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Annual Report

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GEST
GODDARD EARTH SCIENCES AND TECHNOLOGY CENTER

Goddard Earth Sciences and Technology Center (GEST)

Third Annual Report

May 31, 2003

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INTRODUCTION

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INTRODUCTION

Publication of this annual report marks the completion of the third 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 has grown in the past year to over 120 researchers; corresponding administrative staff changes have been made, as well. The breadth of research interests has also grown, necessitating the increase to six research groups, each composed of scientists with related and complementary expertise. Formation of these groups has also provided the structure needed to efficiently manage the organization. In addition, several new projects have been established during this year, providing exciting opportunities for outreach.

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 112 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 202 refereed scientific papers that were authored by GEST faculty and either accepted by or published in major journals.

Most of the research activities in this volume are funded through the program budgets of Goddard Space Flight Center (GSFC) collaborating civil servant scientists. However, an increasing number of GEST researchers have been successful in submitting proposals to NASA and other agencies, and have been awarded funding for their own research projects. Reports of these grant-funded activities are also found in this report, organized by grant number. In some cases, GSFC scientists are listed as co-investigators with GEST PIs. Ninety-five GEST-authored proposals were submitted in the past year; 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 third year with seven 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.

This year marked the inauguration of the GEST Visiting Scientist Seminar Series. The purpose of these monthly seminars was to provide a forum for the exchange of ideas and results of scholarly research for the NASA research and academic communities associated with the Earth and information sciences disciplines. The seminar speakers were usually one of the prestigious Goddard Visiting Fellows who provided a lecture reflecting their individual research results over a wide range of contemporary scientific topics of high interest. During the past year, the seminar location alternated between the UMBC campus and GSFC, with the presentation site selected to reflect the interests of the local scientific community.

Summer Educational Programs and Graduate Fellowships

The Summer 2002 Educational Programs included a new program, the Goddard Coastal Research Graduate Fellowship Program. The GEST Center organized and conducted the following four educational programs at GSFC:

- In the *Visiting Student Enrichment Program (VSEP)*, 25 students in the physical sciences, mathematics, and computer science from high school through graduate school participated over a 10-week period in a wide variety of productive projects with GSFC-based mentors;
- Sixteen advanced graduate students were guided through techniques for working with supercomputers on large, illustrative, computation-intensive problems in the *High Performance Computing (HPC)* summer program;
- The *Graduate Student Summer Program (GSSP)* played host to ten students who worked with GSFC-based scientist mentors. In association with the latter program, we conducted a four-day seminar series entitled, "Climate Change and the Global Water Cycle". Sixteen internationally recognized speakers presented seminars that stimulated thought and discussion amongst the students, researchers, and other interested participants.
- In the *Goddard Coastal Research Graduate Fellowship Program (GCR)*, six students selected for the inaugural year of this program worked with mentors at GSFC's Wallops Flight Facility.

The educational aspect of GEST activities also included the appointment of two GEST graduate fellows, one in the Physics Department at UMBC and one 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 scientists 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.

In 2002 two international workshops were hosted by GEST on the UMBC campus. These workshops contributed to fulfilling the vision of GEST as an international center for ongoing discussion and education on issues relevant to the Earth sciences and information technology. The first meeting was a Data Assimilation Workshop, sponsored by the Stratospheric Processes and their Role in Climate (SPARC), part of the World Climate Research Programme (WCRP). Approximately 40 international experts participated in this three-day workshop in June 2002. The second workshop was the African Monsoon Multidisciplinary Analysis project, which is also linked with WCRP. Approximately 50 international researchers participated in the November meeting.

Global Energy and Water Experiment

A major new focus of the GEST Center involves supporting NASA Earth Science Program objectives through exploiting the opportunities for promoting coordination of broad international environment-related research within the framework of NASA/UMBC cosponsored activities. Such an opportunity developed over the past year with respect to the Global Energy and Water Experiment (GEWEX), an element of the World Climate Research Programme, sponsored by the World Meteorological Organization, the International Oceanographic Commission of UNESCO, and the International Council of Scientific Unions. GEWEX represents the most ambitious attempt to characterize, understand, model, and

predict the behavior of the critical roles of water and energy in the Earth's climate system. For example, improved knowledge of the availability of fresh water is of extreme importance to food production and human health worldwide. Climate is a major factor affecting the distribution of water resources, and GEWEX has been designed to help provide a reliable scientific basis for establishing sound environmental policy.

In April 2003 NASA approved a UMBC proposal to assume responsibility for administering the International GEWEX Project Office (IGPO) within the structure of its GEST Center. The IGPO will be 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: www.gewex.org.

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, the number of researchers at Hampton University, Howard University, and Caelum Research Corporation increased during this third year of GEST. Northrop Grumman Corporation has provided invaluable advice and support through representation on the GEST Executive Board, and participation in the summer 2002 Goddard Coastal Research Graduate Fellowship Program.

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. 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 here. I am also grateful to Drs. Julio Bacmeister, Susan Hoban, Gail Skofronik Jackson, Richard Judelson-Kelley, Steven Pawson, Susan Sakimoto, and Alexander Smirnov, whose innumerable contributions as research group leaders greatly contributed to the progress made in this third year. Recognition for the development of this and the previous year's annual report is given to the leadership of Dr. Tom Low and his collaboration with all the research group leaders. Dr. Low was appointed Associate Director of GEST in May 2002. His work on this report and that of the research groups leaders is greatly appreciated.

