conditions with region-wide above normal NDVI conditions with 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 in press). 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 region during the summer of 2003 continues rainfall trends observed over the region since 1994. Flooding along the Senegal River created conditions for Rift valley fever (RVF) outbreaks which were reported in the region from October through December 2003. In addition, rainfall primed the environment for the initial breeding and subsequent large scale outbreaks of the Desert Locust Schistocerca gregaria (Forksal) in the spring and summer of 2004 that has been the worst in the last 10 years. This poses a great threat to both subsistence and export agriculture across the Sahel region of West Africa and northwestern African countries. Currently we are 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

In the coming year, we will complete analysis of MODIS vegetation index time series in comparison with SPOT Vegetation and AVHRR NDVI time series to provide a coherent multi-satellite data base for agricultural monitoring purposes and to examine patterns of agricultural production in Australia, Africa and South America. In addition, we will investigate the potential for using MODIS data to derive a vegetation-water stress index for large scale agricultural monitoring. The existing work on RVF monitoring will continue in support DoD/GEIS activities. 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 NCC5-494: **Integration of MODIS and AVHRR Time Series with SPOT VEGETATION Products Towards Consolidated Land Observation**

GEST Investigator: Pierre Defourny

Collaborators: Compton Tucker (GSFC), Assaf Anyamba (GEST), Jorge Pinzon (SSAI), Chris Justice (UMD)

Abstract

Research on medium and coarse spatial resolution time series has produced various regional and global land products but their combined use to support the end-users remains an area of research. The overarching research question is how can these data be combined to utilize the main strengths of the various products to enhance the quality and the robustness of the operational applications? During the first six months of the research, three case studies have been selected. The first one focuses on the combination of the GLC2000 global land cover derived from 1-km multispectral SPOT VEGETATION time series with the 26-year long-term AVHRR NDVI times series recently released by the GIMMS group. The second concerns the synergy of daily MODIS and SPOT VEGETATION data for crop monitoring. The last case study aims to develop an international platform to consolidate the forest mapping and monitoring effort in the framework of the Congo Basin Partnership.

Description of Research

Research on medium and coarse spatial resolution time series has produced various regional and global land products. From the user perspective, these products' diversity has to be transformed into consolidated and uniform output. For technical and programmatic reasons the operational combination of these products has not been fully investigated. Therefore the research objective of this one year study is to propose a pathway to develop synergistic use of the data currently available for three main application areas: the global land cover mapping, the agriculture monitoring and the tropical forest monitoring.

Accomplishments in the Reporting Period

During the first six months of the research, three case studies were selected in order to enhance the quality and the robustness of the operational applications. They all took advantage of recently released data sets and on-going NASA projects.

The first case study aimed to combine the great spatial consistency of the GLC2000 global land cover map with the unique long term AVHRR NDVI time series in order to consolidate class labeling and to characterize their respective phenology. Indeed recent research completed in the NASA GIMMS group succeeded in correcting the 8-km AVHRR NDVI product for the orbital drift induced changes in the sun-target-sensor geometry and for the difference in sensors' calibration. This research effort provided the first global long term record derived from remote sensing for ecological applications. The Global Land Cover 2000 map was also recently produced from a year-long 1 km multispectral global time series acquired by SPOT VEGETATION. While very heterogeneous from the methodological point of view, this product was found spatially very consistent and included 16 different land cover classes. The on-going research tries to combine the temporal information derived from the GIMMS NDVI time series with the GLC2000 class delineation to consolidate this global land cover information. Pilot processing for Africa is on-going.

The second case study investigated how the daily multispectral MODIS and VEGETATION observations could improve current operational crop monitoring systems. Three tests of 1000 x 1000 km were selected for the method development. This included alternative compositing strategy development and crop-specific information extraction from the 250-m

MODIS Surface Reflectance product. Major investment was made to take advantage of the existing MODIS and VEGETATION experiences.

Finally, the third case study deals with technical and institutional development to propose an international platform in order to combine the various on-going various forest mapping and monitoring efforts in the framework of the Congo Basin Forest Partnership (CBFP). Indeed, the CBFP initiative launched in September 2002 at the World Summit on Sustainable Development in Johannesburg, South Africa, aims to improve communication and coordination among its 29 member governmental and non-governmental organizations vis-à-vis their projects, programs, and policies to promote sustainable management of the Congo Basin Forest ecosystems and wildlife and improve the lives of people living in the region. Such coordination and the identification of priorities require a better knowledge of the current situation and monitoring of the forest ecosystem. The diverse sources of data and the lack of international coordination among the information provider programs prevent the delivery of up-to-date and synthetic information to decision makers at the regional level. Based on the CBFP structure, an international platform for scientific and technical cooperation was proposed to improve significantly the information production and dissemination process. The USAID Central African Regional Program for the Environment (CARPE) is a 20-year regional initiative started in 1995. The program includes a remote sensing component providing land cover map, forest change map and deforestation monitoring. Other international partners of CBFP have also developed regional activities in this field. The institutional challenge is to combine the best available data to deliver synthetic information to the decision makers. The first report on the state of the forest entitled "The Forests of the Congo Basin – A preliminary Assessment" included some international contributions and was successfully published by the CARPE Editorial Board early February 2005. As a follow up of this first success an international discussion is being conducted to develop an institutional framework for technical collaboration. Meanwhile specific technical solutions have to be identified to combine recently produced local and national land cover maps and regional deforestation change mapping.

Objectives for the Coming Year

The first two case studies respectively related to the AVHRR-GLC2000 land cover fusion and the MODIS-VEGETATION complementary for crop monitoring will be completed in the upcoming five months. Their experimental results are expected to be submitted to peer reviewed scientific journals for publication. For the third case study supporting the CBFP initiative the institutional development should receive some international support during the coming year and the technical methodology must be proposed to consolidate this information.

Task C-00-923-02: **AERONET Ground Based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Oleg Dubovik

Abstract

Research performed during this fiscal year addressed several aspects. The main efforts were focused on the development and implementation of new AERONET inversion code aimed at improving aerosol retrieval products for AERONET. The new inversion code has a number of unique capabilities: the retrieval code can utilize the measurements from different observational geometries (e.g. solar almucantar and principal plane); simultaneous retrieval of aerosol and surface properties from combined up-looking ground based measurements and down-looking satellite or aircraft measurements. Polarization capabilities were added to the retrieval code. The code has shown good performance in inverting new AERONET data were intensity and polarization is measured at

five wavelengths. In both intensity and polarization retrievals AERONET has a unique capability to account for particle non-sphericity by employing light scattering of poly-disperse randomly oriented spheroids instead of conventionally used spheres. This capability was proposed for desert dust retrievals and implemented in operational AERONET processing. The spheroidal model was also successfully tested for fitting laboratory measurements of full scattering matrices. Also, effort was spent on developing retrievals of aerosol emission from global satellite observations using the GOCART aerosol transport model. Specifically, the method uses an "adjoint" operation to the aerosol transport of the GOCART model that allows inversion with the original space (2 x 2.5 degrees) and time (20-60 min) resolution of the GOCART model. A version of retrieval algorithm has been developed, tested and applied to the retrieval of location and strength of fine aerosol emission from a combination of MODIS and AERONET observations. In addition, there were a number of collaborations with other researchers involved the analysis of AERONET aerosol retrievals in different specific locations and time periods. Nineteen peer-reviewed journal papers that were authored or co-authored by the GEST center PI were published, or accepted during this time period.

Description of Research

The lack of detailed knowledge of the optical properties of aerosols is recognized as one of the largest uncertainties in climate forcing assessments. Ground-based aerosol remote sensing does not provide global coverage; however its wide angular and spectral measurements of solar and sky radiation are best suited to reliably and continuously derive the detailed aerosol optical properties in key locations. Therefore, ground-based aerosol measurements are widely used for both the validation of satellite retrievals of aerosol properties and derivation of high accuracy information on local aerosol properties. The research in this GEST activity is focused on the development and improvement of the retrieval algorithm deriving detailed aerosol optical and microphysical properties from the measurements made by automatic sun-sky scanning radiometers of the Aerosol Robotic Network (AERONET; project leader: Brent N. Holben, GSFC). AERONET was initiated by NASA as one of the major ground-based remote sensing facility aimed for validating aerosol retrieval by sensors based on EOS platforms. In addition, the research activity includes analysis of aerosol retrievals based on a combination of AERONET data with co-located satellite and aircraft data.

Accomplishments in the Reporting Period

In this fiscal year, a book chapter [Dubovik, 2004] has been published. The chapter proposes a generalized multi-term least-square-type formulation that complementarily unites advantages of a variety of practical inversion approaches, such as Phillips-Tikhonov-Twomey constrained inversion, Kalman filters, Newton-Gauss and Levenberg-Marquardt iterations, etc. The proposed methodology has resulted from multi-year efforts to develop inversion algorithms for retrieving comprehensive aerosol properties from ground-based data.

The paper [Dubovik et al. 2004] has been published on the possible use of satellite observations to independently derive the global distribution (and strength) of aerosol emission sources that is recognized as a major factor limiting the accuracy of global aerosol modeling. The paper describes and tests a method for retrieving global sources of absorbing (fine mode) tropospheric aerosols from satellite observations by inversion of Georgia Tech/Goddard Global Ozone Chemistry Aerosol Radiation (GOCART) model. This model uses the assimilated meteorological data from the Goddard Earth Observing System Data Assimilation System (GEOS DAS) and provides four-dimensional distribution of aerosol mass at several atmospheric layers (20-30) with horizontal resolution of 20 latitude by 2.50 longitude. The model time step is 20 minutes for advection, convection and diffusion and 60 minutes for other processes. The developed inversion method uses a so-called "adjoint" operation to the aerosol transport model. The approach based on developing an "adjoint" operator reduces computational requirements of the inversion to match the computation

requirements of forward modeling. Both numerical test and the results of actual MODIS data inversion have shown that the developed method allows the appropriate retrieval of the location and the strength of the global aerosol emission.

The GEST Center PI also contributed to several other papers studying various aspects of optical, physical and chemical aerosol properties.

Objectives for the Coming Year

A primary objective for next year is to further development and improvement the inversion code employed by AERONET for retrieval aerosol optical properties from measurements of atmospheric radiation. Specifically, it is planned to explore the potential of full polarization measurements in operational AERONET retrievals. Also, it is planned to establish a new approach for retrieving both surface and aerosol properties from combined AERONET/satellite data. In addition, it is planned to continue developing global measurements/modeling inversion approach.

Task 00-923-02: **AERONET Ground Based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Thomas F. Eck

Collaborator: Brent N. Holben (GSFC)

Abstract

Analysis of aerosol optical properties from various sites in Asia and other locations allow us to study the dynamics of biomass burning and urban/industrial aerosol optical properties and the transport of aerosols in this region. These properties can vary with seasonal and regional changes. Also examined are the large dynamics in both size distributions and spectral single scattering albedo by quantification in both the fine and coarse mode dominated aerosol cases.

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 climate and for the validation of satellite retrievals of aerosol properties. This GEST task is centered on the analysis of measurements made by automatic sun-sky scanning radiometers which are globally distributed as a part of the NASA managed Aerosol Robotic Network (AERONET; project leader: Brent N. Holben, GSFC). The measurements of spectral direct sun intensity and sky radiance distributions are utilized to infer a complete description of the column integrated optical properties of the aerosols. These ground-based remote sensing retrievals of aerosol optical properties are analyzed to better understand the dynamics of aerosol properties as a function of source region, transport, aging processes, and interaction with clouds.

Accomplishments in the Reporting Period

Attended the AERONET Workshop in La Rabida, Spain from May 10-14, 2004 and presented a seminar titled "Aerosol Optical Properties in Southeast Asia From AERONET Observations" [Eck et al. 2004]. Also, at the AERONET workshop, made a presentation on the AERONET methodology for reference instrument calibration and field instrument inter-calibration. Participated in workshop discussions regarding the AERONET federated network, including instrument calibration at distributed sites. Continued 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. The almucantar retrievals processed with the new Dubovik spheroid model algorithm were utilized since non-spherical desert dust particles are frequently present in this region in spring. 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. A journal paper on this analysis is currently in press at the *Journal of Geophysical Research*. Traveled to the United Arab Emirates (UAE) in August 2004 for two weeks in order to participate in the Unified Aerosol Experiment in the UAE or UAE2. While in the UAE the focus was on troubleshooting AERONET instrument problems at AERONET sites that were priority sites for aircraft flight missions. Attended the first UAE2 workshop in Monterey, CA from February 9-10, 2005 and presented analyses on the spatial and temporal dynamics of aerosol in the region with emphasis on the fine mode pollution component. Specific meteorological event case studies during UAE2 were analyzed, with special emphasis on the fine mode particle dynamics. Additional analysis compared aerosol optical depths (AOD) at a mountain site in UAE to one near the base to study vertical aerosol distribution and also comparison of AOD between an AERONET site on the Persian Gulf to one on the Gulf of Oman (a mountain range separates these two sites). Analysis of the aerosol optical properties in Thailand and Vietnam continued, most recently including comparison of MODIS instrument satellite retrievals of AOD to measurements made at AERONET sites. A presentation describing this analysis of Southeast Asian AERONET data was made at the AGU Fall Meeting in San Francisco on December 15, 2004. The PI also received the American Meteorological Society (AMS) Editor's Award from the *Journal of Applied Meteorology* at the AMS Annual Meeting in San Diego on January 12, 2005. The citation for this award reads "for exercising extraordinary diligence and tact in a review that led to notable improvement of an important piece of work." Additionally, the PI 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) 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 retrievals of aerosol size distributions, refractive indices, and single scattering albedo from sites that typically are dominated by fine mode aerosols. Another topic of focus will be the analysis of data collected from the mesoscale network of AERONET sunphotometers located in the UAE in summer of 2004. These sites often exhibit 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 products from MODIS as an input to the retrieval.

Grant 00000977: **Closure in Model Prediction, In-Situ Measurements and Remote Sensing of Aerosol Mass Concentration**

GEST Investigator: Santiago Gassó

Collaborators: Si-Chee Tsay (GSFC), Jeffrey Reid (NRL/Navy), Douglas Westphal (NRL/Navy)

Abstract

Aerosol Fine Mode Fraction (FNM) is one of the MODIS derived parameters used as an indicator of anthropogenic activity, but the realistic validation of such a parameter has not yet been achieved. Data from the ACE-Asia field campaign is used to compare remotely derived FNM with the same parameter derived from *in situ* measurements. The comparison shows that the remotely sensed FNM is fairly close to true

(*in-situ*) values. In addition, it is shown that FNM is a good proxy of human activity only when single layers of aerosols are present in the column. When multiple layers are present, the FNM approximates to an average of the FNM of the individual layers in the column. In addition, it is found that FNM correlates very well by physical properties such as ratio of accumulation mode to total mass concentration.

Description of Research

Satellite remote sensing and dispersion models are excellent tools for global characterization of aerosol distribution. Satellites measure the actual aerosol content and the models simulate the physical and chemical processes that result in the observed aerosol distributions. By comparing them, it is possible to obtain a realistic picture of aerosol global distribution and investigate different climatic effects. However, satellite retrievals derive optical parameters such as the optical depth whereas aerosol models predict mass concentrations. Prior to comparing both derivations, a conversion must be performed either from optical depth to mass or vice versa. The latter has been the method of choice in the most recent studies. However, little attention has been paid to the transformation from optical depth to mass. The object of this project is to explore the advantages and limitations of deriving aerosol mass concentrations from satellite optical properties.

Accomplishments During the Reporting Period

The first phase of this project focused on the improvement of retrievals of aerosol mass concentration using the MODIS sensor onboard the Terra and Aqua satellites. Currently, the MODIS standard aerosols retrieval algorithm does not provide a reasonable estimate of aerosol mass concentration [Gassó and Hegg 2003]. Any estimation of mass concentration from space relies on a parameterization of the aerosol parameters derived by MODIS, namely optical depth, FNM and effective radius. Although several studies exist focusing on the accuracy of optical depth retrievals, very few have focused on FNM validation. Because the latter determines the proportionality constant between optical depth and mass concentration, an estimation of the validity of FNM retrievals was attempted. The database selected for comparisons of retrieved and measured fine mode fraction was extracted from the Aerosol Characterization Experiment – Asia (ACE-Asia) data set. FNM was derived using a method developed by O'Neill *et al.* [2001] using as input the optical depth measurements from the same sun photometer both onboard an aircraft and used to measure the *in situ* fine mode fraction. The data preparation required the selection of a number of profiles where optical depth, *in situ* size distribution, and fine mode measurements were simultaneously available in the column. In addition, a series of corrections to the *in situ* measurements of optical properties were applied. As result, a total of 20 profiles (out of 28 available) were selected for comparisons.

The comparison between retrieved and *in situ* optical depth was excellent ($r^2 = 0.89$) and it shows that the *in situ* data selected is able to reproduce the ambient optical properties measured by the remote sensing instrument. The comparison between retrieved and measured FNM showed that the O'Neill method tends to underestimate with respect to the *in situ* data. This result is in agreement with Kleidman *et al.* [submitted] who intercompared the O'Neill method with different remote sensing instruments (AERONET and MODIS).

The derived and measured FNM for a whole column tends to be clumped in the value range from 0.4-0.8. Since many of the profiles during ACE-Asia contained aerosol layers with distinctive physical features in the column (namely a pollution layer near the surface and a dust layer aloft), a new method of comparing retrieved and *in situ* data was successfully attempted by using information of individual layers in each profile. As a result, the number of points available for comparison was expanded and the magnitude of FNM extended to 0.1-0.9 reflecting the nature of each layer.

These results highlight an important point. FNM can be used as a proxy for human activity (either smoke or pollution with associated FNM of 0.8-1.0) as long as there is a single layer in the column. If multiple layers are present, such as

those observed during ACE-Asia, the resulting FNM is characteristic of an intermediate value of the FNM of the layers present in the column. Once we validated that the *in situ* data reproduces the retrieved optical properties, we compared the *in situ* FNM with *in situ* aerosol size distribution parameters. The comparison showed that FNM correlates very well with those ratios. This suggests that FNM can be a good proxy of the physical properties that can be obtained by global models.

Objectives for the Coming Year

Our first objective is to model the FNM and look for possible relationships (and if possible a parameterization) with the aerosol volume concentration. Secondly, we will add to our ACE-Asia comparison FNM derived by MODIS that will become available during the next year [Allen Chu, personal communication]. Finally, we would like to extend these comparisons to data from other experiments such as the SAFARI and PRIDE.

Task 900-03-041: **Spectral, Angular, and Vertical Characterization of Aerosols for Radiative Properties**

GEST Investigator: Charles K. Gatebe

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

Abstract

Research under this task has led to extension of a sophisticated aerosol inversion scheme developed for Aerosol Robotic Network (AERONET) 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. This research is in the second phase where tests and validation of the new algorithm are being conducted. By using CAR data from different parts of the world—southern Africa, East Coast of the United States, Brazil, and the Persian Gulf region—a wide variety of aerosol types will be encountered, including biomass burning, sulfate, biogenic, marine, desert, and continental. This will make the algorithm more useful for deriving aerosol effects on radiation budgets and to test and advance models of aerosol optical properties and their relation to aerosol chemical and physical processes. The new algorithm will also be used for performing atmospheric correction from the CAR measurements, especially the surface bidirectional Distribution Reflectance Function (BRDF) needed for developing, validating and applying models to data products from such sensors as Moderate-resolution Imaging spectroradiometer (MODIS), Multi-angle Imaging Spectroradiometer (MISR), Polarization and Directionality of Earth's Reflectance (POLDER), and Sea-viewing Wide Field-of-view Sensor (SeaWiFS).

Description of Research

This study seeks to characterize aerosol 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), and the Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS, July-August 2001). 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 MODIS and the Tropospheric Ozone Measuring System (TOMS).

Accomplishments during the Reporting Period

One of the major accomplishments during this period was achieved in developing a code for combining multi-instruments data – CAR, AERONENT, and Ames Airborne Tracking Sensor (AATS) to retrieve comprehensive aerosol properties and surface BRDF with the new inversion algorithm. This work was done in collaboration with O. Dubovik (GEST), A. Sinyuk, Gala Wind, and G. T. Arnold (SSAI). In addition, the new algorithm was modified to allow inversion from CAR data alone, and/or combined with AERONET, and/or AATS, and involved detailed study of different assumptions made in the accuracy of each data source and impacts on the quality of the retrieved products. The representation of surface bidirectional reflectance continues to be a major factor in radiative transfer models. Work has commenced to examine impacts on retrievals using two types of BRDF models (*e.g.*, the linear hybrid model and the Modified Rahman-Pinty-Verstraete model).

Under this task, we participated in the International Radiation Symposium 2004, which took place in Busan, Korea from August 23-28. Results of CAR measurements of the ocean BRDF acquired during the Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) campaign of 2001 [Gatebe *et al.* 2005] were presented at this symposium.

Work on installing CAR on a new aircraft owned by South African Weather Service began in May 2004. A lot of effort has gone into conceiving, designing and developing a new mounting frame and fairing for CAR, performing structural tests, arranging for inspection with South Africa Civil Aviation Authority (CAA), and preparing source documentation. This project is now gearing for final inspections of the CAR mounted on the aircraft. Also planned are flight tests to determine the new 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.

Objectives for the Coming Year

Using the new inversion algorithm described in the foregoing sections, the investigators plan to retrieve 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 in this proposal with CAR data acquired while underflying 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 923-46-188: **NPP Algorithms and Data Systems**

GEST Investigator: Peter Merheim Kealy

Collaborators: Bruce Guenther (GEST), Robert Murphy (IPO), Jeff Privette (GSFC), Neal Baker (IPO)

Abstract

This research involves science and engineering support to the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) mission. The research focuses on the area of algorithm development and algorithm operational implementation for near real time weather and tactical purposes. The NASA NPP will provide data continuity between EOS era measurements and the NPOESS measurements. This research supported the NPP that relies on NPOESS for sensors and ground segment processing. Divergences between the needs of real time operational users and the NASA long-term climate mission are being identified and optimal solutions sought.

Description of Research

The main purpose of this research is to support the NPP team and the Integrated Program Office (IPO) in the optimal development for the output products required. The operational products may be used as a basis for research by the climate community. The algorithm optimization process impacts all subsystems within the program from sensor requirements, algorithm integration within the operational ground system, through to on-orbit calibration and validation strategies. The research is accomplished through technology review and project coordination among government, industrial and academic partners.

Accomplishments During the Reporting Period

As the NPOESS and NPP systems are under development, the results of this research are used primarily as inputs to the continuing system design and optimization of these multi-billion dollar programs. The results of research are usually delivered as presentations and technical memos at internal program meetings.

A major thrust to this research has been support to the NPP Science Team that was selected in October 2003. Their remit is to assess the

suitability of the real time operational products as a basis for climate data records. The Science Team is organized into several disciplines: land, oceans, atmosphere, atmospheric soundings, and ozone. This task helped coordinate the flow of information between the team and appropriate entities within the government and industry.

The NPP program contains an SDS (Science Data Segment) which is the ground Algorithm processing capability dedicated to the NASA-centric climate processing needs of the climate research community. This task helped define the functionality of the elements within the segment. In addition this task has supported risk reduction engineering opportunities regarding the Command, Control and Communication (C3) and the operational ground processing segments to ensure that low level capabilities are in place and validated prior to launch.

A further accomplishment of this research is the refinement of operational algorithms. A large amount of the task has been devoted to improving the geophysical processing code as it is transformed into operational code. This is done in close coordination with the NPP Science Team and industry. A particular focus has been on the processing of raw satellite data into calibrated radiances that form the basis of downstream products. Both on-line and off-line components have seen improvement over this period.

As the space borne sensors are built and tested certain sensor features are observed. Research was conducted to fully characterize the effects and to suggest hardware or software mitigation strategies.

Objectives for the Coming Year

The algorithm related system engineering optimization will continue in the next year. A focus will be on influencing the on-ground sensor test programs and their interaction with the calibration and geophysical products. Support to the NPP science team continues, as will support to the development of the NPP Science Data Segment that will be used as an interface from the NPOESS system to the global climate research community.

Task 000-00-975: **Antarctic Comprehensive Model from Airborne, Shipborne, Ground, Satellite Magnetometer Data**

GEST Investigator: Hyung Rae Kim

Abstract

An Antarctic Comprehensive Model (ACM) is proposed to represent all the internal and external geomagnetic components. Spherical cap harmonic expansions that represent the model will be implemented up to maximum index of 120 (equivalent 110 km wavelength or to order 360 for global spherical harmonics, in the region below 60°S latitude). The Comprehensive Model (CM4) by Sabaka *et al.* [2004], which is globally represented from spherical harmonics up to degree and order 65, was more representative of the field in equatorial and mid-latitudes than the high latitudes since CM4 only partially accounted for the complicated external fields predominant in polar regions. Because of this, such external field coupling can mask internal fields. The ACM is integrated with gravity-derived crustal thickness variations relevant for retrievals at satellite altitudes. The proposed ACM also includes the ADMAP magnetic data to constrain the predictions at the surface, which were not modeled in CM4 because of the insufficient amount of global surface data. This proposed ACM is possible because all the necessary data sets are available including aeromagnetic, shipborne, ground and satellite data as well as the data from the 25 magnetic observatories in the Antarctic. The modeling techniques required for the implementation of this model are already developed.

Description of Research

The internal part of the main magnetic field and its secular variations over the Antarctic were

developed by De Santis *et al.* [2002] and Gaya-Piqué *et al.* [2004] using a spherical cap harmonic analysis. They recently produced regional components from Ørsted and CHAMP satellite observations, respectively, and by using the same technique we will combine these with the longer wavelengths (>100 km) ADMAP data. To obtain such resolution, conventional global spherical harmonic expansions have to be computed to degree (*n*) and order (*m*) 360 (110 km wavelength), which has not yet been done because it causes an ill-posed inversion, especially at the higher-order coefficients due to the large number of parameters. The most recent global spherical harmonic CHAMP model was computed at *n* and *m* 90 or 440 km wavelength [Maus *et al.* 2004]. However, for spherical cap harmonics, the half-angle cap size required to cover the study area is 30°. Therefore, we can compute a maximum cap harmonic expansion of index 120 (corresponding to *n* in global spherical harmonics), which will produce a 1° or 110 km wavelength resolution at the surface. This factor will expedite the computation speed and significantly simplify the inversion instability in the least squares scheme. We expect to gradually increase the maximum order to about 0.5° or 55 km wavelengths at the surface. To model the external fields we will characterize 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. The long-wavelength magnetospheric current field component in the measurements can be determined in the first index terms as function of Dst [DEFINE] values, which was commonly used in global harmonics. The induced field from the magnetospheric currents can be derived in a similar way to Magsat by Langel *et al.* [1996]. For the polar ionospheric and field-aligned current fields, Ritter *et al.* [2003] detected PEJ magnetic field from CHAMP satellite data and found a good agreement with the ground observatory network data. Torta *et al.* [1997] developed the spherical cap harmonic model for the ionospheric current field and its induced field from the European observatory data and Weimer [2003] constructed field-aligned current model from DE-2 and ground data using the spherical cap expansions. Therefore, we will implement these techniques to characterize the polar external fields in the region south of 60°S latitude. In particular, note that it is known that in polar regions, field-aligned currents (FAC) in the ionosphere and magnetosphere are predominant in the horizontal component (X and Y) measurements. The concurrent measurements from several satellites orbiting at different local times and locations (future SWARM constellation mission) will permit us to model explicitly these external fields because the gradient measurements from SWARM data will be useful to regularize FAC that tends to show great disturbance in these component measurements. Therefore we will have the computer analyses ready in advance of the SWARM mission.

Accomplishments During the Reporting Period

The investigator made progress in the computation of spherical cap harmonic expansions with high indices equivalent to the wavelengths criteria for the representation of magnetic anomalies. In order to see the high frequency features at a lower altitude, the spherical cap index necessary for half-angle cap of 30 degrees is up to 120, which is equivalent to degree 360 for spherical harmonics for the global representation. To deal with this size of non-sparse matrices, parallel programming is very helpful to speed up the computation to get 1.46×10^4 unknown coefficients. As a result, all the programs are being parallelized and run in a supercomputing cluster. This modeling will be extended, using the novel method by Kim *et al.* [2004], to extrapolate into areas where no observations are available in the ADMAP compilation. Furthermore, the World Digital Magnetic Anomaly Map (WDMAM) project was launched to grid all the available surface digital magnetic anomaly maps to the Earth's surface. This Antarctic magnetic modeling will give insight into the structure of the magnetic anomalies with altitudes that lead us to better understand the crust and history of the Earth.

The investigator has collaborated with a Hungarian colleague (Dr. Kis) on geological modeling over the Pannonian Basin in Hungary. Dr. Kis was invited by Dr. Taylor (GSFC) to present his algorithm in gravity modeling last

November and has completed the work, using CHAMP satellite data provided by Dr. Kim, for submission of this research. Another colleague from South Korea also visited last April, and introduced a space project with multi-satellite missions of South Korea. Dr. Kim is collaborating in this project and recently submitted the paper to a Korean journal about the utilization of scientific satellite data.

Objectives for the Coming Year

The investigator plans to participate in AGU Spring meeting in New Orleans this May for the study of Antarctic magnetic modeling. Also, this work will be subitted to the IAGA meeting which will be held in Toulouse, France this July. Currently in revision is an accepted paper that will give new insight on the reconstruction of Southeast Indian Ocean and East Antarctic plates using aeromagnetic and satellite magnetic observations. Upon the acceptance of the pending proposal to Mars Data Analysis Project sponsored by NASA, we will start researching the magnetic field of Mars. Ongoing is an active collaboration with OSU on a paper regarding the history of Mars' magnetic field. A number of other ongoing activities include geopotential modeling of Iceland and satellite gravity-derived crustal thickness modeling in Greenland.

Task 913-54-205: **Testing, validating and improving the MODIS aerosol algorithms and products.**

GEST Investigator: Rong-Rong Li

Collaborator: Yoram Kaufman (PI, GSFC), Lorraine Remer (PI, GSFC)

Abstract

Atmospheric products have been derived operationally from multi-channel imaging data collected with the Moderate Resolution Imaging Spectro Radiometers (MODIS) on board both the NASA Terra and Aqua spacecraft. The MODIS aerosol algorithms are developed to provide the global aerosol information over land and ocean on the daily, monthly, and yearly basis. Accurate derivation of aerosol products on the global scale is important and quite difficult. This research is to test, improve, and validate the MODIS aerosol algorithms and products.

Description of Research

The central goal of the MODIS aerosol research group is to develop aerosol algorithms for retrieving global aerosol properties over land and ocean from the Terra and Aqua MODIS data sets. The research also includes scientific investigations of aerosol radiative forcing on climate, aerosol cloud interaction, and fire/smoke/burn scar environment.

Accomplishments during the Reporting Period

Several major accomplishments were achieved in this reporting period. Fires and burn-scar detection using MODIS Near Infrared Channels were investigated. Remote sensing of burn scars is important to the understanding of ecology and post-fire recovery. In contrast to active fires that last for as short as a few hours, burn scars generally last from a few weeks to several months, therefore potentially allow more reliable detection through satellite remote sensing. We developed a technique using MODIS near infrared channels (1.24 µm and 2.13 µm) to detect the burn scars. This technique is very useful for near real-time burn scar recognition in an operational direct broadcasting system. A paper based on this study was published in the jounal *IEEE Transactions on Geoscience and Remote Sensing* [Li 2004].

A technique for masking residual snow/ice to improve MODIS aerosol retrievals was derived. Through analysis of several years of MODIS aerosol products, we found that the aerosol products over land areas were slightly contaminated by snow and ice, particularly during the snow-melting season over the snow/non-snow boundary areas. We have developed an empirical technique using MODIS near-IR channels centered near 0.86 and 1.24

and an 11-µm thermal emission channel to mask out these snow-contaminated pixels. Improved aerosol retrievals have been obtained from both the Terra and Aqua MODIS data sets. The technique has been implemented into the recently updated Collection 5 version of the MODIS operational algorithm for retrieving aerosols over land. A paper based on this research was published in the journal of *IEEE Geoscience and Remote Sensing Letter*s [Li 2005].

Global cirrus detection and their effects on the aerosol retrievals were studied. Several quantitative evaluations of thin cirrus effects on MODIS aerosol retrievals have been made. The 1.38 µm channel on the MODIS is very sensitive to identify and quantify thin cirrus on a global basis. The channel is located in the center of a strong water vapor absorption band, which eliminates illumination from the earth surface and low clouds. This channel is used to produce the MODIS cirrus reflectance data product and to mask out cirrus for the MODIS aerosol products. Because thin cirrus occurs quite frequently, very few pixels would be available for aerosol retrievals if all the thin cirrus-contaminated pixels were eliminated. The MODIS Collection 4 aerosol algorithm adopted a compromise approach. Pixels with the 1.38-µm channel apparent reflectance values greater than or equal to 0.01 are screened out. Pixels with 1.38-micron channel reflectance less than 0.01 are assumed to be cirrus free, and aerosol retrievals are made from these pixels. The assumption would result in over-estimates of the values of MODIS AOTs over these pixels. The cirrus contamination effects on aerosol retrievals over ocean were estimated. The results from these studies were presented at the AGU fall Meeting in 2004.

Through this study, it has been found that the typical thin cirrus effects on AOT retrievals are in the range between approximately 0.01 and 0.03. The Aqua MODIS data show more cirrus clouds than the Terra MODIS data. As a result, the Aqua MODIS AOTs are affected more by thin cirrus clouds than the Terra MODIS AOTs. In the future, it is possible to remove the thin cirrus scattering effects during the MODIS aerosol retrieval processes.

Evaluation of cloud-aerosol mis-classification was studied. The accuracy of the MODIS cloud mask produced by researchers at University of Wisconsin was evaluated for possible contamination by areas of heavy aerosols. It has been found that the cloud products can be used in the presence of aerosol up to aerosol optical thickness of 0.6. For aerosols with optical depths greater than 0.6, the cloud products sometime incorrectly classify heavy aerosols as clouds.

Objectives for the Coming Year

Our objective is to further improve MODIS global aerosol retrievals. For example, the thin cirrus contamination effects in aerosol products should be removed. This task will analyze more MODIS data, and develop operational techniques for cirrus corrections. Another objective is to make quantitative studies on aerosol – cloud interactions.

Task 923-32-162: **Algorithm Analysis for Land Surface and Atmospheric Products for VIIRS**

GEST Investigator: Alexei Lyapustin

Collaborators: Yujie Wang, GEST

Abstract

In recent theoretical studies we 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 the 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, we are 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.

Description of Research

The main objective of our research is the development of advanced aerosol retrieval - atmospheric correction algorithms for the EOS MODIS imaging spectrometer, and Landsat ETM+ imager. These new algorithms are 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 (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 most accurate atmospheric correction of satellite data. This indirect approach can be used for validation studies over non-homogeneous surfaces at arbitrary spatial and spectral resolution of satellite measurements.

Accomplishments During the Reporting Period

In the past year, research focused on the development of the basic functionality of the ASRVN system, in collaboration with AERONET and MISR teams. As a result, we implemented a processing system that operationally receives Collection 4 MISR data for more than 160 AERONET sites globally and concurrent AERONET data on aerosol and water vapor, and makes automatic atmospheric correction. ASRVN generates the following products: bi-directional reflectance factors (BRF), surface albedo, vegetation indices, and incident and reflected radiative fluxes in the MISR bands for the area of 32 by 32 pixels at 1.1 km resolution around each AERONET site. Currently, we are working on the development of the user web-interface for the ASRVN products, which will be broadly used for the validation research. Based on our first results, we conducted a local validation study of MISR BRF and albedo products [Lyapustin *et al.* 2005]. This study showed that MISR offers high quality surface reflectance that correctly reproduces spectral dependence, time series, and spatial pattern. However, it also revealed that MISR BRF is slightly less anisotropic in the visible spectral range, and has a negative average albedo bias of -0.005. The paper by Lyapustin *et al.* [2005] gives a detailed analysis of simplifying assumptions of the operational MISR algorithm that may explain found discrepancies.

In parallel, research continued on the accurate parameterization of the radiative transfer code SHARM-3D that is required to develop efficient atmospheric correction algorithm for operational processing of satellite data. The research encompasses the 3D and broadband aspects of the radiative transfer. Based on obtained results, three publications will be submitted to the central peer reviewed journals in the March-May timeframe. In 2004, the radiative transfer code SHARM of Dr. Lyapustin obtained NASA copyright and received a NASA Space Act Award.

Objectives for the Coming Year

Our efforts, 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 present algorithm of atmospheric correction does not yet realize the full potential of MODIS measurements for climate change research. For example, retrieving the surface BRF in the Lambertian approximation, biases of aerosol retrieval over non-vegetated surfaces, absence of the radiative energy conservation constraint and other factors limit the accuracy of the MODLAND processing.

The second task will be the expansion of the ASRVN system to include operational

processing of MODIS data. With the development of the MODIS processing stream, this task will conduct an extensive validation analysis of MODIS surface reflectance products. With the accumulation of the ASRVN products from MISR instrument, validation assessment of MISR surface reflectance to the regional and global level using several years of reprocessed Collection 4 data will be extended.

Finally, as a part of a NPP grant, analysis will continue of the VIIRS aerosol retrieval and atmospheric correction algorithms/codes of NGST contractor. Also planned is the generation of synthetic VIIRS data with code SHARM-3D for evaluation of aerosol and surface reflectance EDRs.

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

GEST Investigator: Alexander Smirnov

Collaborator: Brent N.Holben (PI), GSFC

Abstract

Research performed during the last reporting period focused on the refinement of AERONET processing algorithms, and implementation of new precipitable water processing. Data acquisition with a hand-held sunphotometer in areas underrepresented in the AERONET system (both continental and over the oceans) provided an opportunity to create a link between new and previously acquired data. Participation in a major field campaign in the United Arab Emirates allowed improving significantly our knowledge on aerosol optical properties in that very complex region. Ten peer-reviewed papers authored or co-authored by the GEST investigator were submitted, accepted or 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 kinds of remote sensing measurements over direct in-situ aerosol sampling or laboratory analysis is their large-scale (column integrated quantities) and global sampling.

Accomplishments During the Reporting Period

The foundation of the AERONET measurements program is the study of aerosol optical depth. We improved processing algorithm using a new set of formulas for the computation of the molecular contribution into total optical depth based on the more accurate computations of the spectral depolarization factor for each constituent of air. New ozone climatology was implemented based on the twenty year Total Ozone Monitoring Sensor (TOMS) record and a new processing method for water vapor retrievals allowed elimination of the 13% bias of other methods and instruments. Certain improvements were made to account for water vapor absorption in the 1020nm channel. Necessary adjustments were made for a short-wave IR channel at 1640nm where the absorption of carbon dioxide, water vapor and methane can become significant, especially in the clear atmospheric conditions.

The study of the long-term regional aerosol variability is important especially in the areas where AERONET monitoring stations are absent. There are neither WMO Global Atmospheric Watch (GAW) sites nor AERONET sites in Central Asia and the scarcity of data obtained in that particular area motivate researchers to analyze and evaluate all available information. Atmospheric aerosol optical

properties over Isysk-Kul Lake (elevation 1650m) acquired with a hand-held sunphotometer can be considered background for central Asia and are in agreement with the multi-year means from background sites of the AERONET. Optical depth trends over Issyk-Kul Lake showed no changes in the aerosol loading in the last 10 years.

Aerosol optical depth measurements over the oceans included a transect in the Atlantic from the North Sea to Cape Town and then a crossing in the South Atlantic to Ushuaia, Terra del Fuego. The hand-held sunphotometer was pre-calibrated against the AERONET master-instrument and the AERONET processing algorithm was applied to the acquired data. Aerosol optical depth values were close to background oceanic conditions in the open oceanic areas not influenced by continental sources or long-range aerosol transport. Relatively turbid conditions in the Atlantic were associated with Saharan dust transport. Mostly important was the fact that in the "roaring forties" of the South Atlantic, aerosol optical depth was just occasionally slightly higher than in background oceanic conditions, varying mainly within same range as in other remote oceanic areas.

The United Arab Emirates Unified Aerosol Experiment (UAE2) was a multi-agency international initiative to study various aerosol types (dust, smoke and pollution) and their mixtures. AERONET established a mesoscale network of 15 instruments in the desert, coastal area and the Arabian Gulf. Particular dust and pollution events were studied in detail and synergy with the satellite information and transport models will be subject of the ongoing research. Deployed for the first time, a spectral polarization instrument allowed significant improvements in the determination of atmospheric optical state. Established regression statistics agree well with the qualitative analysis.

Objectives for the Coming Year

Our FY 05-06 goals focus on the development of the quality assured columnar precipitable water product, development of the cirrus cloud optical depth measurement methodology, participation in the UAE2 data analyses, and establishment of additional AERONET sites.