We would like to thank Dr. Mitchell K. Hobish, who served as scientific editor of this volume, which required carefully editing, integrating, and formatting the many pieces and contributions into a single consistent document; Vanessa McNeill and Heidi Harting-Rex for the detail work of copyediting; and Lisa Richard, for performing the layout of this document.

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 that we are continuing to strive for.

Robert J. Curran
Director

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EXECUTIVE SUMMARY

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Executive Summary

This has been the third year of existence and continued growth for the Goddard Earth Sciences and Technology Center (GEST), operating under a cooperative agreement between the NASA Goddard Space Flight Center (GSFC) and the University of Maryland, Baltimore County (UMBC). GEST is a consortium led by UMBC, and includes Howard University, Washington D.C.; Hampton University, Hampton, Virginia; Caelum Research Corporation, Rockville, Maryland; and Northrop Grumman Corporation, Baltimore, Maryland. This third annual report describes research activities during the period from April 1, 2002 to March 31, 2003, and includes 112 contributed research reports in seven sections: Seasonal-to-Interannual Prediction, Land Surface and Hydrology, Climate and Trace Species, Aerosols and Lidar, Clouds, Information Science and Technology, and contributions by a distinguished group of GEST Visiting Fellows. The bibliography lists 202 peer-reviewed journal and book articles published or pending publication by GEST authors in the past year. The GEST faculty has also been involved as PIs or co-Is in 95 proposal submissions this reporting period, almost double the number of submissions in the previous year.

GEST Educational Programs are described, which include four Summer Enrichment Projects in the Earth and information sciences that were conducted in 2002 for an enrollment of 57 high school, undergraduate, and graduate students. One new summer student program was added for 2002: the Goddard Coastal Research Graduate Fellowship Program (GCR), to provide opportunities for graduate students in physical and biological oceanography to learn instrumentation technologies and techniques. As part of our summer program, a weeklong seminar series was conducted, entitled “The Global Water Cycle and Climate Change”, directed to our summer students, but open for general attendance. Programs are described which have sponsored opportunities for visiting scientist and graduate student fellowships in collaboration with GEST and GSFC researchers. Under the sponsorship of GEST, U.S. and international Earth system scientists have visited GSFC laboratories or field experiment sites as visiting research scientists to collaborate during extended appointments or for short stays. A new initiative has brought the International Global Energy and Water Experiment (GEWEX) Project Office (IGPO) within the structure of the GEST Center. The IGPO will be responsible for international coordination of all aspects of GEWEX with the worldwide scientific community and the space agencies.

The role of GEST in GSFC’s mission specifically, and the Earth sciences, generally is clear. We look forward to an increased depth and breadth of collaborative work in future endeavors.

Tom Low
Associate Director

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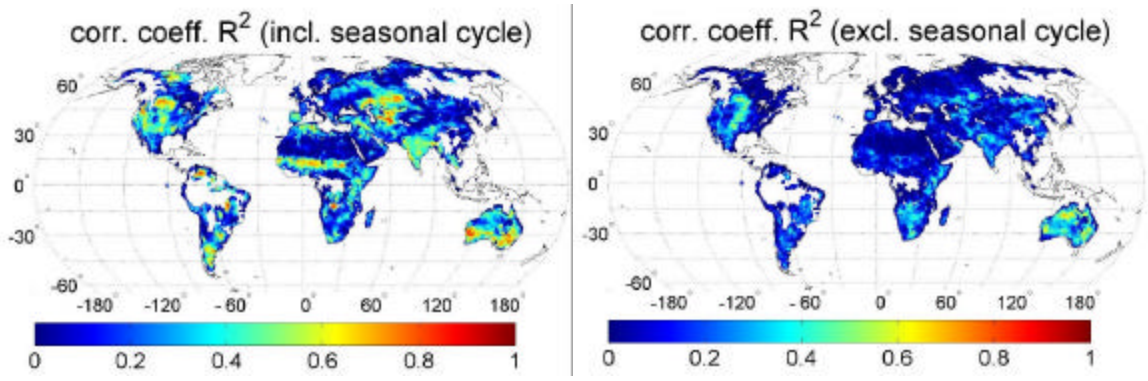
Seasonal-to-Interannual Climate Prediction Research Group



Correlation coefficient R^2 (percent of variance explained) for monthly mean surface soil moisture from SMMR and the NSIPP Catchment Model. The left panel includes the seasonal cycle (monthly anomaly correlation); the right panel excludes it.

Seasonal-to-Interannual Climate Prediction Research Group

Overall, 2002 was an exciting and challenging, year for NASA's Seasonal-to-Interannual Prediction Project (NSIPP). Given the obvious difficulty in forecasting weather for more than several days in advance, it may be hard to understand how "climate forecasts" for up to a year are even contemplated. Although no precise distinction between "weather" and "climate" exists, a useful distinction would be one based on time-scale. Weather can be thought of as consisting of atmospheric phenomena that have time scales ranging from several hours to several days, while climate refers to "average" or "typical" conditions over a period of weeks to months. Examples of weather phenomena range from summer thunderstorms, which grow and decay in the space of a single afternoon, to Atlantic coast northeasters, which may last for several days. A "climate" event, on the other hand, might be a drought or prolonged period of cold weather. Weather forecasts attempt to predict the impacts of weather events on relatively small regions, even down to the scale of individual cities or counties. Climate forecasts do not attempt to predict with such detail. Rather, they attempt to predict conditions for a given month or season over a larger region, usually in comparison to "normal" conditions. However, this distinction between weather and climate is not always clear-cut. Some individual weather events, such as hurricanes or the President's Day snowstorm of 2003 on the East Coast of the U.S., can substantially alter seasonal precipitation totals over a large area. The occurrence of such events cannot be predicted more than one to two weeks in advance. Thus, even moreso than weather forecasts, climate forecasts are inherently statistical.