Task 900-37-172: **Simulation of Aerosol Effects on Climate**

GEST Investigator: Toshihiko Takemura

Collaborator: Yoram J. Kaufman (PI, GSFC)

Abstract

Global aerosol and cloud distributions from the year 2000 to 2004 are simulated by an aerosol transport-radiation model, SPRINTARS, which has been developed in previous studies. The simulated monthly mean parameters of aerosol and cloud are compared with the MODIS retrieval and then tuned by model parameters. The simulated aerosol optical thickness is simulated well over areas where a large amount of aerosols exists, though it is smaller than MODIS over remote areas from aerosol sources because of the possible MODIS aerosol optical thickness overestimates. The simulated cloud fraction and cloud droplet effective radius are in reasonable agreement with the MODIS retrieval including seasonable variations.

Description of Research

The MODIS retrieval by GSFC produces very useful data related with aerosols and clouds, enabling comparison of SPRINATRS with MODIS on the aerosol and cloud parameters which are important for evaluating the aerosol direct and indirect effects on global scale. Simulation of the climate responses to the aerosol effects such as change in surface temperature, hydrological cycle, and radiative budget due to anthropogenic aerosols with SPRINTARS validated by MODIS. To estimate the aerosol climate effects using the MODIS

data as mentioned above will be my contribution to NASA's efforts.

Accomplishments in FY 04-05

We developed a three-dimensional global aerosol transport-radiation model, SPRINTARS, which treats main tropospheric aerosols, *i.e.*, black carbon, organics, sulfate, soil dust, and sea salt. The model is coupled with an AGCM. The aerosol transport processes in the model include emission, advection, diffusion, sulfur chemistry, wet deposition, dry deposition, and gravitational settling. The aerosol direct effect, in which aerosol particles scatter and absorb the solar and thermal radiation, and indirect effect, in which they alter the microphysical and optical properties of cloud droplets acting as cloud condensation nuclei, are also calculated by coupled with the radiation and cloud-precipitation processes of the AGCM. Recently SPRINTARS has been connected with an ocean model, so that the climate responses to the aerosol direct and indirect effects can be evaluated. Takemura *et al.* [2005] indicated that a decrease in the cloud droplet effective radius by anthropogenic aerosols occurs globally, while changes in the cloud water and precipitation are strongly affected by a variation of the dynamical hydrological cycle with a temperature change by the aerosol direct and first indirect effects, in which the cloud droplet size decrease if the aerosol particle number concentration increases leading to the higher cloud albedo, rather than the second indirect effect, in which a decrease in the cloud droplet size results in an inhibition of precipitation and an increase in the cloud water. However, the cloud water can increase and the precipitation can simultaneously decrease in regions where a large amount of anthropogenic aerosols and cloud water exist, which is a strong signal of the second indirect effect. As mentioned above, we constructed an inclusive modeling system for the estimation of climate change by aerosol particles.

There is, however, still a large uncertainty in the aerosol effects on the climate system, especially in the aerosol-cloud interaction. The Third Assessment Report of the Intergovernmental Panel on Climate Change estimated that the global mean radiative forcing due to anthropogenic aerosols is 0 to -2.0 W m-2 without a plausible value for the first indirect effect, and could not do that for the second one because of much less confidence. Therefore the aerosol and cloud parameters retrieved from the satellite-borne MODIS sensor operated by NASA are introduced into the aerosol climate simulation by SPRINTARS in this research.

First, the aerosol and cloud distributions were simulated by SPRINTARS from the year 2000 to 2004 nudging the wind, temperature, and specific humidity by reanalysis data. A parameterization based on the Köhler theory has been introduced into SPRINTARS in which the cloud droplet number concentration depends not only on the aerosol particle number concentration but also the aerosol size distribution, chemical properties of each aerosol species, and updraft velocity. The horizontal resolution of the triangular truncation was set at T106 (approximately 1.125˚ by 1.125˚ in longitude and latitude), which was close to 1.0˚ by 1.0˚ resolution of quality-assured MODIS monthly data, and the vertical resolution at 20 layers. SPRINTARS was tuned by changing in aerosol- and cloud-related parameters using MODIS data. Then the simulated aerosol optical thickness is simulated well in urban, desert, and biomass burning regions where the aerosol optical thickness is high. It is, on the other hand, smaller than the MODIS over remote ocean regions from aerosol sources, though it is in good agreement with the ground-based aerosol remote sensing data from AERONET operated by GSFC. It is reported that the retrieval of the small optical thickness from MODIS is difficult. The simulated cloud fraction and cloud droplet effective radius are in reasonable agreement with the MODIS retrieval including seasonable variations, though the MODIS cloud droplet effective radius is a little higher systematically. The cloud optical thickness simulated by SPRINTARS and retrieved from MODIS are, however, largely different. The MODIS one is artificially high along coasts at high-latitudes, and the SPRINTARS one may also have a problem in a derivation method.

Objectives for FY 05-06

The simulated cloud top pressure will be compared with MODIS to verify the vertical structure of clouds. To analyze the simulated aerosol and cloud parameters in more detail, the MODIS daily data will be used. Then change in meteorological parameters not only cloud but also precipitation, temperature, and wind due to aerosol effects will be simulated and analyzed by SPRINTARS.

Task 923-32-162: **AERONET-based Surface Reflectance Validation Network (A-SRVN)**

GEST Investigator: Yujie Wang

Collaborators: Alexei Lyapustin (GEST), J. Privette (NASA)

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 a significant amount of effort. We present an alternative approach of indirect validation of the surface reflectance product over Aerosol Robotic Network (AERONET) sunphotometer sites. The concept is to collect the best ancillary information on atmospheric aerosol and water vapor to 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 a relatively large non-homogeneous area of study, and can be easily extended to a regional and then global scale within the AERONET infrastructure.

Description of Research

The main objective of this research is to develop an AERONET-based Surface Reflectance Validation Network (A-SRVN). This includes collecting the best ancillary information on atmospheric aerosol and water vapor through AERONET stations, developing a generic sensor and resolution independent aerosol retrieval/atmospheric correction algorithm and comparing retrieved surface reflectance with MISR and MODIS surface reflectance products.

Significant effort has been made in the development of the theory and numerical codes for 3-D atmospheric radiative transfer over non-homogeneous and anisotropic surfaces [Lyapustin and Knyazikhin 2001, 2002; Lyapustin 2002]. The new theory allows us develop a sensor and resolution independent algorithm that applies to all scales of remote sensing, different instruments and different sun-view geometries. Based on this new theory, we can develop an iterative algorithm to accurately retrieve land surface BRDF and albedo from satellite Top of Atmosphere (TOA) measurements with the help of in-situ AERONET sunphotometer measurements. In order to conveniently compare retrievals of this algorithm with MODIS/MISR products, two popular BRDF models are used separately to simulate land surface BRDF: the Li-Sparse linear hybrid model, which is used in MODIS BRDF product; and the MRPV model, which is used in MISR land surface reflectance products.

Accomplishments During the Reporting Period

In the past year, we successfully established an A-SRVN system which currently covers 32x32km areas around 166 AERONET stations. A rigorous 3-D radiative transfer atmospheric correction algorithm for MISR L1B data has been integrated into this system. Software has been developed for concurrent AERONET/MISR data receiving, data format conversion, data subsetting and database

management. This system is able to run under operation mode now.

As a preliminary step of validation, we also conducted a local comparison between our retrieval, MISR BRDF and albedo products over two sites, GSFC (Greenbelt, Maryland) and Mongu (Zambia), for 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 our retrieval, which leads to a conclusion that MISR Collection 4 offers high quality surface reflectance products, based on our limited number of sites analyzed.

Objectives for the Coming Year

We will develop a 3-D radiative transfer atmospheric correction algorithm for EOS MODIS data and integrate it into our A-SRVN system. Together with the algorithms developed for MISR images, the AERONET-based Surface Reflectance Validation Network (A-SVRN) will be fully established.

We also will develop a series of toolkit for this system, including an image reprojection tool, pixel time series retrieval, cloud mask generation, and other statistic tools.

Considering algorithm improvement, we plan to explore the use of "transient" model [Gao *et al.* 2000] in our algorithm, to eliminate the problem of negative values at high angles in the Li-Sparse linear hybrid model. We also plan to add a non-spherical solution of aerosol to our algorithm to extend the algorithm performance to the world locations where dust transport plays an important role.

Task 913-60-214: **Retrieving Aerosol Properties over Bright-Reflecting Surfaces: An Extension of Current MOD04/MYD04 Products**

GEST Investigator: Jennifer C. Wei

Collaborators: Chrsitina N. Hsu (PI, GSFC), Si-Chee Tsay (Co-PI, GSFC)

Abstract

Satellite remote sensing and retrievals of aerosols over bright-reflecting surfaces have been problematic for years. Over these regions, the surface contribution to the radiance received by satellite sensor is generally larger than that over vegetated areas. In addition, it is still not clear how the aerosol absorption and angular properties vary due to particle non-sphericity. As a result, even the most sophisticated satellite sensors (*e.g.*, Terra/MODIS) still could not provide information for the areas containing significant bright sources. Although recent operational studies have indicated that the aerosol retrievals from MODIS might be useable for reflectance up to 0.25, coverage will still be lacking over large portions of the Earth's surface.

Recently, we have developed a new algorithm, the so-called Deep Blue, to resolve the difficulty in retrieving aerosol properties over bright-reflecting surfaces. We applied this algorithm to the MODIS and SeaWiFS measurements, particularly over arid and semi-arid regions. In these research studies, the validity of aerosol products from Deep Blue will be examined extensively, using a synergy of ground-based and space-borne observations acquired from the Unified Aerosol Experiment in United Arab Emirates (UAE2) campaign 2004. Important issues in Deep Blue aerosol retrievals, such as the effects of polarization and surface bidirectional reflectivity, are addressed. A "minimum reflectivity technique" is used for processing a huge volume of global observations to generate a database of surface reflectivity.

Description of Research

This research is mainly to implement the Deep Blue algorithm for the use of MODIS satellite instrument over bright-reflecting surfaces.

Accomplishments During the Reporting Period

Satellite remote sensing in the presence of dust sources and where the underlying surface is bright, often lacks an accurate retrieval. A new algorithm was developed [Hsu *et al.* 2004], known as Deep Blue, to alleviate the bright-surface problem to further infer aerosol properties. MODIS is the sensor data used by the Deep Blue algorithm.

In order to retrieve aerosol properties, accurate knowledge of the underlying surface properties is important, particularly over arid and semi-arid regions. A new surface reflectance database is built for the 412, 470, and 670nm channels using MODIS radiances using the "minimum reflectivity technique," that required processing a huge volume of global observations.

A set of Look-Up Tables (LUTs) is being created using a polarized radiative transfer model [Dave 1972] for the simulation of radiances for a range of solar and viewing geometries at the top of the atmosphere (TOA) that encompass measurements from a satellite. However, the polarized TOA radiances measured by MODIS are sensitive to sensor effects. The sensitivity of the polarization correction is currently under investigation using pre-launch characterization data.

One of the key components for achieving accurate aerosol retrievals from satellite observations is a comprehensive understanding of surface spectral BRF's (Bidirectional Reflectance Factors). A spectroradiometer dataset is analyzed during UAE2 to characterize the surface spectral-directional reflectance. The spectral BRF's varied widely from less than 5% around 350 nm to over 40% at longer wavelengths.

Objectives for the Coming Year

A thorough sensitivity study for polarization correction will be investigated in the calculated radiances at 412 and 490 nm for a Rayleigh-scattering atmosphere. By utilizing the above outputs and techniques, we can then calculate aerosol index and aerosol optical depths. A better understanding in aerosol microphysical properties that represent different aerosol type will be investigated by incorporating data from both laboratory and aircraft measurements. Our objective is to enrich current MODIS level 2 products by adding absorbing aerosol index, aerosol optical depths, and aerosol particle size information.

Task 913-57-211: **Measurement-based Aerosol Radiative Effect and Forcing**

GEST Investigator: Hongbin Yu

Collaborators: Yoram Kaufamn (PI, GSFC), Mian Chin (PI, GSFC), Lorraine Remer (GSFC)

Abstract

The goal of this work is to review the measurement-based understanding of aerosol direct effect and forcing and to explore a use of emerging measurements from new and enhanced satellite sensors in reducing the uncertainty for model-based assessments. A measurement-based climatology of aerosol direct radiative effect is developed from AERONET measurements of a full set of aerosol properties in conjunction with MODIS albedo. It serves as a baseline product for evaluating model- and satellite-based assessments. To assess global aerosols and their direct effects, we integrate aerosol retrievals from MODIS and MISR with GOCART model simulations through an optimum interpolation with a Kalman Filter. The integrated global aerosol distributions are then used as inputs to a radiative transfer model for calculating aerosol direct radiative effects on solar radiation under clear sky conditions. The derived aerosol direct effects are compared with a dozen independent measurement-based and model-based assessments. A report documenting research findings will serve as one of a set of CCSP synthesis and assessment products that will

support policymaking, adaptive management and provide inputs to the fourth IPCC assessment.

Description of Research

The latest IPCC report based largely on model simulations summarizes that the uncertainty for the aerosol direct radiative forcing is about a factor of 2 to 3 and that for the indirect forcing is much larger and difficult to quantify. These uncertainties raise questions about the interpretation of the 20th century temperature record and complicate the assessment of aerosol impacts on the environment. Reduction of these uncertainties requires a coordinated research strategy that will successfully integrate data from multiple platforms and techniques. In recent years, a great deal of effort has gone into improving aerosol measurements and data sets, including the establishment of ground-based networks (*e.g.*, AERONET), the development and implementation of new and enhanced satellite sensors (*e.g.*, MODIS, MISR), and the execution of intensive field experiments in major aerosol regimes around the globe. As a result of these efforts it is now feasible to shift the estimates of aerosol radiative effect and forcing from largely model-based to increasingly measurement-based. Under the auspices of NASA HQ and the framework of the U.S. Climate Change Science Program (CCSP) we, in collaboration with aerosol scientists from an international community, are reviewing measurement-based understanding of aerosol direct radiative effect and forcing.

Accomplishments during the Reporting Period

Since its inception in 1993, the AERONET has been collecting a full set of aerosol properties needed for aerosol radiative effect calculations for both fine-mode and coarse-mode aerosols over about 200 stations around the globe. We take advantage of these valuable data to generate an aerosol forcing climatology that can provide the research community with a ground-based baseline product for evaluating satellite- and model-based estimate of aerosol direct effect. We also demonstrate how the aerosol direct solar effect is determined by a combination of aerosol and surface properties by looking at various aerosol types (biomass burning smoke, mineral dust, and industrial/urban pollution) under different geographical regions. Biomass burning aerosols are found to have an average aerosol direct effect (normalized by the visible optical depth) over South America that is larger by ~35% at the top of atmosphere (TOA) but smaller by ~38% at the surface than that over South Africa, because of stronger absorption by the South Africa smoke. The surface albedo is another important factor in determining aerosol direct effect, especially for mineral dust. As the surface albedo varies from ~0.1 to ~0.35, it is observed that the normalized aerosol direct effect by dust ranges from -44 to -17 Wm-2τ--1 at the TOA and from -80 to -48Wm-2τ-1 at the surface over the Saharan deserts, Arabian Peninsula, and their surrounding oceans. We also find that the normalized aerosol direct effect of fine-mode aerosol is larger at the TOA but smaller at the surface in comparison to that of all-mode aerosol because of its larger single-scattering albedo and smaller asymmetry factor. Cloudy-sky aerosol direct effect is usually not negligible for the MODIS observed cloud optical thickness but the TOA effect with clouds is sensitive to the relative location of aerosols and cloud layer.

Both satellite retrievals and model simulations have their own uncertainties and data assimilation or objective analysis should form an optimal estimate of aerosol distributions by combining them with weights inversely proportional to the square of errors of individual descriptions, as demonstrated in [Yu *et al.* 2003] for the MODIS and GOCART integration. In this CCSP work, we refined the integration approach mainly in two aspects. First we objectively estimated the uncertainty of GOCART simulations through comparisons with AERONET measurements. Second, MISR retrievals were incorporated into the process. In particular, we integrated GOCART simulations with MODIS retrievals over ocean and MISR retrievals over land, because of the high accuracy of MODIS over-ocean retrievals and the complete coverage of MISR over-land retrievals. Such integrations have been completed for year 2001 on a monthly basis. The integrated aerosol distributions were then used as inputs to a radiative transfer model to assess

aerosol direct effects on solar radiation, in conjunction with MODIS land albedo products and following the framework established in Yu *et al.* [2004]. In collaboration with a number of researchers from the international community, we have compared the calculated aerosol direct effects with independent assessments from measurements (*e.g.*, AERONET climatology, MODIS radiance, CERES broadband fluxes, POLDER radiance, SeaWiFS aerosols, and a number of intensive field experiments) and model simulations (*e.g.*, six AEROCOM models). Such comparisons show that an integration process can improve the model performance of quantifying aerosol direct effect. Our comprehensive review also resulted in the identification of outstanding issues and recommendations for future research priorities.

These research findings were presented at several scientific meetings, including AGU fall meeting, AEROCOM workshop, and NASA/GSFC aerosol update. We recently submitted a paper to the *Journal of Geophysical Research* that documents the methods of deriving aerosol forcing climatology from AERONET measurements and examines geographical variations of aerosol forcing determined by a combination of aerosol, surface, and cloud properties. We are documenting the intercomparisons of aerosol direct effect assessments from satellite and *in situ* measurements, model simulations, and satellite-model integrations. The document shall serve as a CCSP report and be distributed for expert review and public comment during the following months. To disseminate the findings more effectively and provide the research community an easy access to the results, we are developing web pages to accommodate major research findings.

Objectives for the Coming Year

We shall revise the CCSP report by taking into consideration comments from expert review and the public. A review paper will be prepared based on the CCSP report for journal publication. We also plan to work on several outstanding scientific issues as identified in the report.

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

The health and well-being of many indigenous people in the Arctic are tightly connected with the status of reindeer husbandry that depends in turn on the state of reindeer pastures. The state of pasture lands was a subject of study of certain land features of the sub-Arctic tundra in Chukotka (Russia) by Synthetic Aperture Radar (SAR) as part of the NASA Land Cover-Land Use Change Program and the project "Reindeer Mapper." The study was funded also by NASA HQ and included the use of SAR data from the Alaska Satellite Facility (ASF). Preliminary results of the study show a sensitivity of SAR image patterns to different kind of tundra vegetation. Also, the tundra surface gives a well-defined seasonal variation of the backscatter coefficient. In addition the seasonal variations of radar backscatter of tundra lakes and tundra fire scars were studied.

Description of Research

The "Reindeer Mapper" concept was developed to create a system for information management and knowledge sharing to improve management of reindeer herds and to increase the adaptive capacity and resilience of reindeer herders to the multiple changes occurring across the Arctic. This system is being designed to bring indigenous traditional and local knowledge together with scientific and engineering knowledge, remote sensing, and information technologies to address environment, weather, climate, pollution, and land use change issues to

improve decision making for sustainable reindeer husbandry, and, finally, to improve the quality of life of reindeer herders. Geographic information systems (GIS), remote sensing technologies, and traditional knowledge from indigenous people are the main components of the project. This pilot project is part of the Land Cover-Land Use Change (LCLUC) Program.

Accomplishments during the Reporting Period

Research efforts were made to obtain SAR data and to carry out their preliminary analysis in conjunction with ground-based measurements. The Chukotka Autonomous Okrug (ChAO) has been selected as an initial pilot region. In addition, two research areas were selected within the ChAO: Anadyr River Research Area (ARRA) and Vaegi Village Research Area (VVRA). ARRA is characterized by a diversity of landscape features and by the fact that VVRA is a high fire risk area. Studies of seasonal changes of SAR backscatter from certain land features in these areas have been conducted for four seasons for the period between the years 2000 to 2004. These studies are being carried out to determine the usefulness of SAR time series data for characterization of reindeer pastures and to demonstrate that SAR could provide useful information about some of the key parameters which characterize pasture quality. Preliminary results provide information on seasonal changes in data from the tundra, from a set of sub-Arctic lakes, and tundra fire scars. A ground-based vegetation map of the ARRA was used for comparison with some SAR image texture features. This vegetation map was available through collaboration with the Institute of the Biological Problems of the North of Russian Academy of Science (Magadan, Russia). SAR results were compared with ground-based data as well as meteorological data from local weather stations. A similarity analysis was applied to some reindeer pasture areas to characterize the seasonal correlations in their backscatter. It was shown that tundra fire scars are easily detected features and the radar data can be applied for land use inventory purposes. In addition, the data provide information on the significance of snow masking effects on radar tundra fire scar signatures in winter. Based on these results, an assessment of some snow parameters was done. Observation of tundra lakes reveals well defined seasonal variations and differences between several groups of the lakes. Similar seasonal variations are detected in tundra backscatter as well as fire scar backscatter. To validate the SAR data a joint proposal with Russian collaborators to the Civilian Research and Development Foundation (CRDF) is being prepared.

Objectives for Coming Year

Activities will focus on SAR data for estimating the ecological condition of reindeer pastures and land use and land change parameters. Collaboration with Russian partners to carry out validation experiments will be pursued.

Task 913-54-205-B: **MODIS Radiative Transfer**

GEST Investigator: Viktor Zubko

Collaborators: Yoram Kaufman (PI, GSFC), Vanderlei Martins (JCET), Alexander Marshak (GSFC)

Abstract

One important problem in cloud physics is how to retrieve the vertical properties of a cloud from satellite or airplane observations of reflected solar light. The common properties are effective radius of water droplets or ice particles, number density and particle size distribution, liquid/ice water content, and extinction coefficient. A possible approach to solve the problem is to use pre-calculated look up tables of the reflectance for clouds based on a simpler cylindrical geometry structure and homogeneous distribution of the cloud parameters. To prove that the approach does work, we first need to be able to simulate the reflectance from a realistic 3D cloud. Secondly, we need to create an

appropriate inversion scheme that would restore the realistic cloud properties by using the simpler cloud models.

Description of Research

The work carried out under the GEST task included: a choice of the realistic cloud model for the simulations; a choice and testing of a numerical approach for 3D radiative transfer calculations for the realistic clouds; calculations and testing of the top-of-atmosphere and airplane-height reflectance of the realistic clouds; and calculation of the look up tables of the reflectance for simpler clouds of cylindrical structure.

Accomplishments during the Reporting Period

Numerical experiments with the fractal cloud model by Alexander Marshak showed that it could be used for simulations of realistic complex clouds. With the approach, we generated a set of cloud models, which were used in the next stages of the work. The models include the cloud top heights and optical thicknesses for each pixel with some fraction of holes.

After experimenting with various 3D codes, we decided to use the Spherical Harmonics Discrete Ordinate Method (SHDOM) for our simulations of cloud. Because the approach is semi-analytical, it is the fastest 3D radiative transfer code ever created. We first checked the code by calculating the reflectance for a simple cubic cloud. Then we performed more testing for cylindrical clouds. The tests were successful.

In the next step, we started working with the 3D radiative transfer calculations with SHDOM for the fractal clouds. A program was developed that performs all necessary pre- and post-processing of input and output data. It generates a 3D distribution of the main cloud parameters: particle effective radius, liquid/ice water content, particle number density, and extinction coefficient, together with the visualization block for building plots and images. It generates the cloud 3D-structure file and then the SHDOM input parameter file. Next, a visualization capability allows researchers to view the images and 2D slices of the resulting reflectance as well as to visualize images and plots of the Probability Distribution Functions (PDFs) for the reflectance for several wavelengths. Additionally, PDFs for the particle effective radius, optical thickness and effective radius as a function of two reflectances (eg. 0.67 and 2.1μm) can be produced.

The radiative transfer calculations were done for a set of various cloud models that included both usual cumulus clouds and deep convective clouds with high icy parts.

A large look up table of the reflectances has been calculated for a cylindrical homogeneous cloud of 5 km vertical size with the following parameters: it has 3 wavelengths (0.67, 2.1, and 2.25μm), 6 values of solar zenith angle (0 – 70 Degrees), 11 values of view angle (0 – 80 Degrees), water and ice phases, 5 cloud geometric aspect ratios (from 5:1 to 5:5), 2 values of the vertical optical thickness (50 and 100), and 5 values of the particle effective radius (5 to 40μm).

Objectives for the Coming Year

We will continue to work on cloud radiative transfer tasks at GSFC.

Information Science and Educational Technology Research Group

GEST Scientist Dr. Susan Hoban and a student from Central Park Middle School, a NASA Explorer School in Schenectady, NY, work on a telescope together. Their project addresses National Science Content Standards for **Earth and Space Science** *and* **Science and Technology**. *Photo provided by Dr. 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 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. The GEOSS concept was launched at the first Ministerial Inter-governmental Earth Observations Summit hosted by the USA in 2003. To aid this international effort, the US 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 US plan mirrors the international GEOSS by focusing on nine societal benefit areas, and an end-to-end integrated systems approach.

While much effort has gone into automating routine spacecraft operations, applying intelligent automation to increase science return (i.e., science data acquisition and analysis) is a relatively new area of emphasis. IS & ET faculty are studying ways to automatically monitor science goals of spacecraft to improve understanding about the capabilities needed onboard for success, potentially increasing in science returns, and reducing perceived risks associated with increased use of automation.

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 parallelizing 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 is 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. At the same time, a 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.

Susan Hoban

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

GEST Investigator: Susan Hoban, Daniel Laughlin, Marci Delaney

Collaborators: Robert Gabrys (PI, GSFC), Horace Mitchell (GSFC),Wade Cisler (GSFC), Shane Keating (GST)

Abstract

The LT/LEARNERS team successfully piloted a virtual review panel for NASA using an online discussion tool for the LEARNERS II proposal review. Laughlin was selected to lead the Games Initiative for NASA's Office of Education. NASA Explorer School News is now produced in Spanish. Hoban designed and, assisted by Delaney, implemented the NES-program-wide Challenge math and science activity. Hoban and Laughlin were designated to coordinate acquisition, installation and operation of the GSFC node of NASA's Digital Learning Network.

Description of Research

NASA's Education Office of Technology and Products sponsors the LT/LEARNERS initiative, which seeks to support science, technology, engineering and mathematics (STEM) education through the infusion of NASA science content into classroom activities through research on and evaluation of information technology-based educational products. New in FY05 is an initiative to study the use of computer games as educational applications. 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, the NES Challenge, and the Digital Learning Network. *NES News* is a monthly electronic newsletter distributed in English and Spanish to the NASA Explorer Schools' teachers, administrators, students, and their families. Hoban supervises this effort; Laughlin is the editor of *NASA Explorer Schools News*, and Delaney develops the content and layout for this publication (http://learners.gsfc.nasa.gov/NESNews). The NES Challenge is a science and mathematics activity to engage middle school students in measurement and analysis. Delaney and Keating are integral parts of this effort (http://learners.gsfc.nasa.gov/challenge). NASA's Digital Learning Network (DLN) is a video conferencing and web casting system dedicated to educational use. Hoban and Laughlin work with the Office of Public affairs to coordinate the Goddard node of the DLN.

Accomplishments during FY04-05

The Educational Technology ARENA comprises a suite of advanced information technology resources for the purpose of validation and evaluation of technologies for NASA's educational applications. During 2004, the hardware for the Educational Technology ARENA was purchased and installed in the Scientific Visualization Studio at Goddard. The ARENA comprises basic hardware platforms (using common operating systems, *e.g.*, Windows versions, Mac, Linux), a suite of hand-held computers to align with evolving trends in this area, and virtual reality capabilities, including a GeoWall.

The LT/LEARNERS team successfully piloted a virtual review panel for NASA using an online discussion tool for the LEARNERS II proposal review. Reviewers from across the country participated in asynchronous text-based conversations to reach consensus on proposal ratings. Additionally, Hoban and Laughlin participated as reviewers in the NASA's Education Office of Technology and Products educational product review for 2004.

Following recommendations in the Report of the President's Commission on Implementation of United States Space Exploration Policy, a new initiative is being undertaken to research the best methods for NASA to tap the power and popularity of computer and video games to

inspire and educate. Laughlin was selected to lead the Games Initiative for NASA's Office of Education.

Initially distributed exclusively to the NES schools, *NES News* is now available to the general public through NASA's Educator Resource Center Network and NASA's Central Operation of Resources for Educators. New in 2004, *NES News* is now also available in Spanish.

The efforts of the NES Telescope Working Group, chaired by Hoban, resulted in the NES Challenge. Hoban designed and is responsible for implementing the NES Challenge, an NES program-wide activity, which includes multi-media curricular support for math and science content. Four video segments were produced by the eSPI group at Goddard, in which Marci Delaney was featured as host. These segments, in concert with text-based content guidance for teachers developed by Hoban, were served from the Challenge website to support a series of four DLN video-conferencing events with the NES Challenge schools. Hoban and Delaney assisted the schools with judging of the Local Challenge events and will coordinate the finalists from each school in their participation in the NES Student Symposium to be held at NASA Johnson Space Center in May.

NASA's Digital Learning Network (DLN) is a new initiative intended to provide video conferencing and web casting to schools. Hoban and Laughlin have been designated to coordinate acquisition, installation and operation of the GSFC node of the DLN. The NES Challenge is being used as a pilot to test the capabilities of the system. Efforts to develop DLN capabilities are being coordinated with Goddard TV through the Office of Public Affairs.

Objectives for FY05-06

The LT/LEARNERS team will hire a new research associate to develop evaluation protocols for the Educational Technology ARENA. The Games Initiative will coordinate a summer games camp for students to evaluate their use of computer games, and a workshop will be held in the fall with participants from a broad audience to discuss the possibility of a NASA-sponsored educational game. *NES News* will continue to be produced on time, on budget. A series of DLN events will be designed for use in the NASA Explorer Schools in the Goddard service region. Additional activities depend upon the outcome of several outstanding proposals, and new funding opportunities will be sought.

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

GEST Investigator: Susan Hoban

Collaborator: Nand Lal (PI, GSFC)

Abstract

Work under this task includes participation in NASA's Applied Information Systems Research Program and work with the Chief Information Officer (CIO) at GSFC on issues relating to information science and educational technology at GSFC. Activities include research and development in advanced technologies for NASA missions and science research programs. The GEST investigator also advises a master's degree student in the Computer Science and Electrical Engineering Department at UMBC.

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 and moderated a session entitled "Space Science Computation and IT Applications" at Information Technology and Computing Conference (IITC) 2004, held in Las Vegas, NV, April 5-8, 2004.

The GEST investigator organized and served as a panel chair and reviewer for the Applied Information Systems Research program proposal review panel, held in Crystal City, VA, May 11-13, 2004.

The GEST investigator collaborated with the PI on a redesign of the content management system for the Applied Information Systems Research program.

The investigator also serves on the master's degree committee of Mr. Somesh Kumar in the Computer Science and Electrical Engineering Department at UMBC. Mr. Kumar is expected to graduate 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.

Task 588-45-185: **Science Goal Monitor: Tools for Science Goal Capturing and Onboard Goal Monitoring**

GEST Investigator: Anuradha Koratkar

Collaborators: Julie Breed (PI, GSFC), John Jung (GSFC), Sandy Grosvenor (GSFC)

Abstract
Science Goal Monitor (SGM) is a prototype software tool being developed to test new strategies for implementing science driven automation in missions. SGM enables scientists to specify what to look for and how to react in descriptive rather than technical terms. It provides a framework for specifying goals and reactions, and then monitors streams of science data to identify occurrences of the key events previously specified by the scientist. When an event occurs, the system autonomously coordinates the execution of the scientist's desired reactions.

The SGM focused on two collaborations. The first is the EO-1 mission which analysizes data received from the MODIS instruments flying on the Aqua and Terra satellites with a dynamic autonomous request for higher-resolution images from the EO-1 satellite based on a set of scientific criteria involving forest fires, floods, volcanoes, or other phenomena. The second is Yale University's SMARTS (Small and Moderate Aperture Research Telescope System) observing program, which is modeling and testing ways in which SGM can be used to improve scientific returns on observing programs involving intrinsically variable astronomical targets.

Description of Research
Anuradha Koratkar was the science lead for the SGM project. SGM was being developed for infusion into NASA's future missions in order to (1) handle exponentially increasing volumes of scientific data; (2) improve the ability to react to dynamic, opportunistic scientific goals; and (3) help reduce mission operations costs so that multi-spacecraft missions such as constellations, sensor webs, etc., will be financially feasible. Intelligent automation of science operations (*i.e.*, science data acquisition and analysis) was the aim of this research project.

Accomplishments During the Reporting Period
We established the following objectives for the Science Goal Monitor for this year. We used

the gamma-ray science scenarios to develop a working prototype science goal monitor for the SMARTS telescope. We upgraded planning and processing tools for the telescope operations, so that SGM can eventually interface with them for automatic analysis and determination of the status of the science goals. Finally, we developed an initial protocol and standard for describing astronomical observing goals.

Often many of the detectors on earth observing satellites observe cloud covered tracks. For many detectors this is useless. In the sensor web domain, we can determine "near real time" if an observation will have a high probability of being cloud free by accessing real-time weather data. If the observation has a high probability of being cloud free, then the observation is executed; else the satellite time can be used more effectively for another observation. In this manner the sensor web can be used to maximize the returns from our assets. To demonstrate that cloud free images to maximize the scientific value of the image can be obtained, SGM accessed real-time weather data from the GOES satellite, and then coordinated with EO-1 planning. Using a mix of the scenarios in the Earth science domain, SGM scheduled requests for primary and alternate scenes to be taken aboard EO-1. One to four hours before an EO-1 image was scheduled to be executed, SGM accessed and analyzed the latest GOES cloud cover data and autonomously notified EO-1 if the primary scene was cloud covered, in which case, EO-1 took an image of the alternate scene. This allows EO-1 to best use its high demand imaging time while minimizing lost imaging time to cloud-covered scenes.

Objectives for the Coming Year

The core SGM project is now completed.

Task 900-37-172: **Parallel Numerical Kernels for Climate Models Based on the Object-Oriented Features of Fortran 90 and the Parallel Extensions of Co-Array Fortran (CV526556)**

GEST Investigator: Robert W. Numrich

Collaborator: Tom Clune (PI, GSFC), V. Balaji (GFDL)

Abstract

Standard methods for the development of high-performance parallel applications are awkward to use and scale poorly to large numbers of processors. New approaches to parallel programming are needed for machines with tens or hundreds of thousands of processors, which will be available by the end of the decade. This project investigates the effectiveness of some new approaches to parallel programming including Co-Array Fortran, plus a new Fortran 95 interface to the one-sided communication library called ARMCI, and a new Driver/Kernel model that provides a unified memory model independent of the underlying architecture.

Description of Research

We investigate alternative parallel programming models for applications important to the Earth Sciences community. To expand existing applications to new architectures, existing parallel programming models need to be extended. The level of abstraction needs to be raised to make it easier to define computational data structures and algorithms specific to particular disciplines, and the details of parallel programming need to be easier for scientists to use. We need a way to combine related applications together in a natural way. Co-Array Fortran, a simple extension to Fortran 95, is one way to provide a mechanism to accomplish these goals. To provide the same functionality to programmers with no access to Co-Array Fortran, we have defined a Fortran 95 interface to the ARMCI Library, which provides a portable communication library that runs on all existing platforms. We have also defined a new programming model that allows programmers to write numerical kernels at a low level of abstraction, to obtain performance, without

having to consider the details of the parallel implementation, which we raise to a higher level of abstraction in a driver. We intend to implement a prototype for this new model by identifying Design Patterns from the object-oriented community, which are very effective for producing robust code that is reusable, easy to maintain, and extensible.

Accomplishments During the Reporting Period

Co-Array Fortran [Numrich and Reid 1998] is a simple extension to Fortran 95 that provides a simple syntax to define parallel data structures and to express parallel algorithms. It is one of a triad of alternative programming models based on simple extensions to existing languages. The idea behind these extensions is that a mechanism for pointing from data structures in local memory to data structures in remote memory is sufficient to provide an efficient parallel programming model. The other members of the triad are Unified Parallel C [Carlson *et al.* 1999], an extension to the C language, and Titanium [Yelick *et al.* 1998], an extension to Java. Each of these extensions uses syntax that makes sense for the particular language, but the underlying programming model is essentially the same.

In the past year, Co-Array Fortran has been submitted to the Fortran Standards Committee to be included as part of the language for the next version, which is being called Fortran 2008. John Reid and the GEST Investigator have written a revised specification for Co-Array Fortran, which will be formally presented to the international Fortran Standards Committee WG5 at its next meeting this May in Delft, Netherlands. In addition to adding some new functionality, we have added some extensions that take advantage of the new object-oriented features of Fortran 2003. In particular, we consider a form of asynchronous execution based on co-array syntax. This extension follows naturally from the Co-Array Fortran model and provides a simple way to express new programming models for machines, for example, with processors-in-memory. In such machines, we might send code to the data rather than data to the code. No other model provides such a simple way to express this programming concept.

Meanwhile, in the absence of standard Co-Array Fortran compilers, we have designed a Fortran 95 interface for the ARMCI Library. This library is a portable communication library written in C that provides one-sided message-passing capability, which is more efficient than MPI code, and it is available on more platforms than the popular Shmem Library. Since Fortran 95 has no standard interface to the C language, it has been a challenge to design an interface that works for all compilers. We are in the process of testing the interface, measuring its performance, and applying it to the solution of the shallow water equations as a test case. This new interface will allow programmers to write code that switches between co-array syntax and ARMCI Library calls depending on the availability of a Co-Array Fortran compiler.

We have started a project to investigate the use of Design Patterns [Gamma *et al.* 1995] for the development of large-scale application codes for the Earth Sciences. We have identified six design patterns for grid-codes, codes that apply finite difference operators to fields defined on underlying physical grids. We intend to implement a prototype halo-update in the Driver/Kernel model by using the Strategy Pattern to define the kind of architecture involved. A Builder Pattern takes the strategy as input and returns a Composite Pattern, which represents the domain decomposition of the problem for a particular architecture. We intend to use the Mediator Pattern to pick the best communication method for a given architecture, and we intend to use the Observer Pattern to implement asynchronous communication among domains transparently to the programmer. The Iterator Pattern allows the programmer to traverse the domain decomposition either locally or globally independent of architecture.

Objectives for the Coming Year

This GEST appointment ends in April 2005.

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

GEST Investigator: Kevin Olson

Collaborator: 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 GSFC, 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. Finally, as part of the round-3, Earth and Space Sciences, Computational Technologies (ESTO/CT) PARAMESH is being used to create another astrophysics software framework, known as IBEAM, which incorporates relativistic fluid flow and radiation transfer for the simulation of gamma ray burst fireballs.

Accomplishments
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 work of this author over the past year and also previous years has focused on further developing and extending a software package known as PARAMESH. PARAMESH is a package designed to give an application developer an existing, serial code which operates using a logically cartesian mesh. 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.

During that 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. 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 been added to PARAMESH using the HDF5 library developed at NCSA. Related to this, PARAMESH also now provides the capability to output data in a format which can be read and displayed using the ChomboVis data visualization package developed as part of an ESTO/CT cooperative agreement with Lawrence Berkeley Laboratories.

PARAMESH is now being developed using an Open Source development paradigm. We hope to attract a new set of developers, both from inside and outside NASA, who will accelerate development and testing of the PARAMESH software. This is in its early stages.

Finally, the investigator continued his duties as part of the in-house team of scientists for the ESTO/CT project (ended October 2004).

Objectives for the Coming Year

We hope to attract new developers who will participate fully in the writing and maintaining the PARAMESH code base. It is hoped that this will greatly speed the development of PARAMESH, facilitate the finding and fixing of bugs in PARAMESH, and result in a better product.

One of the specific goals for the upcoming year is to add support for performing the I/O operations of PARAMESH using the portable and parallel I/O library known as NetCDF. This is in addition to the HDF5 which has already been added and discussed above.

Another specific goal for the upcoming year is to begin work on a C interface to PARAMESH so that a user of PARAMESH is not forced to write their code in Fortran 90/95. We have had several requests for this feature from our user base and intend to respond by adding this feature.

Finally, work will continue to support the two main users of PARAMESH. These groups are the FLASH code group at the University of Chicago and the group lead by Dr. Joan Centella at GSFC. These two codes are important test beds to help improve the overall performance of PARAMESH.

Task: 902-00-005: **Executive Science/Technology Support to NASA/HQ-Science & Applications Mission and Vision**

GEST Investigator: Sushel Unninayar

Collaborator: 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 (incorporating 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); and the new Global Observing Systems' initiative of the World Meteorological Organization (WMO/GOS).

In addition, support is provided to 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) at Goddard. 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). The task also supports NASA HQ in a variety of other NASA/ESE's internal, interagency, and

international programs, such as the Global Water and Energy Cycles Program (GEWEC); U.S. participation in the GCOS, as called for by the Conference of Parties (COP) to the UNFCCC; the science assessments of the IPCC, the international WCRP/GEWEX program, the international IGOS, and now the Earth Observing System (EOS)-GEOSS, the Committee on Earth Observation Satellites, etc.