The reason scientists believe climate forecasts are possible at all is because, on time scales longer than a few weeks, the overall behavior of the atmosphere is controlled by external forcing. This is different from the situation at "weather" time-scales, for which the rapid internal, chaotic dynamics of the atmosphere are critical. The most important external forcings for climate prediction are soil moisture and sea-surface temperature (SST). Both the ocean surface and land surface are systems with relatively long "memory" compared with that of the atmosphere; that is, changes within these systems take place over periods of months to years, or possibly even decades, compared with days to weeks for fluctuations in the atmosphere. The key to successful climate prediction lies in forecasting changes in these surface conditions, and then correctly simulating their effects on the atmosphere. This requires accurate models of ocean and land-surface dynamics, including the behavior of ground water and vegetation. Accurate atmospheric models are also important, not only because the atmosphere is where the phenomena of interest, *e.g.*, drought, rain, and heat waves occur, but also because interactions of land and ocean systems with the atmosphere can determine how surface conditions evolve over the course of months.

Equally important for prediction is accurate knowledge of initial conditions for the slow components of the climate system: land and ocean. An important part of NSIPP's research is devoted to better specifying global land-surface and ocean states from satellite and *in situ* measurements. Coarse or incomplete satellite measurements and sparse *in situ* measurements must be processed using sophisticated models that combine statistical and physical information about land and ocean systems to produce useful initial states for coupled climate models. Reichle has used Kalman filter techniques to estimate soil wetness from measurements of radio brightness. The technique can provide useful information at scales smaller than the footprint of radio measurements.

Other GEST investigators within NSIPP have contributed to the development of the component models (land, ocean, and atmosphere) that make up the coupled climate prediction system. Mahanama has worked on validating a new "catchment" based land surface model. This model uses a topographically based decomposition of the land surface to efficiently estimate run-off and other terrain-driven hydrological processes. The catchment model is currently being incorporated in NSIPP's coupled forecasting system. Vintzileos led the implementation and validation of the NSIPP Version 1 coupled forecasting system during 2002. The Version 1 system uses an improved atmosphere model, and has demonstrated skill superior to the previous Version 0 system in six-to-twelve-month SST forecasts.

GEST researchers have also used NSIPP models and data sets to examine fundamental questions in atmosphere and ocean dynamics. Some of this research addresses the potential utility of climate forecasts. Ferreira studied the interannual variability of precipitation over South America using both observations and atmospheric model simulations, addressing basic questions about the effects of heating anomalies and heating/dynamical coupling on climate. Bacmeister examined physical causes for a common error in model simulations of tropical precipitation, the so-called “double-ITCZ” bias, present in most current atmospheric models. It is exacerbated when these models are coupled to ocean models and may distort the behavior of coupled forecasts.

A significantly improved coupled forecast system was implemented in the NSIPP. This system appears to be doing a good job of predicting the recent evolution of the modest El Niño that developed during 2002, although hindcasts initialized last (in the spring of 2002) did not perform well, perhaps due to interference from an unusually strong Madden-Julian Oscillation signal in the western Pacific during that time. Precipitation anomalies in the tropics were generally well predicted, but NSIPP precipitation forecasts for the eastern U.S. were near normal throughout 2002, despite the presence of severe drought through September 2002 and unusually rainy conditions from October on. During 2003 further improvements to the coupled model/forecasting system will be tested and/or implemented, including updated cloud and microphysics parameterizations in the atmosphere model and catchments in the land-surface model. Along with these model developments, the resolution of our routine forecasting runs may double, from around 200x200 km to 100x100 km.

The Seasonal-to-Interannual Prediction Research Group looks forward to another exciting (and challenging) year in 2003, as nature continues to test our understanding of the climate system.

Julio Bacmeister

Task 971-00-002: **Atmospheric Model Development for the NASA Seasonal-to-Interannual Prediction Project**

GEST Investigator: Julio T. Bacmeister

Collaborator: Max J. Suarez (GFSC)

Abstract

Implementation of unified microphysical parameterizations for both convective and large-scale cloud condensate was completed in the NASA Seasonal-to-Interannual Prediction Project (NSIPP) atmospheric general circulation model (AGCM). The aim of this work is to improve the NSIPP AGCM's simulation of atmospheric moist processes, including precipitation boundary-layer cloud formation. The improved microphysical parameterizations also facilitated analysis of the so-called "double intertropical convergence zone (ITCZ)" bias in the NSIPP AGCM. This bias is a persistent source of error in most current AGCM simulations of tropical precipitation. The double-ITCZ bias is exacerbated in coupled climate models, and may lead to significant errors in coupled forecasts.