Accomplishments during the Reporting Period

Work over the reporting period involved continued and extensive interactions with the U.S. Climate Change Science Program (CCSP—incorporating the USGCRP and the Presidential initiative on CCRI) 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). The CCSP represents, de facto, the U.S. response to the COP dealing with UN Convention on Climate Change, which has not yet been ratified by the U.S. A new strategy was proposed to accelerate development of the interagency implementation plan for the CCSP-Global Water Cycle (GWC), focusing on three integrating themes, and involving the Interagency Working Group (IWG), Science Steering Group (SSG), and the external research and applications communities.

The investigator provided 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. He is principle author (with NASA-HQ) on a presentation by the U.S. delegation to the UN-COPUOS/STSC on remote sensing of the environment in January 2005, at Vienna, Austria. He is also principle author (with NASA/HQ and NASA-Stennis)on using NASA research results for a Global Earth Observation System of Sytems. Another paper prepared by the investigator (with 10+ US agencies) is “Global water Cycle program of the US-GCRP/CCSP--Our Changing Planet--2006.” The GEST investigator is also coauthor of the international IGOS-P-Global Water Cycle Theme, published in fall 2004. He wrote and reviewed sections of all other inputs to the U.S. CCSP.

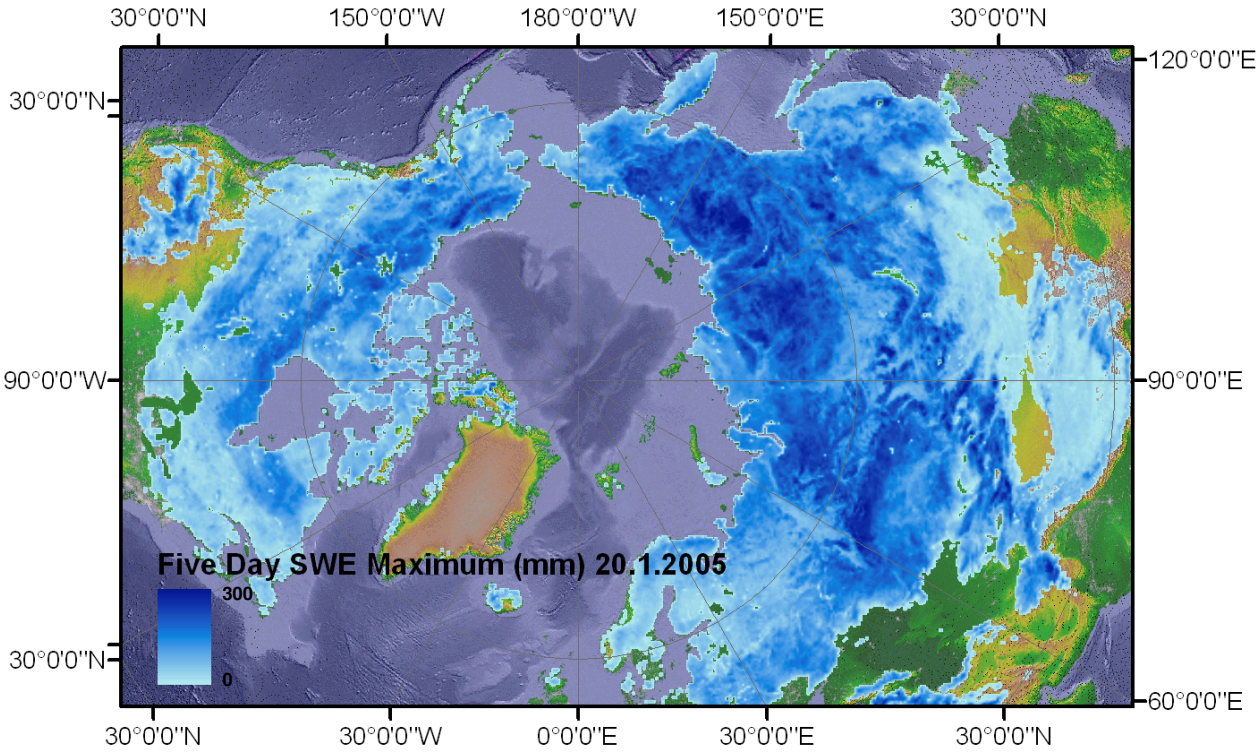
Work continued on the implementation of the agency-wide plans for NASA’s Energy Water Cycle Study (NEWS). The GEST investigator was appointed the "Executive Coordinator" for the Panel review of proposals for this agency-wide solicitation, in March 05. The GEST investigator was appointed to Chair a keynote session at the International Conference on the Remote Sensing of the Environment for Sustainable Development, St. Petersburg, Russia, June 2005.

Research continued on forced, bounded, nonlinear, chaotic-dynamic systems, and the improvement of Earth system observing systems and prediction models using an end-to- end integrated systems approach to enable NASA assets' to deliver the necessary products for decision support systems for operational resource management and the strategic planning of long-term policy. Initial concepts were also promulgated and presented to NASA and the USGCRP/CCSP for the development of "A North American Water Cycle Program," and a new "Integrated Modeling Earth/Climate system modeling framework.”

Objectives for the Coming Year

The investigator will continue to provide policy-level executive science/technology support to NASA’s Science programs, U.S. Interagency programs, 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.

Hydrological Science Research Group



The above figure is a 5-day maximum snow water equivalent (SWE) estimate for the period of 20 January 2005. The blue shading represents the SWE overlying an Earth shaded relief map. The SWE estimates are taken from the Version 4 product. A Version 5 update is currently in its implementation phase and represents an improvement over version 4 through enhanced snowpack parameterization (grain size and density), enhanced resolution implementation (at the finer footprint scale rather than coarser 25 km grid scale) and through the advantage of the lower frequency measurements at 10 GHz that AMSR-E has to offer. Validation is ongoing. Figure provided by Dr. Richard Kelly.

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. This effort integrates remote sensing data of different land surface variables with land surface physical model outputs (such as soil moisture 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, perhaps, 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 land surface model (LSM) implementation from local to global scales. The previous numerical LSM systems, specifically National Land Data Assimilation System (NLDAS) and its global counterpart (GLDAS) have matured are now used as test-bed frameworks to develop new modeling concepts. These systems use global and regional satellite and ground-based observing systems that are coupled to a land surface modeling framework to produce optimal fields of land surface states, and energy and water fluxes. The new generation system, the Land Information System (LIS), is in a maturing stage and is being used in a wide variety of applications at GSFC. LIS uses high-performance computing to increase modeling resolution in terms of both space and time discretization. For example, the LIS initiative is attempting to model terrestrial water cycle components on a spatial grid of 1 km x 1 km.

Several group members are involved with LIS from the perspectives of both coupling high resolution Earth system models using advanced computational technologies and hydrological science applications. For example, progress is being made in 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. The LIS project has demonstrated the advantage of estimating water and energy fluxes at relatively fine spatial resolutions. A project that is concerned with the high resolution modeling of land-atmosphere ammonia exchanges is an example of the LIS fidelity. 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 LIS. For example, soil moisture estimates from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) on the Aqua platform is being evaluated to determine its appropriateness for data assimilation into LSMs. Other sources of data are also being assessed for their utility in forcing these LSMs, notably various precipitation products from models, satellite observations, and reanalysis sources. An example of how these data sets come together is in a project that is examining the regional climate in the Caribbean. Finally, LIS and NASA LSM 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 US agencies such as the Department of Agriculture and the Department of 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 in addition to newly developed instrument systems for the estimation of key hydrological variables. Progress continues to be made in developing methods to better estimate global snow mass and soil moisture using 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. New and novel approaches in applying state-of-the-art electromagnetic models for microwave remote sensing of snow are also being developed. These model will further our understanding of how remote sensing observations can be more effectively coupled with hydrologic models of land surface processes. The coupling is being investigated through the application of data assimilation methodologies and GEST is becoming well-placed to become a significant player in the field of cold land processes observation and modeling. In ocean and near-shore studies, airborne lidar remote sensing continues to be used for phytoplankton biomonitoring and another study is concerned with the investigation of sea surface salinity using Aquarius (a planned Earth System Science Pathfinder mission). The correction of biases in TOPEX and Jason-1 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. Last, there are several efforts underway to support the science behind the NASA Earth System Science Pathfinder satellite missions that are planned in the forthcoming years. For example, one project is conducting numerical simulations that further our understanding of the various mechanisms controlling ocean salinity in relation to surface freshwater fluxes over seasonal and inter annual time scales. This research is of direct importance for the Aquarius satellite mission. Another project undertaking science experiments to determine the nature of soil moisture retrievals from HYDROS is being conducted as part of the risk reduction research activity for that mission. Our understanding of these different variables in the global energy and water cycle systems will increase with these exciting science developments derived from the 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.

Richard Kelly

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 Investigators: Kristi R. Arsenault (PI)

Collaborator: Paul Houser (GMU/CREW), David Toll (GSFC), Steven Hunter (DOI/USBR), David Matthews (USBR-Retired), Steffen Meyer (DOI/USBR)

Task 974-52-199: **NASA National Applications for Water Management**

GEST Investigators: Kristi R. Arsenault

Collaborator: David Toll (PI; GSFC), Paul Houser (GMU/CREW), Ana Pinheiro (NRC), Jonathan Triggs, Joe Nigro (SSAI), Jared Entin (NASA HQ)

Abstract

Current water resource management agencies (*e.g.*, U.S. Bureau of Reclamation) rely mostly on point measurement data for many of their hydrological prediction and decision support system models. In helping to expand their databases with more spatially distributed observed and modeled moisture and energy flux variables, the goal is to improve these water resources management tools and to help the managers make more informed decisions. NASA's suite of satellite and model products are being further developed and evaluated to be benchmarked and eventually incorporated into such agencies' operations. Using the Land Information System at NASA, remotely sensed snow cover, vegetation, land surface temperature and other products are being tested in different land surface models to produce more physically realistic data products, concentrating mostly on evapotranspiration, snow water equivalent, and runoff, which are identified as essential to water resource managers.

Description of Research

Water resources management issues are critical to several U.S., state and local government agencies, many companies, and the public. In helping these different sectors to address key water resource issues, the NASA Water Management Application program has ongoing applied research projects which are testing and implementing different NASA observations and modeling products into other agency-based decision support systems (DSSs). The NASA earth-observing satellite products are assimilated or used as parameters for the land surface models (LSMs) in the Land Information System (LIS) software at NASA. Then the model output is validated and evaluated in the partnering agencies' DSSs, with the aim to provide them with more complete spatial and temporal information and help water resource managers make more informed water resource management decisions.

Accomplishments in FY 04-05

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. Depending on the observation, certain satellite products are used as state variables in the models and other products are used mainly as model parameters. One key water resource-related state variable evaluated in more detail is the snow cover products from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the EOS Terra and Aqua satellites. The MODIS 500m snow cover daily and 8-day products were compared with the *in situ* Snowpack Telemetry (SNOTEL) stations and two LSMs, the NOAA Noah LSM and the NCAR Community Land Model, version

2 (CLM2), in the Washington state region. The results show that the MODIS products do detect the snow cover presence well, when clouds are not present, in comparison to the *in situ* measurements, especially during the wintertime and even in heavily forested regions. However during middle to later spring months, the MODIS snow cover did not detect the snow presence in the forested areas as well, due to the snowpack hidden in the shadows of the trees. The two LSMs tend to produce opposite conditions of each other, where the Noah LSM underestimates the snowpack and melts it off too soon in spring. CLM2 tends to overestimate the snowpack in comparison to the observations and has a lag in snowmelt in the spring months. Despite the LSM issues, in certain spring months examined, the models performed better than the MODIS products where the models estimated snowpack to exist, as seen with the *in situ* stations, when MODIS did not. An algorithm is in the process of being developed to merge these observations within the LSM environment to produce improved snow cover and water equivalent products to be tested by the partner agency collaborators.

Another ongoing project also involves different satellite products with the suite of LIS LSMs, but the focus has been centered on water demand and consumption in the state of New Mexico and the Middle Rio Grande River Basin. Different satellite vegetation products have been used to parameterize the Noah and CLM2 LSMs to measure how sensitive the models are to these parameters. Experiments were performed with both MODIS and AVHRR land cover and leaf area index (LAI) products. For the Noah LSM experiments, the results show that the AVHRR-based runs produce greater latent heat flux amounts over a day than the MODIS-based runs in areas that were classified as grassland versus the open shrubland classification in the MODIS-run. For sensible heat, the values in the AVHRR-run exceeded those of the MODIS-run by as much as 40 W m-2 for many areas of New Mexico. The MODIS product identified forested areas primarily as evergreen needleleaf forest whereas AVHRR identified the same areas as woodland or open shrubland. Such differences can cause great differences in the partitioning of the energy fluxes. If the LSM was coupled to an atmospheric numerical prediction model, like one used for national forecasts as is the case with the Noah LSM, then it is essential to incorporate the most accurate energy and moisture fluxes to produce the most accurate prediction possible. Further studies on the accuracies of the parameters in the model are being conducted. Also, the model output will be further validated against eddy covariance flux towers that have been installed and deployed this year in the Middle Rio Grande River region.

Objectives for the Coming Year

The first objective is to finish testing the assimilation algorithms on the MODIS snow cover and LAI products together in the LIS LSMs and finish running the different LSM permutations for the case studies used in the projects. These case studies will then be evaluated further by the partnering agencies, mainly the U.S. Bureau of Reclamation. In the Columbia Basin project, the goal is test the MODIS snow cover products in both the Noah and CLM2 LSMs and run with improved, higher resolution atmospheric forcing information to further resolve the scaling issues currently found with the North American Land Data Assimilation System forcing dataset. In the New Mexico region, downscaling experiments will be further set up and conducted at resolutions below 1 km to better capture the high spatial variability found in the land cover, soils, and microclimate surrounding the Rio Grande River.

Task 902-09-103: **Coordinating and Implementing NASA Global Water Cycle Research**

GEST Investigators: Robert Schiffer

Collaborator: Debbie Belvedere (GSFC), David Toll (GSFC)

Abstract
This GEST center activity, based at GSFC, supports scientific collaboration and coordination for NASA's global water and energy cycle research. Specifically, planning task-forces consisting of researchers from the broader scientific community as well as NASA scientists have been assembled. These task forces have worked to produce and enable implementation plans that not only uphold NASA's Earth Science Enterprise (ESE) Strategy, but also answer to the emergence of cross-cutting water-cycle research initiatives brought forth by inter-agency and government-administrative science panels.

Description of Research
Considerable attention has been given to the importance of the global water and energy cycle in assessing the consequences of natural and human-induced climate change. In particular, the U.S. Global Change Research Program (USGCRP) "Plan for a New Science Initiative on the Global Water Cycle" and the subsequent National Research Council response, have identified the global water cycle as a critical research theme in order to advance climate-change research in the coming decades. More recently, the current administration's Climate Change Science Program (CCSP) has identified the water-cycle as a critical cross-cutting theme that all science agencies must address in a coordinated and optimally synergistic fashion. As such, the challenge faced by NASA and other government research-agencies is to construct an ambitious, focused and coordinated implementation plan that will significantly advance our understanding of and predictive capabilities within this cross-cutting, scientific theme and, generally speaking, climate-change science.

Accomplishments in FY 04-05
This year's goal was to partner, assist, and enable activities within the NASA water cycle office to perform at a higher level of operation for projects and activities by providing excellent integration and coordination. As a co-project manager assistant, this involved developing skills to scientifically engage and coordinate various hydrologic activities.

In the past year, the final version of the NEWS implementation document was completed and posted to the scientific community-at-large and management of NASA (and other government research agencies) via placement on the NASA Water Cycle website. Currently work is underway to prepare for the NEWS panel review meeting which will select and fund selected proposals to meet the needs of the NEWS NRA. The GEWEX GAP science and implementation plan was also completed in the Spring of 2004 and is currently about to be formally reviewed by NSF. Efforts to merge GAPP and PACS into CPPA are progressing.

In an effort to increase collaborations with the scientific community, several proposals were submitted covering topics in Education, Outreach and Water Cycle. Assistance was provided as an end-to-end Proposal Manager for multiple proposals submitted by the former Principal GSFC Collaborator.

Contribution to the Cold Land Processes Experiment project through field work, of which the goal is to measure the water content of snow from space using satellite remote sensing, was accomplished.

Objectives for the Forthcoming Year:
The NASA Energy and Water cycle Study NRA and long-term implementation strategy for NASA Headquarters (HQ) consists of a core project, science team members, and NRAs that

solicit the contributions and collaborations of the community-at-large. We have continued to support relevant NASA HQ water-cycle program activities and potential core projects as well as community-based scientific collaborations that emerge from the NASA-wide water cycle initiative. Our planning and coordination efforts work in tandem with the inter-agency Climate Change Science Program (CCSP), the GEWEX Americas Prediction Project (GAPP) and the USGCRP elements to advance water-cycle science and prediction.

Task 972-21-143: **Advanced Laser Fluorescence Technologies for Coastal Biomonitoring.**

GEST Investigator: Alexander M. Chekalyuk

Collaborator: John Gerlach (GSFC, WFF), Ken Moore (Virginia Institute of Marine Science)

Abstract

The major research effort in March 2004 – February 2005 was focused on development of advanced laser fluorescence (ALF) technology for estuarine and coastal environmental biomonitoring. 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 following priority areas: estuarine water quality, estuarine biodiversity, and estuarine land use and habitat change. At least several critical components still remain missing or not adequately sampled to characterize the estuarine ecosystem biodiversity and habitat change. The ALF technology seeks to improve measurements of pigment concentration, including chlorophyll-a and phycobiliprotein pigments, assess phytoplankton physiological/nutrient status, provide basic taxonomic phytoplankton characterization, 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 estuarine and coastal environments. Three successful field measurement campaigns conducted in the reported period with the house-built Laser Phytoplankton Analyzer (ALF) and Laser Excitation-Emission Matrix Fluorometer (LEEM) resulted in identifying several key ALF technological solutions and spectral deconvolution algorithms that account for the complexity of the laser-stimulated emission signatures on the surveyed sites in the lower Chesapeake Bay and South Carolina. The ALF prototype system is currently at its final development stage and will be tested and deployed during coming spring and summer field campaigns.

Description of Research

A 2-year project "Advanced Laser Fluorescence (ALF) Technology for Estuarine and Coastal Environmental Biomonitoring" is currently under development. Research activities include 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 spatiotemporal gaps in satellite validation/calibration over meso- and synoptic scales. ALF development and operational utilization will yield valuable bioenvironmental information to enhance our understanding of coastal and estuarine ecosystems and will improve existing capabilities of monitoring natural estuarine environments. Comparative analysis of ALF surveys along with NOAA water quality data will provide important feedback to evaluate the efficiency of efforts to prevent and mitigate anthropogenic contamination and degradation of coastal and estuarine ecosystems.

Accomplishments during the Reporting Period

Two ALF field campaigns were conducted in close collaboration with the Virginia Institute of Marine Science (VIMS) in June and September 2004. Water samples were collected n the York River and Chesapeake Bay in the vicinity of the Chesapeake Bay in Virginia National Estuarine Research Reserve (CB-VA NERR). The house-built LPA instrument was utilized to provide hyperspectral emission measurements at 5 laser excitation wavelengths (473, 532, 640, 650 and 666 nm) and the PDP fluorescence induction assessments of phytoplankton physiological status. The LEEM fluorometer was used for hyperspectral emission measurements at selected excitation wavelengths in the blue-green spectral area (409, 435, 450, 460, 478, 495, 525, and 532 nm). The Data Flow flow-through monitoring system was operated on a boat along the York River to provide supporting underway measurements of water temperature, dissolved oxygen, salinity, Chl-a concentration and water turbidity. Laser fluorescence measurements were conducted in the VIMS laboratory; the water samples were filtered for the HPLC pigment analysis and fluorescence chlorophyll assessments. The third field campaign was conducted in collaboration with Belle W. Baruch Institute for Marine and Coastal Science (University of South Carolina) at the North Inlet – Winyah Bay (NI-WB NERR) in July 2004. Laser fluorescence measurements were conducted with the LPA and LEEM fluorometers in the Belle W. Baruch Institute Marine Laboratory. The collected water samples were filtered for the HPLC pigment analysis, chlorophyll extraction measurements, and microscopic taxonomic determinations. The laser fluorescence assessments with the selected excitation wavelengths showed high correlation with independent supporting measurements of comparable characteristics.

ALF technological solutions were identified on the basis of thorough analysis of the data acquired during the conducted field deployments. They include: (1) utilization of two, blue and green, compact lasers as excitation sources for various ALF measurements, (2) Hyperspectral emission detection with a high-resolution CCD spectrograph, and (3) spectral deconvolution of the acquired emission spectra. A compact, laptop-footprint ALF prototype system, which implements the above technological requirements and solutions, is currently under development. The ALF instrument includes 2 miniature lasers, a compact hyperspectral CCD spectrometer with a fiber light collector, a Pump-During-Probe (PDP) sensor with a PMT detector and a 14-bit digitizer, a flow-through sample unit with a miniature pump, a GPS module for shipboard operation, and a laptop PC with a USB instrument controller. The ALF instrument is designed to provide discrete laboratory sample analysis and continuous flow-trough underway measurements onboard a small vessel or motorboat. In the latter case, combined with the Data Flow system that yields the standard water quality data set, it provides for detailed bio-environmental characterization in coastal and estuarine aquatic areas.

Objectives for the Coming Year

New laser analytical methods and data processing algorithms will continue to be developed, and utilized for evaluation in coastal studies, environmental surveys and satellite validation. New field laser measurements will be conducted in the Chesapeake and Delaware Bays, the Middle Atlantic Bight, and in the National Estuarine Research Reserve of Oregon State. The objective of the planned research is two-fold: to test and evaluate the ALF technology in a broad range of coastal, estuarine, and freshwater environments, and to make more potential end users familiar with the new ALF technology thus facilitating its future operational utilization.

Task 974-52-198: **Scanning Multichannel Microwave Radiometer Snow Water Equivalent Assimilation**

GEST Investigator: Jairui Dong

Collaborator: Paul R. Houser (PI, GSFC), David L. Toll (PI, GSFC), Kristi Arsenault (GEST), James L. Foster (GSFC), Jeffrey P. Walker (Australia), Chaojiao Sun (GEST), Richard Kelly (GEST)

Abstract

This task focuses on assimilating the Scanning Multichannel Microwave Radiometer (SMMR) snow water equivalent (SWE) products into land surface model to generate optimal global SWE products.

Description of Research

This task supports four projects. The first is "Assimilation of remotely-sensed snow water equivalent (SWE) observations over the North America in the catchment-based land surface model," focused on assimilating the satellite products into NASA catchment-based land surface model to generate global SWE products. The second project is "An intercomparison of 'LDAS' evapotranspiration and soil moisture estimates with the regional reanalysis data." In this project the overall objective is to provide improved evapotranspiration (also including soil moisture) estimates and therefore water availability estimates for water resources application. Research also supports the HYDROS science effort. HYDROS will provide the first global views of Earth's changing soil moisture and land surface freeze/thaw conditions, leading to breakthroughs in weather and climate prediction and in the understanding of processes linking water, energy, and carbon cycles. Finally, work on "optimal land initialization for seasonal climate predictions" is ongoing. The primary objective of this work is to explore the optimal initialization of the land system in NASA's Seasonal-to-Interannual Prediction Project (NSIPP) using relevant remotely sensed observations within a land data assimilation framework.

Accomplishment During the Reporting Period

Understanding the uncertainty in both the remotely sensed snow water equivalent (SWE) retrieval and the physically based model SWE simulation is critical for their successful utilization, and quantifying the uncertainties is a prerequisite before meaningfully applying the data to assimilation systems. The Scanning Multichannel Microwave Radiometer (SMMR) SWE retrieval error has been evaluated to be dominated by the snowpack mass, with secondary factors being the distance to open water and air temperature. For a practical application, the remotely sensed SWE retrieval error is prescribed with an uncertainty of the monthly varying constants after omitting satellite retrievals for locations closer than 200km to significant open water, times with presence of liquid water in snowpack due to relative high temperature, and the model SWE estimates greater than 100mm. Forecasts of the model error characteristics, forward propagation of land surface dynamics, has been validated to accurately interpret the model SWE product by modifying the prescribed model error covariance.

The spatially complete and temporally continuous uncertainty maps for both remotely sensed SMMR SWE estimates and NASA GMAO's catchment-based CLSM model SWE simulation have been generated and evaluated for accurately interpretation of both dataset uncertainty. The remotely sensed SWE retrieval error is prescribed with an uncertainty of the monthly varying constants and three considerations: 1) omitting satellite retrievals for locations closer than 200km to significant open water, 2) times with presence of liquid water in snowpack due to relative high temperature, and 3) the model SWE estimates greater than 100mm. Error estimates of model SWE have been significantly improved by simply reducing the prescribed model error covariance from the

original $(10\ mm)^2$ to $(1\ mm)^2$. With emphasis on the relative magnitude of the uncertainty levels in practical assimilation applications, error estimates for the remotely sensed SWE retrieval and the model SWE simulation demonstrate more optimal interpretation of both data products.

A series numerical experiments by a degraded simulation starting from middle winter in 1979 and a degraded simulation starting from middle summer in 1986 have demonstrated that assimilating the remotely sensed SWE observations with above three considerations has better performance than other approaches, such as the pure model simulation and assimilation where SMMR data are available. Comparison has made between *in situ* measurements, SMMR retrievals, model forecasts, and assimilations, which are based on multiyear model simulation and assimilation with remotely sensed SMMR SWE observations from July 1979 to June 1987. Overall, the assimilated SWE medians compare well with *in situ* observations at seasonal and interannual variability. Together with the error estimates, the more accurate snow products can be easily generated. Assimilation on individual pixels shows that SMMR SWE data at early snow season play key roles in controlling the assimilation paths during the middle snow season. Comparison between the model forecast and assimilation runs shows the entire system, such as runoff and long wave radiation, has been improved through assimilating the remotely sensed SWE.

Objectives for the Coming Year

Evapotranspiration (ET) has been identified by Reclamation and EPA (and other agencies such as USDA and NOAA) as critical for determining water availability affecting various applications. The investigator is attempting to improve LDAS/LIS ET through the Community Land Model (CLM2), and Noah land surface models by incorporating primarily MODIS satellite derived products.

Task 974-03-070a: **Coupling High Resolution Earth System Models Using Advanced Computational Technologies**

GEST Investigator: Joseph L. Eastman

Collaborator: C. D. Peters-Lidar (GSFC), W.-K Tao (GSFC), P.R. Houser (GSFC)

Abstract

Understanding and predicting water, energy, and carbon cycles are of critical importance to such real-world applications as agricultural production, water resource management, and flood, weather, and climate prediction. The primary objective of the work performed under these tasks is to apply advanced computational technologies to the problem of coupling high-resolution (*e.g.*, 1 km, or cloud-scale) Earth system models. Specifically, this work is being done to combine the emerging technologies of the Earth System Modeling Framework (ESMF) and the Land Information System (LIS) to couple complex Earth system model components. The land surface models of the LIS include the Community Land Model (CLM) and the National Centers for Environmental Prediction (NCEP)/Oregon State University/Air Force Hydrologic Research Laboratory (NOAH) Land Surface Model (LSM). These state-of-the-art land surface models will be coupled to the Weather Research and Forecasting (WRF) model and the Goddard Cumulus Ensemble (GCE) model to enable high-resolution modeling.

Description of Research

The coupling of the WRF to the LIS system will enable the WRF model to employ an ensemble of LSMs. In addition, the LSMs can be used offline to spin-up the most accurate initial land surface conditions. These improvements are most critical as one increases resolution to the point that individual clouds can be resolved. After initial coupling and analysis of synthetic

idealized simulations has been performed the coupled system will be applied to a variety of case days. It is likely that the improved initial conditions will lead to an improvement in simulating the meteorology of the case days.

Accomplishments during the Reporting Period

The coupling of WRF to LIS system was accomplished following the ESMF methodology. This was done by treating LIS as a subcomponent to WRF. We then designed a series of idealized simulations to check the model for consistency and to demonstrate that the coupled system produced results similar to the WRF model with the same LSM, NOAH in this case. Parameter tables were configured so that the models used the values for these parameters. In addition, line by line comparisons of the NOAH models in LIS and WRF were performed to ensure consistency in model physics. Once this was accomplished we began a series of integrations that used idealized model configurations. We spanned the range of soil moisture conditions, from stressed soil moisture to saturated soil moisture initializations. The simulations were performed for barren soil and grass over the initial soil profiles. It was found that the coupled system and non-coupled systems produced similar results within a statidtical confidence level.

In addition, we have populated our GrADS/DODS server with numerous datasets for the IHOP 2002 field campaign. These datasets serve to initial the WRF atmospheric modeling system for specific case day simulations. The data is also used to enable model evaluation. After reviewing the data, a case day, June 12th, 2002, was chosen as our initial test case. Model integrations for this case day are in progress.

Objectives for the Coming Year

Our first objective is to evaluate the sensitivity of the coupled system to initial conditions. Using a 15-year spin-up from the LIS offline system, we will compare model performance to the WRF SI (Standard Initialization) initialization conditions. Secondly, we plan to identify other case studies that encompass a variety of large scale forcing regimes. Finally, the other LSMs in LIS will also be included in the evaluation. Results will be reported at the WRF User's Workshop this June.

Task 974-03-070b: **Regional Climate Studies in the Carribean**

GEST Investigator: Joseph L. Eastman

Collaborator: R.E. Waide (LTER, Co-I)

Abstract

Accurate assessment of the vulnerability of tropical islands to climate change is crucial to the developing nations. Our focus is on the island of Puerto Rico, which is growing rapidly and undergoing subsequent stress on its natural resources. A carefully designed study has been designed to examine the effects of increasing CO_2 on the local hydrological cycle. This study employs a mesoscale modeling system coupled to a dynamic plant model and employs fine resolution, cloud resolving scales.

Description of Work

The majority of mesoscale modeling studies do not include truly interactive vegetation schemes. In addition, most vegetation and meteorological models have been calibrated for the mid-latitudes. This study will focus on adapting the coupled modeling system to the tropics.

Accomplishments during the Reporting Period

A series of 4 month long integrations were performed on an 8 processor cluster to determine the effects of doubled CO_2 radiatively, doubling CO_2 biology, and the non-linear interaction between the radiative and biological components. The finest grid, employing a 1km

grid spacing, was centered over and encompassed the island of Puerto Rico. The factor separation technique of Stein and Alpert [1993] was used to extract the contributions of the pure factors and interaction between. Unlike previous studies using this coupled model system [Eastman *et al.* 2001a, b] that used a finest grid spacing of 50km, it was found that the interaction term was the same order of magnitude as the pure factors themselves. It is believed that at the cloud resolving scales used in this study that non-linear feedbacks are a direct contribution to this result. It was also found that under increasing atmospheric CO_2 that convergence zones and changes in solenoidal circulations resulted in a shift in precipitation patterns and over the course of the month a reduction in island wide rainfall. For an island already facing water shortages these results should be considered by the policy makers.

Objectives for the Forthcoming Year

Subject to successful renewal of this grant we will be adding four additional integrations that will allow us to assess the impact of land use change on the island. The previous results are nearly ready for submission to *Global Change Biology* and will be submitted in the near future.

Task 972-37-169: **Empirical Algorithm Refinement for TOPEX/POSEIDON and Jason-1 Altimeter Range Bias Correction by Using Operational Global Wave Model Data.**

GEST Investigator: Hui Feng (Hampton University)

Collaborators: Douglas Vandemark (PI, GSFC/WFF), Brian Beckley (Raytheon/ITSS), Janet Campbell (University of New Hampshire), Yves Quifen (IFREMER/FRANCE), Tran Ngan (CLS/France), Pat McCormick (Hampton University)

Abstract

Ocean surface waves induce a bias on the altimeter range measurements, the sea state bias (SSB). We have explored the feasibility of utilizing an operational global wave model to extract the reliable high-order wave field statistics for the SSB model refinement. An overall assessment for a third generation ocean wave model (Wavewatch III) has been completed, focusing upon the sensitivity of the WW3 wave model outputs to changes in the wind forcing fields. We found that the high quality of wind fields from high spatially-resolved satellite measurements is critical for the wave model to estimate variations in the high-order wave spectral moments. These are the parameters that are expected to contain information of interest to SSB studies.

Description of Research

In the satellite altimeter range measurements, there is a bias induced by ocean surface waves, the so-called sea state bias (SSB), the largest existent source of error in altimeter range measurements. The correction to the SSB becomes critical for accurate altimetry range measurements of the sea level. The latest theory and observations have indicated that long wave orbital velocity and short-scale surface wave slope variances, which are related to the second and fourth-order moments of a given wave spectrum, directly drive the SSB and its variability. The current operational SSB correction model relies on two parameters available directly on board: the altimeter-derived wind speed and significant wave height. Though effective, the two-parameter SSB model is limited because the altimeter-derived wind speed is not uniquely mapped to the *in situ* wind and is dependent actually on the overall sea state, and the utilization of wind speed and wave height, even if they are “accurate”, does not parameterize the bias physically. One means is to obtain more reliable wind measurements such as by scatterometers, and the other is to obtain measurements of higher-order ocean wave moments to capture more subtle physical SSB signatures through a global wind wave model.

One of the objectives in this task is to evaluate the use of a global wave model to extract the reliable high-order wave field parameters directly related to the SSB. The central goal is to develop improved empirically-based SSB correction algorithms by including wave information from global wave model outputs.

Accomplishments During the Reporting Period

We have implemented a third generation wave model (WaveWatch III) developed by NOAA/NWS/NCEP and the model has been run operationally for the data generation of wind wave field parameters that include high-order spectral parameters.

Four distinct wind forcing fields have been used to drive the wave model for wind forcing sensitivity analysis. The wind field data, the corresponding WW3 model-estimated wave field parameters, and altimeter TOPEX (side B)-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.

Using the merging datasets, we completed an overall assessment for a third generation ocean wave model (Wavewatch III) at both global and regional scales, focusing upon the sensitivity of the WW3 wave model outputs to changes in the wind forcing fields. In particular, we documented the value of using high resolution satellite-measured wind fields. Four distinct types of global wind field products were selected in this study to drive the wave model, including one from the NCEP/NCAR atmospheric model reanalysis and the other three wind fields into which satellite-observed winds were assimilated in different degrees. The wave model was adopted onto a global grid of 1º in latitude and 1º in longitude, and was run in a hindcast mode for the entire year of 2000. The three model parameters (including wave height, Hs; mean zero-crossing wave period, Tz; and mean surface slope, MSS, variance) of wave fields were evaluated in tandem with altimeter TOPEX observations from the total wave energy to the higher-order wave spectral moments. An important finding from this study is that high quality wind fields, built with high spatially-resolved satellite measurements are critical for the wave model to estimate variations in the high-order wave moments which actually contain information of interest to the SSB. The linkage of the modeled high-order wave parameters to altimeter on-board range bias was also shown. This work was presented in the Topex/Jason-1 Science Working Team Meeting, St. Petersburg, Florida, Nov.4-6, 2004. A manuscript of this work will be submitted to a peer-reviewed journal in March 2005.

Objectives for the Coming Year

The goal is to identify SSB-related signals from the wave model, and to develop improved empirically-based SSB correction algorithms

With the large merging dataset with collocated wave model outputs and altimeter measurements, we have proposed to adopt a neural network approach to assess the SSB model skills and effectiveness under the direct (sea surface height anomalies) or nonparametric SSB estimates. The bottom line is to recognize one or two more critical wave field parameters in addition to the altimeter-observed surface wave height and wind speed for the SSB correction refinement. The key for this effort is to define a number of metrics to statistically identify one or two parameters derived from operational wave model. Extensive neural network training will be designed and processed to help the identification. This work will be done in collaboration with our colleagues in France.

In an alternative way, we propose to apply a fuzzy classification algorithm to the multi-parameter space of a wind-wave field that is partially measured by altimeter and also estimated by our wave model to try to identify significant “classes.” We expect these classes to be both meaningful physically and statistically related to the sea state bias. In this way, we will not identify only one or two wave field parameters but will define a few classes with comprehensive signatures of the wave field for the SSB refinement.

Task 974-03-070: **Enhancement and application of hydrological functionalities in the NASA/GSFC Land Information System (LIS)**

Investigator: Matthew Garcia

Collaborator: Christa D. Peters-Lidard (GSFC)

Abstract
Mr. Garcia is involved in two specific projects, under the direction of Dr. Peters-Lidard, that involve enhancements to the cross-platform operation and hydrological functionalities of the NASA/GSFC Land Information System (LIS). Activities oriented on these projects in the reporting period, and in relation to several project proposals, have contributed substantially to Mr. Garcia's principal goal of full LIS-based land-surface hydrologic capability for the purposes of research investigations on, and applications to, flood and water resources management problems.

Description of Research
Mr. Garcia has performed work primarily for two projects on which Dr. Peters-Lidard is a Principal Investigator. The Army Remote Moisture System (ARMS) is 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. This project has involved contributions from Mr. Garcia in the form of enhanced LIS capabilities for cross-platform operation, data source and dataset handling, and hydrological functionality through the Noah land surface model (LSM).

Mr. Garcia is also involved in a project oriented on the applications of NASA-derived datasets and LIS capabilities to issues in water resources engineering and management. This work has involved the fundamental evaluation of precipitation data source and dataset (product) reliability. This project is oriented primarily toward the utility of TRMM-derived data products for water resources planning and management worldwide and will involve the enhancement of LIS-oriented capabilities for the examination of regional hydrological processes.

Accomplishments during the Reporting Period
The GSFC LIS [Peters-Lidard *et al.* 2004, Kumar *et al.* 2004, Tian *et al.* 2004; http://lis.gsfc.nasa.gov) has been developed primarily from North American and Global Land Data Assimilation Systems (NLDAS and GLDAS, respectively) [Mitchell *et al.* 2004; Rodell *et al.* 2004; http://ldas.gsfc.nasa.gov) for the purposes of extending their capabilities to high spatial and temporal resolutions in a flexible, high-performance computing environment. As such, LIS development has been oriented on the handling of gridded datasets from both NASA and other federal sources for data assimilation and the determination of energy and water states (*e.g.*, snow depth and soil moisture) and fluxes (*e.g.*, evaporation, transpiration and runoff) for the initialization of numerical weather prediction systems with more realistic conditions. The preparation of LIS for replacement of standalone Noah modules in ARMS has required enhancements to both platform-related capability and data source handling, especially the processing of point datasets as for precipitation measurements.

The LIS was developed on a Linux platform for application in a dedicated cluster-computing environment such as that built for the LIS project at GSFC. For ARMS, which relies primarily on Windows-based GIS functionality for communication of decision-support to the user (a U.S. Army Corps of Engineers Officer, typically), the process of porting LIS to the Windows environment was led by Mr. Garcia. A version of LIS for Windows was delivered to the USACE project partner in December 2004, and subsequent versions of LIS are in development

with full consideration of Windows-related requirements (*e.g.*, system library availability, directory- and file-handling procedures).

The preparation of LIS for test simulations includes handling of USDA Agricultural Research Service datasets for the Walnut Gulch Experimental Watershed in Arizona. Breakpoint-precipitation datasets are collected at nearly 100 gauges throughout the watershed and must be processed for use in LIS. Mr. Garcia has developed processing methods and computational modules for the temporal disaggregation and spatial interpolation of these numerous point datasets. Initially developed and delivered to project partners at the USDA/ARS and USACE/TEC as stand-alone applications, these modules are now incorporated into LIS to complete an end-to-end processing system for the disaggregation and gridding of point measurements over an area of interest for the purposes of LSM forcing. Mr. Garcia has also assisted the USACE project partner in the set-up of USDA/ARS Parameter Estimation Tool (PEST) methods for the calibration of hydraulic parameters at project test sites. This methodology relies on successive executions and evaluations against known outcomes for the determination of optimal parameter values in point-based simulations and may prove useful for the calibration of area-wide hydrologic behavior in regions of interest.

Finally, Mr. Garcia has contributed to the progress of a project led by Dr. Peters-Lidard in the area of NASA applications in water resources planning and management with the establishment of a website for communication and dissemination of project-related information (http://hsb.gsfc.nasa.gov/trmm-lis). This website carries project task-oriented research results and is updated on a monthly (or more frequent) basis. One such research result includes an ongoing evaluation of precipitation datasets by Mr. Garcia, including analysis of precipitation occurrence statistics and comparisons between traditional and LIS-oriented data sources.

Objectives for the Coming Year

Mr. Garcia will continue with the development of enhanced hydrologic functionalities in LIS for application to the ARMS and other projects on which the LIS team is currently working. Project related tasks, including the evaluation of precipitation datasets for use in LIS and the formulation of hydrologic routing routines and modules, will continue. Mr. Garcia also holds responsibility for the formulation of additional LIS-oriented functionalities, including the handling of additional data sources and datasets from partner agencies, and for maintenance and upgrades to ARMS-related functionalities within the LIS structure. In relation to Mr. Garcia's work on the ARMS project, publication of the parameter estimation methods and procedures described above is also planned.