Description of Research

The principal goal of the NSIPP is to develop a fully coupled atmosphere/land/ocean climate prediction system. This system will be used to produce global climate forecasts with six-to-twelve- month lead times and to study the impacts of satellite-based ocean and land-surface observations on climate predictability. Useful forecasts can be obtained with imperfect models by mathematically accounting for known errors. However, there is reason to believe that forecast skill will improve as the models of each climate component (atmosphere, land, and ocean) become more accurate and complete.

Accomplishments during the Reporting Period

The implementation of a single-phase prognostic condensed water variable (*i.e.*, prognostic clouds) was completed. The final step in the implementation was to unify the treatment of condensate in the model's convective parameterization with that of large-scale condensate. While this step is not essential, many AGCMs employ distinct micro-physical parameterizations for convective and large-scale condensates. Unified treatment of these processes will streamline interpretation of results and the inevitable tuning of model parameters. Also, by removing spurious differences between convective and large-scale microphysical algorithms more physically based distinctions between convective and large-scale moist processes, such as different sub-grid-scale condensate distributions, can be sensibly explored in the AGCM framework. A promising avenue for such studies is intercomparison of simulated three-dimensional precipitation fields with global three-dimensional data from NASA's Tropical Rainfall Monitoring Mission (TRMM). Initial comparisons of NSIPP AGCM precipitation fields with TRMM data have already begun. These initial comparisons are good in some respects, but show substantial room for improvement. In particular, these comparisons point out the need to examine comparative cloud-to-rain autoconversion rates over land and ocean.

In addition to the basic model development described above, physical explanations for the so-called "double-ITCZ bias" in climate models were examined. The double-ITCZ bias refers to a tendency for AGCMs to form two narrow, parallel bands (the ITCZs) of intense rain along across the region extending from approximately 10°S to 10°N across much of the Pacific Ocean. By contrast, in nature there is a tendency for rain to concentrate in a single ITCZ along 10°N, with rainfall in the southern hemisphere concentrated in a broader swath (the southern Pacific convergence zone, or SPCZ), aligned NW-SE from the maritime continent. The double-ITCZ bias is present to varying degrees in almost all current AGCMs. In nature, precipitation occasionally tends toward a double ITCZ configuration during intense La Niña events, when strong, cold sea-surface temperature (SST) anomalies are present across the equatorial Pacific. 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. This equatorial divergence induces ocean upwelling and equatorial SST cooling, which intensifies the double-ITCZ pattern. Thus, even AGCMs with comparatively weak double ITCZs in forced-SST mode can create strong double ITCZs when coupled with an ocean general circulation model (OGCM).

The NSIPP AGCM has been relatively free of the double ITCZ bias. It has been known for some time that strong re-evaporation of rain reduces or eliminates the spurious southern ITCZ in the NSIPP AGCM. While it has been lucky and useful to have such a reliable "tuning knob" for the model, the physical basis for this sensitivity has not been clear. This is especially frustrating in light of the fact that other AGCM groups have not found this sensitivity in their models. A series of intensive, short (two-year), forced-SST simulations were performed to isolate mechanisms responsible for the formation and/or suppression of the double ITCZ. These simulations showed that re-evaporation reduces boundary layer/convection coupling and that strong re-evaporation leads to intensified mid-tropospheric water vapor transport. These two factors apparently combine to "dry out" the region of the spurious southern ITCZ in experiments with strong re-evaporation. Experiments, in which mid-tropospheric water vapor transport was artificially suppressed, exhibited a strong, spurious ITCZ even when strong re-evaporation rates were enforced.

These results are encouraging because they suggest a physical explanation for the sensitivity of the NSIPP AGCM's tropical rainfall simulation. It is also of interest that by distorting the AGCM's circulation a strong double-ITCZ bias can be forced, even with strong re-evaporation. This suggests why other models may not show a sensitivity similar to that found in the NSIPP AGCM. If their tropical circulations vary significantly from that in the NSIPP AGCM, mid-tropospheric water vapor removal may not be vigorous enough to eliminate the southern ITCZ.

Objectives for the Coming Year

Model sensitivities to empirical parameters in the new cloud and entrainment parameterization will be characterized. Extended runs (10+ years of simulation time) forced with observed SSTs will be performed with the new model to understand its response to El Niño/Southern Oscillation-related SST perturbations. Integration of the new atmospheric model into NSIPP's coupled modeling system will also begin. The analysis of double-ITCZ/wave coupling will be completed and submitted for publication.

Task 971-00-002: **Role of Land-Surface Processes and Regional and Global Interactions in the Seasonal-to-Interannual Variability of the Atmosphere in the Amazon Region**

GEST Investigator: Rosana Nieto Ferreira

Collaborators: Max Suarez (PI, GSFC), Randal Koster (GSFC), Tom Rickenbach (UMBC/JCET)

Abstract

Analysis of NASA Seasonal to Interannual Prediction Project Atmospheric General Circulation Model (NSIPP-1 AGCM) simulations have suggested that Pacific Ocean sea-surface temperature (SST) anomalies alone may determine most of the strengthening of the South American Monsoon System that is observed during El Niño years. During the January-March 1998 (JFM98) El Niño period, the South American Low-Level Jet (SALLJ) and precipitation in subtropical South America were nearly twice as strong as during the JFM99 La Niña period. Application of an objective analysis tracking technique to infrared satellite imagery showed that larger and more numerous convective cloud systems occurred in subtropical South America during JFM98 than during JFM99. The differences between the two years may be attributed to Southern Oscillation (SO) and submonthly variability associated with the South Atlantic Convergence Zone (SACZ). A study of the moisture budget for periods of active

versus inactive SACZ showed that the active SACZ regime is most efficient in drawing tropical moisture into the extratropics. Idealized simulations are used to study the formation of the SALLJ, SACZ, and SO influences in South America.