In addition to ongoing project-related work, Mr. Garcia has participated in the proposal of several new projects to NASA Research Announcements within the reporting period that may become active in the coming year. One additional proposal to a potential corporate partner may also become an active project for Mr. Garcia and will lead to significant advancements in LIS-oriented hydrologic functionalities in the coming year.

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

GEST Investigator: S. Daniel Jacob

Collaborators: David LeVine (Deputy PI, GSFC), Sirpa Hakkinen (GSFC), Nick Shay (University of Miami), George Halliwell (University of Miami), Gray Lagerloef (Earth and Space Research)

Abstract

The primary focus of this research is on sea surface salinity and ocean mixing. Numerical simulations and observational research have led to understanding and quantification of sea surface salinity (SSS) variability due to surface forcing changes and oceanic mixing. These contribute to changes in the mean ocean state in addition to meridional heat and freshwater transports in the ocean. In addition, these numerical SSS realizations provide the surface boundary conditions necessary for a salinity simulator forward algorithm. As part of a secondary effort, mixing parameterizations generally 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. Multiple schemes were evaluated by comparing simulations with observations.

Description of Research

Oceanic fresh water transport has been shown to play an important role in the global hydrological cycle. With more than 70% of global evaporation and precipitation occurring over world's oceans, small changes in these parameters could cause major changes in the terrestrial water budget. SSS is representative of surface fresh water fluxes; the upcoming NASA Earth System Science Pathfinder (ESSP) Aquarius mission will provide excellent spatial and temporal SSS coverage to better estimate the net transfer. However, SSS is also controlled by advection and mixing processes; therefore, as part of the Aquarius science team, the GEST investigator conducts numerical simulations to understand and quantify various mechanisms controlling SSS in relation to surface freshwater fluxes over seasonal and inter annual time scales. The second effort led by the GEST investigator focuses on identifying the most appropriate oceanic mixing parameterization for use in coupled predictive models of hurricane track and intensity. *In situ* and remotely sensed data are used to evaluate and identify different mixing parameterizations in hurricane-forced numerical models in collaborating with scientists from the University of Miami.

Accomplishments during the Reporting Period

In nature and in coupled models, ocean-atmosphere feedbacks of freshwater are mutually compensated by evaporation and precipitation. However, in standalone ocean general circulation model (OGCM) studies, precipitation is prescribed from forcing/flux data sets, and evaporation is determined based on a variety of surface boundary conditions. Sea surface temperature and salinity evolution depend upon these boundary conditions, through which water mass formation and thermohaline circulation are affected in OGCM simulations. In general, however, in most OGCM simulations, only one of the many forcing/flux datasets is used in combination with one or few surface boundary conditions, the choice of which depends on the availability and personal preference. Although individually these data sets have been carefully calibrated and adjusted for balanced fluxes, standard deviations of annual mean precipitation and evaporation field for an ensemble of six data sets exceed 500 and 250 mm/yr, respectively. Additionally, the choice of vertical mixing parameterization representing subgrid scale (SGS) processes in the ocean also introduces variability in OGCM simulations. Significant effort was devoted to investigate these issues by using a numerical model.

A synergistic effort is also being conducted to develop the salinity simulator forward algorithm in relevance to the Aquarius mission. Consistent surface and atmospheric conditions are necessary to model and understand various sources of variability affecting the satellite observed brightness temperatures. While the National Centers for Environmental Prediction (NCEP) atmospheric general circulation model (AGCM) uses optimally interpolated satellite sea surface temperatures (SSTs), a consistent SSS field is simulated using the numerical model. To achieve these objectives, a massively parallel version of the hybrid coordinate ocean model configured in a fully global domain at two horizontal resolutions (2° and 0.72°) resolution was implemented on the GSFC Compaq SC45 super cluster. In contrast to the near-global configuration used in the prior reporting period, this model uses a coupled energy loan ice model to simulate the accumulation and melting of ice in the polar regions. A bi-polar patch is specified at the North Pole while the rest of the model domain is specified using the Mercator projection.

The model initialized from the Levitus 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 our previous results, the climatological University of Wisconsin Madison Coupled Ocean-Atmospheric Data Set (UWM-COADS) is used during the spin-up phase followed by the use of National Centers for Environmental Prediction (NCEP) reanalysis fields for actual calendar days. For our purpose, the NCEP fields from the year 2001 are used initially, that will be extended to cover three complete three-year cycles of Aquarius starting in the early 90s to the present. During the spin-up phase phase, the model surface salinity is relaxed to that of Levitus climatological values. Based on our previous experience with the near-global model, this maintains the model state from drifting away from climatology significantly. However, with the NCEP forcing, our experiments use either no relaxation or relaxation of the surface temperature such that the sea surface salinity is allowed to evolve freely. In the case of surface temperature relaxation, the fields remain completely consistent with the AGCM fields because the observed SST is provided as a boundary condition in the NCEP reanalysis. The live access server (LAS) set up at http://aquarius1.gsfc.nasa.gov:8080/las/servlets/dataset hosts many of the available and relevant flux data sets used in these simulations.

As part of the National Oceanic and Atmospheric Administration (NOAA)-sponsored project on upper ocean mixing parameterizations, two configurations of the Hybrid Coordinate Ocean Model were set up to simulate upper-ocean response during hurricanes Gilbert (1988), Isidore (2002), and Lili (2002). Initial conditions for Gilbert case were derived from extensive in situ observations of temperature and salinity. For Isidore and Lili, the initial fields are derived from a basin scale HYCOM simulation. Using appropriate forcing fields, simulated upper ocean response for five state-of-the art mixing schemes are compared to observational data. The comparison statistics indicate two schemes perform much better in these simulations and will be recommended for use in the operational coupled hurricane intensity prediction model at the NOAA Environmental Modeling Center.

Objectives for the Coming Year

The major focus for the coming year will be on completing and refining the ocean component of the Salinity forward simulator. Modeling of the SSS variability for different forcing data sets and its impact on oceanic thermohaline circulation also will be continued in the coming year. Due to the coarse resolution of the near-global model, the magnitude of oceanic current systems are biased lower; therefore, estimates of the relative magnitudes of advection, mixing, and surface fluxes will be intrinsically biased. Consequently, future research will use high-resolution limited area models that are nested within the global models to investigate the relative roles of these mechanisms in mixed-layer evolution. More-realistic forcing data sets, based on remotely sensed data, will also be used in these simulations, with three higher-resolution sub-domains in the Atlantic, Pacific, and Indian Oceans. Ocean response simulations for

Hurricanes Gilbert, Isidore, and Lili will be further refined to investigate the vertical resolution dependency of the model data comparisons. Additionally, regional circulation features and associated heat and salt budgets in the Eastern Equatorial and North Pacific will be investigated using a combination of in situ, remotely sensed and numerical model analyses.

Task 974-05-086: **Calibration and Validation of an Algorithm for Retrieving Snowpack Parameters at Global to Regional Scales using NASA's Aqua Satellite Remote Sensing Instruments.**

GEST Investigator: Richard E.J. Kelly

Collaborator: James L. Foster (GSFC)

Abstract

Snow monitoring from satellite remote sensing is important for effective water resource management, flood hazard prediction and climate change studies. Routine monitoring of global area extent and water equivalent of snow will improve climate modellers' global simulations and predictions of climate behaviour. In addition, resource managers will be able to manage more effectively demands for water supply and avoid hazardous flooding events from melting snow. This research effort is designed to develop, apply and validate a snow area mapping and snow water equivalent algorithm that uses data from NASA's Aqua satellite launched in 2002. Snow water equivalent has been retrieved from satellite Earth observation instruments for several years now but, with Aqua, the spatial resolution and error of snowpack estimation are being improved.

Description of Research

Dr. Kelly is the principal investigator for NASA's Advanced Microwave Scanning Radiometer - EOS (AMSR-E) snow water equivalent (SWE) product. The production of a reliable and well-defined algorithm to monitor snow cover at various time and space scales is of great importance to both research community (*e.g.*, climate modellers) and environmental management community (*e.g.*, water resource managers). It is essential to monitor and map snowpack resources within specified ranges of accuracy in order that we can explain better and perhaps improve our predictions of climate changes in the future. Global snowcover is a highly variable environmental parameter in both space and time. Great efforts are currently underway to map daily snow area at local and global scales using the Moderate Resolution Imaging Spectroradiometer aboard the Terra satellite (MODIS). With the successful launch of Aqua in 2002 the potential availability of microwave data from AMSR-E is providing an exciting possibility to map SWE at spatial scales half that currently available. Furthermore, the addition of two low frequency microwave channels on AMSR-E is improving our ability to map successfully snowpacks in a variety of states (*e.g.*, wet sow, dry snow, layered snow). The research being pursued here is focused on the development, calibration and testing of algorithms to effectively map SWE using passive microwave data from AMSR-E.

Dr. Kelly is also the science lead in the development of an Earth System Science Pathfinder proposal called the Cold Lands Processes Pathfinder that seeks to produce a satellite capable of measuring globally sampled SWE to unprecedented levels of accuracy. This is a multi-institutional effort with collaborators at the Jet Propulsion Laboratory, the National Oceanic and Atmospheric Administration and the science community at national and international levels. As part of this effort, regular meetings are held around the country to plan the concept and to develop the science underpinning the concept with respect to theoretical and field experiment studies.

Accomplishments During the Reporting Period

AMSR-E product validation proceeded at three distinct spatial scales: grid cell scale, river basin scale and regional to global scale. First, testing of products at the pixel scale using the multi-scale NASA Cold Lands Processes Field Experiment (CLPX) data was undertaken. While this dataset is spatially and temporally limited with respect to AMSR-E regional/global snow activity, it provides an opportunity to test the algorithm performance using multi ground, airborne and satellite data in three small, well instrumented locations in Colorado. The effect of snow grain size is known to strongly influence the microwave response to snow and this experiment dataset has enabled us to better understand the effect of snow pack properties on the AMSR-E retrievals.

AMSR-E retrievals were tested using GEWEX Asian Monsoon Experiment (GAME) data. Specifically, seven field sites are located near Yakutsk in Siberia and consist of daily snow depth measurements spanning the winter of 2002-2003 and 2003-2004 have been undertaken. The spatial density of field sites enabled within-AMSR-E IFOV snow depth variability to be analysed. This work, conducted in collaboration with Japanese Aerospace Exploration Agency (JAXA) and used for AMSR-E and AMSR verification, has shown the breakthrough value of using information from the 36 GHz AMSR-E channels to dynamically parameterize the retrieval methodology.

Second, at the river basin and regional scale, the work has advanced the validation effort using data from the Northern Great Plains (with colleagues at the USGS), Canada (with colleagues at the Canadian Meteorological Services Center) and for the Ob basin, Siberia, in conjunction with colleagues at Centre National d'Etudes Spatiales in France. Publications and presentations from all these experiments have been published in the literature and presented at conferences. Furthermore, a landmark study by Chang *et al.* (J. Hydrometeorology, in press) has demonstrated how sparse point snow data should be used to validate passive microwave estimates of snow depth or snow water equivalent.

At the third scale of variability, the regional/global scales, the investigator has continued to compare AMSR-E snow depth estimates with ground measurements. The World Meteorological Organization's Global Telecommunication System network is the most extensive data set for this use and is best suited to regional scale testing. However, the sampling is sparse; the maximum spatial density of measurements is 1 site per 40 km2 with the average density is 1 site per 160000 km2. Testing at this scale requires up-scaling the spatial domain of the satellite estimates to a 1º x 1º lat/lon grid or larger in order to obtain a statistically significant number of ground stations within a spatial domain cell to average and compare with the satellite data. This research is ongoing.

The researcher has also been concerned with concurrent SWE algorithm maintenance for the AMSR-E science team. In addition, research efforts have continued to maintain the JAXA SWE product for AMSR-E. The algorithm has been maintained at the baseline level during the continued validation phase. However, we are now in a position to significantly refine the algorithm to take advantage of findings discovered during validation experiments at different scales.

Objectives for the Coming Year

The investigator plans to continue the validation of the AMSR-E product at the three distinct spatial scales. We will focus particularly on the regional to global scales. The project will also deliver an improved SWE estimation algorithm to NASA that will include, at a later stage, information about SWE estimate uncertainty. By the middle to late summer of 2005, the bulk of the testing of the AMSR-E SWE algorithm will be complete and researchers will be focusing on science questions related to global patterns of snow accumulation and ablation. Presentations will be made at different international conferences and it is anticipated that several papers summarizing the algorithm development and validation will be submitted for publication.

Task 971-00-002: **Land Information System (LIS) development and applications**

GEST Investigator: Sujay Kumar

Collaborator: Christa Peters-Lidard (PI, GSFC), Paul Houser (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 in 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 of 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. The accurate assessment of the spatial and temporal variation of the global land surface water can be used to improve our understanding and more efficient management of natural processes. LIS can also be used in countless “what-if” studies, to assess the impact of land surface parameters on climate change and resource utilizations.

Accomplishments in FY 04-05

The land surface state fluxes and states produced by land surface models in LIS at 1km resolution were evaluated by comparing with the surface observations from the Coordinated Enhanced Observing Period (CEOP) project for a number of locations spread around the world. The results showed that water and energy flux estimates at 1km were more representative of the flux station observations compared to the estimates produced at coarser resolutions. The study also demonstrated the need for high resolution meteorological and land surface parameter inputs for improving the representation of land-atmosphere boundary conditions. Further, the effect of land surface heterogeneity at increased spatial scales and the effectiveness of sub-grid tiling approaches in representing heterogeneity were studied by conducting simulations at the CEOP locations. The existing sub-grid tiling approximations were not effective in capturing the true land surface heterogeneity and their impact on estimation of land surface fluxes and states.

LIS has adopted a number of scientific standards and paradigms to enhance interoperability and enable interaction with other earth system models. Using the design principles of the Earth System Modeling Framework (ESMF), LIS is coupled to the atmospheric models Goddard Cumulus Ensemble (GCE) and the Weather Research and Forecasting (WRF) models. The ability of LIS to provide better representations of the land surface boundary is used to enhance the

understanding of the water and energy cycle dynamics.

The high resolution land surface modeling tools in LIS are being used as the backbone of a prototype operational soil moisture modeling system used to aid the development of Future Combat Systems (FCS) for the U.S. Army. Operational weather prediction centers of National Center for Environmental Prediction (NCEP) and Air Force Weather Agency (AFWA) are currently deploying LIS to provide land surface conditions for their operational forecast systems. The flexible modeling system in LIS has been used in the international land surface model inter-comparison project called the Global Soil Wetness Project (GSWP). LIS has been used as the test-bed for a number of land surface model simulations for GSWP.

LIS is used in many different applications and, to support each application area, the software design has been enhanced by the addition of new features. A key new capability in LIS is the addition of data assimilation algorithms. For example, one-dimensional data assimilation using the extended kalman filter (EKF) to support the assimilation of observation data was implemented in LIS.

Objectives for the Coming Year

The coupled modeling system using LIS and WRF/GCE will be used in simulations over a regional area in Oklahoma and results will be evaluated against field observations. The primary objective is to demonstrate the impact of improved land surface characterization in the atmospheric model predictions. The use of scalable computing technologies and scientific standards will be employed to make the system computationally efficient.

The use of LIS to provide the land surface conditions in operational weather predictions systems of NCEP and AFWA is currently underway. The transition to their operational systems will be conducted in the coming year.

LIS has also been chosen to provide distributed modeling support for the Romanian destructive water abatement project. Algorithms for stream channel routing and distributed routing models will be implemented in LIS as part of this effort. This work will be conducted in collaboration with the National Center for Atmospheric Research (NCAR) and Baron Advanced Meteorological Systems, Inc.

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

GEST Investigator: Jesse Meng

Collaborators: Paul Houser, (GSFC), Christa Peters-Lidard (GSFC), Matt Rodell (GSFC), Jon Gottschalk (NOAA), Kristi Arsenault

Abstract

A Global Land Data Assimilation System (GLDAS) [http://ldas.gsfc.nasa.gov/] has been developed, which makes use of various new satellite- and ground- based observation systems within a land surface modeling and data assimilation framework, to produce optimal global land surface states and water and energy fluxes for hydrological and climatological research. A Land Information System (LIS) [http://lis.gsfc.nasa.gov] has been initiated in 2002 and reached a key milestone in early 2005, which inherits the primary components of GLDAS and expands the capability to a high performance infrastructure for land modeling and data assimilation. GLDAS/LIS has many user options to perform land simulations including, land surface initialization of climate variability, various land soil and vegetation parameters, multiple land surface models, and multiple atmospheric forcing. In 2004, the GLDAS and LIS teams have conducted many GLDAS/LIS experiments to test and evaluate the sensitivity of the land climatology to those

execution options. Results have been presented by various GLDAS and LIS team members at various conferences.

Description of Research

Land surface temperature and wetness affect and are affected by numerous climatological, meteorological, ecological, and geophysical phenomena. Therefore, accurate, high resolution estimates of terrestrial water and energy storages are valuable for predicting climate change, weather, biological and agricultural productivity, and flooding, and for performing a wide array of studies in the broader biogeosciences. The goal of GLDAS/LIS is to develop a system to produce high quality, high resolution, global fields of land surface states and water and energy fluxes in near real time.

Accomplishments in FY 04-05

An important GLDAS/LIS application is to provide enhanced land states and fluxes for numerical weather and climate prediction systems as the lower boundary conditions. Accurate information of land states, namely, soil moisture, soil temperature, and snowpack, is critical in prediction systems because of their regulation of simulated water and energy fluxes between the land and atmosphere over a variety of time scales. Starting 2004, research funded by the NASA-NOAA Joint Center for Satellite Data Assimilation is ongoing to establish a parallel LIS and execute on the NOAA NCEP supercomputer to support the development and execution of the NCEP operational Global Forecast System (GFS). We have learned from the multi-institution (NASA, NCEP, and several universities) North American Land Data Assimilation System (NLDAS) [Mitchell *et al.* 2004] that land states simulated by different land surface models (LSMs) tend to have large departures, even though they reveal similar signals of climate variability. When we propose enhanced land states from the offline LSM execution to prediction systems, the offline execution must be compatible with the corresponding land component coupled in the 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. The parallel NCEP LIS is executing on the same NCEP IBM supercomputer on which the operational GFS is executing. It also uses the same compiler and libraries as used for GFS. Attributing to the plug-in functionality of LIS, we are able to customize this NCEP LIS to the identical configuration as the land component in GFS, including the same grid specification, land-sea mask, terrain, soil and vegetation classes, soil and vegetation parameters. We first configure LIS with to experimental mode of GFS on the gaussian horizontal grid of T62 (~1.875 degree resolution). The Noah LSM [Eck *et al.* 2003] is executed, forced with the NCEP Global Reanalysis II [Kanamitsu *et al.* 2002], which also outputs on the same T62 grid, and the optional AGRMET radiation and CMAP precipitation. Results from a one-month benchmark shows that LIS is generating identical output to that from a companion execution of same Noah LSM with the global expansion of the NCEP NLDAS. The high performance architecture of LIS is about 30% more efficient in computing time. The efficiency is more significant when LIS is executing on multiple CPUs. This implementation sets a successful example of porting and executing LIS on users' own computing systems with standard LIS and user-defined configurations.

Objective for the Coming Year

Several extensive NCEP LIS executions are planned for a period of twenty-six months from 01 November 2002 to 01 January 2005 using both the modeled and observed forcing options to evaluate the impact of enhanced forcing to the land simulation. Preliminary results shows that, with the observation based forcing, the LIS/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 opposing to the corresponding prediction from the experimental coupled GFS/Noah [Meng *et al.* 2005]. Further research activities are planned to initialize the experimental GFS with the LIS output to evaluate the impact of enhanced land conditions to the GFS prediction. Since LIS is executing the same Noah code as in the experimental GFS, the LIS output can

provide all the land variables that GFS needs for continuous integration.

The current operational GFS executes on the gaussian horizontal grid of T254 (~0.5 degree resolution) with the OSU LSM [Pan and Mahrt 1987]. In an ongoing system upgrade plan, a new GFS that executes on the gaussian T382 grid (~0.3 degree resolution) with the Noah LSM will be deployed in early 2005. Key advances from OSU to Noah include the soil layers changing from two (10 and 190 cm thick) to four (10, 30, 60, and 100 cm thick), addition of frozen soil physics and patchy snowpack treatments, and improvements in bare soil evaporation, snow albedo, and ground heat flux under snowpack and non-sparse vegetation. For the new GFS deployment, it is essential to generate a set of land initial conditions though the spin-up process that cycles the same Noah for extensive period (at least two years) to reach an equilibrium distribution of the new four soil layers structure. However, considering the deployment schedule, it is impractical to execute a fully coupled GFS/Noah simulation for such an extensive period. A LIS execution has become an ideal alternative. We have implemented a second NCEP LIS configured to the new GFS/Noah specifications for the same twenty-six months execution from 01 November 2002 to 01 January 2005. Sample outputs from selected days in year 2004 are delivered to the GFS developing group for testing and preparation for the operational deployment. In the future, LIS will be executed in near real time on both T382 and T62 grids to provide update land states for the operational and experimental GFS executions.

Task 975-31-154 **Electromagnetic Models for Microwave Remote Sensing of Snow and Applications**

GEST Investigator: Marco Tedesco

Collaborator: Edward Kim (GSFC)

Abstract

The sensitivity of microwave remote sensing techniques to snow and other cold land process parameters and the retrieval of cold lands physical properties is an object of strong interest in the Earth Science community. Measured backscattering coefficients or brightness temperatures are strongly influenced by snow depth, grain size, temperature, fractional volume, wetness, soil moisture, and soil freeze/thaw state, etc.. The development and implementation of theoretical models together with field observations are fundamental to a better understanding of this important element of the climate system.

Several empirical approaches exist but, however, they have the obvious limitation that the entire parameter space of the target cannot be sufficiently well known to allow estimation of more specific target properties. Semi-empirical models are obtained by combining the theory and experimental data, which are used to determinate propagation and scattering parameters of snow (*i.e.*, absorption, extinction and scattering coefficients). Finally, theoretical models offer the advantage to be general and not related to experimental data. In the research a model based on the Dense Media Radiative Transfer Theory (DMRT) is considered.

The DMRT describes the propagation and scattering in a dense medium, defined as a medium where the particles occupy a fractional volume (bigger than 10 %). In a non-tenuous electrically dense medium (such as snow) the dielectric properties of the particles are significantly different from those ones of the background medium and the assumption of independent scattering is not valid anymore, as there is more than one scatterer within a wavelength distance. Under these conditions, the Conventional Radiative Transfer (CRT) theory is not valid and the DMRT can and must be

used. The DMRT takes the following into account: scattering of correlated scatterers, the pair distribution function of scatterer positions, and the effective propagation constant of a dense medium. The improved equations also preserve the advantages of the CRT with energy conservation and reciprocity obeyed. The form of the equation remains the same as the CRT equations so that numerical solutions are calculated in the same manner.

Description of Research

The goal of the research is to develop and improve 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 together with intensive ground truth. Research objectives include development of methods for forward simulation of microwave signatures from land surface models to support assimilation of microwave remote sensing data, testing of existing and new retrieval algorithms, and comparison against ground truth data, as well as the publication of results in journals and reports.

Accomplishments during the Reporting Period

Microwave brightness temperatures at 18.7, 36.5, and 89 GHz collected at the Local-Scale Observation Site (LSOS) of the NASA Cold-Land Processes Field Experiment in February, 2003 (third Intensive Observation Period) were simulated using a DMRT model, based on the Quasi Crystalline Approximation with Coherent Potential (QCA-CP). Inputs to the model were averaged from LSOS snow pit measurements, although different averages were used for the lower frequencies vs. the highest one, due to the different penetration depths and to the stratigraphy of the snowpack. Mean snow particle radius was computed as a best-fit parameter. Results show that the model was able to reproduce satisfactorily brightness temperatures measured by the University of Tokyo's Ground Based Microwave Radiometer system (GBMR-7). The values of the best-fit snow particle radii were found to fall within the range of values obtained by averaging the field-measured mean particle sizes for the three classes of Small, Medium and Large grain sizes measured at the LSOS site. The ability of forward 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).

The NASA Cold-land Processes Field Experiment-1 (CLPX-1) involved several instruments in order to acquire data at different spatial resolutions. Indeed, one of the main tasks of CLPX-1 was to explore scaling issues associated with microwave remote sensing of snowpacks. To achieve this task, microwave brightness temperatures collected at 18.7, 36.5, and 89 GHz at LSOS test site by means of the University of Tokyo's Ground Based Microwave Radiometer-7 (GBMR-7) were compared with brightness temperatures recorded by the NOAA Polarimetric Scanning Radiometer (PSR/A) and by SSM/I and AMSR-E radiometers. Differences between different scales observations were observed and analyzed. They may be due to the topography of the terrain and to observed footprints. Also when comparing data acquired only by the two satellites, differences were found. Different acquisition times and footprint positions, together with different calibration and validation procedures, can be responsible for the observed differences.

Inversion techniques based on Genetic Algorithms (GA) were studied, tested and proposed to invert the equations of an electromagnetic model based on DMRT theory under the Quasi Crystalline Approximation with Coherent Potential to retrieve snow depth, mean grain size and fractional volume from

microwave brightness temperatures. The technique was initially tested on both noisy and not-noisy simulated data. During this phase, different configurations of genetic algorithm parameters were considered to quantify how their change could affect the algorithm performance. A configuration of GA parameters was then selected and the algorithm applied to experimental data acquired during the NASA CLPX. Snow parameters retrieved with the GA-DMRT technique are then compared with snow parameters measured on field. The technique was also applied to satellite data giving very satisfactory results.

Objectives for the Coming Year

We will continue the analysis of the CLPX 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 (1kmx1km) will be modeled by using the DMRT. Input to the electromagnetic model will be derived from kriging the data collected on ground. Also the microwave data collected over the Meso Scale Areas (MSA, 25kmx25km) of the CLPX will be simulated by using input parameters derived from geo-statistical analysis of the snow parameters collected on ground.

In the coming year, the DMRT model will be compared to other existing models for simulating the microwave emission of snow covered terrains such as 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. This will improve the understanding of the physical assumptions made for the different models and will help to evaluate the capabilities of the models to reproduce the measured brightness temperatures. Moreover, the analysis will help to check the consistency of the results of the different electromagnetic models considered.

Finally, during the coming year, a comparison of snow products derived from optical (MODIS) and microwave (AMSR-E) sensors for mountain areas (*e.g.*, the Sierra Nevada) will be carried out to study the possibilities of an algorithm combining both microwave and optical data and to evaluate the accuracy of the products on mountain areas, fundamental storages of fresh drinkable water.

Task 974-44-184: **Land Information System**

GEST Investigator: Yudong Tian

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

Abstract

Land surface models predict terrestrial water, energy and bio-geophysical processes critical for applications in weather and climate prediction, agricultural forecasting, water resources management, hazard mitigation and mobility assessment. We have developed the Land Information System (LIS) as a leading edge land surface modeling and data assimilation framework, to support broad land surface research and application activities. Taking advantage of the increasingly available observational data and high performance computing and communication technology, we have established LIS as a high-resolution, real-time land modeling system ready for both research and operational applications.

Description of Research

The advance of remote sensing technology in recent years has enabled us to monitor and measure the Earth's land surface at an unprecedented scale and frequency. For example, NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) satellites are monitoring the Earth's surface every 1 to 2 days,

with a spatial resolution as high as from 1 km up to 0.25 km. Such observations provide a huge volume of valuable data of the Earth's land surface properties, such as vegetation, moisture and energy fluxes.

To fully exploit NASA's unique resource of satellite observations to improve the understanding, monitoring and forecasting of our home planet's environment, we have been developing a high-resolution and high-performance land surface modeling system, the Land Information System (LIS) [http://lis.gsfc.nasa.gov/]. By performing modeling and data assimilation at spatial scales comparable to that of the satellite observations, we will be able to resolve and study more important physical and dynamical processes which were not possible with low-resolution models.

Accomplishments during the Reporting Period

We have successfully incorporated the following land surface models into the LIS: the Community Land Model (CLM), the NOAH Land Surface Model and the Variable Infiltration Capacity Model (VIC). These state-of-the-art land surface models are now driven by LIS under a common framework, which is in turn powered by a high performance computing design and high throughput data management technologies.

More importantly, we have achieved our performance goal of enabling LIS to simulate the land surface physics and dynamics in a wide range of spatial scales from 100 km up to 1km in real-time with any of the land surface models incorporated. Such a capability will greatly enhance our study and understanding of land surface processes at various time and spatial scales.

In addition, we have adopted the best software development practices to ensure LIS' portability and interoperability. In particular, we have implemented the Earth System Modeling Framework (ESMF) within LIS to make it ready to couple with other Earth system models. LIS is now being coupled to atmospheric models including Weather Research and Forecasting (WRF) model and the Goddard Cumulus Ensemble (GCE) model to enable high-resolution modeling of land-atmosphere interactions.

Finally, we have designed and developed an innovative data visualization system, the Land Explorer. Fully integrated with LIS' data management system, Land Explorer greatly simplifies the data visualization process and reduces the data management burden. This web-based system automatically interfaces with LIS' data server, with intuitive controls such as zooming, panning and animation. The Land Explorer has been demonstrated at various occasions, and we plan to introduce it to the broader science community.

Objectives for the Coming Year

As LIS is transitioning from development to production mode, we are turning our focus to science investigations, using LIS as a powerful tool and platform. In particular, we want to address two critical scientific questions: the scaling and heterogeneity of land surface properties, and their influence on the land surface water and energy fluxes; and more realistic land surface modeling with high resolution parameter data and better tiling definitions. We will disseminate our scientific results and data via the efficient data management system we've built for LIS. In addition, as several national operational centers, including NCEP, US Army and Air Force Weather Agency, are requesting LIS to be ported and built on their local systems, we will provide effective service to them to ensure fast adoption and smooth operation.

Task 974-52-199: **Improving Decision Support Tools using NASA Data for Water Resource Management**

GEST Investigator: Jonathan M. Triggs

Collaborators: D. Toll (GSFC), J. Entin (NASA/HQ), K. Arsenault, Paul Houser (GMU/IGES), J. Nigro (SSAI), A. Pinheiro (NRC), T. Engman (SAIC), Ed Partington (EPA), Jim Carleton (EPA), Gary Shenk (CBP), Richard Kelly, Phil Pasteris (USDA/NRCS)

Abstract

Through the National Applied Sciences Program, NASA is partnering with other federal agencies to improve water management decision support systems (DSSs) using data unique to NASA. This project, in cooperation with the NASA Applied Sciences Working Group at GSFC is focusing on specific DSSs of two agencies for this task: the Environmental Protection Agency's (EPA) Better Assessment Science Integrating Point and Non-point Sources (BASINS) and the U.S. Department of Agriculture Natural Resources Conservation Service's (USDA/NRCS) Snow Survey and Water Supply Forecasting (SSWSF) tool. These DSSs are being evaluated, and NASA products are currently being tested within this framework. Specific variables studied under this task include precipitation, snow, and land cover change.

Description of Research

Many federal agencies rely on decision support tools (DSTs) for efficient water management and decision-making. The primary goal of this research is to help improve partnering agencies' DSSs using operational data unique to NASA. These DSSs include EPA's BASINS and USDA/NRCS's SSWSF system. Most of the work in the past year has been focused on BASINS, as the SSWSF study has only recently commenced. For BASINS, spatially interpolated precipitation data and MODIS-based land use parameters are being tested in the Patuxent River and the entire Chesapeake Bay Watershed. For the SSWSF, NASA satellite and Land Information System (LIS) snow products will be tested for improvement to the DST. Other potential variables to be tested include Shuttle Radar Topography Mission (SRTM) data, MODIS land cover change, Tropical Rainfall Measuring Mission (TRMM) precipitation data, and AMSR-E snow products. After these NASA products are evaluated and tested, they will be compared with standard DST output from the corresponding federal agency, and benchmark reports will be completed, documenting any improvements to the decision support process.

Accomplishments during the Reporting Period

Research collaborations were established and developed with NASA's partner agencies to properly evaluate and assess their needs. By the end of the period, many connections were made with water researchers at the USDA and EPA.

Within the context of a NASA-USDA Interagency Working Group and Memorandum of Understanding (MOU), a project is being developed whereby NASA snow products will be tested in a USDA DST used in the Upper Klamath River basin in Northern California and Southern Oregon. The system has been evaluated, and several strategies were developed, ultimately leading to a research proposal submitted during the reporting period. This work seeks improvement of water supply estimates over the current method of point-specific snow measurements (*e.g.*, SCAN, SNOTEL, and snow survey methods).

For the EPA BASINS project, the Hydrological Simulation Program – Fortran (HSPF) model was identified as a critical model for decision support. It was also determined that the Chesapeake Bay Program (CBP) is currently using a sophisticated version of HSPF to model the entire Chesapeake Bay watershed. Because of CBP's direct support of EPA, this new collaboration is proving to be beneficial. Spatially improved precipitation data is being tested for possible improvement to HSPF output, both for CBP and EPA BASINS. Remotely-

sensed and gauge-based precipitation data are combined into a multi-sensor precipitation product, then spatially interpolated by the NASA LIS. While results are forthcoming, the procedures being developed show promise with respect to current and future satellite-based precipitation measurements from NASA space-based precipitation sensors.

Objectives for the Coming Year

Evaluation of BASINS and HSPF will continue, along with testing of appropriate NASA precipitation and land use data. Incorporation of certain other NASA products will be assessed with partnering federal agencies to see if they may improve DSS capabilities. Work will also continue with USDA/NRCS to study whether and how NASA snow products will improve water supply forecasting in the semi-arid West. Continued development of USDA and EPA collaborations will be pursued, and new contacts will be established as necessary. Verification and validation procedures will be documented, possibly leading to benchmark reporting during the coming year.

Task 974-44-183: **High Resolution Modeling of Land-Atmosphere Ammonia Exchanges**

GEST Investigator: Yihua Wu

Collaborator: Christa D. Peters-Lidard (GSFC), Dr. 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, we 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

Parameterization of plant ammonia compensation point is a key issue in modeling the bi-directional exchanges of ammonia between the atmosphere and biosphere. Plants can act as both source and sink for atmospheric ammonia (NH_3), depending on the gradient of ammonia concentration between the air and plants. Ammonia emission from the stomata occurs if the mole fraction of NH_3 in the air is lower than the NH_3 compensation point, which is defined as the equilibrium mole fraction of gaseous NH_3 in the substomatal cavity. On the other hand, atmospheric ammonia deposition via the stomatal pathway occurs if the mole fraction of NH_3 in the air is higher than the plant NH_3 compensation point. Therefore, correctly computing the plant NH_3 compensation point is very important for ammonia plant/air exchange modeling. Plant ammonia compensation point varies considerably from area to area, plant to plant, and stage to stage of plant. Ammonia compensation points have significant diurnal course, respond rapidly to changes in external N supply, and may vary dynamically corresponding to the deposition and emissions

processes [Wu *et al*. 2005]. Measurement of the ammonia compensation point is very expensive and time consuming. Interest in parameterization of the ammonia compensation point has been increasing with recognition of the significant ammonia effects on atmospheric chemistry, ecosystem health and climate changes. A new parameterization for plant ammonia compensation point has been developed based on the following assumptions: (1) In plant intercellular fluids (apoplast), ammonium nitrogen exists primarily in two forms: ammonium ions ( ) and dissolved free ammonia (NH_3 (aq)); (2) An equilibrium exists between these two forms of ammonia-N and the concentration of each species is governed by the pH of the apoplast; (3) The activity coefficient of all the species involved in the dissociation reaction equals unity. The new parameterization indicates that ammonia compensation point is a strong function of leaf temperature and the ratio of in-the-plant apoplast which is a useful indicator of emission and absorption potential of plants.

An ammonia flux dataset from a field experiment conducted in a soybean field in Duplin County, North Carolina the summer of 2002 [Walker *et al.* 2005] was analyzed. Data from 9 days were selected for this study based on data control. In general, ammonia concentrations peak a few hours after sunrise and begin to decrease. This diurnal variation is driven by the diurnal variations of the boundary layer depth and the balance between the emission rate from nearby ground level sources (soybean plants and animal production facilities) and removal rate from the boundary layer (mostly in deposition). Ammonia concentrations at this site are usually higher when winds are from southwest. We hypothesize that these higher atmospheric ammonia concentrations are related to the advection of emissions from hog farms located to the SSW of the site where relatively denser animal production facilities are located. For example, on DOY185 a net deposition while on DOY194 there was a net emission. Ammonia concentration was much higher on DOY 185 than on DOY 194. The wind direction was SSW (214.58 degree) on DOY 185 while the wind direction was EEN (84.77 degree) on DOY 194. Differences in weather conditions on these two days also contribute to the differences in flux direction. Determined by the ammonia concentration gradient between the air and stomata, depositions occur in the early morning and late afternoon and with emissions between late morning and early afternoon.

The new parameterization of ammonia compensation point has been incorporated in the MLBC model [Wu *et al.* 2003], and was tested using the data described above. The model was run for these days with a time interval of 30 minutes. Totally, 3 runs were conducted: Run 1 without the ammonia compensation point parameterization, Run 2 with the ammonia compensation point parameterization in which the ratio of in apoplast is constant, and Run 3 with the ammonia compensation point parameterization in which the ratio of in apoplast is dynamic corresponding depositions and emissions. All of the simulations commenced at 0000 LST on DOY 170. Outputs of modeled fluxes of H_2O, CO_2 and NH_3 were compared with measurements to evaluate the model performance. The model performance is evaluated in three ways: 1) summary statistics which describe the distribution of measurements and model outputs, 2) model performance measures which describe quantitatively the model performance, and 3) informative graphs which describe qualitatively the model performance. The model outputs captured major deposition and emission signals, although some peak emissions are missed. The average difference between modeled and measured ammonia fluxes are well within the median measured error when the dynamics of and H+ are considered in the model.

Objectives for the Coming Year

Our first objective is to incorporate the new model into the NASA LIS system. Secondly, we plan to conduct more field experiment to get necessary data to test some hypothesis proposed in the paper by Wu et al. [2005]. Finally, we plan to run more tests on the model using a dataset from a corn field.

Task 974-52-197: **(1) Global Validation of EOS-AQUA Land Surface Dynamics using Data Assimilation. (2) HYDROS Risk Reduction Research Activities. (3) Assimilation of AMSR-E and MODIS land data products into Noah land surface model.**

GEST Investigator: Xiwu Zhan

Collaborator: Paul Houser (GSFC)

Abstract

Several advances have been made through work on the Aqua Land Product Validation, Hydrosphere State Mission (HYDROS), and AMS-E and MODIS data assimilation projects. The investigator has participated in and made presentations at several national and international scientific conferences, including being part of the organizing committee of the Ecosystems' Dynamics, Agricultural Remote Sensing and Modeling, and Site-Specific Agriculture meeting for SPIE's Meeting on Environment Remote Sensing. Several approaches for soil moisture retrievals from HYDROS radar and radiometer observations have been examined using the Kalman Filter data assimilation algorithm and a manuscript on the results of this effort is in review for publication in the IEEE TGARS journal. The Kalman filter data assimilation algorithms are also being implemented in NASA's Land Data Assimilation System for broader data assimilation research and operations by the GEST investigator collaborating with other LIS developers. The GEST investigator wrote or participated in seven proposals responding to various NASA research opportunity announcements.

Description of Research

The AMSR-E soil moisture product validation project is to determine the nature and variability of uncertainties in selected global soil moisture and snow products, measured by the EOS-AQUA AMSR-E sensor on a variety of time scales, and to analyze the effects of these uncertainties on the predictability of the global surface water and energy balance using land surface data assimilation techniques in near real-time. Specifically, we are using innovative land surface data assimilation techniques to check the quality control, physical consistency, and systematic realism of global EOS-AQUA land observations, in the context of the collaborative, real-time Land Data Assimilation System (LDAS) project.

The HYDROS risk reduction research activities include developing the HYDROS Observing System Simulation Experiment data set and soil moisture retrieval algorithm for a quantitative assessment of the accuracies of the algorithms.

Accomplishments During the Reporting Period

For the AMSR-E soil moisture validation project, the quality of AMSR-E soil moisture data product version B01 was preliminarily assessed as poor and the validation using a data assimilation activity included developing the Kalman filter data assimilation algorithm for implementation in the Land Information System (LIS) for generic land surface models collaborating with LIS project team. Several Kalman Filter algorithms have been tested for retrieving soil moisture from HYDROS radar and radiometer observations. Results have shown their advantages over the traditional soil moisture retrieval algorithm and have been presented to the HYDROS science team.

The GEST investigator gave a presentation on "Retrieving surface soil moisture from simulated Hydros L-band radiometer and radar observations using Kalman filter data assimilation" to AMS Annual meeting in Seattle, WA in January; participated in the AMSR-E Science Team meeting in Fort Collins, CO in August; participated in the organization of Conference on Ecosystems' Dynamics, Agricultural Remote Sensing and Modeling, and

Site-Specific Agriculture of the SPIE Meeting in Denver, CO in August; presented a poster titled "Landcover change of semi-arid area in Northeast China since 1950s" to the SPIE Denver meeting in August; participated in the Science Team meeting of NASA's HYDROS mission in Miami, FL in March and in San Francisco, CA in November; and gave a presentation on "Jointly retrieving surface soil moisture from Active and Passive Microwave observations using Cubist Data-Mining Technique" to AGU Fall Meeting in San Francisco, CA in December. A summer graduate student from GMU for the GSSP program was mentored and a research report from the student was accepted. A manuscript on "A Bayesian approach for retrieving surface soil moisture from Hydros L-band radiometer and radar observations" was developed for publication in *IEEE Transactions on Geoscience and Remote Sensing* [submitted]. Several other manuscripts are being prepared to report the results mentioned above. Finally, seven research proposals were developed, including: 1) Using the Kalman filter to derive high resolution satellite data product of soil moisture for regional climate and hydrologic studies and societal applications (PI, step 1 and 2 for NASA NEWS NRA); 2) Modeling the impact of land cover land use changes on the regional climate and hydrologic cycle in semi-arid areas of Xinjiang, China (PI, step 1 for NASA NEWS NRA); 3) Surface Water dynamics: Data assimilation of multi-sensor multi-platform data for hydrological process studies (Co-PI with PI at University of New Hampshire, step-1 and step-2 for NASA NEWS NRA); 4) Quantification of parameter uncertainty in regional climate models using satellite observations (Co-I with PI at Lawrence Livermore National Laboratory, step-1 and step-2 for NASA NEWS NRA); 5) Hydrological Modeling and Data Assimilation System for Detecting Global Changes (Co-I with PI at University of New Hampshire for NASA MAP NRA); 6) Land Data Assimilation to Enhance Earth System Observation, Modeling and Prediction (Co-I with PI at NASA HSB for NASA MAP NRA); and 7) Integrate NASA's Global Soil Moisture Remote Sensing and Modeling Data into USDA's Global Crop Production Decision Support System (PI for NASA Decision CAN).

Objectives for the Coming Year

The following tasks will be accomplished to complete the AMSR-E project: 1) Compare the AMSR-E soil moisture data product version B02 with the older version; 2) Compare the AMSR-E soil moisture retrievals with field observations from SMEX data; 3) Compare AMSR-E soil moisture retrievals with LIS-Noah model simulations; 4) Compare AMSR-E soil moisture retrievals with EKF-LIS-Noah assimilation results; 5) Report the intercomparison results via conference or refereed journal papers.

For the HYDROS project, two more refereed journal papers are planned. For the new NOAA-NASA-DOD Joint Center for Satellite Data Assimilation project, Kalman filter data assimilation algorithms will be implemented in the Land Information System (LIS) to assimilate AMSR-E soil moisture and MODIS land surface temperature and snow observation data products into the Noah land surface model for use in the operational numerical weather prediction systems.

Task 971-32-161: **Air-Sea-Ice Interaction**

GEST Investigator: Yunhe Zhao

Collaborator: Antony K. Liu (PI, GSFC)

Abstract

The physical characteristics of sea ice and snow change rapidly during the summer warm season in the Arctic. Therefore, the results of feature tracking based on finding common features in two sequential satellite images are very poor for

most of the time in summer in the Arctic. A new method for deriving summer sea ice motion using daily buoy pressure field data and the relation between sea ice motion and pressure field obtained from Principal Component Analysis (PCA) of them in non-summer months was developed. This method gave good results in a 2002 summer case study. Using PCA, component structures of 24 winter season (December to March, 12/1979- 03/2003) sea ice motion anomaly and surface pressure anomaly in the Arctic Ocean were analyzed. In addition to confirming that wind forcing is the major driving force of sea ice motion in the Arctic, the results identified the modes of pressure field anomaly that drive the first few components of sea ice motion anomaly. Also it was found that Arctic Oscillation (AO) index correlates with the mode 1 of sea ice motion only in seasonal scale, and North Atlantic Oscillations (NAO) index does not correlate highly with sea ice motion. Although satellites have provided wind observations over open oceans, wind observations over the Arctic sea ice are still largely provided by a limited number of buoys. The development of an algorithm deriving wind vectors from satellite-derived sea ice motion data is underway. The preliminary result of this algorithm is promising.

Description of Research

This research focuses on satellite ocean 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

Snow melt, pond formation/drainage, and ice ablation in the Arctic in summer cause both active and passive microwave signatures to fluctuate rapidly. Thus, during summer in the Arctic, two sequential daily satellite images may appear very different in the texture of features and their sizes and shapes. Therefore, the results of feature tracking based on finding common features in two sequential daily images are very poor for most of the time in summer in the Arctic. A new approach must be used to derive summer sea ice motion in the Arctic. Noticing that sea ice motion in the Arctic are mainly driven by wind forcing, a new method deriving summer sea ice motion using daily buoy pressure field data and the relation between sea ice motion and pressure field obtained from a PCA study in non-summer months was developed. This method has been used to derive sea ice motion for the summer of 2002. The derived summer sea ice motion show good agreement with the sea ice velocities derived from buoys.

To understand how Arctic sea ice drift and atmospheric surface pressure interact, component structures of 24 winter season (December to March, 12/1979- 03/2003) sea ice motion anomaly and surface pressure anomaly in the Arctic Ocean were analyzed by using PCA. The results show that in seasonal scale all the first three modes of PCA of sea ice motion are highly correlated with their counterparts of PCA of pressure field with correlation coefficients greater than 0.6; in monthly scale modes 2 and 3 from two PCA studies are highly correlated at above 0.57, but the modes 1 from two PCA correlate at 0.49; and in daily scale, the modes 2 and 3 from two PCA are correlated highly again at above 0.69, but modes 1 of two PCA studies correlate at only 0.4. Therefore, in daily and monthly scales, other modes of pressure field anomaly or factors other than wind such as boundary effect may play roles in the change of mode 1 of sea ice motion. In fact, mode 1 of PCA of sea ice motion correlates with mode 4 of pressure field anomaly at 0.48 in monthly scale. However, those factors disappear or cancel out in the seasonal scale. Also it is found that only in seasonal scale sea ice motion correlates highly with Arctic Oscillation (AO) index, and in all three scales sea ice motion does not correlate highly with North Atlantic Oscillations (NAO) index.

Although satellites have provided wind observations routinely over the open oceans, the wind observations over Arctic sea ice are still largely provided by a limited number of buoy data. Therefore, numerical modeling of sea ice in the Arctic has to rely on reanalysis product from NCEP/NCAR or ECMWF to compute the forcing terms. Studies have shown that these two reanalysis products have large uncertainty in the Arctic. Since wind forcing is a major driving force of sea ice motion in the Arctic, as confirmed by PCA study mentioned above, sea ice motion derived from satellite data can be used to derive wind vectors if the relation between them is well understood. By studying the relation between buoy-derived geostrophic wind vectors and satellite-derived sea ice velocities, the development of an algorithm deriving wind vectors from sea ice motion derived from the satellite data was underway. The preliminary result from this algorithm is promising.

Objectives for the Coming Year

The newly developed procedure for deriving summer sea ice motion in the Arctic will be improved, and error analysis of the derived summer sea ice motion data will be performed. The development of the algorithm deriving wind vectors over Arctic sea ice from sea ice motion derived from satellite data will continue, and the result of the algorithm will be validated and compared with NCEP/NCAR and ECMWF wind data. SAR images in conjunction with the ONR field experiment of R/V Revelle in April 2005 in the Luzon Strait will be processed and analyzed. 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.

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

Collaborator: Einar-Arne Herland (European Space Agency (ESA)), Jin Huang (National Oceanic and Atmospheric Administration (NOAA)), Chu Ishida (Japanese Aerospace and Exploration Agency (JAXA), Tokyo, Japan), Toshio Koike (University of Tokyo, Japan), Jan Polcher (Paris, France), John Roads (Scripps Institute of Oceanography), Bill Rossow (National Aeronautics and Space Administration), Robert Schiffer (University of Maryland, Baltimore County), Paul Try (Science and Technology Corporation), Soroosh Sorooshian (University of California, Irvine), Gilles Sommeria (World Climate Research Programme, Geneva), Avinash Tyagi (World Meteorological Organization), Peter van Oevelen (ESA), Josef Aschbacher (ESA)

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. Scientists from over 30 countries participate in major projects aimed at determining the hydrologic cycle and energy fluxes by means of global measurements of atmospheric and surface properties; modeling the global water cycle and its effects on the atmosphere, oceans, and land surfaces; 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 deal with land-atmosphere coupling processes and models, cloud system modeling, global data set development, water resource applications, and the effective use of earth observations in climate science.

During the past year Rick Lawford has served 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. This position provides management, service and coordination functions for more than 1000 scientists worldwide who are working on the water and energy cycles and supports the information and management needs of the World Climate Research Programme.

Rick Lawford also holds 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 takes the lead in implementing this program through the international partners of IGOS (including space agencies) by developing plans and strategies for Earth observations of water cycle variables.

Description of Research

The research undertaken within GEWEX is directed at the development and application of planetary Earth science and observations to the problems of world climate and understanding the global water cycle and its influence on the world's water resources. In particular, efforts are directed to producing consistent descriptions of the means, variability and trends of the Earth's energy budget and water cycle along with the generation of data sets for the development and validation of climate and hydrologic models. A metric of scientific success entails improvements in the ability to close water budgets on a regional and global basis 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 and cloud surface 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 has been the initiator and primary supporter of WCRP's Coordinated Enhanced Observing Period (CEOP). As GEWEX Phase II advances, more GEWEX efforts are being directed at supporting the Coordinated Observation and Prediction of the Earth System (COPES) strategy.

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 quantify the feedbacks in the climate system. This understanding is incorporated into models through improved parameterisations and leads to improved predictions at both weather and climate time scales. The results of these developments then are tested in collaborative studies with the water resource and applications communities who are encouraged to assess how these predictions can be of benefit for economic and social development.

The GEST investigator's role is to direct the office that coordinates this research and synthesizes the results and establishes processes for making them useful for different communities. The information and synthesis roles are aided by a website, the organization of scientific meetings, and the preparation of review articles for different publications. The promotion of the program is done through the GEWEX Newsletter and participation on committees involving the development of observational systems. In addition, he facilitates opportunities for GEWEX projects by liaising with potential funding agencies. Within the framework provided by the program, Lawford apples his expertise to gaining a better understanding of regional and global water resource issues and to the development of better observational systems (especially space-based systems) that could support GEWEX science.

Accomplishments during the Review Period:
During 2004, Rick Lawford addressed some of the priority 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 Spring AGU/CGU/EEGS/SEG meeting in Montreal and for the January 2005 American Meteorological Society conference in San Diego. 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 Rick Lawford represented GEWEX or IGWCO or both). In addition, Rick organized the GEWEX/ IGWCO/ UNESCO workshop on trends in the global water cycle that has provided background information for consideration by scientists working on the water cycle and climate change in the Intergovernmental Panel on Climate Change (IPCC) Working Group I. In addition, he has carried out reviews that have been consolidated into journal articles such as (Lawford et al. 2004) which chronicles the development of hydrometeorological activities within the GEWEX program and Sorooshian et al. (2005) which provides an overview of the GEWEX program.

In 2004, Rick Lawford worked with the European Space Agency to strengthen European participation in GEWEX by hiring a European GEWEX coordinator who promotes and reports on the development of the GEWEX project in Europe. Through the office that he manages, Rick has provided support for the GEWEX

program by overseeing the production of four newsletters during the past year that have focused on separate themes including: global data products, precipitation, clouds and radiation, land surface processes, and monitoring their distribution to more than 2100 subscribers. He continues to guide other outreach activities including the maintenance of the GEWEX web page, completion of a Phase I accomplishments brochure and the production of manuscripts and reports for publication.

Over the past year he advanced the plans and arrangements for the 5th international GEWEX science conference to be held in June 2005 in Orange County California. He promoted the conference through brochures and briefings and secured funding support. Over 300 papers have been submitted to the conference by scientists from 27 countries. He also helped to plan a pan-WCRP monsoon workshop to be held in conjunction with this science conference.

Rick Lawford has reviewed a number of documents in 2004 to provide GEWEX views on issues such as the iLEAPS program of International Geosphere Biosphere Programme and the Implementation plan for the Global Climate Observing System (GCOS) as well as proposals to granting agencies such as the Department of Energy and manuscripts submitted to journals for publication. He has also supported the chair of the SSG and the chairs of GEWEX panels by assisting in the development of meeting minutes, negotiating and carrying out or following up on action items arising from meetings. This support includes coordinating the preparations for the GEWEX Scientific Steering Group meeting in Kunming China, both in terms of providing briefings and written material and developing strategies to implement recommendations from the meeting. It also included preparing reports on GEWEX and CEOP activities to the Joint Scientific Committee of WCRP.

During the past year Rick Lawford has been responsible for the development and publication of the Integrated Global Water Cycle Observations (IGWCO) theme report (published in June 2004), and for leading the development of the IGWCO implementation plan. In this role he made numerous presentations on the theme including a high level presentation to the principals of the Group on Earth Observations at a special event held at the Earth Observation Summit II. Rick Lawford was also asked to lead a team to prepare the water resources socio-economic section in the Global Earth Observation System of Systems "Ten Year Implementation Plan" that was accepted in Brussels in April 2004. Rick also participated in the development of the Implementation Plan for the Global Climate Observing System (GCOS). Within the IGWCO framework, Rick continues to promote the development of indicators to enhance the dialogue between scientists and policy makers. In addition, he has been developing plans for IGWCO capacity building that would include workshops in the developing countries around the world and for activities such as developing proposals for a training session on Earth Observations at the Commission of Sustainable Development.

Rick has also been active in contributing to international program proposals and science plans. During 2004, he served on the framing committee of the Global Water System Project (GWSP). He has participated in reviews of papers and proposals as well as providing input to a number of documents being prepared by WCRP and WMO.

Objectives for the Coming Year:

During the coming year, Rick Lawford will strengthen links between GEWEX and other closely related activities including COPES and the Global Water System Project (GWSP). Priority will be given to coordinating the 5th International Science Conference on the Global Energy and Water Cycle to ensure that it is a success. He will continue to provide overall support for the GEWEX program in terms of organizing workshops, meetings and conferences; maintaining a web page; publishing a regular Newsletter; and preparing minutes of meetings and writing reports and occasional articles to inform the science community about the project. He will also support the review of various GEWEX elements including the International Satellite Land Surface Climatology

Project (ISLSCP), the GEWEX Hydrometeorology Panel, the Water Resources Application Project and a new aerosols and climate activity. In addition he will develop and support the implementation of the Integrated Global Water Cycle Observations theme by chairing the Executive committee, representing WCRP on the theme executive committee and lead the implementation of the theme. At the request of NASA, he will also undertake some coordination and program planning responsibilities, seek interagency funding support and hire a coordinator for the Northern Eurasia Earth Science Partnership Initiative (NEESPI).

Goddard Visiting Fellows Program in the Earth Sciences

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Goddard Visiting Fellows Program in the Earth Sciences

The Goddard Earth Sciences and Technology Center (GEST) and the NASA Goddard Earth Sciences Directorate solicited qualified Ph.D. scientists for collaboration in scientific research relating to the observation, analysis and modeling of physical processes within the earth-atmosphere system, and to relevant global change issues. Selected candidates were appointed as Visiting Fellows to pursue independent research in collaboration with scientists in the Laboratories within the Earth Sciences Directorate, and have full access to NASA computing facilities and other resources at either the Goddard Space Flight Center (GSFC) in Greenbelt, MD or at the Goddard Institute for Space Studies in New York, NY. This solicitation was aimed at all levels from post-doctoral to senior scientists, particularly, university faculty interested in sabbatical arrangements.

Research interests in the Earth Sciences Directorate include attaining knowledge and understanding of the components of the Earth system through experimental and theoretical studies using NASA technology, information science, and space observations. The approach includes instrument, algorithm and model development involving remote sensing and in situ measurements. 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 geological and geophysical processes of solid Earth and the planets, and global land surface properties, both vegetative and biological. Research interests include Earth and planetary gravity and magnetic fields, Earth's rotation, plate motion, volcanic activity, post-glacial rebound, land surface topography, 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.

Information Science and Technology Research
Involves computer science, computer engineering, computational science, and information science research in support of NASA Earth science. Research interests include numerical algorithms and high performance/parallel computing; data assimilation and data fusion; 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 derives from various space-based and airborne sensors, field campaigns, and models.

Appointments are normally for periods up to one year with terms with negotiable start dates. Visiting Faculty appointments are made at UMBC. Applications are reviewed and selections normally made by

April each year. Under special circumstances, appointments can be made at other times of the year. Review is conducted by a panel of university and NASA scientists based on relevance to NASA's missions, expertise and credentials offered, and clarity and feasibility of stated research goals within the proposed time frame and available resources. Compensation is commensurate with experience and qualifications.

Goddard Visiting Fellows previously selected, included in this reporting period, are:

Goddard Visiting Fellows selected in 2004:

Zev Levin
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Pierre Defourny
Environmetry and Geomatics Research Group
Dpt of Environmental Sciences and Land use Planning
Faculty of Bio-engineering, Agronomy and Environment
Université Catholique de Louvain (UCL)
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B-1348 Louvain-la-Neuve (Belgium)
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Post-Docs selected in 2004:

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Goddard Visiting Fellows selected in 2003:

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Robert Schiffer, Chief Scientist

Task **The Use of Cloud Models and Remote Sensing Measurements for the Study of the Effects of Aerosols on Clouds and Precipitation**

GEST Investigator: Zev Levin

Abstract

Prof. Zev Levin has been with GEST since October 2004. During the period of this report his main research work related to aerosol-cloud-precipitation interactions. This work consisted of running a 2D detailed cloud model in order to investigate the effect of pollution on cloud growth and precipitation development. The work thus far revealed that under the same meteorological conditions, polluted clouds produce smaller cloud particles and less precipitation than clean clouds. The addition of a few large hygroscopic particles in the form of sea salt or mineral dust coated with sulfate or mineral dust coated with sea salt, could enhance precipitation development of polluted clouds, but has very little effect on clean clouds. In contrast, the addition of ice nuclei from natural sources (*e.g.*, dust storms) or from polluted sources lead to reduce rain amounts from both clean and polluted clouds. It was further found that under the same meteorological conditions, polluted clouds tend to grow deeper and have wider horizontal extend than clean clouds. These last points are important for remote sensing from space, because increase in cloud lifetime and horizontal extend mean higher cloud fraction, which has important implications for climate change. Finally, since under similar meteorological conditions these polluted clouds precipitate less, they leave more water vapor at higher altitudes and thus help to distribute water vapor from the lower levels to the upper regions of the troposphere.

Description of the Research

The research consisted of running a 2D numerical cloud model with detail microphysics which was developed at my laboratory at Tel Aviv University. The uniqueness of this model is in its accuracy and efficiency. This element is highly important when dealing with rain development which is such a non linear process. The simulations were conducted on a number of cases for which some data on local meteorological conditions and concentrations and size of aerosols were available. The experiment from which these data were taken was the MEIDEX experiment which we conducted on board the Columbia Space shuttle in its last tragic mission. Although the data from the space shuttle was lost, all the data from the airplane that flew in the region is available. The aerosols properties below cloud base were used as initial conditions for the model runs. A large number of simulations were performed and it was found that, under the same meteorological conditions:

- The rain from maritime (clean) clouds as compared to continental (polluted) clouds - starts earlier, produces larger amounts of rain and falls over a wider area.
- The lifetime of a continental cloud is longer than the maritime cloud.
- Giant cloud condensation nuclei, GCCN increase the growth of drops and graupel particles in continental clouds by collection and riming, respective
- GCCN enhance the amount of rain from continental clouds but has little effect on maritime clouds.
- The amount of rain falling on the ground decreases when more IN enter the clouds.
- The addition of high concentrations of dust as IN increases the height of the continental cloud.
- The enhancement of ice content due to dust increases cloud's horizontal dimensions.

Accomplishments in FY 04-05

Prof. Zev Levin is part of an international panel assigned by the WMO and IUGG to assess the role of pollution in modifying precipitation. He was the principal contributor to one of the most important chapters in this assessment

(observations of aerosols on precipitation) and was a major contributor to three other chapters. In addition, a number of simulations of cloud-aerosols interactions were carried out.

Objectives for FY 05-06

The main objectives include the analysis of cloud and precipitation data from MODIS and TRMM over the Mediterranean. This will be an extension to the work carried out by Dr. Yoram Kaufman and Dr. Ilan Koren from the Climate and Radiation Branch who carried out a preliminary study of the effects of pollution on clouds and radiation in the Atlantic. The data analysis will be complemented with cloud model simulations using the Tel Aviv University Cloud model. In addition, a new paper will be written on the comparison of the effects of aerosols on tropical (large) and sub tropical clouds and precipitation.

Task: **Integration of MODIS and AVHRR time series with SPOT VEGETATION products towards consolidated land observation.**

GEST Investigator: Pierre Defourny

Collaborators: Compton Tucker (GSFC), Assaf Ayamba, Jorge Pinzon (SSAI), Chris Justice (UMD)

Abstract

Research on medium and coarse spatial resolution time series has produced various regional and global land products but the combination of them to support the end-users applications has been hardly proposed. The overarching research question is how can be combined the main strengths of the various products to enhance the quality and the robustness of the operational applications. During the first 6 months of the research, three cases studies have been selected. The first one focuses on the combination of the GLC2000 global land cover derived from 1-km multispectral SPOT VEGETATION time series with the 26-year long term AVHRR NDVI times series recently released by the GIMMS group. The second concerns the synergy of daily MODIS and SPOT VEGETATION data for crop monitoring. The last case study aims to develop an international platform to consolidate the forest mapping and monitoring effort in the framework of the Congo Basin Partnership.

Description of Research

Research on medium and coarse spatial resolution time series has produced various regional and global land products. From the user perspective this products diversity has to be transformed into consolidation and enhancement of the available information. For technical and institutional reason the operational combination of these products has been hardly investigated. Therefore the research objective of this 1 year study is to propose a pathway to develop synergistic use of the data currently available for three main application areas: the global land cover mapping, the agriculture monitoring and the tropical forest monitoring.

Accomplishments in FY 04-05

During the first six months of the research started in Aug. 2004, three cases studies have been selected in order to enhance the quality and the robustness of the operational applications. They all take advantages of recently released datasets and on-going NASA projects.

The first case study aims to combine the great spatial consistency of the GLC2000 global land cover map with the unique long term AVHRR NDVI time series in order to consolidate the class labeling and to characterize their respective phenology. Indeed recent research completed in the NASA GIMMS group succeeded to correct the 8-km AVHRR NDVI product for the orbital drift inducing changes in the sun-target-sensor geometry and for the difference in sensors calibration. This research effort provided the first global long term record derived from

remote sensing for ecological applications. On the other hand the Global Land Cover 2000 map was also recently produced from a year-long 1 km multispectral global time series acquired by SPOT VEGETATION. While very heterogeneous from the methodological point of view this product was found spatially very consistent and included 16 different land cover classes. The on-going research tries to combine the temporal information derived from the GIMMS NDVI time series with the GLC2000 class delineation to consolidate this global land cover information. Pilot processing for Africa is going on.

The second case study investigates how the daily multispectral MODIS and VEGETATION observations could improve the current operational crop monitoring systems. Three tests of 1000 x 1000 km have been selected for the method development. This includes alternative compositing strategy development and crop-specific information extraction from the 250-m MODIS Surface Reflectance product. Major investment has been made to take advantage of the existing MODIS and VEGETATION experiences.

Finally the third case study deals with technical and institutional development to propose an international platform in order to combine the on-going various forest mapping and monitoring efforts in the framework of the Congo Basin Partnership (CBFP). Indeed the CBFP initiative launched in September 2002 at the World Summit on Sustainable Development in Johannesburg, South Africa, aims to improve communication and coordination among its 29 member governmental and non-governmental organizations vis-à-vis their projects, programs, and policies to promote sustainable management of Congo Basin Forest ecosystems and wildlife and improve the lives of people living in the region. Such coordination and the identification of priorities require a better knowledge of the current situation and monitoring of the forest ecosystem. The diverse sources of data and the lack of international coordination among the information provider programs prevent the delivery of up-to-date and synthetic information to decision makers at the regional level. Based on the CBFP structure, an international platform for scientific and technical cooperation is proposed to improve significantly the information production and dissemination process. The USAID Central African Regional Program for the Environment (CARPE) is a 20-yeqr regional initiative started in 1995. The program includes a remote sensing component providing land cover map, forest change map and deforestation monitoring. Other international partners of CBFP have also developed regional activities in this field. The institutional challenge is to combine the best available data to deliver synthetic information to the decision makers. The first report on the state of the forest entitled “The Forests of the Congo Basin – A preliminary Assessment” finally included some international contributions and was successfully published by the CARPE Editorial Board early February 2005. As a follow up of this first success an international discussion is going on to develop an institutional framework for technical collaboration. Meanwhile specific technical solutions have to be identified to combine recently produced local and national land cover maps and regional deforestation change mapping.

Objectives for the Coming Year

The two first case studies respectively related to the AVHRR-GLC2000 land cover fusion and the MODIS-VEGETATION complementary for crop monitoring will be completed in the 5 coming months. Their experimental results are expected to be submitted to refereed scientific journals for publication. For the third case study supporting the CBFP initiative the institutional development should have got some international support during the coming year and technical methodology must be proposed for the information consolidation.

Task: **Simulation of Aerosol Effects on Climate**

GEST Investigator: Toshihiko Takemura

Collaborators: Yoram Kaufman (GSFC)

Abstract

Global aerosol and cloud distributions from the year 2000 to 2004 are simulated by an aerosol transport-radiation model, SPRINTARS, which has been developed in previous studies. The simulated monthly mean parameters of aerosol and cloud are compared with the MODIS retrieval and then tuned by model parameters. The simulated aerosol optical thickness is simulated well over areas where a large amount of aerosols exists, though it is smaller than MODIS over remote areas from aerosol sources because of the MODIS aerosol optical thickness may overestimates. The simulated cloud fraction and cloud droplet effective radius are in reasonable agreement with the MODIS retrieval including seasonable variations.

Description of Research

The MODIS retrieval by NASA GSFC produces very useful data related with aerosols and clouds, enabling comparisons of SPRINATRS with MODIS on the aerosol and cloud parameters which are important for evaluating the aerosol direct and indirect effects on global scale. Simulations are then created of climate responses to the aerosol effects such as change in surface temperature, hydrological cycle, and radiative budget due to anthropogenic aerosols with SPRINTARS validated by MODIS. The goal is to estimate the aerosol climate effects using the MODIS data as mentioned above.

Accomplishments in FY 04-05

A three-dimensional global aerosol transport-radiation model, SPRINTARS, has been developed which treats main tropospheric aerosols, *i.e.*, black carbon, organics, sulfate, soil dust, and sea salt. The model is coupled with an AGCM. The aerosol transport processes in the model include emission, advection, diffusion, sulfur chemistry, wet deposition, dry deposition, and gravitational settling. The aerosol direct effect, in which aerosol particles scatter and absorb the solar and thermal radiation, and indirect effect, in which they alter the microphysical and optical properties of cloud droplets acting as cloud condensation nuclei, are also calculated by coupled with the radiation and cloud-precipitation processes of the AGCM. Recently SPRINTARS has been connected with an ocean model, so that the climate responses to the aerosol direct and indirect effects can be evaluated. Takemura *et al.* [2005] indicated that a decrease in the cloud droplet effective radius by anthropogenic aerosols occurs globally, while changes in the cloud water and precipitation are strongly affected by a variation of the dynamical hydrological cycle with a temperature change by the aerosol direct and first indirect effects, in which the cloud droplet size decrease if the aerosol particle number concentration increases leading to the higher cloud albedo, rather than the second indirect effect, in which a decrease in the cloud droplet size results in an inhibition of precipitation and an increase in the cloud water. However, the cloud water can increase and the precipitation can simultaneously decrease in regions where a large amount of anthropogenic aerosols and cloud water exist, which is a strong signal of the second indirect effect. As mentioned above, an inclusive modeling system has been constructed for the estimation of climate change by aerosol particles.

There is, however, still a large uncertainty in the aerosol effects on the climate system, especially in the aerosol-cloud interaction. The Third Assessment Report of the Intergovernmental Panel on Climate Change estimated that the global mean radiative forcing due to anthropogenic aerosols is 0 to -2.0 W m-2 without a plausible value for the first indirect effect, and could not do that for the second one because of much less confidence. Therefore the aerosol and cloud parameters retrieved from the satellite-borne MODIS sensor operated by

NASA are introduced into the aerosol climate simulation by SPRINTARS in this research.

First, the aerosol and cloud distributions were simulated by SPRINTARS from the year 2000 to 2004 nudging the wind, temperature, and specific humidity by reanalysis data. A parameterization based on the Köhler theory has been introduced into SPRINTARS in which the cloud droplet number concentration depends not only on the aerosol particle number concentration but also the aerosol size distribution, chemical properties of each aerosol species, and updraft velocity. The horizontal resolution of the triangular truncation was set at T106 (approximately 1.125˚ by 1.125˚ in longitude and latitude), which was close to 1.0˚ by 1.0˚ resolution of quality-assured MODIS monthly data, and the vertical resolution at 20 layers. SPRINTARS was tuned by changing in aerosol- and cloud-related parameters using MODIS data. Then the simulated aerosol optical thickness is simulated well in urban, desert, and biomass burning regions where the aerosol optical thickness is high. It is, on the other hand, smaller than the MODIS over remote ocean regions from aerosol sources, though it is in good agreement with the ground-based aerosol remote sensing data from AERONET operated by NASA GSFC. It is reported that the retrieval of the small optical thickness from MODIS is difficult. The simulated cloud fraction and cloud droplet effective radius are in reasonable agreement with the MODIS retrieval including seasonable variations, though the MODIS cloud droplet effective radius is a little higher systematically. The cloud optical thickness simulated by SPRINTARS and retrieved from MODIS are, however, largely different. The MODIS one is artificially high along coasts at high-latitudes, and SPRINTARS one may also have a problem in a derivation method.

Objectives for FY 05-06

The simulated cloud top pressure will be compared with MODIS to verify the vertical structure of clouds. To analyze the simulated aerosol and cloud parameters in more detail, the MODIS daily data will be used. Then change in meteorological parameters not only cloud but also precipitation, temperature, and wind due to aerosol effects will be simulated and analyzed by SPRINTARS.

Task: **Currents in the Earth's Crust – Causes and Consequences**

GEST Investigator: Friedemann T. Freund

Collaborators: P. Taylor (GSFC), D. Ouzounov (SSAI)

Abstract

The discovery of electronic charge carriers that can be activated in igneous rocks by the application of stress opens a new avenue to better understand geodynamic processes in the Earth's crust, possibly also on Mars and other rocky solar system bodies. The stress-activated electronic charge carriers can create electric currents, which can potentially reach millions, even billions of amperes. This casts new light on the magnetic signatures in the Earth's crust, on the Moon and on Mars. The activation of highly mobile p-hole charge carriers in crustal rocks leads to positive surface potentials, which may be powerful enough to perturb the ionosphere. The arrival of p-holes at the Earth's surface is predicted to lead to narrow-band mid-infrared emission due to the exothermal recombination of p-holes and their radiative decay. Both the ionospheric perturbations and the stimulated mid-IR emission (hole-hole recombination luminescence) are of interest to the remote sensing community as potential indicators of impending earthquake activity.

Description of Research

The Earth's crust is constantly subjected to tectonic stresses. The stresses cause plates to move relative to each other on geological time scales, leading to orogenesis and mountain building. On shorter time scales, the tectonic movements create faults and lead to the

catastrophic release of accumulated stresses. This produces earthquakes.

The work performed under this GEST Fellowship is a continuation of my work at the NASA Ames Research Center and the Department of Physics, San Jose State University. It centers on the physical processes that accompany the application of stress to igneous rocks, including stresses that are far below those needed to cause catastrophic failure.

Accomplishments During the Reporting Period

The core of this research is to study the activation by stress of electronic charge carriers, specifically positive holes (p-holes for short). Important aspects were electrical conductivity measurements as an indicator of the appearance of these elusive charge carriers both inside and outside the stressed rock volume. In the course of the year, however, the attention shifted to measuring not the electric currents that flow under externally applied voltages but the currents that are self-generated in the stressed rock volume. The most important aspect was the capacity of the p-holes to flow out of the stressed rock volume into the surrounding unstressed rocks. In so doing they produce a variety of signals, which became topics of study in their own right.

Two aspects stand out. First, the fact that the p-holes generate positive surface charges, which can be measured in laboratory experiments using non-contact capacitive voltage sensors. These surface charges had been theoretically predicted and play an important role as diagnostic tools. In the context of geodynamic processes and remote sensing they are of interest as the possible cause of ionospheric perturbations, which have been widely reported to occur prior to major earthquakes. The linkage between large-scale ionospheric perturbations and positive surface charges due to the accumulation of p-hole charge carriers has special weight because all other mechanisms, which have been proposed in the literature to explain the observed ionospheric perturbations, suffer from a lack of a plausible physical process.

Second, the arrival of p-hole charge carriers at the rock surface is predicted to lead to enhanced recombination. This recombination, however, is highly exothermic, meaning that it releases a large amount of energy per event. Prior to this GEST Fellowship we have conducted a series of laboratory infrared (IR) emission experiments aimed at verifying the predicted emission of mid-IR photons of specific energies or wavelength from the surface of large blocks of rock placed under stress. These experiments had been carried out in collaboration with GSFC engineers, in particular Murzy Jhabvala and Anh La at GSFC, and with remote sensing specialists at the University of California at Santa Barbara, with an infrared spectroradiometer, which is used routinely in MODIS ground truth verification experiments.

A portion of the time during the GEST Fellowship was dedicated to the analysis of these laboratory spectral data. The highlight of the work was the demonstration that stresses activate two types of electronic charge carriers: p-holes and electrons. The boundary between stressed and unstressed rocks acts as a diode, letting p-holes pass but rejecting electrons. Hence, given the right conditions, a two-current system can be set up, carried by p-holes and by electrons respectively. The two currents are of equal magnitude but they flow out of the stressed rock volume in opposite directions. The two currents are coupled via their respective electric field and have the propensity to fluctuate.

The new laboratory observations lead to a re-evaluation of many reported field observations related to pre-earthquake activity. This re-evaluation will require time. It will most surely involve heated debates in the geoscience community because the implications that come out of this work are far-reaching. They require a paradigm change, which, as history has shown, is always a long drawn-out process.

Objectives for the Coming Year

The GEST Fellowship was for one year.

Educational Programs

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Educational Programs

The summer of 2004 was GEST's fourth year managing three GSFC education programs. Considerable financial constraints were again problematic this year for two programs; however, all three programs were able to operate at full capacity with the financial assistance to the Earth and Space Data Computing Division (ESDC) by the Earth Sciences Directorate. All three programs were highly successful and provided an invaluable experience to the students.

Visiting Student Enrichment Program (VSEP)

VSEP is open to high school, undergraduate and graduate students in the computer sciences, mathematics, and physical sciences. The 2004 VSEP internship lasted for nine weeks, one week shorter than it has traditionally been. The program taught students how to write a report in the style preferred by NASA publications; how to write an abstract, which were compiled at the VSEP student seminars; and how to create a computer-driven slide presentation.

VSEP 2004 supported fifteen students chosen from 250+ completed applications. The student population included two graduate students (Masters), twelve undergraduate students and one high school student. Of the fifteen students, only three were local. Students were housed in apartments at the University of Maryland, College Park and were shuttled to GSFC daily. Planned events for students included six lectures, one report-content class with follow-up tutorial sessions, two field trips (NSA Cryptology Museum and Smithsonian Air and Space Museum's Udvar-Hazy Center) and two social activities.

Additional changes were implemented into this year's program to meet the needs of the twenty-first century student. Primarily, the application process was put on-line and all applications were stored in a database that mentors could access while on Center. Students had one-on-one meetings with the program coordinator in the third week of the internship to identify students' needs and concerns with their projects. Weekly updates were then implemented to ensure the students' success in the program. Students also went through a critique circuit for their written reports which were due prior to their departure from the program.

A list of the projects completed during VSEP 2004 is given below. All reports are available for public review on the GEST website (http://gest.umbc.edu/student_opp) as well as the VSEP website (http://vsep.gsfc.nasa.gov). Names in parentheses are the student's mentors and names marked with an asterisk indicate GEST faculty members.

Education web programming and data security.
Ron Ogden (Antonio Mannino, Code 971)

Transfers between Earth-Moon libration orbits and lunar orbits.
Scott Francis (David Folta, 595)

XML query language project.
Dennis A. Petesch, Jr. (Lola Olsen, Code 902)

NES Challenge 001: Return to the Moon.
Natalie Vershov (Susan Hoban*, Code 900.1)

Interactive web application for NCCS systems usage statistics.
Babatunde Azeez (Hamid Oloso, Code 931)

Development of dynamic web and database-based applications.
Angie Albers (Mike Witkowski, Code 931)

Profiling and tuning the global modeling initiative (GMI) code and parallelizing the 'Penelope Monte Carlo Particle Transport' simulation package.
Ghalib Bello (Hamid Oloso, Code 931)

Research and testing of Transmission Control Protocol (TCP) modifications to improve network performance.
Andrea McLeod (Pat Geary, Code 933)

Applications of the 'Reversible Jump Markov Chain Monte Carlo' algorithm.
Richard Windle (Samir Chettri, Code 935)

Data management in the Land Information System (LIS).
Peter Anderson-Sprech (Christa Peters-Lidard, Code 974)

A web-based user interface to MAPSS.
Gregg Rapoza (Charles Ichoku, Code 913)

It is unfortunate to report that due to the GSFC transformation process, funding for VSEP by the Earth-Sun Division and the ESDC has been cut and therefore we will be unable to continue the program. The response by students to this news has been overwhelming. Some of the comments received include:

"I'm sad to hear that the program is ending. I had a wonderful summer, meeting and learning from all of the really great people at GSFC. I'm glad to have been able to take advantage of the opportunity while it was still available and I'm sorry for those who will never have a chance to benefit from it."

"I'm sorry to hear they are closing VSEP. It was an awesome program. I got so many interviews in the past two years just because I have worked at NASA. And I am very thankful for that."

"VSEP is ending? That is sad. It was such a good program."

Graduate Student Summer Program (GSSP)
The intent of the GSSP is to encourage graduate students in the Earth sciences to conduct genuine research at NASA 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: Goddard Space Flight Center, Goddard Institute for Space Studies and Wallops Flight Facility.

The theme for the four-day seminar series to initiate the program was "Modern Themes in Earth Science," wherein a variety of GSFC and GEST scientists were invited to speak on the most popular research occuring at GSFC. Nine students were selected this year out of forty-two completed applications. The student population included two doctoral students and eight Masters students, of which only one student was local. Two students were placed at WFF, while the remaining students were at GSFC. Individual meetings were conducted after the end of the second week of the program with each student to monitor their progress, mentor relationship and project comprehension. These meetings were then followed up by visits to each student at their work stations throughout the program. The program coordinator visited the WFF students one week into their internship, then contacting them by telephone for the remainder of the program. GSSP students were given the opportunity to participate in the field trips organized by VSEP, but also had their own social activities. All students were required to present a twenty-minute seminar on the work completed in the ten-week program. 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). Notably, one student's GSSP paper, co-authored by a GEST faculty member who served as a mentor, has been accepted for publication in a scientific journal. Another student's summer research was presented at an AGU meeting, with her travel being supported by the GSFC mentor. Below is a list of the projects completed during GSSP 2004. Names in parentheses are the student's mentors and names marked with an asterisk indicate GEST faculty members.