Description of Research

This project focuses on the variability and predictability of South American circulation and convection organization on seasonal-to-interannual timescales. South American circulation and precipitation are modulated by the SO on interannual timescales, and by the SACZ and frontal passages on submonthly timescales. Observations and NSIPP-1 AGCM simulations are used to study how the SO and SACZ affect the SALLJ, the Amazon and Atlantic Intertropical Convergence Zones (ITCZs), the water budget over South America, and the precipitation and convective system formation over South America. A second phase of this research is to isolate features in the atmospheric heating that produce strong responses in the South American region. This is done by conducting simulations using a simplified version of the NSIPP-1 AGCM, in which specified heating distributions are imposed.

Accomplishments during the Reporting Period

NSIPP-1 Atmospheric Model Intercomparison Project (AMIP)-style simulations reproduce the mean observed JFM circulation over South America during normal years. During El Niño years, the AMIP simulations capture the observed, enhanced trade winds and decreased precipitation in the Amazon Basin and Atlantic ITCZ, as well as the observed enhancement of the SALLJ and some of the observed enhancement of precipitation in subtropical South America. A 20-year long NSIPP-1 “perpetual El Niño” simulation was produced by forcing the model with climatological SST and a Pacific El Niño anomaly. The results obtained in the “perpetual El Niño” simulation were very similar to those of the El Niño years in the AMIP simulation, suggesting that Pacific Ocean SST anomalies alone determine most of the observed strengthening of the South American Monsoon System (SAMS) observed during El Niño years. This includes the strengthening of the SALLJ, the increase in trade easterlies and decrease in precipitation in the Atlantic ITCZ and Amazon Basin, and, to a lesser extent, the increase in precipitation over subtropical South America.

Preliminary analysis of the NSIPP-1 Dynamical Seasonal Prediction (DSP) simulations suggests that there is hope for predicting the summertime precipitation and circulation in South America. The interannual variability of the tropical precipitation and circulation in South America and adjoining oceans is dominated by a single parameter: the interannual variability of SST anomalies. The SALLJ and SACZ are less predictable because they are strongly influenced by baroclinic waves whose nature is more chaotic.

A simplified version of the full NSIPP-1 AGCM is being used to isolate the impact of different heating distributions on the circulations controlling the SALLJ and SACZ. These calculations employ the dynamical core of the model and a number of physical parameterizations related to friction and momentum dissipation. The first step is to try to reproduce the full GCM's mean summertime circulation using the full-GCM’s archived heating fields as forcing. Initial calculations, using an idealized surface drag, showed that the mean climate produced by these simulations was strongly dependent on the strength of the friction applied in the lower troposphere. Stronger low-level friction has the effect of producing a steady circulation that has a Southern Hemisphere midlatitude jet that is too close to the Equator, at 30°S (rather than the observed 45°S). Weaker low-level friction produces a mean circulation that is in better agreement with the full GCM circulation. However, the weak low-level friction simulations do not produce a steady-state solution, and the Southern Hemisphere midlatitude jet slowly oscillates between 30°S and 45°S. Subsequent calculations, using surface drag, momentum mixing, and gravity wave drag (exactly as in the full GCM), come closer to producing the full GCM climatology. Nevertheless, important differences remain between the forced, simplified-model and the full-model solutions. These differences are believed to be due, in part, to the lack of interaction between heating and dynamical fields in mid-latitudes in the forced runs. This hypothesis is being tested by restricting the region, in which imposed heating is applied to the tropics.

Objectives for the Coming Year

In the coming year, studies of climate bifurcation in the NSIPP-1 dynamical core simulations will continue, as will studies of the formation and maintenance of the SACZ and SALLJ. The relationship between heating/dynamics interaction and the overall global circulation will be clarified.

Task 971-00-002: **Intercomparison of Soil Moisture Memory in Two Land-Surface Models**

GEST Investigator: Sarith Mahanama

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

Abstract

A heavy rain or a dry period can produce an anomaly in soil moisture, which can take weeks to months to dissipate. It is important to understand how land-surface models (LSMs) used with atmospheric general circulation models simulate this soil moisture "memory," since this memory may have profound implications for long-term weather prediction through land-atmosphere feedback. Thus, the differences in soil moisture memory produced by two different LSMs developed for the NASA Seasonal-to-Interannual Prediction Project (NSIPP) were investigated: the Catchment LSM and the Mosaic LSM [Mahanama *et al.* 2003].

Description of Research

In any coupled forecast system, LSMs compute water and energy budgets at the land surface, and latent and sensible fluxes at the land-atmosphere boundary. Precipitation forecasts of coupled systems over a continent could be influenced by the performance of the LSM. Furthermore, the principal objective of the NSIPP is to develop a fully coupled atmosphere-land-ocean climate prediction system. Both the NSIPP Catchment and the Mosaic LSMs are currently being used in different versions of the NSIPP forecast system, as each LSM employs a distinctly different para-eterization scheme. Thus, investigating the soil moisture memory produced by the two LSMs and understanding memory differences through the differences in parameterizations are warranted.