Land cover and its impact on monsoon precipitation over Southeast Asia.
Sudipta Sarkar (Christa Peters-Lidard, Code 974)

Characteristics and correction of NPOL during periods of webs attenuation.
Paul Frank (John Gerlach, Code 972)

A comparison of methods measuring surface coastal circulation: CODAR vs. satellite estimation using the maximum cross-correlation technique.
Aurélie Moulin (John Moison, Code 972)

Simulations of biomass smoke emissions and comparisons of aerosol optical properties to in situ and remote sensing observations.
Rebecca Matichuk (Peter Colarco, Code 916)

A multidisciplinary study of ongoing deformational processes in the Yakutat Transitional Zone, Southeastern Alaska.
Katy Wiest (Jeanne Sauber, Code 921)

Relationships between the vertical structure of deep convection and upper tropospheric humidity.
Jonathon Wright (Andrew Dessler, Code 916)

Cross-Validation of AMSR-E soil moisture retrievals and surface soil moisture simulations from NASA's Global and Data Assimilation System (GLDAS).
Alok Sahoo (Xiwu Zhan*, Code 974)

Temporal and spatial patterns of vegetation greenness and rainfall variability in the West African Sahel.
Stefanie Herrmann (Assaf Anyamba*, Code 923)

NASA Summer School for High Performance Computational Earth and Space Sciences (HPC)

The HPC Summer School is a three-week intensive course open to doctoral students in the Earth or space sciences who incorporate large-scale numerical modeling on massively parallel architectures for their dissertation research. This highly competitive program is run by the Earth and Space Data Computing Division and the Computational Technologies Project (CT). NASA GSFC is home to world-class computing facilities, which include a 1392-processor HP/CPQ SC45 alpha cluster, a 384 processor SGI Origin 3800, a 512-processor commodity cluster, and numerous middle-sized supercomputing platforms. Local GSFC scientists from the ESDC and invited speakers from around the country are the instructors for the course. Lectures are presented on developing software for scalable architectures, computational fluid dynamics and particle methods, along with hands-on parallel computer training and small-group tutorial sessions.

Fifteen students participated in the 2004 HPC Summer School, of which three were local students. Students were housed in single accommodations at the University of Maryland, College Park and were provided with daily transportation to GSFC. At the end of the program, all students were given the opportunity to give a short presentation on their dissertation research.

The HPC Summer School has also lost funding support from the Earth-Sun Division and the ESDC and the program will not be offered in 2005. Many students have written to show their support to the program. Some comments received include:

"…It was a great experience for me. The programming skills have been helpful in graduate school, and the exposure to big science gave me perspective in choosing my post-doc."

"That summer school was awesome… I'm at the University of Georgia now as a postdoc. I found what I learned at summer school very useful."

GEST Graduate Fellowship

No new graduate fellowships were awarded this year. Eric A. Eaton, who had been selected last year, was awarded an additional year of funding. Mr. Eaton is working on his PhD in the Department of Computer Science and Electrical Engineering. His advisor is Dr. Marie des Jardin. Mr. Eaton's main research interest is artificial intelligence. His current research is to incorporate qualitative knowledge into inductive machine learning, incremental learning in the presence of context changes, constrained clustering and life-long learning.

Marci Delaney

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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 collaborative work at GSFC, 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.

During the past year, those scientists who visited GSFC under the auspices of GEST included:

Visiting Scientist	Affiliation	GSFC Code Visited
Arakawa, Akio	University of California, Los Angeles	910
Balaji, V.	NOAA, New York City	931
Boonjawat, Jariya	Chulalongkorn University, Thailand	913
Cai, Ming	Florida State University	910
Carver, Robert	The Pennsylvania State University	912
Chemtob, Steven	NASA Goddard Space Flight Center	974
Cheung, Samson	NASA Ames Research Center	910
Chou, Ming-Da	National Taiwan University	910
Davis, Anthony	Los Alamos National Laboratory	913
Derimian, Yevgeny	Ben Gurion University, Israel	913
Diab, Roseanne	University of Natal, South Africa	916
Diaz, Ana	Universidad de La Laguna, Spain	916
Doser, Diane	University of Texas, El Paso	921
Ehrendorfer, Martin	University of Innsbruck, Germany	900.3
Garcia, Matthew	Colorado State University	974
Gombert, Dale	Washington Department of Fish & Wildlife	900.1
Hahnenberger, Maura	University of Utah	913
Han, Mei	University of California, Irvine	912
Harshvardhan	Purdue University	913
Hartmann, Dennis	University of Washington	910
Hurtado, Jose	University of Texas, El Paso	921
Jacobson, Mark	Stanford University	910
Kim, Min-Jeong	University of Washington, Seattle	975
Koch, Roland	University of Innsbruck, Germany	900.3
Krishnamurti, T.	Florida State University	910
Ladstaetter, Annette	University of Bremen, Germany	916
Lee, Wen Chau	National Center for Atmospheric Research	912
Linde, Timur	University of Chicago	931
Lindzen, Richard	Massachusetts Institute of Technology	913
Lingle, Craig	University of Alaska, Fairbanks	921
Lohmann, Ulrike	Swiss Federal Institution of Technology	910
Matichuk, Rebecca	University of Colorado, Boulder	916
Medaglia, Carlo	University of Rome, Italy	912
Meskhidze, Nicholas	Georgia Institute of Technology	916
Mohr, Karen	University of Albany	912
Muehlbauer, Andreas	University of Innsbruck, Germany	900.3
Nenes, Athanasios	Georgia Institute of Technology	913
Nerger, Lars	Alfred-Wegener-Institut, Germany	900.3

Visiting Scientist	Affiliation	GSFC Code Visited
Perlwitz, Judith	Goddard Institute for Space Studies	900.3
Pincus, Robert	NOAA-CIRRES	913
Pinheiro, Ana	NASA Goddard Space Flight Center	974
Reichardt, Jens	Meteorolgisches Observatorium, Germany	916
Rosenfeld, Daniel	The Hebrew University of Jerusalem	913
Sabbah, Ismail	Kuwait University	913
Santer, Benjamin	Lawrence Livermore National Lab	913
Sawatdiaree, Sivinee	National Instititute of Meteorolgy, Thailand	913
Schofield, Oscar	Rutgers University	916
Seifert, Axel	National Center for Atmospheric Research	912
Somerville, Richard	Scripps Institution of Oceanography	910
Stephens, Graeme	Colorado State University	910
Sun, De-Zheng	Climate Diagnostics Center (NOAA)	910
Surapipith, Vanisa	Ministry of Natural Resources, Thailand	913
Thongboonchoo, Narisara	University of Iowa	913
Walker, Jeff	University of Melbourne	974
Wiest, Katy	University of Texas, El Paso	921
Wilcox, Eric	Princeton University	910
Wu, Chun-Chieh	National Taiwan University	912
Yu, Hongbin	Georgia Institute of Technology	913
Yu, Jun	University of Vermont	974
Zahid, Jabran	University of California, Berkley	612.1
Zipser, Edward	University of Utah	910

APPENDICES

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Adler, R. F., G. Gu, S. Curtis, and G. Huffman (2004), Means, variability and extremes of precipitation in the global climate as determined by the 25-year GEWEX/GPCP data set, presented at American Geophysical Union (AGU) Fall Meeting, San Francisco, California, December 13-17.

Amitai, E., X. Llort, L. Liao, and R. Meneghini (2004), A framework for global verification of space-borne radar estimates of precipitation based on rain type classification, presented at The 2nd TRMM International Science Conference, Nara, Japan, September 6-10.

Anyamba, A. (2004), Satellite monitoring systems for eco-climatic conditions associated with zoonitic diseases, presented at WHO/FAO/OIE Joint Consultation on Emerging Zoonotic Diseases in Collaboration with the Dutch Health Council, Geneva, Switzerland, May, 3-5.

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Yu, H., Y. Kaufman, M. Chin, M. Zhou, L. Remer, R.E. Dickinson, Q. Tan (2004), A Synergy analysis of global aerosols and assessment of direct radiative effect, presented at American Geophysical Union (AGU) Fall Meeting, San Francisco, California, December 13-17.

Zender, C. and H. Bian (2004), Mineral dust aerosol and tropospheric ozone: Sensitivity to season, uptake rate, and chemical composition, presented at European Geosciences Union 04, Steamboat Springs, Colorado, August 23-27.

Zhan, X. W. and P. R. Houser (2004), Jointly retrieving surface soil moisture from active and passive microwave observations using cubist data-mining, presented at American Geophysical Union (AGU) Fall Meeting, San Francisco, California, December 13-17.

Zhan, X. W., P. R. Houser, J. C. Shi (2004), Assimilating AMSR-E observations into the NOAH Land Surface Model for better water cycle predictions. presented at the Second International Workshop on Catchment-scale Hydrological Modeling and Data Assimilation, Princeton, New Jersey, October 25-27

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Zhang, Y., Hongbin Yu, R. Fu (2004), Influences of biomass burning on land-atmosphere interactions and dry-to-wet transition over Amazonia, presented at American Geophysical Union (AGU) Fall Meeting, San Francisco, California, December 13-17.

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Ziemke, J. R., S. Chandra, and P. K. Bhartia, A 25-year data record of stratospheric and tropospheric ozone from TOMS Cloud Slicing: Implications for stratospheric ozone recovery, presented at American Geophysical Union (AGU) Fall Meeting, San Francisco, California, December 13-17.

Grant Proposals and Status

(sorted by funding agency)

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Determination of the Effects of Non-Modality on the Data Assimilation and Numerical Weather Prediction Problems	ATM division of NSF	Errico (GEST)		Funded
Distributed Modeling Support for the Romanian Destructive Water Abatement (DESWAT) program	Baron Advanced Meteor. Systems	Kumar (GEST), Garcia (GEST)	Gochis (NCAR), Yates (NCAR)	Funded
Narrow-Band LED Light Engines for Advanced Fluorescence Monitoring in Coastal and Estuarine Environments	CICEET	Chekalyuk (GEST)		Not Awarded
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 Inst. of Research	Anyamba (GEST), Tucker (GSFC)	Coldren (WRAIR), Linthicum (USDA)	Funded
Peta-Scale Application Development Analysis	DoE	Lucas (Univ. of So. Cal.)	Numrich (GEST)	Funded
Advances in 3-dimensional atmospheric radiation: I3RC toolbox, interactive aerosol retrieval, and cloud inhomogeneity parameterization	DoE's ARM Prog.	Cahalan (GSFC)	Wen (GEST)	Funded
Improving USBR Water Supply, Demand Monitoring and Forecasting Using NASA Earth Science Data	EPA	Boyle (Univ. Nevada)	Arsenault (GEST), Toll (GSFC)	Pending
Integrating MODIS and NPP VIIRS Observations into the USDA FAS Decision System	FAS-USDA/ NASA	Justice (UMCP)	Hansen (SDSU), Descloitres (SSAI), Reynolds (FAS-USDA), Anyamba (GEST), Tucker (GSFC), Masuoka (GSFC), Tarpley (NOAA)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
The Application of NASA EOS MODIS Data to Agricultural Assessment and Forecasting by the USDA Foreign Agricultural Service	FAS-USDA/ NASA	Justice (UMCP)	Anyamba (GEST), Tucker (GSFC), Doorn (FAS-FAS), Reynolds (FAS-USDA)	Funded
Development of a Low Cost UAV Radar for Measurement of Precipitation and Surface Winds in Tropical Storm Genesis	Goddard Instrument R&D	Heymsfield (GEST)		Funded
Airborne Transport Of Aerosols Into The South Atlantic Ocean: Assessment Of Sources, Horizontal Fluxes, Iron Fertilizing Potential And Impact On Climate	IAI/NSF	Gaiero	Gassó (GEST), Chemale, Conceição, Bidart	Funded
Great Lakes Region Ozonesonde Network (GLRON)	Indiana Space Grant Consortium	Morris (Valparaiso Univ.0		Funded
Climate Variability and Agricultural Production in the Semi-Arid Lands of Eastern Kenya	Intl. START-IGBP Secretariat	Shisanya (Kenyatta Univ.)	Anyamba (GEST)	Funded
"Science As Inquiry" Professional Development for NES Teachers	NASA	Shelton (NASA JSC)	Hoban (GEST), Linares (UPR)	Pending
A community-driven North American disturbance record and processing system for land satellite data	NASA	Masek (GSFC)	Hall (JCET), Wolfe (SSAI), Masuoka (GSFC), Cohen, Lyapustin (GEST)	Funded
A Global Model Analysis of Anthropogenic Aerosol Radiative Forcing Using Data from Terra and Aqua Satellites, Ground-Based Networks, and In-Situ Measurements	NASA	Chin (GEST)	Remer (GSFC), Kaufman, Dubovik (GEST), Colatz	Funded
A Global Modeling Initiative (GMI) Study of the Sensitivity of Transport to Meteorological Fields	NASA	Duncan (GEST)	Chin (GEST), Mickley, Olsen (GEST)	Pending
A Prototype Satellite Simulator Model for Combined Radar-Radiometer Precipitation Estimation	NASA	Olson (JCET)	Grecu (GEST), Meneghini (GSFC), Li	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
A Skewed-PDF Model for Moist-Turbulence and Shallow-Convection in Data Assimilation Systems	NASA	Helfand (NASA)	Bacmeister (GEST), Norris (GEST)	Pending
A Water Cycle Solutions Network	NASA	Houser	Belvedere (GEST), Toll, Schiffer, Policelli, Welty (CUERE), Lawford (GEST), Vorosmarty, Imam, Gupta (GEST), Shuttleworth, Matthews, Schlosser	Pending
Additional Ozonesondes in Houston, Texas in Support of INTEX-B and AURA Validation	NASA	Morris (Valparaiso University)	Few (Rice Univ.), Fraser (Rice Univ.), Celarier (GSFC), Wolf (Valparaiso University)	Pending
Aerosol radiative forcing and effects on tropospheric chemistry: Modeling and uncertainty analysis in the GMI framework	NASA	Chin (GEST)	Liu (GEST), Duncan (GEST), Bian (GEST), Diehl (GEST)	Pending
Air Quality Project on Extending High Resolution Modeling of Land-Atmosphere Ammonia Exchanges	NASA	Peters-Lidard (GSFC)	Wu (GEST)	Funded
Airborne Radar Measurements in Support of Aura Validation	NASA	Li (GEST)	Heymsfield (GSFC), Racette (GSFC), Tian (GEST)	Pending
An AGCM Study of Extreme Winter Weather Events over the United States and their Links to ENSO	NASA	Siegfried Schubert	Yehui Chang (GEST)	Funded
An integrated approach of enhancing the quality of Aura aerosol retrieval, supporting Aura validation, and analyzing Aura data	NASA	Chin (GSFC)	Allen (UMCP), Bian (GEST), Diehl (GEST), Dubovik (GEST), Remer (GSFC), Torres (JCET), Wenig (NRC), Yu (GEST)	Pending
An Interagency Approach to Water Resources Evaluation and Management in the Maghreb Region	NASA	Jaskinski (GSFC)	Arsenault (GEST)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
An Introduction to a Virtual Learning Environment For Astronomy: Pre-service Training and Professional Development	NASA	Hoban (GEST)	McMahon (CSULB)	Not Awarded
Analysis and Validation of the Aerosol and Surface Reflectance EDRs over Land for the Visible/Infrared Imaging Radiometer Suite	NASA	Lyapustin (GEST)	Wang (GEST), Privette (GSFC), Holben (GSFC)	Funded
Analysis of Multi-Wavelength Radar Data	NASA	Meneghini (GSFC)	Liao (GEST)	Funded
Antarctic Comprehensive Model from Airborne, Shipborne, Ground, Satellite Magnetometer Data	NASA	Kim (GEST)		Funded
Applications, Evaluation and Improvement of a Coupled, Global and Cloud-Resolving Modeling System	NASA	W. K. Tao (GSFC)		Pending
Assimilation of AMSR-E data and application to the initialization of soil moisture reservoirs in a seasonal forecasting system	NASA	Reichle (GEST)	Koster, Zhan (GEST), Jambor, Bacmeister (GEST), Houser	Funded
Assimilation of Constituents for Evaluation and Intercomparison of Aura Observations (ACEi-Aura)	NASA	Lary (GEST)		Funded
Assimilation of GRACE Derived Terrestrial Water Storage Variations	NASA	Rodell (GSFC)	Reichle (GEST)	Pending
Atmospheric Data Assimilation Development	NASA	Gelaro (GSFC)		Pending
Atmospheric Modeling, Assimilation and Source-Sink Est. for the Carbon Cycle	NASA	Pawson (GSFC)	Gupta (GEST), Reichle (GEST)	Not Awarded
Atmospheric solar radiative transfer	NASA	Cahalan (GSFC)	Wen (GEST)	Funded
Atmospheric Transport of Trace Gases and Aerosols: Evaluating Models and Observations	NASA	Schoeberl (GSFC)	Morris (Rice Univ.)	Funded
AURA Validation by Airborne UV-VIS Differential Optical Absorption Spectroscopy	NASA	Stutz	Janz, Mount, Bucsela (GEST), Spurr, Sander	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Backtrajectory, AERONET, MODIS, GOCART, MPLNET, Aerosol Synergism (BAMGOMAS)	NASA	Holben (GSFC)	Weaver (GEST)	Funded
Calibration and Analysis of Global Latent Heating Estimates Using Passive and Active Microwave Sensor Data	NASA	Olson (JCET)	Grecu (GEST), Shie (GEST)	Pending
Chemical Forecasting and Quick-Look CTM Analysis in Support of INTEX-A	NASA	Jacob (Harvard Univ.)	Pawson (GSFC)	Funded
Chemistry-Climate Studies Using General Circulation Models	NASA	Stolarski (GSFC)	Bacmeister (GEST), Douglass (GSFC), Gupta, Hollandsworth-Frith (GSFC), Kawa (GSFC), Newman (GSFC), Nielsen (GSFC), Olsen (GEST), Pawson (GSFC), Perlwitz (GSFC), Waugh (GSFC)	Pending
Closure in Model Prediction, In-Situ Measurements and Remote Sensing of Aerosol Mass Concentration	NASA	Gassó (GEST)	Tsay (NASA)	Funded
Consistency Analysis of Tropical UT/LS Water Vapor Distribution and Variability Observed by the A-Train Satellites: Analysis of Convection Controlled Variability in Tropical UT/LS Water Vapor	NASA	Gupta (GEST)		Pending
Constraining the CO_2 missing sink	NASA	Kawa (NASA)	Erickson, Denning, Collatz	Funded
Cryospheric experimental synthetic aperture radiometer (CESAR): a UAV-mounted synthetic aperture radiometer for cryospheric applications	NASA	Markus	Tedesco (GEST)	Pending
CRYSTAL-FACE Analyses	NASA	Heymsfield (GSFC)	Li (GEST), Tian (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Developing an Integrated Capability to Characterize, Understand and Predict Urban-Induced Modifications to Hydrometeorological Processes	NASA	Shepherd, Burian	Eastman (GEST), Peters-Lidard, Tao	Not Awarded
Development of a High-Resolution Earth System Model for Satellite Data Assimilation, Weather and Climate Applications	NASA	Atlas (GSFC), Houser (GSFC), Fukumori (JPL), Lin (NOAA)	Yeh (GEST)	Pending
Development of an Infrared Multi-anlge Imaging Spectral Radometer (IRMISR) for Diurnally Unbiased Measurements of Cloud Heights and Winds	NASA	Lancaster (GEST)	Sirota (Sigma Space), Spinhirne (GSFC)	Funded
EARTH+ Dynamic NASA Earth Science Exploration For Blind Learners	NASA	Shelton (NASA JSC)	Hoban (GEST), Linares (UPR)	Pending
Effect of Prestorm Land-Surface Characteristics on Landfalling Tropical Cyclones	NASA	Pielke	Eastman (GEST), Nicholls, Niyogi	Pending
Effects of Convection and Lighting on Tropospheric Chemistry Using The GMI Model	NASA	Pickering, Allen	Lary (GEST)	Pending
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 (GEST), Koster, Sun, Todling (GSFC)	Pending
Enhanced remote sensing of atmospheric aerosol by multi-sensor AERONET/MISR/ MODIS retrieval	NASA	Dubovik (GEST)	Martonchik, Kaufman, Holben	Funded
EPA Nonpoint Source Water Quality Using NASA Earth Science Data	NASA	Toll, Partington, Townsend, Ni-Mesiter	Carleton, Shenk, Arsenault (GEST), Eshleman, Triggs (GEST), Nigro	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Estimating Earth's Climate by Assimilating Satellite Observations of the Ocean and Atmosphere with a Coupled Earth System Model	NASA	Fukumori	Lee, Ghil, Kondrashov, Rosati, Lin (GEST), Philander, Sun	Pending
Exploring the integration of remotely sensed observations in the high-resolution prediction of global land-surface hydrological processes: An uncertainty investigation driven by the goal of optimality	NASA	Anagnostou (Univ. of CT)	Peters-Lidard (GSFC), Hossain (TTU), Garcia (GEST)	Pending
Fires as a Disturbance in the Earth-Atmosphere System, a Pilot Study Using MODIS Data and Experimental Algorithms	NASA	Vermote	Dubovik (GEST)	Funded
Forecast and Analysis of Aerosol Distribution and Transport Using MODIS Near Real Time and Geostationary Satellite Measurements and Trajectory Model for INTEX-B	NASA	Chu (JCET)	Remer (NASA), R.-R. Li (GEST)	Pending
Fundamentals of Lunar Exploration: Supporting NASA's ESMD Pipeline at the High School & Undergraduate Levels	NASA	Hoban (GEST)	Stockman (SSAI), Smith (TSU)	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 (GSFC)	Margulis, Reichle (GEST)	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)	Pending
Grid-Enabled Data Mining Technology with the Land Information System	NASA	Tian (GEST)	Peters-Lidard, Houser (GSFC)	Not Awarded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Ground-based Aerosol Measurement and Characterization	NASA	Holben	Dubovik (GEST), Eck (GEST), Nelson, Smirnov (GEST)	Funded
GSFC Visitor Center Program for IS Informal Education, and exhibits for self-guided and structured visit programs	NASA	Henderson	Williamson-Taylor, Summey, Hildebrand, Houser, Belvedere (GEST)	Pending
High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)	NASA	Heymsfield	Carswell, Frasier, Li (GEST), Schaubert	Pending
I3RC workshop and 3D Radiative Transfer	NASA	Cahalan (GSFC), Marshak (GSFC)	Wen (GEST)	Funded
Impacts of soil moisture uncertainty and evaporation sensitivity on sub-seasonal rainfall and temperature prediction	NASA	Koster (GSFC)	Reichle (GEST)	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 (U. Md.)		Pending
Improved Understanding of TRMM PR Derived Products Using Aircraft Radar Observations	NASA	Heymsfield (GSFC)	Tian (GEST), Li (GEST)	Funded
Improved Water Resources Decisions From the ET Toolbox Using NASA Earth Science Products	NASA	Hendricks (New Mex. Tech. Univ.)	Arsenault (GEST)	Pending
Improvement to the Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)	NASA	Wang (GEST)	Evans, Racette, Heymsfield, Li (GEST)	Funded
Improving gravity wave parameterization for next generation troposphere/middle atmospheric general circulation models	NASA	Bacmeister (GEST)		Pending

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 (NASA)	Cosgrove (SAIC), Garcia (GEST), Houser (NASA), Koren (NOAA/ NWS), Rodell. (NASA), Seo (UCAR NOAA/NWS), Smith (NOAA/NWS), Toll (NASA)	Pending
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), Arthur Hou (NASA), Oreopoulos (JCET), Platnick (NASA)	Pending
Improving USDA NRCS Snow and Water Supply Forecasting Using NASA Data in the Upper Klamath River Basin	NASA	Kelly (GEST)	Pasteris (USDA), Triggs (GEST), Arsenault (GEST), Foster (GSFC), Toll (GSFC), Rodell (GSFC). Engman (SSAI)	Pending
Improving USDA NRCS Snow and Water Supply Forecasting Using NASA Data in the Klamath River Basin	NASA	Kelly, Pasteris (NRCS)	Triggs (GEST), Arsenault (GEST), Engman, Foster, Toll, Rodell	Pending
Integrated Learning of Urban Environment	NASA	Meister	Houser, Campbell, Belvedere (GEST), Kumar (GEST), Salmun, Solecki, Scalzo, Reynolds, Gong	Pending
Integrated Learning of Urban Environment	NASA	Ni-Meister (Hunter College, CUNY)	Houser (NASA)	Pending
Investigating the Energy and Hydrological Cycle by Examining Cloud Systems over (Selected) Tropical and Midlatitude Regions	NASA	Shie, Tao (GSFC)	Li (GEST)	Not Awarded
Jet/ISM Interactions: A study of the Inner Optical Filament in Centaurus A	NASA	Koratkar (GEST)		Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Land Data Assimilation to Enhance Earth System Observation, Modeling and Prediction	NASA	Houser (NASA)	Bosilovich (NASA), Crow (USDA), Peters-Lidard (NASA), Pinheiro (NASA), Rodell (NASA), Waler (UMB), Zhan (GEST)	Pending
Latent Heating Estimates from Airborne Observations to Support the Analysis and Forecasting of Tropical Cyclone	NASA	Grecu (GEST)	Olson (JCET)	Pending
Magnetic Exploration of the Martian Crust	NASA	Frese (OSU)	Kim (GEST), Potts (OSU), Taylor (NASA)	Pending
Measurements of Trace Gas (NO2, SO2, HCHO, O3) Amounts, Aerosol Properties, and UV Irradiance for Aura Validation Using Overlapping Spectral Measurements from Four Different Instruments	NASA	Herman	Labow (SSAI, Cede (SSAI)	Pending
Measurements, Modeling and Analyses in Support of Aura and Other NASA Satellite Observations of the Earth's Atmosphere	NASA	Carn (JCET)	Krotkov (GEST), Krueger (JCET), Schaefer, Bluth, Prata	Pending
Meteorological and constituent forecasting in support of field mission and validation experiments	NASA	Pawson (GSFC)	Kawa (GSFC), Hayashi	Pending
Microphysics and cloud dynamics in two remote tropical oceanic regions: Satellite, field and cloud-resolving model studies	NASA	Sobel (Columbia University), Perez (Columbia University)	Tao (GSFC), Shie (GEST)	Pending
Model Investigations of Upper-Tropopshere/Lower-Stratosphere Water Vapor and Transport into the Stratosphere	NASA	Olsen (GEST)	Gallus (GSFC)	Pending
Moist physics development for GEOS-5 using single column models with parameterized dynamics	NASA	Bacmeister (GEST)		Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Multi-scale Convergence of Cold-land Process Representation in Land-surface Models,Microwave Remote Sensing, and Field Observations	NASA	Kim (GEST)	Tedesco (GEST)	Funded
Multi-scale forward modeling and retrieval of snow parameters: evaluation for future snow missions using CLPX-1 and CLPX-2 observations	NASA	Kim (GEST)	Tedesco (GEST)	Pending
Multi-scale Modeling Studies of Tropical Cloud Systems-Aerosol-Chemistry Interactions for TCSP	NASA	Tao (GSFC), Simpson (GSFC), Starr (GSFC)	Li (GEST), Shie (GEST)	Pending
Multi-Sensor Data Registration	NASA	Meneghini (GSFC)	Liao (GEST)	Funded
Multi-wavelength Raman Lidar Measurements for Studies of the Aerosol Indirect Effect and AERONET Algorithm Development	NASA	Whiteman (JCET)	Veselovskii, Demoz, Lin (GEST), Dubovik (GEST)	Funded
NASA Energy and Water Cycle Study (NEWS) Product Driven Research Integrated for Water Resources Applications	NASA	Toll	Arsenault (GEST), Policelli, Habib, Robertson, Oglesby, Nigro, Triggs (GEST)	Pending
Observing System Experiments (OSE and OSSE) to Evaluate and Enhance the Impact of Current and Future Satellite Observations	NASA	Atlas (GSFC)	Jusem (SAIC), Reale (GEST)	Pending
Ocean Surface Topography and Vertical Structure Variability	NASA	Jacob (GEST)	Beckley (RITSS)	Not Awarded
OMI Tropospheric NO_2 Column Retrievals	NASA	Pickering	Bucsela (GEST)	Pending
Optimal land surface temperature estimation and assimilation for global hydrological applications	NASA	Houser (NASA)	French, Meng (GEST), Pinheiro	Funded
Optimal Merging of AMSR-E Snow Water Equivalent and MODIS Snow Cover	NASA	Rodell (GSFC)	Reichle (GEST), Dong, Kelly (GEST), Sun	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Observations Through Data Assimilation				
Orbiting Carbon Observatory (OCO)	NASA	Crisp (JPL)	Pawson (GSFC)	Funded
Pathways to predictability on sub-seasonal timescales: Assessing the role of tropical forcing and land surface conditions	NASA	Schubert (GSFC)	Reichle (GEST)	Pending
Physically-Based Continuous Fields and Land Cover Mapping Algorithm Using MODIS and Multi-Source Data	NASA	Hall (JCET)	Peddle (GSFC), Huemmrich (JCET), Lyapustin (GEST)	Funded
Precipitation Response to Cyclic Forcing	NASA	Bell (GSFC)	Kim (GSFC), Kundu (GEST), Li (GEST), Sud	Not Awarded
Quantifying the sources and Transport of Combustion Gases and Aerosols Using MOPITT, MODIS, MISR and Complementary Satellite Observations	NASA	Jacob (Harvard Univ.)	Pawson (GSFC)	Funded
Rapid Prototyping of Sonification Schemes to Inform the Development of Tool to Make NASA Images Accessible to Blind Students	NASA	Maynard (GSFC)	Hoban (GEST), Laughlin (GEST)	Funded
Regional Climate Studies in the Caribbean	NASA	Gonzalez	Eastman (GEST), Waide	Funded
Satellite data in modeling and prediction of seasonal-to-interannual climate variability	NASA	Rienecker (GSFC)	Reichle (GEST)	Pending
Seasonal and Annual Climate Variation and Sea Ice Redistribution Study Using Sea-Ice Motion and Deformation Derived from Satellite Multi-Sensors	NASA	Liu (GEST)	Zhao (GEST)	Pending
Sensitivity of eastern Pacific tropical cyclogenesis in the NASA finite-volume General Circulation Model to improvements in the representation of the large-scale low-level moisture flux convergence	NASA	Reale (GEST)	Atlas (GSFC)	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Single Column Modeling Studies of Water Isotopes and other Trace Constituents in the Tropical Tropopause Layer (TTL)	NASA	Bacmeister (GEST)	Lary (GEST)	Pending
Single column modeling studies of water isotopes and other trace constituents in the tropical tropopause layer	NASA	Bacmeister (GEST)	Gupta (GEST)	Pending
Space Lidar for Extended Time Series Atmospheric and Climate Measurements	NASA	Spinhime (GSFC)	Lancaster, Coyle (GSFC), Krainak (GSFC), Kay (American Univ.)	Funded
Spectral and Angular Characterization of Ocean Reflectance using Multiple Sensors with Emphasis on Coastal Zones	NASA	Gatebe, King (GSFC)	Dubovik (GEST), McClain	Pending
Spectral Signatures of aerosols from Satellite Data	NASA	Weaver (GEST)		Funded
Spectral, Angular, and Vertical Characterization of Aerosols for Radiative Properties	NASA	King (GSFC), Gatebe (GEST)	Dubovik (GEST), Tsay	Funded
Strengthening Institutional Capacity in Undergraduate Geoscience Program at Alabama A&M	NASA	Tadesse	Coleman, Houser, Mbila, Taylor, Tsegaye	Pending
Studies of Tropical Cyclone Genesis and Tropical Cirrus Using ER-2 Radars	NASA	Heymsfield (GSFC)	Li (GEST), Racette (GSFC), Tian (GEST)	Pending
Study of 3D Effects in Landsat Atmospheric Correction	NASA	Lyapustin (GEST)	Wang (GEST)	Funded
Study of ozone variability from intra-seasonal to decadal time scales using satellite measurements and the GMI global model	NASA	Ziemke (GEST)	Chandra (GEST), Douglass, Stolarski	Funded
Superactive-Active-Passive (SAP) Shipboard/Ariborne/Satellite Analysis of Phytoplankton Pigment, Group, and Physiological Variability in Coastal Ocean	NASA	Chekalyuk (GEST)	Hoge	Pending
Support the Global Modeling	NASA	Strahan (GEST),	Douglass	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Initiative at NASA Goddard Space Flight Center, NASA Atmospheric Chemistry Modeling and Analysis Program		Clune (GSFC)		
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	Fishman	Chandra (GEST), Ziemke (GEST)	Funded
The Global Aerosol System and its direct and indirect forcing of climate	NASA	Kaufman	Remer, Chin, Dubovik (GEST), Feingold, Koren (GEST), Martins, da Silva, Torres (JCET)	Funded
The Interaction between surface fluxes, aerosols and clouds on the transition of convective system type and wet season onset over the Amazon	NASA	Fu (Georgia Tech.)	Peterson (Univ. Alabama Huntsville), Yu (GEST)	Pending
The Land Information System Demonstration Project	NASA	Houser (NASA)	Peters-Lidard (NASA), Arsenault (GEST), Toll (NASA), Garcia (GEST)	Pending
The Role of Freshwater Fluxes and Ocean Mixing on Sea Surface Salinity and Upper Ocean Salt Budget	NASA	Jacob (GEST)		Not Awarded
The Structure and Evolution of Tropical Convection and Anvil Clouds	NASA	Wang (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), Mussa, Duncan (GEST), Herzog (GSFC), Pickering (GSFC), Allen (GSFC)	Pending
The Use of NASA Land Data Assimilated Products to Improve Flood and Drought Risk Analysis and	NASA	Arsenault (GEST)	Houser (GSFC); Matthews, Hartzell, Meyer, Sharp (USBR)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Forecasting for Water Resources Management in the Columbia River Basin				
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	Tao (GSFC), Jin (Ames Research Center), Simpson (GSFC), Peters-Lidard (GSFC)	Shie, Lang (SSAI)	Pending
The validation of Aura ozone measurements using Cloud Slicing	NASA	Chandra (GEST)	Ziemke (GEST), Tie, Bhartia	Funded
Toward an Improved Understanding of the Global Fresh Water Budget	NASA	Hildebrand (NASA)	Kelly (GEST)	Pending
Tropospheric ozone data products derived from TOMS measurements and comparisons with 3D chemical transport models	NASA	Chandra (GEST)	Ziemke (GEST)	Funded
UAV Radar for Tropical Storm Wind and Precipitation Structure	NASA	Heymsfield (GSFC)	Li (GEST), Racette (GSFC), Tian (GEST)	Pending
Unified Non-Lambertian 3-D Retrieval and Validation of Land Surface Reflectance From MODIS	NASA	Lyapustin (GEST)	Wang (GEST), Descloitres (SSAI), Slutsker (SSAI), Holben (GSFC)	Funded
Unified Retrieval and Validation of Land Surface Reflectance from MODIS	NASA	Lyapustin (GEST)	Wang (GEST)	Funded
Use of Neural Network Techniques in the Physics Parameterizations of Atmospheric General Circulation Models	NASA	Suarez	Lary (GEST)	Pending
Using Infrared Satellite Data for Assimilation and Model Evaluation	NASA	Joiner (GSFC)	Atlas (GSFC), Duncan, Weaver (GEST), Bowman (GSFC)	Pending
Using NASA model and data to improve air quality forecast	NASA	Chin (GSFC)	Yu (GEST), Allen (UMCP), Chu	Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
of particulate matter over the U.S.			(JCET), Grell, McQueen (NOAA), Schere, Mathur (EPA), Barna (NPS), Fox (CIRA), McHenry (Baron Advanced Meteorological Systems)	
Using satellite measurements to improve the modeling of low and middle clouds and their climate feedbacks	NASA	M. Zhang (SUNY/ Stonybrook)		Pending
Utilizing Snow Crystal Studies and Scanning Electron Microscopy for Improving Snow Water Equivalent Estimation from Passive Microwave Snow Algorithms	NASA	Foster (NASA)	Kelly (GEST)	Pending
Validating OMI instrument long-term stability with deep-convective cloud albedo analysis	NASA	Hu (LARC)	Zhou (GEST)	Pending
Validation of Aura ozone data through assimilation	NASA	Stajner (SAIC)	Pawson (GSFC), Wargan (SAIC), Chang (SAIC), Hayashi (GEST)	Pending
Validation of AURA/OMI UV and aerosol products with ground based measurements dispersed over OMI footprints	NASA	Brooks (Drexel Univ.)	Krotkov (GEST)	Pending
Validation of Non-Conicident Trace Species Measured by AURA Using Trajectory Mapping and Statistical Analysis	NASA	Morris (Valparaiso University)	Sparling (JCET), Lary (GEST), Schoeberl (GSFC)	Pending
Validation of the DPR Estimates	NASA	Meneghini (GSFC)	Liao (GEST)	Funded
Variability of aerosols distribution and optical properties simulated by GOCART model using TOMS, aerosol data and AERONET measurements	NASA	Ginoux	Chin (GEST), Torres (JCET), Dubovik (GEST)	Funded
Variability of Oceanic Vertical Structure, Transports	NASA	Jacob (GEST)		Pending

Proposal Title	Funding Agency	PI	Co-I(s)	Status
and Air-Sea Fluxes on Seasonal to Decadal Time Scales				
Water and Earth Science Education for Under-represented Students (WESEUS)	NASA	Radamacher	Hogue, Houser	Pending
An Intercomparison of LDAS Evapotranspiration and Soil Moisture Estimates with the Regional Reanalysis Data	NASA NEWS	Toll (GSFC)	Arsenault (GEST)	Pending
Global Precipitation Analysis for Climate and Weather Studies	NASA NEWS	Adler (GSFC)		Pending
Multi-wavelength Raman Lidar Measurements for Studies of the Aerosol Indirect Effect and AERONET Algorithm	NASA Radiation Sciences Prog.	Whiteman (JCET)		Funded
Optimal land initialization for the operational NCEP Global Forecast System	NASA/ NOAA	Meng (GEST), Mitchell		Funded
Satellite and Field Experiment Analysis of Subseasonal and Synoptic Variability of the Eastern Pacific ITCZ and Its Effect on Tropical Cyclogenesis	NASA/TCSP	Adler (GSFC)		Pending
Proposal to NASA to support the 6th International Workshop on Adjoint Applications in Dynamic Meteorology	NASA's Office of Earth Science	Errico (GEST)		Funded
Anatomical distribution of UV radiation in the USA	NIH	Kimlin	Krotkov (GEST), Slusser, Labow (SSAI), Stamnes (Stevens Inst. of Tech.)	Pending
An Intercomparison of LDAS Evapotranspiration and Soil Moisture Estimates with the Regional Reanalysis Data	NOAA	Houser (GSFC)	Zhan (GEST), Arsenault (GEST)	Funded
Evaluation of Upper Ocean Mixing Parameterizations	NOAA	Jacob (GEST)	Shay, Halliwell (Univ. of Miami)	Funded
Simulation of Shortwave VIIRS Testbed for Aerosol and Land Surface EDRs	NOAA	Lyapustin (GEST)	Wang (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
The North American Monsoon onset and maintenance sensitivity to land and ocean surface conditions	NOAA	Bosilovich (GSFC)	Arsenault (GEST), Chern, Houser (GSFC)	Funded
Variability of North Pacific on Yearly and Decadal Time Scales	NOAA	Jacob (GEST)	Hakkinen (GSFC)	Not Awarded
An Intercomparison of LDAS Evapotranspiration and Soil Moisture Estimates with the Regional Reanalysis Data	NOAA GEWEX	Toll (GSFC)	Houser (GSFC), Arsenault (GEST), Pinheiro (NRC)	Funded
Improved Water Demand Forecasting for Water Resources Managers	NOAA GEWEX	Matthews (USBR)	Toll, Houser (GSFC), Arsenault (GEST), Pinheiro (NRC)	Funded
Advanced Laser Fluorescence (ALF) Biomonitoring in the Middle-Atlantic NERR Sector and Great Lakes	NOAA/ CICEET	Chekalyuk (GEST)	Moore	Pending
Including Atmospheric Aerosols in the Optical Path Transmittance Model (OPTRAN)	NOAA/ NASA	Weaver (GEST)		Funded
Subseasonal and Synoptic Variability in the Tropical Eastern Atlantic Ocean and Its Neighboring Continent	NOAA/ OGP—CLIVAR	Garcia (GEST)		Funded
Climate Process Team for Tropical Clouds	NSF	Bretherton (U. of Washington)		Funded
Collaborative Research: Mesoscale Variability during EPIC 2001	NSF	Shay (Univ. of Miami)	Jacob (GEST)	Pending
Ground-based Measurements of Trace Gases Using MAXDOAS in Clean and Polluted Environments in Support of Aura Satellite Observations	NSF	Mount	Janz, Bhartia, Bucsela (GEST), Levelt, Swart	Pending
Mesoscale Variability during EPIC 2001	NSF	Shay (Univ. of Miami)	Jacob (GEST)	Not Awarded
Variability of Water Cycle Components on Tropical Islands	NSF	Harmsen	Eastman (GEST), Miller, Gonzalez	Not Awarded
Proposal to ONR to Fund Research at GEST on the Development and Applications of Adjoint	ONR	Errico (GEST)		Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Models and Ensemble Techniques				
SAR Remote Sensing of Nonlinear Internal Waves in the South China Sea	ONR	Zhao (Caelum)		Funded
Upgrade of Urban Pollution Emission Sources in the Navy Aerosol Analysis and Prediction System	ONR	Gassó (GEST)	Westphal (NRL), Reid (NRL)	Funded
Rice University Tropospheric Ozone Pollution Project	Shell Center for Sustainability (Rice Univ.)	Morris (Rice Univ.)	Fraser	Funded
Tropospheric Ozone Pollution Project (TOPP): Investigating Air Quality Through Additional Ozonesonde Launches in Houston, Beaumont, and East Texas	Texas Commission on Env. Qual.: New Tech. R&D Prog. to Support the Texas Emissions Reduction Plan	Morris (Valparaiso Univ.)	Fraser, Few (Rice Univ.)	Funded
Chemical Tracer Transport in CRYSTAL-FACE: Mesoscale Forecasts and Cloud Model Analysis	U. of Maryland, College Park (Subcont.)	Shie (GEST)		Funded

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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, Kristi attended The Ohio State University in Columbus, Ohio, on a graduate fellowship 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. Kristi was awarded a NASA Goddard Space Flight Center Graduate Internship for the summer of 2000 where she applied the catchment-based land surface model to small catchment site. Kristi 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 which are mostly addressed by other agencies. Also, she is working on her Ph.D. at George Mason University.