Accomplishments during the Reporting Period

To better understand the effects of precipitation and net radiation on soil moisture memory, the NSIPP Catchment LSM and the Mosaic LSM were forced with a wide variety of idealized climates. The imposed climates had average monthly precipitation ranging from 15 mm to 500 mm, and monthly net radiations (in terms of water equivalent) ranging from 20 mm to 400 mm, with consequent changes in near-surface temperature and humidity. For an equivalent water holding capacity, the two models maximize memory in distinctly different climate regimes. Memory in the NSIPP Catchment LSM exceeds that in the Mosaic LSM when precipitation and net radiation are of the same order; otherwise, memory in the Mosaic LSM is larger. The NSIPP Catchment and the Mosaic LSMs were also driven off-line, globally, for a period of 15 years (1979-93) with realistic atmospheric forcing. Global distributions of one-month-lagged autocorrelation of soil moisture for boreal summer were computed. An additional global run with the NSIPP Catchment LSM—employing the Mosaic LSM's water-holding capacities—was also performed. These three global runs allow determination of how intermodel differences in soil moisture memory are related to differences in physical parameterizations, such as those for evaporation and runoff production.

Objectives for the Coming Year

River discharges are the most measured hydrologic observation and the integrator of the land surface hydrological processes; this parameter can easily be used to evaluate the performance of land surface models at large scales. River runoff simulations of the NSIPP Catchment and the Mosaic with observations in major river basins around the world will be compared when both LSMs are forced off-line using European Center for Medium-range Weather

Forecasts' global forcing data set for the period 1979-1993. Pathways using observed river discharges will be investigated to get a sense of the observed state of soil moisture memory in large river basins.

Task 971-00-002: **Land Data Assimilation in Support of the NASA Seasonal-to-Interannual Prediction Project**

GEST Investigator: Rolf Reichle

Collaborators: Michele Rienecker (PI, GSFC), Randal Koster (GSFC), Paul Houser (GSFC), Matt Rodell (GSFC), Max Suarez (GSFC), Christa Peters-Lidard (GSFC), Dennis McLaughlin (MIT), Dara Entekhabi (MIT), Jeffrey Walker (University of Melbourne, Australia), Marc Stieglitz (Columbia University)

Abstract

The use of Kalman filtering techniques has been investigated to estimate soil moisture from remote sensing observations for land initialization of seasonal climate forecasts. The assimilation algorithms include a one-dimensional version of the Extended Kalman filter (EKF) and one- and three-dimensional versions of the Ensemble Kalman filter (EnKF). Because of its flexibility, efficiency, and performance the EnKF is preferable to the EKF for soil moisture initialization problems. The three-dimensional version of the EnKF can make use of potential horizontal correlations in model, forcing, or observation errors and can further decrease soil moisture estimation errors compared to one-dimensional filters.

Description of Research

A central goal of the NASA Seasonal-to-Interannual Prediction Project (NSIPP) is to develop a land data assimilation system that makes optimal use of existing and planned remote sensing observations for improved predictions of seasonal-to-interannual climate variations. Seasonal climate forecasting must rely on the correct initialization of the slow components of the Earth's systems, specifically the oceans and the land surface. At the land surface, soil moisture controls the partitioning of moisture and energy fluxes to the atmosphere and is a key variable in weather and climate prediction. The memory associated with soil moisture is likely the chief source of mid-latitude forecast skill.

Accomplishments during the Reporting Period

Part of last year's research was to assess the relative merits of the EnKF and the EKF for soil moisture initialization within the NSIPP forecast system. In a twin experiment for the southeastern United States observations of near-surface soil moisture, have been assimilated once every three days into the NSIPP Catchment Model, with all catchments treated independently [Reichle *et al.* 2002b]. Both filters produce satisfactory estimates of soil moisture. In the application described here, the EKF and the EnKF, with four ensemble members, are equally accurate at comparable computational cost. Because of its flexibility, efficiency, and performance, the EnKF is the more promising approach for soil moisture initialization problems. Key advantages of the EnKF are that the EnKF performance can be increased by increasing the ensemble size; the EnKF can account for a wider range of model errors and can be extended to account for horizontal error correlations.

Errors in estimates of land surface variables are likely to be horizontally correlated because of large-scale errors in meteorological forcing fields (typically available at scales coarser than the catchment resolution), large-scale errors in model parameters, and un-modeled fluxes of water across catchment boundaries. The research described here has been done to determine whether such horizontal error correlations can be exploited to improve soil moisture estimation accuracy.

In a multi-year twin experiment for the Great Plains of the United States synthetic observations of near-surface soil moisture were assimilated into the NSIPP Catchment Model. Gauge-based precipitation data were used to force the "true" model solution, and European Center for Medium-range Weather Forecasts (ECMWF) reanalysis data were used for the prior (or background) fields. The difference between these two data sets is thought to be representative of errors that could be encountered in a global assimilation system.

The EnKF is applied to each catchment independently (1D-EnKF) or simultaneously (3D-EnKF). The 3D-EnKF uses potential correlations in model, forcing, and observation errors between different catchments to propagate observation information laterally, in particular from observed to unobserved locations. Both filters provide satisfactory estimates of soil moisture. The average actual estimation error in the (volumetric) root zone moisture content is 1.5% for the 3D-EnKF, 1.9% for the 1D-EnKF, and 3.6% without assimilation. Obviously, taking horizontal error correlations into account improves soil moisture estimation accuracy. The price for the improved estimation accuracy is a computational cost. As applied here, the 3D-EnKF requires about 1.6 times the computational effort of the 1D-EnKF, but the exact factor depends on the experiment setup and is likely to increase for global assimilation. Soil moisture estimation errors are smallest for error correlation scales around two degrees, which coincides with the horizontal scale of the precipitation difference fields as independently determined.

Another area of research has been the production of a 15-year climatology for the NSIPP Catchment Model, using corrected ECMWF reanalysis forcing data (1979-1993). Soil moisture from these integrations has been compared with soil moisture retrievals from the Scanning Multichannel Microwave Radiometer (SMMR) for 1979-1987. A comparison of these data reveals large discrepancies in the climatologies of modeled and satellite-retrieved soil moisture. These discrepancies will have to be taken into account when SMMR retrievals are assimilated into the Catchment Model for hindcast initialization. Finally, time series correlations between SMMR soil moisture retrievals and Catchment Model integrations have been computed. In many regions of the globe, model soil moisture can explain a fair amount of the variability of the SMMR retrievals. When the seasonal cycle is removed and anomalies are correlated, the model can explain a significant amount of the variance only in the U.S. Great Plains and in Australia. Nevertheless, these results indicate that careful assimilation of SMMR soil moisture likely improves the knowledge of true soil moisture conditions.

Objectives for the Coming Year

The first objective for the coming year is to complete global retrospective soil moisture assimilation products using historic satellite observations and to prepare for global assimilation of currently operational satellite data. Secondly, these soil moisture products will be tested in seasonal hindcasts and forecasts of mid-latitude summer precipitation with the NSIPP General Circulation Model. Thirdly, the joint assimilation of soil moisture and snow data will be explored.

Task 971-00-002: **Physics and Predictability of the El Niño – Southern Oscillation Phenomenon**

GEST Investigator: Augustin Vintzileos

Collaborators: Michele Rienecker (PI, GSFC), Max Suarez (GSFC), David Adamec (GSFC)

Abstract

The main objective of NASA's Seasonal-to-Interannual Prediction Project (NSIPP) is to investigate the usefulness of observations made by satellites in predicting climate on seasonal-to-interannual time scales. The project is based on a two-tier approach. The first tier consists of developing a forecasting system to predict sea-surface temperatures (SSTs). These temperatures are then used to predict atmospheric statistics by second-tier activities. The forecast of SSTs is based on the use of a coupled general circulation

model of the atmosphere and the global ocean, in which observations are injected (assimilated) into the ocean part.

Description of Research

General circulation models of the coupled atmosphere–ocean system are generally considered as the most promising tool to predict phenomena like the El Niño–Southern Oscillation (ENSO). However, these models still suffer from significant drawbacks with respect to the simulation of key tropical Pacific processes. Detecting and correcting these processes yields better forecasts and a better understanding of the physics of the coupled tropical climate. How good the models have to be and how close the initializations have to be to reality with respect to the longest possible useful forecast is still unknown, and is one of the main themes of this research.

Accomplishments during the Reporting Period

In previous years, the NSIPP Version 0 forecasting system was designed and developed. Analysis of hindcasts and forecasts made with this system established its ability to forecast the ENSO phenomenon with a lead of up to twelve months. This analysis detected a number of deficiencies in the representation of climate fields by the model and resulted in a series of improvements that were incorporated in the definition of Version 1 of the NSIPP forecasting system.

Initial experimentation with Version 1 was performed during the first part of 2002. Detecting and correcting several technical issues, many of which were related to the migration of the system to a new computing platform, were then completed. Hindcast experiments (covering the period 1993–2001), and forecasts (for 2002 and beyond) were executed in the second part of 2002 in parallel with a very long (100 years) simulation made with the coupled general circulation model, in free (not forecast) mode. Currently, the hindcast period is being extended to also cover the 1987-1992 period to include the 1987-1988 ENSO event in evaluating the predictive capability of the NSIPP forecasting system. The Version 1 forecasting system is the official forecasting tool of NSIPP as of January 1, 2003. It is run in a quasi-operational basis, and forecasts are posted at the beginning of each month on the NSIPP Web server, http://nsipp.gsfc.nasa.gov/exptlpreds xptl_preds_main.html.

A preliminary analysis of the results from the forecasting system shows that Version 1 is much better than Version 0 in all respects. Initialization shocks are much less intense, and the mean simulated climate is drifting only slightly. The result is an ENSO forecast that shows a correlation of 0.6 with the observed phenomenon ten months after initialization. This is a great improvement when compared with Version 0, for which the 0.6 correlation level was reached after only six months. A preliminary analysis of the long simulation with the free coupled general circulation model used in the Version 1 forecasting system has also been conducted. Despite some drawbacks, the realism in the representation of phenomena like ENSO is quite good, thus allowing studies of relevant physical phenomena.

Objectives for the Coming Year

Questions that will now be resolved by using this forecasting system as a tool involve the physics of ENSO and the mechanisms responsible for the error growth in ENSO forecasts. This research will permit forecast errors to be related to particular deficiencies either in initial conditions or the model formulation. Particular attention will be given to the forecast analysis of the 2002 warm ENSO event. Also to be addressed, is the existence and predictability of coupled modes of variability, which (though weaker than ENSO) might nevertheless be significant in terms of seasonal forecasting.