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 has led efforts in atmospheric model development. His current interests include cloud and convection parameterization, as well as parameterization of orographic effects for tropospheric climate models. He has published over 30 refereed papers in the fields of gravity wave dynamics, atmospheric transport, and parameterization development for climate models.

Dr. Susanne E. Bauer is a research fellow with the Earth Institute at Columbia University in New York City. Her Ph.D. (2000) is from the University Hamburg, in Germany. Her dissertation work took place at the Max Planck Institute for Meteorology in Hamburg, Germany, where she developed a mesoscale atmosphere-chemistry model. After receiving her doctorate, she worked for two years as a postdoctoral researcher at the Laboratoire des Science du Climat et de l'Environnement, National Center for Scientific Research (France) (CNRS)/ Climate and Environment System Research Center (CEA), in Gif-sur-Yvette, Paris. Her primary interest is in atmospheric chemistry, especially heterogeneous chemical reactions between aerosols and gas-phase species.

Ms. Deborah Belvedere is the Program Assistant to the Water Cycle Office at NASA's Goddard Space Flight Center. Her work supports scientific collaboration and coordination for NASA's global water and energy cycle research. Specifically, planning task-forces consisting of researchers from the broader

scientific community as well as NASA scientists have been assembled. These task forces have worked to produce and enable implementation plans that not only uphold NASA's Earth Science Enterprise (ESE) Strategy, but also answer to the emergence of cross-cutting water-cycle research initiatives brought forth by inter-agency and government-administrative science panels. Currently she is involved in a NASA Energy and Water cycle Study and the GEWEX Americas Prediction Project (GAPP) and serves as Proposal Manager working with Principal GSFC Collaborator. Ms. Belvedere is interested in taking on additional management responsibilities in regard to large projects at NASA, especially as they pertain to the water and energy cycle. Debbie received her Bachelor of Arts degree in Music performance from Oswego State University, Oswego, NY. She worked as a teacher, musician, and business owner before coming to Goddard in 1995. She brought with her strong people skills, an ability to work independently, and management experience. She is an effective facilitator with a strong desire to grow professionally. Debbie started at Goddard over eight years ago as a secretary, but has worked her way into a strong Program Assistant even participating annually in field work with the Cold Land Processes Experiment. Ms. Belvedere is a member of the American Geophysical Union and the American Meteorological Society.

Mr. Timothy Berkoff received a BS in Optics from the University of Rochester in 1988. He has more than 15 refereed publications, numerous conference proceedings, and is an inventor on two patents in the field of optical sensing. From 1988 to 1997, he worked at the Naval Research Laboratory, where he conducted laboratory experiments demonstrating novel interferometric and fiber Bragg sensing techniques. This experience also involved in the design and implementation of new fiber sensing techniques in the field, including the successful demonstration of interferometric sensors on surface and submersible ships. In 1997, Mr. Berkoff joined Aerodyne Research where he designed and flight-tested a new water vapor instrument based on a Zeeman-split Argon discharge lamp. While at Aerodyne, he also gained experience in tunable diode laser spectroscopy for trace gas species and utilized simulation software based on the HITRAN database to identify complex spectral profiles. Mr. Berkoff Joined UMBC in 1999, and is working on the development and demonstration of lidar sensing methods and instrument for atmospheric measurements. He designed and modeled receiver optics for a Raman airborne spectroscopic lidar instrument, and has experimentally demonstrated the remote detection of Raman scattering using a holographic optical element as a dispersive telescope. Currently, Mr. Berkoff is the Instrument Manager for the Micro-Pulse Lidar Network (MPLNET) where he is responsible for maintenance of existing MPL systems, and the design and development of lidars for MPLNET.

Dr. Huisheng Bian received a B.S. in atmospheric science from Nanjing University in 1985, a M.S. in 1988, and a Ph.D. from University of California, Irvine in 2001. From 1988 to 1995, she worked in Chinese Meteorological Academy as an assistant researcher, where her research interest was regional air quality modeling. Her Ph.D. work focused on improving, validating, and applying UCI global chemistry transport model for tropospheric ozone simulation, as well as on developing a module (Fast-J2) to accurately simulate stratospheric photolysis in global chemistry models. Upon graduation, Dr. Bian became interested in atmospheric aerosols, their distribution and their photolytic and heterogeneous impacts on tropospheric chemistry. Her current major research interest involves developing a unified tropospheric and stratospheric chemistry transport model to be applied to Aura data and problems in the global dimensions of multi-scale air quality.

Dr. Eric Bucsela is an Associate Research Scientist at GEST. Dr. 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 NASA Goddard Space Flight Center through affiliations with Raytheon, SSAI and most recently, UMBC. 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 NO2 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).

Prior to his GEST appointment, ***Dr. Sushil Chandra*** was a senior scientist at NASA Goddard Space Flight Center (GSFC) where he conducted research in the fields of aeronomy, ionosphere, and many other aspects of atmospheric science. His terminal degree is a Ph.D. in Physics from Pennsylvania State University. He has over 100 publications, most all of which are in refereed journals and most of those as first author. Sushil 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, Sushil 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, Sushil 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, Sushil 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 inter-annual variability associated with QBO and El Nino events. Chandra is PI and Co-I for several NASA funded proposals. He was recently 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. Sushil Chandra became a visiting research scientist within GEST in April, 2003.

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 the climate system and the accuracy of data assimilation systems. Dr. Chang's publications deal with EOF modeling, diagnostics of climate and data assimilation systems, dynamical seasonal prediction and the impact of ENSO on extratropical low frequency noise in seasonal forecasts. Dr. Chang joined GEST in September 2001 as an Associate Research Scientist.

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.

Dr. Warren B. Cohen is a research forester with the Pacific Northwest Research Station of the USDA Forest Service, and director of the Laboratory for Applications of Remote Sensing in Ecology at the Corvallis Forestry Sciences Laboratory in Oregon. He received his doctorate in forest science in 1989 from Colorado State University, with emphases on remote sensing and wildland fire behavior. Currently, he conducts research in remote sensing and related geographic and ecological sciences. His primary focus is translation of remote sensing data into useful ecological information, with significant activity in analysis and modeling of vegetation structure and composition across multiple biome types. His research involves spatially explicit modeling of ecological processes with significant attention to scaling from fine to coarse grain. He is assistant professor (courtesy) in three departments at Oregon State University (Forest Science, Geosciences, and Computer Science), where he intermittently teaches a graduate-level remote sensing and landscape ecology course, advises graduate students as both a major and minor professor, serves on interdepartmental committees, and gives guest lectures and seminars. He is on the editorial board of the journal *Remote Sensing of the Environment*.

Dr. Robert J. Curran is the director of GEST. He obtained his B.S. degree from Creighton University, and his Ph.D. in physics from the University of Arizona. He has over 30 years of experience with NASA, including 12 years as a research scientist at GSFC, and 12 years as a program manager at NASA Headquarters. His research experience includes radiation characteristics of clouds and aerosols. At NASA Headquarters he managed a wide variety of remote sensing, modeling, and sensor development projects associated with two separate research programs.

Dr. Pierre Defourny is taking a sabbatical year from the Université catholique de Louvain (Belgium), where he has been a professor and has coordinated the remote sensing research group in the Department of Environmental Sciences since 1994. From 1991 to 1993 he was appointed remote sensing specialist by the Asian Institute of Technology in Bangkok (Thailand). He received his PhD in agricultural engineering from Université catholique de Louvain. He has been actively involved in various international programs for agriculture and natural resources monitoring. His main interest is multi-scale multi-sensor approaches for crop and forest monitoring.

Ms. Marci P. Delaney is the Program Coordinator for GEST. She manages three student summer programs, coordinates the short-term visitors program and organizes conference/workshops. She also is a member of the team which handles the publication of the monthly newsletter for NASA Explorer Schools. Marci is an integral member of the NES Challenge Coordination Team. She earned her M.Sc. in Biological Oceanography at Memorial University of Newfoundland in 1998 in St. John's, Newfoundland, and is in the process of completing her Ph.D dissertation with Memorial University, expecting to graduate in 2005. Her graduate research focus is the effects of small-scale turbulence on the marine microbial food web, with an emphasis on cold-ocean environments. She also continues to consult as a science content specialist to companies that produce educational materials for grades K-12.

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 (CAS), 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 the 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. Oleg Dubovik received a BS an MS (in 1985) in physics (optics) from the Belarus State University (Minsk, Belarus). He received a PhD in physics and mathematics from the Institute of Physics (Minsk, Belarus) in 1992. Starting from 1985 Dr. Dubovik began his research experience at the Institute of Physics (Minsk, Belarus), employed first as assistant research staff and later (after receiving his PhD) as a research scientist. In the period from 1995 to 1997, Dr. Dubovik worked in the National Institute for Environmental Studies (Tsukuba, Japan) as visiting scientist supporting ILAS/ADEOS project. From April of 1997 through to the present, Dr. Dubovik has been working at GSFC. During his career he has been involved in conceiving, developing, and implementing inversion algorithms for deriving aerosol size distribution, refractive index (including single scattering albedo), and derived optical properties of aerosols from multispectral solar transmission measurements as well as multiangular sky radiance measurements. At present Dr. Dubovik is in charge of the retrieval algorithm developments for inversion algorithm has the worldwide AERONET project. Authored 67 papers published in refereed scientific journals.

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).

For the past 15 years, ***Dr. Joseph L. Eastman*** has concentrated on numerical modeling at a variety of scales. These include research on land-induced circulations and there effect on dispersion modeling, development of moist processes, and climate. He has been responsible for the development of numerous parameterizations that have been integrated into various numerical modeling systems. He has also designed a chemistry module for use in atmospheric models and isactively pursuing the coupling of a meteorological model with a variety of other models. These models include an ocean model (Princeton Ocean Model), canopy model (LEAF-2), and a photosynthesis model (GEMTM). First employed professionally by Dr. Walter A. Lyons in 1987, he aided in the design of a ground conductivity model for use in simulating a lightning detection network. He also performed considerable meteorological and dispersion modeling for the Kennedy Space Center while employed by Dr. Lyons. In 1990, he was accepted to the graduate school at Colorado State University. During that time he was under the guidance of Dr. Roger A. Pielke, achieving his masters in 1994, and Ph.D. in the Graduate Degree Program in Ecology in 1999. In 1993, he was elected President of the local chapter of the American Meteorological Society. In his postdoctoral appointment he was in charge of providing direction for the Long Term Ecological Research (LTER) national modeling efforts on massively parallel platforms. This included coupling meteorological models to synchronous and asynchronous ecosystem models. His most recent work concentrated on the assessment of climate change, with special examination of the relative contributions of CO2 and human induced land change. In his current research position he is continuing regional climate research using coupled atmospheric and ecological models. In addition, he is investigating the effects of land-surface interactions on hurricanes.

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 23 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 70 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 9 international workshops,

including 5 of the 6 International Workshops on the Application of Adjoint Models in Dynamic Meteorology and 4 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.

Mr. 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 the GEST, he spent almost three years as a software development engineer with an industrial company. Dr. Feng has various experience in applied mathematics, oceanography, ocean remote sensing and software development. His specific research interest is in the area of the inverse algorithms for remotely-sensed signals to recover oceanic geophysical parameters. His current research interest is in the area of inverse algorithm developments to retrieve oceanic geophysical parameters from remotely sensed signals. His Ph.D. research focused on inversion algorithm development for ocean color spectra to retrieve in-water optically-active constituent concentrations. His work in the GEST task 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.

Dr. Friedemann T. Freund is currently GEST Fellow at the Planetary Geodynamics Laboratory, NASA Goddard Space Flight Center, for the period May 2004-May 2005. Dr. Freund received his B.Sc. in Chemistry and Ph.D. in Mineralogy/Crystallography from Marburg University, Germany, in 1954 and 1959, respectively. He was a Post-Doc at Pennsylvania State University in 1960-1962, then Assistant Professor of Chemistry at the University of Göttingen, Germany from 1962 to 1969, and Professor of Geosciences at the University of Cologne, Germany from 1970 to 1987. He came to the NASA Ames Research Center in 1985 as a Senior NRC Research Associate and has remained associated with NASA Ames through the SETI Institute in Mountain View, CA and the Department of Physics, San Jose State University, San Jose, CA, where he is Adjunct Professor. He held Visiting Professor or Visiting Scientist appointments at Stanford University (1973, 1974), University of Namur, Belgium (1974-1976), University of Dijon, France (1977), Cornell University (1981), and Arizona State University (1982-1984). His main research interests have centered on defects in crystals, in particular those caused by incorporation of H2O, CO2 and other fluid components, valency fluctuations in the oxygen anion sublattice of minerals, rock physics in relation to earthquake and pre-earthquake phenomena. Origin of Life.

Dr. Carlos Garcia received a B.S. degree in physics from the State University of Campinas (Brazil) in 1977. He received his M.Sc. (1986) and Ph.D. (1989) degrees from the University of Southampton, England. From 1979 to the present he has worked at the Department of Physics, University of Rio Grande (Brazil), as a lecturer and researcher in the fields of physical and satellite oceanography. Dr. Garcia has served as head of the Department of Physics (1994-1996) and rector of the University of Rio Grande (1997-2000). His activities at the university include lecturing, research, and supervision of undergraduate and graduate students on the fields of physical and satellite oceanography. He is coordinator of the Group of High Latitudes Oceanography (http://www.goal.ocfis.furg.br), which develops oceanographic research in the Southern Ocean within the Brazilian Antarctic Program.

Mr. Matthew Garcia is a generic carbon-based humanoid resident of Earth who just happens to recognize the pervasive and all-encompassing role of water, and specifically precipitation, in the natural environment provided to us by God. Academically, Mr. 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 and proceeds to affect all of Earth's residents. 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, flood and water resources management problems. Outside of work, Mr. Garcia delights in the pleasures of hiking, biking, flyfishing, reading history, watching baseball, and teaching his wife and toddler daughter how to use the home computer.

Dr. Virginia Garcia received a B.S. degree in oceanography from Federal University of Rio Grande, Brazil, in 1983. She received her Ph.D. (1989) from the University of Southampton, England in Biological Oceanography. Her dissertation involved primary production and physiological studies with the bloom-forming phytoplankton *Gyrodinium aureolum*. From 1991 to the present, she has been working at the Department of Oceanography, Federal University of Rio Grande (Brazil), as lecturer and researcher in the fields of biological oceanography, primary production, and phytoplankton ecophysiology. Her research interests also include physiology and ecology of harmful marine microalgae. Dr. Garcia was coordinator of the postgraduate program on biological oceanography at FURG, in 1994-1995, and has been part of the postgraduate committee since 1994. Her activities at the Rio Grande University include lecturing, research, and supervision of undergraduate and graduate students.

Originally from Argentina, ***Dr. Santiago Gassó*** obtained a master degree from the University of Buenos Aires (1992) in Applied Physics working on the modeling of water pressure in polymer reservoirs. He moved to the Unites States where he completed his PhD thesis in Geophysics at the University of Washington, Seattle (2001) specializing on the role of ambient humidity on aerosol optical properties as measured by in-situ instrumentation and satellite data. Currently, he is working in a Navy sponsored project to simulate global visibility conditions with an aerosol transport model. In addition, he is currently funded by NASA and IAI/NSF to conduct studies on aerosol mass concentration as estimated by different methods (satellite, modeling and in-situ).

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.

Mr. Jonathan C. Gottschalck received both his B.S. and M.S. degrees in meteorology from the Pennsylvania State University in 1994 and 1996, respectively. While in graduate school his research focus was in the area of land surface processes, studying the impacts of doubled CO_2 on canopy transpiration using two soil-vegetation-atmosphere transfer models. His work studied these impacts from the vegetation canopy scale to the full global scale; two published papers resulted from this work. After leaving the Pennsylvania State University, Mr. Gottschalck worked as a research associate at the University of Miami from 1997-2001. During this time, he worked in a variety of research areas, two of which included boundary layer and tropical meteorology. He developed a stratus cloud climatology using data from the Atmospheric Radiation Measurement Program Southern Great Plains Site in Oklahoma. Moreover, he investigated the relationship between the Madden Julian Oscillation (MJO) and El Niño. While at the University of Miami, he also taught undergraduate weather forecasting classes and acted as the university meteorologist for all public and press inquires. He joined GEST in February 2001, and is currently a research associate working in the Hydrological Sciences Branch at GSFC. His research has mainly focused on work with satellite precipitation and vegetation datasets and their impact on land surface simulations.

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 is an assistant research scientist at GEST. He received a B.S. in atmospheric physics from Nanjing University in 1986 and a Ph.D. in meteorology and physical oceanography from the Rosenstiel School of Marine and Atmospheric Science (RSMAS) of the University of Miami in 2001. Prior to joining the GEST center, he was a postdoctoral research scientist at Columbia University. Dr. Gu's research is primarily in the field of tropical meteorology and global climate variability and change, which includes tropical waves, the Intertropical Convergence Zone (ITCZ), tropical precipitation and variability on various spatial and temporal scales, and air-sea interaction. He is currently involved in the Tropical Rainfall Measuring Mission (TRMM) science project 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. Mohan L. Gupta received a Ph.D. in Earth System Science from the University of California, Irvine in 1996 under the supervision of Prof. Ralph Cicerone (President-elect of National Academy of Sciences). His Ph.D. work focused on developing, validating, and applying global photochemical transport models to study the chemical balance of the natural and perturbed troposphere. He also worked extensively on the use of isotopes to study the budget and trend analysis of long-lived species, such as methane. Later, Dr. Gupta joined Prof. Turco's group at UCLA to work on testing and validating atmospheric chemistry components of the Earth System Model which comprises of atmospheric and oceanic general circulation models. From 1999 to 2001, he worked at ICF Consulting as a senior associate, and at the Electric Power Research Institute as a project manager on projects related to air quality and Mercury/Nitrogen surface deposition issues. Besides chemistry-climate interactions, atmospheric chemical composition, atmospheric isotopes and biogeochemistry, his current major research interests also involve problems in intercontinental and interhemispheric transport, global dimensions of regional and urban air quality, surface deposition, and atmospheric toxic gases.

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. Jacques Hinderer, a GSFC Visiting Fellow at GEST, completed his doctorate in geophysics in 1980 at the University Louis Pasteur, Strasbourg (France); in 1987, he received a doctorat d'etat (habilitation) in geophysics from the same university. He joined CNRS (Centre National de la Recherche Scientifique et Technique) as researcher in 1986 and became senior research scientist in 1996. He was on sabbatical leave in 1991-1993 at McGill University in Montreal, Canada under the auspices of an international research fellowship from NSERC (National Sciences and Engineering Research Council of Canada). He is the present chair of the geodynamics group, consisting of seven people, at the Institut de Physique du Globe de Strasbourg (IPGS) and the director of the Strasbourg Gravimetry Observatory, in charge of the superconducting and absolute gravimeters operating in France. Since 2001, he has also served as vice-chair of the IPGS. He has been secretary of the Global Geodynamics Project (GGP) since 1997, an international network of superconducting gravimeters. In 1990, he received Young Scientist Award of the European Geophysical Society, and in 1998, he received the Antoine d'Abadie Prize of the French Academy of Sciences. Dr. Hinderer has published over 100 papers in refereed scientific journals, and serves on numerous national and international committees.

Dr. Susan Hoban 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 education.

Mr. Kevin Horgan is a researcher at the Microwave Instrument Technology Branch (MITB) at GSFC. He received his B.S. and M.S. degrees in electrical engineering in 1999 and 2003, respectively, from the University of Massachusetts, Amherst. His previous research, conducted at the Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts, focused on the development of a Ka-band polarimetric radiometer and polarimetric calibration techniques. His current research focuses on polarimetric radiometry and the design of an ultra-stable L-band radiometer for the Aquarius satellite mission to measure global sea surface salinity (SSS).

Dr. Nai-Yung (Christina) Hsu received a Ph.D. in atmospheric sciences in 1991 from the Georgia Institute of Technology, where her research interest was general circulation model (GCM) modeling of ozone photochemistry and transport processes in the stratosphere. In 1994, Dr. Hsu moved to Maryland and began her studies on remote sensing of tropospheric aerosols. She has published over 20 refereed papers, the most recent focusing on remote sensing of aerosols and aerosol-climate interactions. She is a member of the Moderate Resolution Imaging Spectroradiometer (MODIS) and Total Ozone Mapping Spectrometer (TOMS) Science Teams, where her focus is on the properties of aerosols in the ultraviolet (UV) and visible regions of the spectrum, and determining the radiative forcing due to tropospheric aerosols. Her research experience includes developing near-real-time satellite retrievals of aerosols using measurements from Sea-viewing Wide Field-of-View Sensor (SeaWiFS) and MODIS-like instruments over the oceans and over bright-reflecting dust source regions for field campaigns. Dr. Hsu is currently an associate research scientist at GEST, performing her work at GSFC.

Dr. S. Daniel Jacob received a B.E. (Hons.) in Civil Engineering from the Madurai Kamaraj University, Madurai, India (1987), a Masters degree in Ocean Engineering from Indian Institute of Technology, Madras, India (1991). He worked for a few years at the Indian Space Research Organization analyzing Synthetic Aperture Radar data of ocean surface waves and other satellite data before pursuing a Ph.D. at the University of Miami. He was awarded his Ph.D. in Meteorology and Physical Oceanography from the University of Miami Rosenstiel School of Marine and Atmospheric Science in 2000. His dissertation examined the upper ocean heat budget variability due to oceanic mesoscale variability and its effect on the intensification of tropical cyclones. He served as a Postdoctoral Research Associate at the University of Miami, where he was involved in acquiring oceanographic data from the NOAA hurricane hunters using expendable probes and in the Eastern Pacific as part of the Eastern Pacific Investigation of Climate project. He was appointed as an Assistant Research Scientist in GEST in May 2002 based in the Oceans and Ice Branch at GSFC. As a member of Aquarius science team, Daniel conducts research on the effects of surface forcing and ocean mixing on sea surface salinity and also leads an effort to identify an appropriate mixing scheme for use in coupled predictive models of hurricane intensity.

Ms. Urszula Jambor received her B.Sc. degree in atmospheric and oceanic sciences from McGill University, Canada, in 1997, and her M.S. in meteorology from the Pennsylvania State University in 2000. Her graduate work involved evaluating ice clouds produced by parameterizations in numerical prediction models with comparison to corresponding remotely sensed measurements. This research developed her interest in applying remotely sensed data to numerical modeling studies. In the fall of 2000, she joined GEST to begin working at GSFC on the Global Land Surface Data Assimilation System (GLDAS) project.

Dr. Daniel E. Johnson received a B.S. degree in mechanical engineering from the University of Minnesota, Minneapolis, in 1988, and a M.S. in meteorology and Ph.D. in atmospheric science from the University of Wisconsin, Madison in 1991 and 1997, respectively. His primary research interests while in graduate school included developing and implementing a detailed ice-microphysical package for cloud-resolving models to study winter storms. Dr. Johnson was awarded two fellowships with the NASA Graduate Student Researchers Program (GSRP) in 1994, and completed his doctoral research and dissertation at GSFC over the following two years. In 1996, he joined the Laboratory of Atmospheres at

GSFC as a postdoctoral fellow and began conducting research on deep tropical cloud systems using the Goddard Cumulus Ensemble (GCE) model. In 2001, Dr. Johnson joined GEST, and is currently working on developing the GCE model and conducting simulations of deep convective cloud systems in both tropical and midlatitude regions. Dr. Johnson serves as a reviewer for the *Journal of the Atmospheric Sciences*. In December 2001, Dr. Johnson received an Outstanding Scientific Research Award for his research and work in the Mesoscale Atmospheric Processes Branch, Laboratory for Atmospheres, GSFC.

Dr. Peter Merheim Kealy completed a B.Sc. in Geophysics from Reading University, UK in 1987, and Ph.D. in Geophysics from University College, Durham, UK in 1990. During his doctoral and post doctoral studies he has worked in Australia and Africa on a variety of remote sensing instrumentation and ground processing systems, including thermal radiometers, thermal lasers and interferometers. Between 1992 and 1997 he was an optical engineer in the Earth Sciences Division of ESA-ESTEC in the Netherlands, working on sensor and algorithms aspects of the AATSR (radiometer) and MERIS (spectrometer) missions. Between 1998 and 2003 he worked for Raytheon as a systems engineer and program manager on NPOESS-VIIRS (radiometer) and NPOESS-APS (polarimeter). In 2003 he came to work for the NASA-NPP as a group leader within the Project Science Group with responsibility for algorithm related system optimization.

Dr. Richard Kelly received his B.Sc. (Hons.) from the University of Manchester, UK, in 1988 and he received an M.A. (with distinction) in glaciology from Wilfrid Laurier University, Canada in 1990. He completed his Ph.D. in 1994 in the Department of Geography at Bristol University, UK. From 1994 to the present he is a Lecturer in Physical Geography at Birkbeck College, University of London, UK where his major research activities have involved the remote sensing of snow and ice using microwave (active and passive) earth observation systems. His most recent research interests have included combining optical and microwave sensors for UK snow monitoring and the use of synthetic aperture radar for monitoring the mass balance of an ice cap in Norway. He has published in international research journals and at various international conferences. He is a member of the UK's Photogrammetry and Remote Sensing Society (a merged society of the former Remote Sensing Society and the Photogrammetry Society), the International Glaciological Society, the American Geophysical Union and participated at the inception of the Snow and Ice Special Interest group within EARSeL.

Dr. Maeng-Ki Kim completed his education in South Korea. He received a B.Sc. degree in Earth science from the Kongju National University (1988), a master's degree in atmospheric sciences at the Seoul National University (1990), and a Ph.D. in atmospheric science from the Seoul National University (1997). He examined the atmospheric circulation patterns induced by global warming and warming mechanisms related to land-atmosphere interactions in the Northern Hemisphere. Dr. Kim is currently an assistant professor in the Department of Atmospheric Science at Kongju National University, performing research on climate dynamics, and taught from 1999-2003. He has been a Goddard Visiting Fellow at GEST for his sabbatical year since late 2003, based at the Laboratory for Atmospheres at GSFC.

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 Ph.D. in June of 2002. His Ph. D. 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 Ph.D. 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, geopotenital analysis of North America (e.g., Earthscope) and so forth. Since September in 2003, Dr. Kim has been a junior postdoctoral fellow at GEST and GSFC/NASA, 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. Anuradha Koratkar 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 BS from Moscow Institute of Physics and Technology in Physics in 1983, MS (with honor) 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 worked in close collaboration with NASA/TOMS scientists to study volcanic clouds, surface and underwater ultraviolet radiation and aerosols. Dr. Nickolay A. Krotkov, has over 15 years experience in UV radiative transfer modeling, satellite and ground based UV data analysis. He has published over 30 refereed papers where the most recent ones are concentrated on satellite estimation of the surface ultraviolet irradiance and measuring of aerosol UV absorption properties. He is currently employed by the UMBC/GEST Center as a senior research scientist.

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. Prasun K. Kundu received a B.S. degree (with honors) in physics from Calcutta University, India, in 1974, and a M.S. in physics from the Indian Institute of Technology, Kharagpur, India, in 1976. He then joined the High Energy Physics Group at the University of Rochester in New York, where he earned his doctorate in 1981 in theoretical physics for his work on a new class of exact and asymptotic solutions of the Einstein general relativity field equations. From 1980-1982, he was a postdoctoral research associate at the Enrico Fermi Institute, University of Chicago, and subsequently was an instructor from 1982-1985 at the University of Utah, Salt Lake City. Dr. Kundu's postdoctoral work addressed mathematical problems in general relativity and quantum cosmology. In 1985, he joined the Department of Physics and

Astronomy at Ohio University, Athens, as assistant professor, where he taught graduate and undergraduate courses in physics and continued research in relativistic gravitation theory. Since 1992, he has worked at the Climate and Radiation Branch, GSFC, on various rainfall statistics problems related to the Tropical Rainfall Measurement Mission (TRMM), and other satellite- and ground-based remotely sensed precipitation measurements. He was awarded an Exceptional Scientific Support Award in 2000. Dr. Kundu is currently an associate research scientist at GEST.

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. Reginald 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. Throughout his career he has developed various 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. Roger Lang is a professor in the Department of Electrical and Computer Engineering at George Washington University, Washington D.C. He received his M.S. in electrical engineering in 1964 and his doctorate in electrophysics in 1968, both from the Polytechnic Institute of Brooklyn. He was a postdoctoral researcher at the Courant Institute of Mathematical Sciences at New York University from 1968-1969, working on wave propagation in random media with Joseph B. Keller. He has held visiting appointments at the Joint Research Centre, Microwave Signature Laboratory, at Ispra, Italy; the Naval Research Laboratories, Radar Division, in Washington D.C., and GSFC. He is a Fellow of the IEEE, cited for contributions to microwave modeling of vegetation.

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. David 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 UK. 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 David 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 David to be appointed as a Cambridge University lecturer in Chemical Informatics. In 2001 David joined UMBC/GEST as the first distinguished Goddard fellow in earth science at the invitation of Richard Rood (now head of Code 930). His automatic code generation software, AutoChem, has been recommended for the NASA Space Act Award.

Dr. Daniel DeForrest Laughlin received the first M.A. ancient history from the University of Newcastle upon Tyne in 1986 and a 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 has be named to lead the new Games Initiative sponsored by the NASA Office of Education. Laughlins interests include information technology management, cognitive science, digital library technologies, and educational technologies.

Mr. Rick Lawford received his undergraduate degree in physics in 1966 from the University of Manitoba (Brandon College) and carried out graduate studies in meteorology at the University of Alberta, receiving a M.Sc. in 1970, and McGill University from 1971-1973. Early in his career, he worked as a weather forecaster, research meteorologist, and professional trainer in meteorology. He also served as a regional chief of a scientific service division, 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). Mr. Lawford 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. In this position, he managed grants, organized meetings, and developed planning documentation and reports for this continental-scale hydroclimatological experiment. Prior to working for UCAR, Mr. Lawford spent many years working in the fields of hydrology and meteorology with the Canadian government. In his last position, before moving to the U.S., 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 (at the Canadian Ministry of State for Science and Technology), program planning, evaluation, and environmental policy development (at Environment Canada) in Ottawa. Mr. Lawford has recently been appointed Director of the International Global Energy and Water Cycle Experiment (GEWEX) Project Office (IGPO). He is a member of the American Geophys8ical Union, the American Meteorological Society, and the Canadian Meteorological and Oceanographic Society. His work is published on a broad range of topics, he frequently gives conference presentations, and has been listed in *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.

Prof. Zev Levin is the Goldemberg Chair professor in Atmospheric Physics at Tel Aviv University. He graduated in Atmospheric Sciences from the University of Washington in 1970. He spent a year at UCLA working on the cloud physics wind tunnel. Since 1971 he has been at Tel Aviv University. From 1985-87 he served as the Chairman of the Department of Geophysics and Planetary Science. From 1987-1992 he served as the Vice President for Research and Development and Dean of Research of Tel Aviv University. From 2000 to 2004 he was the Head of the newly established school of Environmental Studies. Prof. Levin was a senior visitor professor in many institutes and universities (e.g. NCAR, NASA, Stanford, UCLA, ETH). He was recently elected as the President of the International Commission Clouds and Precipitation. From 1997 to 2004 Prof. Levin was the principal investigator of MEIDEX (Mediterranean Israeli Dust Experiment) on board the space shuttle Columbia in its last tragic mission. Prof. Levin research interests include: Cloud and rain physics (experimental and theoretical), cloud chemistry, weather modification, atmospheric aerosol and nucleation, ice nucleation by bacteria, terrestrial and planetary atmospheric electricity and lightning generation.

Dr. Lihua Li received a B.S. in electrical engineering from Tsinghua University, China in 1988, an 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 cloud microphysical properties retrieval using radar measurements. As a radar 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 radar/scatterometer for flying on an Unmanned Aerial Vehicle (UAV) in support of the study of hurricane genesis. 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. Rong-Rong Li received a Ph.D. (1995) and MS (1989) in Physics from University of Cincinnati, Cincinnati, OH, and a BS in Optical Physics (1982) from the Nakai University, Tianjin, P.R. China. She joined NASA Goddard Space Flight Center in 1993 working with MODIS aerosol research group to analysis remote sensing satellite data to improve MODIS aerosol retrievals over both land and ocean. Throughout ten years of research in the remote sensing field, she has contributed to our understanding of the physics of the atmosphere and improving the MODIS aerosol retrievals. Her main researching interest is to support NASA's EOS projects of the MODIS Terra and Aqua satellite with her experiences in the remote sensing data analysis of the aerosol retrievals, fires and burned scar detections, snow and ice masking, and cirrus detection and corrections.

Dr. Shuhua Li received a B.S. degree from Nanjing Institute of Meteorology, China in 1984, and a M.S. from Macquarrie University, Australia in 1996. He obtained his Ph.D. degree in meteorology from Monash University, Australia in 2000. Dr. Li's research experience includes large-scale atmospheric circulation and energetics, tropical cyclone activity and climate change, and stratospheric dynamics and transport. Dr. Li joined GEST in April 2001, and has worked at the Global Modeling and Assimilation Office (GMAO) to evaluate the finite-volume Data Assimilation System (fvDAS) for reanalysis of stratospheric trace species for the period 1991-1995.

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, to learn climate modeling, cloud parameterizations, and remote sensing. In July 2001 Dr. Lin joined GEST to work on rainfall, heating profile, and cloud assimilations. He also works on simulating satellites in a climate model, and using cloud model results to improve convective parameterizations in general circulation models.

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. In 1993-1996 he was a Principal Investigator in contracts with Russian Space Agency on processing of remote sensing data from space station "MIR". 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 MISR, 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. 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. In 2004, he was selected a Science Team Member in MODIS and NPP Science Teams.

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 forcing. 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. Ashwin Mahesh received a B.Sc. degree from Bangalore University in 1989, an M.B.A. from Pondicherry University in 1991, an M.S. in astronomy from Vanderbilt University in 1993, and a Ph.D. in geophysics from the University of Washington in 1999. Late in 1999, he joined Analytical Services and Materials, Inc. in Hampton, VA, and conducted research on nighttime cloud detection in the Arctic. In September 2000, he began work at GEST. His current research interests include spectral and lidar remote sensing of cloud properties, climate change in the high latitudes, and radiation balance over Antarctica. He is also developing a standard atmosphere of Antarctica for use in climate models. In 2001, he compiled the first annual cycle of cloud properties over the high plateau. In between 2002-2003, he developed the first climatology of blowing snow in the Antarctic plateau.

Dr. Hank Margolis obtained a B.Sc. degree in forest management from the University of Vermont, an M.F. in forest ecology from the Yale School of Forestry and Environmental Studies, and a Ph.D. in ecosystem ecology and silviculture from Oregon State University. His research has concentrated on the ecophysiology of trees and forests, having worked in both boreal and tropical ecosystems. He has been a professor at Laval University in Quebec City, Canada since 1986, where he has taught courses on analysis of tropical forest ecosystems, agroforestry, and general silviculture. He has published over 50 refereed journal articles and has directed more than 25 graduate students and postdoctoral fellows. He became involved in the planning and execution of the NASA-led Boreal Ecosystem–Atmosphere Study (BOREAS) during the 1990s, and was responsible for the Canadian university component of this interdisciplinary field study. He was a Universities Space Research Association (USRA) visiting scientist and a National Research Council (NRC) senior research associate with the Biospheric Sciences Branch of GSFC in 1995 and 1996, respectively. He is currently the program leader and principal investigator of the Fluxnet-Canada Research Network. This network expands the scientific approach developed in BOREAS to a national scale.

Dr. Jesse Meng received a B.S. in atmospheric sciences from National Taiwan University, Taipei, Taiwan, in 1991, a M.S. and a Ph.D. in meteorology from the University of Maryland, College Park, Maryland, in 1997 and 2001, respectively. 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 Research Associate, spending half time at NASA/GSFC, Hydrologic Sciences Branch (Code 614.3), and half time at NOAA/NCEP, 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 consequent changes in land surface states in response to the radiation forcing variation; and 2) implement a parallel GLDAS/LIS at NOAH/NCEP to support the NCEP operational Global Forecast System (GFS).

Dr. Ken-ichi Mizoguchi received a M.S. in oceanography from Kyushu University, Japan in 1994, a M.S. in oceanography from Florida State University in 1997, and a Ph.D. in oceanography from Florida State University in 2001. He was a visiting research associate at GEST from 2002 through 2004, and has been an assistant research scientist at GEST since 2004.

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. He has continues to supervise ozonesonde launches from Rice University and will be a funded participant in 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. Rosana Nieto-Ferreira received a B.S. in meteorology in 1985, and an M.S. in meteorology in 1988, from the University of São Paulo, Brazil. She received a Ph.D. in atmospheric science from Colorado State University in 1994. From 1994 to 1996 Dr. Nieto-Ferreira was a postdoctoral fellow at Colorado State University, studying the role of tropical cyclones in the formation of tropical upper tropospheric troughs. From 1996 to 2000, she was a USRA visiting scientist at GSFC, working with the NASA Seasonal-to-Interannual Prediction Project (NSIPP) group on the application of a variable resolution version of the NSIPP-1 general circulation model to the study of seasonal to interannual variability of the land-atmosphere system in the Amazon Basin. Since October 2000 Dr. Nieto-Ferreira has been a member of the research faculty at GEST, working with the NSIPP group on studies of variability and predictability of South American circulation and convection organization on timescales that vary from synoptic to multidecadal.

Dr. Wenge Ni-Meister received her B.S. degree in meteorology from China, a M.S. in micrometeorology at the University of Connecticut, and a Ph.D. in remote sensing and surface hydrology at Boston University. At the University of Maryland she worked as a postdoctoral student on land surface process modeling and forcing, and on validating a land surface process model with remote sensing data. She joined GEST and the Hydrological Sciences Branch at GSFC in July 2001, working on land data assimilation for NASA's Seasonal-to-Interannual Prediction Project (NSIPP). She also works on another project, studying the effects of subgrid snow-cover variability in vegetated regions on land-atmosphere interactions.

Dr. Mohan Nirala received his B.Eng. degree in civil engineering in 1987 from the Guru Ghasidas University, Bilaspur, India, and his M. Tech. in civil engineering (with a specialization in remote sensing) in 1991 from the Indian Institute of Technology (IIT), Bombay, India. Following the completion of his master's degree, Dr. Nirala joined the University of Bombay as lecturer, and taught courses in civil engineering and remote sensing for over two years. He also worked as a senior civil engineer on several projects in Bombay. In 1996, Dr. Nirala joined the Department of Applied Physics, Electronics, and Mechanical Engineering at the University of Dundee, Scotland, where he completed his Ph.D. in remote sensing in 1999. Immediately after completing his Ph.D., Dr. Nirala joined the University of Illinois at

Urbana-Champaign as a postdoctoral research associate. His research focused on cloud detection and classification algorithms using Multiangle Imaging Scanning Radiometer (MISR) and Moderate Resolution Imaging Spectroradiometer (MODIS) data. Following that appointment, he was awarded a postdoctoral research associateship by the National Academies of Sciences (NAS)/National Research Council (NRC) at GSFC in 2002. His research included multisatellite precipitation estimation and assimilation using microwave and other data products. Dr. Nirala was appointed an assistant research scientist in GEST in May 2003. His current research interests include validation techniques for land surface products and algorithms for the Visible and Infrared Imaging Radiometer Suite (VIIRS), to fly on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) and the NPOESS Preparatory Project (NPP). Dr. Nirala is a member of the American Geophysical Union.

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. Bob Numrich received his B.S. degree in Chemistry from the University of Illinois, Urbana and his Ph.D. in Theoretical Chemistry from the University of Minnesota, Minneapolis. He began his career in supercomputing when he joined Control Data as part of the STAR-100, and later the Cyber-205, consulting group. He was a leader in the development of vector code for these early vector architectures. He joined Cray Research as part of the Cray-2 development group where he continued work on vector codes and began work on parallel codes for the four-processor Cray-2. He also performed extensive analysis of inter-processor memory contention for the Cray-2 and developed simulators and models to describe memory contention. He continued that work on the Cray-3 until that project left Cray Research. Bob was a member of the core team that developed Cray's first massively parallel processor, the Cray-T3D. He invented the get/put model for one-sided message-passing, which became the Shmem Library still in use today and supported on several different systems. The Shmem Library became the model for MPI-2 one-sided communication. Bob also invented the F-minus-minus extension to Fortran, which expressed the one-sided model as an extension to the language. He has extended that model to include all of Fortran 95 under the new name of Co-Array Fortran. His language extension is considered a prime candidate for programming the next generations of parallel machines because of its simplicity and its potential for scaling to large numbers of processors. Bob is currently a Senior Research Associate at the Minnesota Supercomputing Institute, University of Minnesota, Minneapolis. He is developing object-based parallel libraries, which combine the object-oriented features of Fortran 95 with co-array syntax. He is also involved in performance modeling, the definition of a system of units for performance measurement, and the development of computational metrics based on the principle of least action.

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. Dr. Olsen became a research associate at GEST in December 2002 and later appointed assistant research scientist in December 2004. With GEST, Dr. Olsen has continued to concentrate on many facets of upper-troposphere/lower-stratosphere structure and dynamics, including cross-tropopause transport.

Dr. Kevin Olson 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. Norm O'Neill is a physicist who received his Ph.D. in space science from York University (Toronto) in 1982. After four years as a project scientist with a private remote sensing company (Moniteq, Ltd.), he joined the remote sensing faculty of the Université de Sherbrooke where he is currently a full professor. His research centers on analysis of aerosol optical data acquired by ground-based, airborne, and satellite sensors. A significant portion of his research activities has focused on collaborative projects with the classical remote sensing community, where the goal was atmospheric correction of airborne and satellite imagery. From 1997 to 2000, Dr. O'Neill was editor-in-chief of the *Canadian Journal of Remote Sensing,* and from 1996 to 1998, he was director of the doctoral program in remote sensing at the Université de Sherbrooke. Awards and honorific positions have included a National Sciences and Engineering Research Council (Canada) (NSERC) postdoctoral fellowship, a Fonds pour la Formation de Chercheurs et l'Aide Recherche (FCAR) tenure-track fellowship, and a National Research Council (NRC) senior associateship.

Dr. Judit M. Pap received her Ph.D. in astrophysics in 1986, from Eötvös University, Budapest, Hungary, where she worked as a research associate until 1988 when she became a visiting scientist at the Institute for Solar Physics in Freiburg, Germany. She was appointed research associate at the University of Colorado at Boulder in 1989. She was a staff member of the 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, guest investigator on the UARS mission, and co-investigator on the French PICARD experiment. She is principal investigator on various grants from NASA's Office of Space and Earth Sciences. Dr. Pap is involved in a wide range of collaborations with scientists from JPL, UCLA, USC, NRL, SSAI, the University of Hawaii, the University of Arizona, NCAR/HAO, NOAA/SEC, CNRS, (Paris, France), PMOD/WRC (Davos, Switzerland), and the Heliospheric Observatory (Debrecen, Hungary). Dr. Pap has organized several international meetings on solar irradiance variations, and 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 has been elected as chair of the 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 will collaborate with the International Living With a Star (ILWS) program, which will play a major role in solar-terrestrial physics in the next decade and beyond. Dr. Pap has also been the chief editor of AGU Monograph Series No. 141: *Solar Variability and Its Effect on Earth's Climate,* published in March 2004.

Dr. Steven Pawson completed his education in the United Kingdom. He received a B.Sc. in Mathematics from the University of York (1982), a Masters degree in Atmospheric Physics and Dynamics from Imperial College, University of London (1984) and a Ph.D. in Meteorology from the University of Edinburgh (1987). His these examined aspects of the radiation balance and trace-gas transport in the middle atmosphere using satellite data. Following a one-year position as a Research Fellow at the University of Oxford, Steven moved to the Free University of Berlin in 1988. In both positions he was working on the development of middle atmosphere-climate models. In Berlin he became a junior faculty member in 1991, performing research into the middle atmosphere and climate and teaching. He was awarded the Habilitation in 1997. Later that year he took a Visiting Scientist position with the Universities Space Research Association and was a Senior Research Scientist in GEST between December 2000 and October 2004. He is presently the Lead Scientist for Trace Constituents in the Global Modeling and Assimilation Office at GSFC, working on studies of meteorology and climate and the modeling and assimilation of chemical species and meteorology. He has published over 50 refereed journal articles, leads an international model validation program, and has served on numerous national and international committees. He recently completed a four-year term as Editor of the *Journal of Geophysical Research – Atmospheres*.

Dr. Zhaoxia Pu received a Ph.D in atmospheric sciences in 1997 from Lanzhou University, soon after she completed the necessary research at the National Centers for Environmental Prediction (NCEP)/ National Oceanic and Atmospheric Administration (NOAA), Camp Springs, Maryland during 1993-1996. She continued her research at NCEP as a University Corporation for Atmospheric Research (UCAR)/NCEP postdoctoral fellow in 1997-1998. During her five years at NCEP, Dr. Pu joined several NCEP research efforts to improve the NCEP global data assimilation system. She also made significant contribution to developing the NCEP targeting weather observation techniques. In November of 1998, Dr. Pu joined the Universities Space Research Association and worked at GSFC for two years before transferring to GEST as an associate research scientist in October 2000. Dr. Pu's research focuses on atmospheric and oceanographic data assimilation. Her current research emphasizes the application of data assimilation in mesoscale studies of tropical cyclones and mesoscale convective systems. Dr. Pu has published over 10 refereed papers in leading professional journals; she also serves as a reviewer for professional journals. In December 2000, Dr. Pu received an Outstanding Achievement Award from the Mesoscale Atmospheric Processes Branch, Laboratory for Atmosphere, GSFC.

Dr. Udaya A. Ranawake received a B.S. degree in electrical engineering from the University of Moratuwa, Sri Lanka, and M.S. and Ph.D. degrees in electrical and computer engineering from Oregon State University, Corvallis, Oregon. Prior to joining GEST, he worked for four years at Center for Excellence in Space Data and Information Science (CESDIS) on a subcontract with the Department of Computer Science and Electrical Engineering at the University of Maryland, Baltimore County. From 1992 to 1995, Dr. Ranawake was a senior member of the technical staff at Hughes STX Corporation, where he was the task leader for massively parallel research at GSFC. He has been at GEST since July 2000. His research interests are algorithms for scientific computation, parallel and distributed computing, computer architecture, and computer networks. Dr. Ranawake is a member of the Institute of Electrical and Electronics Engineers (IEEE).

Dr. Miodrag Rancić received a Ph.D. in meteorology in 1988 from the University of Belgrade, Yugoslavia, where he worked as a research and teaching assistant, and from 1988 as an assistant professor. In 1989, Dr. Rancić joined the Center for Analysis and Prediction of Storms at the University

of Oklahoma as a postdoctoral faculty member. Dr. Ranĉić worked at the National Centers for Environmental Prediction as a research scientist from 1992-1998, when he transferred to GSFC, employed through the University of Maryland, Baltimore County. In December 2003, Dr. Ranĉić became a research associate professor of physics at UMBC, through affiliation with the Joint Center for Earth Systems Technology (JCET). He joined GEST in July 2000. His research interest is the development of novel numerical methods for weather and climate prediction, in conjunction with modern software development trends, such as application of high-performance computing and object-oriented design. Dr. Ranĉić initiated and contributed to the development of a nonhydrostatic version of the major regional model of the U.S. Weather Service; he also originated a new class of mass conservative semi-Lagrangian schemes for application in numerical models of the atmosphere, and developed a new class of quasi-uniform grids (so-called conformal *cubic* and *octagonal* grids) for application to global atmospheric models. He has over 30 papers published in refereed professional journals or presented at workshops and conferences.

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 Laboratory for Atmospheres at GSFC in December 2004.

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 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. In 2004, Dr. Reichle received the Outstanding Performance Award of the NASA Global Modeling and Assimilation Office (GMAO) for his leadership in developing, organizing, and coordinating the land assimilation activities within the GMAO and with collaborators at Goddard. His main research interest is 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. Joan E. Rosenfield joined GEST in April, 2001 as a Senior Research Scientist. Dr. Rosenfield received an A.B. degree, with a major in chemistry, from Brandeis University in 1961, and a Ph.D. in physical chemistry from the University of Minnesota in 1969. She conducted research into the use of optical rotatory dispersion as an aid in elucidating the electronic structure of molecules at the University of Minnesota from 1969 to 1972. She continued this research at the National Institutes of Health's Laboratory of Chemical Physics from 1973 to 1977. In 1977 Dr. Rosenfield joined the Goddard Modeling and Simulation Facility, where she worked in remote sensing of weather and climate parameters from satellite data. Since 1982 she has worked in the Atmospheric Chemistry and Dynamics Branch at GSFC. There she developed a radiative transfer model used for computing radiative heating rates in the stratosphere and troposphere. She has worked in modeling the radiative, dynamical, and chemical state of the stratosphere, with an emphasis on understanding the stratospheric ozone layer. Dr. Rosenfield's recent publications have dealt with radiative/dynamical processes in the stratospheric polar vortex, the radiative effects of aerosols, and the effects of increasing greenhouse gases on stratospheric trace species.

Dr. Susan E. H. Sakimoto received a B.A. in geology from Whitman College in 1989, a M.A. in earth and planetary sciences from Johns Hopkins University in 1991, and a Ph.D. in earth and planetary sciences (geophysics) also from Johns Hopkins University, in 1995. Her research career has to-date included theoretical, computational, and mission-related research on Venusian magma ascent and volcanism, Martian lava flow topography and emplacement, and Martian volcanic edifices and impact crater topography, using measurements from the Viking, Magellan, and Mars Global Surveyor data sets. Her most recent work is in the physical volcanology of lava channels, combining analytic, experimental, and computational work, and in the topography and emplacement of Martian impact craters, basins, and small volcanic features. This includes extensive work with Mars Orbiter Laser Altimeter (MOLA) topography, performed in collaboration with the MOLA science team. At GSFC she has been a NASA graduate student research fellow (1990-1994), a NRC resident research associate (1995-1997), and a Universities Space Research Association (USRA) visiting scientist (1997-2000). She is currently an associate research scientist at GEST. She has also been an instructor in earth and space sciences since 1998 at the Johns Hopkins School of Professional Studies in Business and Education, she teaches in their Master's of Science in Education Program and Earth Sciences Secondary Teacher Certification Program.

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. Adam Schlosser received his B.S. in physics from the University of Massachusetts, in 1989. He earned his M.S. and Ph.D. in meteorology from the University of Maryland, College Park in 1992 and 1995, respectively, having performed studies in land surface hydrology. He was a UCAR visiting scientist at Geophysical Fluid Dynamics Laboratory, Princeton University from 1995-1997, and a research scientist at the Center for Ocean-Land-Atmosphere Studies (COLA), Calverton, MD from 1997-2001. Since that time, he has been an associate research scientist at GEST, with the role of project scientist in NASA's Global Water and Energy Cycle Project Office.

Dr. Sonia Seneviratne completed most of her education in Switzerland. She first studied Biology at the University of Lausanne (B.Sc./"Attestation de Pré-licence", 1995) and then Environmental Physics at the Swiss Federal Institute of Technology (ETH) in Zurich (M.Sc./"ETH-Diplom", 1999). She conducted her M.Sc. Thesis at the Ralph M. Parsons Laboratory for Hydrodynamics at the Massachusetts Institute of Technology (MIT), Cambridge, MA, under the guidance of Professor Elfatih Eltahir (October 1998-April 1999). Following this stay, she conducted her Ph.D. Thesis at the ETH Zurich (1999-2002), under the guidance of Professor Christoph Schär. Her co-examinators were Dr. Pedro Viterbo (ECMWF) and Prof. Wolfgang Kinzelbach (ETH Zurich). Her thesis examined terrestrial water storage in the context of land-atmosphere interactions and climate change, and investigated a new approach for estimating changes in terrestrial water storage from water-balance computations. She was awarded an honorific post-doctoral fellowship from the National Center of Competence in Research on Climate (NCCR-Climate) from Switzerland, which funded her visit at the Global Modeling and Assimilation Office (group of Dr. Randal D. Koster) and GEST.

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 won an "Annual Outstanding Performance Awards" of Mesoscale Atmospheric Processes Branch, NASA/GSFC in both 2000 and 2004. He also 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 Siniuk received his B.S. and M.S. degrees in physics and theoretical physics from Belarus State University in 1985, and a Ph.D. in physics/optics in 1997 from the Institute of Physics, Minsk, Belarus. Beginning in 1998, he was a research associate in the Laboratory of Optics of Disperse Medium at the Institute of Physics. Later that year, he became a visiting scientist at the Laboratory of

Meteorological Physics, Université Blaise Pascal, France, and became a visiting scientist at the Meteorological Research Institute, Tsukuba, Japan in 1999. Dr. Siniuk was an assistant research scientist at GEST before joining SSAI in 2004. His research interests include satellite remote sensing with emphasis on developing inversion methods for retrieval of aerosol properties.

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 60 peer-reviewed papers in the leading geophysical journals. He is presently one of three Co-Investigators of the AERONET Project.

Mr. Gregory Solyar received a B.S. degree in radio metrology from Odessa Measuring College of Standards Committee of the USSR in 1981, a M.S. in electrical engineering from Odessa State Polytechnic Institute in 1986, and a M.S. in electrical and computer engineering from the Johns Hopkins University in 1998, where his major interest was in nonlinear optics and quantum electronics. He is currently working toward a Ph.D. in the Department of Computer Science and Electrical Engineering at UMBC, where his research interest is in imaging methods and algorithms. In December 2000, he joined Center for Excellence in Space Data and Information Science (CESDIS) and became an associate research scientist at GEST in June 2000. Mr. Solyar has over 15 years of experience in industry and research institutions. During his professional career as a group head at Central Communications Design Bureau, he designed metrology, algorithms, and microprocessor embedded hardware and software for control and measurement equipment for communications lines (1986-1990). At Johns Hopkins University, he designed and experimented with an optical parametric oscillator, passive Q-switched lasers, and laser diodes (1997-1999). At the National Institutes of Health, he researched special surface effects in photomultiplier tubes, and designed, implemented, and tested systems with fast, small detectors for small fluorescent power emission (1997-1998). As a scientist at GEST he specializes in wave-front sensing methods, techniques, and algorithms, including phase-diversity and interferometry.

Dr. Harold Stone received a B.S. degree in electrical engineering from Princeton University (1960), and an M.S. and Ph.D. in electrical engineering from the University of California, Berkeley in 1961 and 1963, respectively. His research activities include extensive work in computer architecture and satellite image processing. He is known for his contributions to the interconnections for parallel computers through his research on the perfect-shuffle interconnection pattern. Dr. Stone has held faculty positions at Stanford University and the University of Massachusetts, and research positions at IBM and NEC. He retired from NEC in 2001, and holds the title of Fellow, Emeritus. He is the author or coauthor of eight textbooks in the areas of computer science and electrical engineering. He has served on the governing board of the Institute of Electrical and Electronics Engineers (IEEE) Computer Society, and was a vice president of that organization Dr. Stone works for GEST as an external consultant to Dr. Jacqueline LeMoigne at GSFC to study image registration and fusion for future formation flying systems with a goal of implementing these registration schemes on high-performance parallel computers that could be carried on spacecraft.

Dr. Susan Strahan received a BS in chemistry from Stanford University in 1980 and a Ph.D. in chemistry from the University of California, Berkeley in 1986. 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. 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. Toshihiko Takemura received his Doctor of Science degree in Meteorology from the University of Tokyo in 2001. The title of his Ph.D. thesis is “A Study on Aerosol Distributions and Optical Properties with a Global Climate Model.” Since then he has worked as a Research Associate at Kyushu University, Japan. He is presently spending one year at NASA GSFC, as a Visiting Scientist, employed by the UMBC GEST. His research is focused on the interactions between aerosols and climate with a global model. Prior to his doctoral study, Dr. Takemura received a Bachelors degree in Science from Tohoku University, Japan in 1997, and Master degree in Meteorology from the University of Tokyo in 1999.

Dr. Marco Tedesco received his Ph.D. in Methods and Techniques for Environment Engineering (2004) from the Institute of Applied Physics ‘Carrara’ of the Italian National Research Council, Firenze, Italy and the University of Basilicata, Potenza, Italy with the thesis titled ‘Microwave Remote Sensing of Snow’. Before starting his Ph.D. he had a one year appointment at the Institute of Research on Electromagnetic Waves (IROE) of the Italian National Research Council (CNR) in Florence (Italy) for the development and validation of techniques for microwave remote sensing of natural surfaces. During his Ph.D., in 2002, he was an Invited Ph.D. student at the Space Laboratory, Helsinki University of Technology, and in 2001 he attended the School on Hydrological Model Forecasting of the Massachussets Institute of Tecnology (MIT). During his Ph.D. he also worked with the Institute of Research on Electromagnetic Waves (IROE) of the Italian National Research Council (CNR) Group of Interaction between Electromagnetic Fields and Matter, publishing several reviewed articles on microwave measurement techniques. On October 2003, until June 2004, he worked as a free lancer with a consulting contract with the University of Maryland Baltimore County. 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.His main research interest concerns remote sensing of snow (modelling, experimental campaigns and retrieval algorithms). He is also interested in the characterization of dielectric properties of natural media.

Dr. Lin Tian received a Ph.D in atmospheric science from the University of Chicago in 1995 where her major research interest was radar meteorology and cloud microphysics. In 1997 she joined University Space Research Association and worked at NASA Goddard Space Flight Center. In October 2000, she joined the Goddard Earth Science and Technology Center. In the past three years, she conducted research in the areas related to the remote measurement of precipitation and understanding of storm structures and microphysical characteristics of precipitation using observations from the ER-2 airborne Doppler radar. She has analyzed EDOP Doppler radar data in support of TRMM to improve rainfall rate estimate. She also studied microphysics of storms such as raindrop size distribution and melting ice particles using EDOP and ground based polarimetric radar data. Other than her scientific research, she has gained tremendous experience in EDOP data collection, processing and software developing. She participated three TRMM field campaigns and CRYSTAL-FACE experiment, and processed all EDOP and CRS data for archiving and distribution.

Dr. 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, building a high-performance computing platform for real-time land surface simulation and data assimilation.

Mr. Jonathan M. Triggs is currently 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 presently 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. Augustin Vintzileos received his PhD. In 1996 from the Université de Paris V, with research conducted at the Laboratoire de Météorologie Dynamique of the CNRS. His subject was the study of climate variability with a global atmosphere-tropical Pacific Ocean coupled model. He also has a DEA. (M.Sc. level) from the same institution, awarded in 1991, and received ahttp://janus.gsfc.nasa.gov/~augustin/london2.jpg M.Sc. in 1990 in computational fluid dynamics from the Imperial College of Science and Technology at the University of London. After holding a position as visiting scientist at the Universities Space Research Association from 1999-2000, he joined GEST, first as a visiting scientist, then as an assistant research scientist participating in NASA'S Seasonal-to-Interannual Prediction Project (NSIPP).

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 Ph.D. in geography from Boston University, Boston, MA in 2002. In July of 2002, Dr. Wang joined GEST center of UMBC as a research associate. During his Ph.D. study, Dr. Wang's research was mostly focused on the prototyping and validation of radiative transfer based EOS MODIS LAI/FPAR algorithm. 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. Zhien Wang is currently an assistant research Scientist at the GEST center. Dr. Wang received a B.S. in Physics, in 1990, a M.S. in atmospheric optics, in 1994, from China, and Ph. D, in meteorology, from University of Utah. He conducted research in remote sensing of atmospheric aerosol and ozone at the Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences (1990-96), and won national research awards for building the first ozone lidar in China. Before joining the GEST on February 2002, he worked at University of Utah as Post-doctoral Research Associate and Assistant Research Professor, and conducted research in cloud property retrieval by combining multiple remote sensors (active and passive). He, together with Dr. Whiteman of GSFC and Dr. Sassen of the University of Alaska, works on Aqua validation and CloudSat algorithm development. He is also a member of the ARM science team to improve the developed experimental cloud classification algorithm into an operational algorithm and to develop new algorithms to study mixed-phase cloud microphysical properties. Now he works at the Department of Atmospheric Science, University of Wyoming as an assistant professor.

Dr. Clark Weaver's scientific initiation was at Ohio State University at the Byrd Polar Research Institute. His Masters Thesis topic was the fractionation of isotopic oxygen in snow over Antarctica. He received his Ph.D. in Atmospheric Science from Colorado State University in 1987. His dissertation was on the mechanism for marine stratocumulus break up. Next, he joined the research group at the Graduate School of Oceanography at University of Rhode Island and studied the transport of mineral dust to ocean drilling sites using paleoclimate models. He joined the Atmospheric Chemistry and Dynamics Branch at NASA Goddard in 1991 and has worked there ever since. His current interests include: stratospheric transport, data assimilation and remote sensing.

Dr. Jennifer C. Wei received a B.S. in atmospheric science from National Taiwan University in 1992, an M.S. in environmental science from New Jersey Institute of Technology in 1995, and a Ph.D. in atmospheric science from the University of Illinois at Urbana-Champaign in 2002. She then joined the Atmospheric Chemistry Division (ACD) at the National Center for Atmosphere (NCAR) as a visiting postdoctoral scientist till 2003. Since then, she continuously collaborates with the ACD modeling group to investigate the mixing process in the upper troposphere and lower stratosphere from the three-dimensional chemical transport model (MOZART). In September 2003, she became a research associate with the Joint Center for Earth Systems Technology (JCET) at the University of Maryland Baltimore County. She used statistical approaches to better understand the mixing processes of atmospheric tracers in the upper troposphere and lower stratosphere region and how they impact data validation for both models and measurements. She started the research in areas of radiative transfer and remote sensing after she joined the Climate and Radiation Branch of NASA/GSFC in April 2004. Her current research interest is the aerosol properties in their climatic and health impact on regional and global scales.

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.

Professor Kathy Whaler received her Ph.D. in 1981 from Cambridge University, UK. After two additional years as a postdoctoral researcher, she moved to a faculty position at University of Leeds, UK. In 1994, she moved to University of Edinburgh to become the chair of the Department of Geophysics, and was department head from 1999-2002. Professor Whaler is a Fellow of the Royal Society of Edinburgh and the Institute of Physics. She has been a visiting scientist at Harvard University, GSFC, Scripps Institution of Oceanography, Victoria University of Wellington, New Zealand, and the Institut fur Geophysik in Göttingen, Germany. She has held a Fulbright Travel Scholarship, been a Cecil and Ida Green Scholar, and a Gauss Professor of the Göttingen Academy of Sciences. Most recently, she has been a visiting senior research scientist at GEST. Professor Whaler's research interests address planetary magnetism, including satellite magnetic field data modeling, geophysical inverse theory, core dynamics and thermal history, magnetotellurics, mantle electrical conductivity, and potential field theory.

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. Fanglin Yang is an assistant research scientist at GEST. He received a B.S. degree in 1989 and a M.S. in 1992, both in meteorology in China. Starting in 1994, he spent almost six years at the University of Illinois at Urbana-Champaign, working as a research assistant while pursing a Ph.D. degree in atmospheric sciences. After receiving his doctorate in 1999, Dr. Yang moved to Washington, D.C. and worked at the National Centers for Environmental Prediction for three years. He joined the Climate and Radiation Branch at GSFC in December 2002, under the auspices of GEST. Dr. Yang's research focuses on climate modeling and diagnosis, using atmospheric and oceanic general circulation models (GCMs) as the principle tool, supplemented by statistical methods and low-dimensional numerical models. His past research covers investigations of radiative forcing and climate changes induced by volcanic aerosols and greenhouse gases, development of atmospheric GCMs, and prediction and diagnosis of climate on

seasonal-to-interannual time scales, forced by anomalous boundary conditions associated with sea surface temperature (SST), snow, and soil moisture. His current research focuses on trends and variability in East Asian monsoonal precipitation. Dr. Yang is a member of the American Geophysical Union. He has served as a reviewer of articles for many professional journals.

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 Ph.D. in Atmospheric Chemistry (2000) from the Georgia Institute of Technology, Atlanta, GA, and a MS (1992) and a BS (1989) both in Atmospheric Physics from the Nanjing University in the People's Republic of China. His Ph.D. thesis is on aerosol radiative effects on the environment. From 1992 to 1996, he was the faculty member at the Department of Atmospheric Sciences of the Nanjing University, where he taught and conducted research in air pollution and atmospheric boundary layer. After his Ph.D. graduation in 2000, he then worked at Georgia Tech as a postdoctoral fellow through 2002, and as a research scientist II from January 2003 to October 2004, focusing on aerosol-cloud-radiation-climate interactions. 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 aerosol climate forcing based on an integration of retrievals from MODIS and MISR, simulations from GOCART model, and measurements from AERONET. His publications covers 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 S. 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 (the USSR Weather Service), Obninsk. His major research interest was application of radar methodology to cloud and precipitation measurements and atmospheric diffusion. From 1969 to 1996, Dr. Yurchak served as a research scientist and senior research scientist at the Institute of Experimental Meteorology, developing radar methodology for atmospheric research. 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 in emergency situations. He also used remote sensing capabilities to study environmental contamination. In July 2002, Dr. Yurchak joined Caelum Research Corporation and started working on NASA's Earth Science and Public Health Program. Dr. Yurchak has been with GEST since July 2002. In June 2003, he joined UMBC**,** where he continued working on NASA's Earth Science and Public Health Program. His current research interests include remote sensing applications for public health issues in the Arctic.

Dr. Ilya Zavorin received his B.S. degree in mathematics and computer science from Santa Clara University in 1993 and his M.A. in applied mathematics from the University of Maryland, College Park (UMCP) in 1997. In August 2001, he completed the Ph.D. degree in applied mathematics from UMCP, where his research topic was convergence of iterative methods applied to large sparse linear systems. He has been involved with GSFC since 1998, working on the use of wavelets for automatic image

registration of multi-sensor data. His current research interests also include optimization methods for image registration and automatic region-of-interest extraction.

Dr. Xiping Zeng received his B.S. and M.S. degrees in atmospheric physics from Nanjing Institute of Meteorology, China. He then did the teaching and research on clouds in that university from 1987 to 1995. From 1995 he began his Ph.D. studies in Physics Department of New Mexico Tech with his focus on the interaction between tropical convection and synoptic large-scale circulations. 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 he is cooperating with the scientists in GSFC, upgrading a cloud-resolving model for the explicit simulation of the interaction between clouds and other factors (e. g. aerosol, radiation, and synoptic large-scale circulations). Dr. Zeng serves as a reviewer for Journal of the Atmospheric Sciences and Journal of Fluid Mechanics.

Dr. Xiwu Zhan received his B.S. and M.S. degrees in Meteorology from Nanjing Institute of Meteorology. He then taught courses and conducted research in Applied Meteorology at the Institute. In 1990 he started his Ph.D. study at Cornell University on sensitivities of land surface water vapor fluxes to atmospheric CO2 increases at leaf, canopy and regional scales. He continued this modeling study at the Hydrology Laboratory of USDA-Agricultural Research Service from 1994 to 1996. Then he joined the Geography Research Faculty of the University of Maryland College Park, where he managed a research team and developed a set of change detection algorithms and the computer software of the MODIS 250m land cover change product as an associate member of NASA's MODIS science team. Before he joined the UMBC-GEST research faculty in 2002, he worked with NPOESS-VIIRS product algorithm development team at Raytheon ITSS Corporation. His current research interests include land surface energy and CO2 flux modeling, generation of remote sensing data product of land surface soil moisture, temperature, and vegetation type, and the assimilation of these data products into land surface models for better forecast accuracy of climate, hydrological and/or ecological models.

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 on-site 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 the effects of atmospheric circulations on sea ice motion and deformation, 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. Her Ph.D. work 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 obtained his education in the United States, terminating with a Ph.D. in Physics from Iowa State University. He has over 50 publications, most all of which are in refereed journals and most of those as first author. Jerry Ziemke originally came to NASA GSFC in 1994 as an NRC research postdoc specializing in atmospheric composition and dynamics. Since arriving at Goddard he has collaborated with scientists both at Goddard and elsewhere on a large range of topics, but primarily studies relating to atmospheric ozone. Since 1996 his main focus has been 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 from satellite data. Jerry Ziemke became an associate research scientist within GEST in March, 2002.

Dr. Viktor Zubko received a Ph.D. in Theoretical Astrophysics (1984) from the Main Astronomical Observatory of the Ukrainian Academy of Sciences, Kyiv, Ukraine, and a MS in Astrophysics (1979) from Taras Shevchenko State University, Kyiv, Ukraine. His Ph.D. thesis is on the modeling of cosmic dust particles in various circumstellar environments. From 1997 to 1999, he worked as a Visiting Scientist at the Department of Physics at the Technion-Israel Institute of Technology. From 2000 to 2001, he was a Research Scholar at the Department of Physics and Astronomy at the University of Kentucky, KY, where he studied coupled radiative transfer and hydrodynamics problems in the cool stellar atmospheres containing dust particles and water vapor. He came to NASA/GSFC in 2001. From 2001 to 2003, he worked at the Infrared Astrophysics Branch where he developed comprehensive models of interstellar dust by using the regularization inversion technique. Since June 2003, he worked at the Climate and Radiation Branch. In May 2004, he joined the GEST Center. In December 2004, he left GEST Center faculty, and he works now as a Scientific Programmer at NASA/GSFC. His research experience includes theory and models of atmospheric aerosols and cosmic dust, polarized radiative transfer, light scattering by small particles, remote sensing of aerosols, numerical inversion techniques for ill-posed problems, principal component analysis.

Faculty and Staff

Faculty	Title
Anyamba, Assaf	Associate Research Scientist
Arsenault, Kristi	Research Associate
Bacmeister, Julio	Associate Research Scientist
Berkoff, Tim	Assistant Research Engineer
Bian, Huisheng	Assistant Research Scientist
Buch, Arnud	Visiting Research Associate
Bucsela, Eric	Associate Research Scientist
Chandra, Sushil	Visiting Research Scientist
Chang, Yehui	Associate Research Scientist
Chekalyuk, Alexander	Research Associate Professor, Hampton University
Chern, Jiun Dar	Associate Research Scientist
Colarco, Peter	Visiting Research Associate, Fellow
Colombo, Oscar	Contingent I
Dong, Jiarui	Research Associate
Doubovik, Oleg	Associate Research Scientist
Duncan, Bryan	Visiting Assistant Research Scientist
Eastman, Joseph	Assistant Research Scientist
Eck, Thomas	Assistant Research Scientist
El-Ghazawi, Tarek	Contingent I
Errico, Ronald	Senior Research Scientist
Feng, Hui	Graduate Student, University of New Hampshire
Garcia, Carlos	Visiting Senior Research Scientist, Fellow
Garcia, Virginia	Visiting Associate Research Scientist, Fellow
Gassó, Santiago	Research Associate
Gatebe, Charles	Assistant Research Scientist
Ginoux, Paul	Assistant Research Scientist
Gottschalk, Jonathan	Research Associate
Grecu, Mircea	Assistant Research Scientist
Gu, Guojun	Assistant Research Scientist
Guenther, Bruce	Senior Research Scientist
Gupta, Mohan	Assistant Research Scientist
Hayashi, Hiroo	Research Associate
Hinderer, Jacques	Visiting Senior Research Scientist, Fellow

Faculty	Title
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Horgan, Kevin	Associate Research Scientist
Hsu, Christina	Associate Research Scientist
Jacob, Daniel	Assistant Research Scientist
Johnson, Daniel	Assistant Research Scientist
Judelson-Kelly, Richard	Associate Research Scientist
Khazenie, Nahid	Visiting Senior Research Scientist
Kim, Hyung Rae	Visiting Research Associate, Fellow
Kim, Maeng-Ki	Visiting Associate Research Scientist, Fellow
Koratkar, Anuradha	Visiting Associate Research Scientist
Krotkov, Nickolai	Senior Research Scientist
Kumar, Sujay	Assistant Research Scientist
Kundu, Prasun	Associate Research Scientist
Kuo, Kwo-Sen	Associate Research Scientist, Caelum Research Corporation
Lancaster, Redgie	Assistant Research Scientist
Lang, Roger	Visiting Senior Research Scientist, Fellow
Lary, David	Senior Research Scientist
Laughlin, Daniel	Assistant Research Scientist
Lawford, Richard	Director, GEWEX IGPO
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Lin, Xin	Associate Research Scientist
Lyapustin, Alexei	Assistant Research Scientist
Mahanama, Sarith	Assistant Research Scientist
Mahesh, Ash	Assistant Research Scientist
Margolis, Hank	Visiting Senior Research Scientist
Meng, Jesse	Research Associate
Merheim-Kealy, Peter	Senior Research Engineer
Minschwanner, Ken	Visiting Associate Research, Fellow
Mizoguchi, Ken-ichi	Research Associate
Morris, Gary	Intermittent Assistant Research Scientist
Nieto-Ferreira, Rosana	Assistant Research Scientist

Faculty	Title
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Norris, Peter	Assistant Research Scientist
Numrich, Robert	Visiting Senior Research Scientist, Fellow
Olsen, Mark	Research Associate
Olson, Kevin	Associate Research Scientist
Pap, Judit	Senior Research Scientist
Pawson, Steven	Senior Research Scientist
Reale, Oreste	Associate Research Scientist
Reichle, Rolf	Assistant Research Scientist
Riishojgaard, Lars-Peter	Senior Research Scientist
Rosenfield, Joan	Senior Research Scientist
Sakimoto, Susan	Associate Research Scientist
Schlosser, C. Adam	Associate Research Scientist
Seneviratne, Sonia	Visiting Research Associate
Shie, Chung-Lin	Associate Research Scientist
Siniuk, Aliaksandr	Assistant Research Scientist
Smirnov, Alexander	Senior Research Scientist
Solyar, Gregory	Research Associate
Strahan, Susan	Associate Research Scientist
Sun, Chiaojiao	Assistant Research Scientist
Tian, Lin	Associate Research Scientist
Tian, Yudong	Assistant Research Scientist
Unninayar, Sushel	Senior Research Scientist
Veselovskii, Igor	Associate Research Scientist
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Acronyms and Abbreviations

Acronym/ Abbreviation	Expansion/Definition
AASE-2	Airborne Arctic Stratospheric Expedition 2
AEROCOM	Aerosol Comparisons
AERONET	Aerosol Robotic Network
AFWA	Air Force Weather Agency
AGCM	Atmospheric General Circulation Model
AGU	American Geophysical Union
AMF	Air Mass Factor
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
AO	Announcement of Opportunity
AO	Atlantic Oscillation
ARMCI	Aggregate Remote Memory Copy Interface
ARMS	Army Remote Moisture System
ARS	Agricultural Research Service
ASTEX	Atlantic Stratocumulus Transition Experiment
AVHRR	Advanced Very High Resolution Radiometer
B.S.	Bachelor of Science
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
CAF	Co-Array Fortran
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAN	Cooperative Agreement Notice
CAPE	Convective Available Potential Energy
CBP	Chesapeake Bay Program
CCD	Convective Cloud Differential
CCSP	Climate Change Science Program
CEOP	Coordinated Enhanced Observing Period
CERES	Clouds and the Earth's Radiant Energy System
CESDIS	Center for Excellence in Space Data and Information Science
CLM	Community Land Model
CLPX	Cold Land Processes Experiment
COARE	Coupled Ocean-Atmosphere Response Experiment
COLA	Center for Ocean-Land-Atmosphere Studies
CPES	Cloud Parameter Estimation 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
DESWAT	Destructive Waters Abatement program (Romania)
DMRT	Dense Media Radiative Theory
DOAS	Differential Optical Absorption Spectroscopy
DoD	Department of Defense
DODS	Distributed Oceanographic Data System

DSSs	Decision Support Systems
DST	Decision Support Tool
DU	Dobson Unit (2.69E20 molecules per square meter)
ECCO-GODAE	Estimating the Circulation and Climate of the Ocean – Global Ocean Data Assimilation Experiment
ECMWF	European Center for Medium Range Weather Forecasting
ENSO	El Niño Southern Oscillation
EOS	Earth Observing System
EP	Earth Probe
EPA	Environmental Protection Agency
ESMF	Earth System Modeling Framework
ESSIC	Earth System Science Interdisciplinary Center
ESSP	Earth System Science Pathfinder
FAO	United Nations Food and Agriculture Organization
FAS	Foreign Agricultural Service
FEWSNET	Famine Earl Warning Systems Network
FIRE	First ISCCP Regional Experiment
fvDAS	finite volume Data Assimilation System
fvGCM	finite-volume General Circulation Model
GAME	GEWEX Asian Monsoon Experiment
GAPP	GEWEX Americas Prediction Project
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	Goddard Earth Observing System
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
GLDAS	Global LDAS
GLRON	Great Lakes Region Ozonesonde Network
GMAO	Global Modeling and Assimilation Office
GMI	Global Modeling Initiative
GMU/IGES	George Mason University, Institute of Global Environment and Society
GOCART	Goddard Global Ozone Chemistry Aerosol Radiation and Transport
GOME	Global Ozone Monitoring Experiment
GPLLJ	Great Plains Low Level Jet
GrADS	Grid 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
HELP	Hydrology for the Environment, Life, and Policy
HSB	Hydrological Sciences Branch
HSPF	Hydrological Simulation Program - Fortran
IDS	Interdisciplinary Science in the NASA Earth Science Enterprise
IGPB	International Geosphere Biosphere Program

INTEX-A	Intercontinental Transport Experiment A
INTEX-B	Intercontinental Transport Experiment B
Intex-NA	Intercontinental Transport Experiment – North America
IOP	Intensive Observation Period
IPCC	Intergovernmental Panel of Climate Change
ISCCP	International Satellite Cloud Climatology Project
JAXA	Japanese Aerospace Exploration Agency
JGR	Journal of Geophysical Research
KNMI	Royal Netherlands Meteorological Institute
LAI	Leaf area index
LDAS	Land Data Assimilation System
LEAF-2	Land Ecosystem Atmospheric Feedback model version 2
LIS	Land Information System
LSM	Land Surface Model
LSOS	Local Scale Observation Site
LTER	Long Term Ecological Research
M.A.	Master of Arts
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
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
MOZART	Model for OZone And Related chemical Tracers
MPI	Message-Passing Interface
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
NCEP	National Center for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NEWS	NASA Energy and Water Cycle Study
NLDAS	North American LDAS
NOAA	National Oceanic and Atmospheric Administration
NOAH	National Centers for Environmental Prediction (NCEP)/Oregon State University/Air Force Hydrologic Research Laboratory
NRA	NASA Research Announcement
NRC	National Research Council
NSIPP	NASA seasonal to Interannual Prediction Project
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
PAVE	Polar AURA Validation Experiment
PBL	Planetary Boundary Layer
PDF	Probability Density Function
PECAD	Production Estimation and Crop Assessment Division
PEST	Parameter Estimation Tool
PI	Principal Investigator
PILPS-2g	Project for Intercomparison of Land surface Parameterization Schemes – Phase 2g
PNA	Pacific North America pattern
POLDER	Polarization and Directionality of the Earth's Reflectance
POM	Princeton Ocean Model
PV	Potential Vorticity
QG	Quasi-Geostrophic
RAMS	Regional Atmospheric Modeling System
RSS	Remote Sensing Systems, Inc.
SAC-SMA	Sacramento Soil Moisture Accounting model
SAGE III	Stratospheric Aerosol and Gas Experiment III
SAIC	Science Applications International Corporation
SBUV	Solar Backscatter UltraViolet radiometer
SCAN	Soil Climate Analysis Network
SCD	Slant Column Density
SCO	Stratospheric Column Ozone
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SHADOZ	Southern Hemisphere Additional Ozonesonde
SHDOM	Spherical Harmonics Discrete Ordinate Method
SI	Standard Initialization
SIO	Scripps Institution of Oceanography
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.
SSI	Streamline Subgrid Integration
SSMI	Special Sensor Microwave Imager
SST	Sea-Surface Tempeature
SSWSF	Snow Survey and Water Supply Forecast
START	SysTem for Analysis, Research, and Training
STE	Stratosphere-Troposphere Exchange
SWE	Snow water equivalent
TCO	Tropospheric Column Ozone
TEC	Topographic Engineering Center
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPP	Tropospheric Ozone Pollution Project
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
UARS	Upper Atmosphere Research Satellite

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
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
USGS	United States Geologic Survey
USWCL	United States Water Conservation Laboratory
UT/LS	Upper-Troposphere/Lower-Stratosphere
UV	Ultraviolet radiation
VCD	Vertical Column Density
VIC	The Variable Infiltration Capacity Model
WRAIR	Walter Reed Army Institute for Research (WRAIR)
WRF	Weather Research and Forecasting

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