Task 971-00-002: **Global Mesoscale Variability from Altimeter and AVHRR Satellite Data**

GEST Investigator: Cara Wilson

Collaborator: David Adamec (PI, GSFC)

Abstract
The global covariability between physical and biological processes in the ocean surface on annual and interannual timescales is examined primarily using Ocean Topography Experiment (TOPEX), sea-surface height (SSH), Sea-viewing Wide Field-of-View Sensor (SeaWiFS) chlorophyll data, and Special Scanner Microwave Imager (SSM/I) wind data. Their spatial and temporal variabilities were examined using empirical orthogonal function (EOF) analysis and other statistical techniques. The approach has been to focus initially on basin scale variability; however, a preliminary global analysis has also been done.

Description of Research
Vertical fluxes of nutrient-rich water from below the nutricline to the ocean's surface can be a limiting factor affecting surface chlorophyll, and the depth of the nutricline plays an important role in the regulation of surface productivity. Because subsurface nutrient data is less available than physical oceanographic data, satellite chlorophyll data has been compared to satellite SSH, because SSH anomalies largely reflects changes in the thermocline depth, and the thermocline and nutricline are often collocated. The global correlations between these two measurements show they are predominately negatively correlated as a smaller (larger) SSH implies a shallower (deeper) thermocline/nutricline, which will increase (decrease) the surface nutrient flux and increase (decrease) phytoplankton concentrations. The strongest correlations between SSH and chlorophyll occur in the Pacific Ocean on interannual timescales associated with El Niño/Southern Oscillation (ENSO) dynamics, as discussed in previous research [Wilson and Adamec 2001]**.** However, there are also large areas in all ocean basins with positive correlations suggesting that surface chlorophyll in these areas are affected by processes other than thermocline depth changes. One of these areas is the western tropical Atlantic Ocean.

Accomplishments during the Reporting Period
A preliminary analysis of the global correlations between SSH and surface chlorophyll has been completed and published [Wilson and Adamec 2002].

The basin-scale dynamics between SSH and chlorophyll in the Indian Ocean have been investigated, focusing on the seasonal cycle and its interannual variations. In the Indian Ocean, Rossby wave generation constitutes an important component of the annual cycle of SSH variability, particularly in the Arabian Sea and in the Southern Tropical Indian Ocean (STIO). Research has shown that the reduced chlorophyll bloom during the 1997/1998 Northeast Monsoon in the Arabian Sea coincided with an anomalously weaker annual upwelling Rossby wave. In the STIO (between 10-15°S), the break in the annual chlorophyll bloom between 90-100°E appears to be related to the arrival of the annual downwelling Rossby wave. Between 10-15°S interannual variability in Rossby propagation affects chlorophyll levels during the quiescent period in the western Indian Ocean. However, further south, near 20°S, there is little interannual variability in Rossby wave propagation and correspondingly little interannual variation in the seasonal chlorophyll cycle. Currently, the forcings behind the interannual variations in Rossby waves initiation and propagation are being investigated using SSM/I wind data.

The global analysis of chlorophyll and SSH covariability has shown that for the entire western tropical Atlantic, it appears that surface chlorophyll levels are not driven by thermocline forced surface nutrient flux. A proposal was submitted to NASA in December, with V. Coles (University of Maryland Center for Environmental

Science, Horn Point Laboratory), to do an in-depth study of biophysical coupling in the Atlantic using a comprehensive synthesis of satellite data, ocean model results generated using synoptic forcing, and *in situ* subsurface data. This project would include analysis of the effect of atmospheric forcing on surface chlorophyll by examining both satellite wind fields and aerosol concentrations.

Objectives for the Coming Year

As the investigator has left GEST, there are no objectives for the coming year.

Task 971-00-002: **NSIPP Ocean Diagnosis and Data Assimilation**

GEST Investigator: **Dongliang Yuan**

Collaborators: Michele Rienecker (PI, GSFC), William K. Dewar (Florida State University)

Abstract

Diagnosis of the spurious mixing in the Poseidon quasi-isopycnal ocean model shows that there is very large implicit mixing along the outcropping isopycnal surfaces in the model. This spurious mixing is deleterious to model simulation of the thermohaline circulation of the world oceans. The roles of the Kelvin and Rossby waves in the seasonal-to-interannual circulation of the Pacific Ocean are studied. The reflection of the Rossby waves at the Pacific western boundary is very different from what is derived from linear theory. Surface temperature balances are examined in an assimilation study of the satellite sea-surface temperature data. The study shows significant differences between the simulated and assimilated results in the mixed-layer temperature balances at interannual time scales.

Description of Research

Spurious mixing in the Poseidon model has a negative impact on its performance in coupled climate simulations. Extraction of the Kelvin and Rossby waves from the Poseidon model hindcast elucidates the wave dynamics that govern the seasonal-to-interannual oscillations of the equatorial Pacific Ocean. Assimilating satellite-derived sea-surface temperature data is important in simulating the observed mixed layer temperature balances in the Poseidon ocean model and to estimating the surface heat flux over the equatorial Pacific Ocean.

Accomplishments during the Reporting Period

This past year, work continued with Florida State University professor William K. Dewar on diagnosing spurious mixing in the Poseidon quasi-isopycnal model. On the basis of work done in 2001, a coarse-resolution Poseidon model was deployed over the North Pacific basin and integrated toward equilibrium under the forcing of zonally averaged wind stress and heat and salt fluxes. The spurious diffusivity of the numerical model in the assumption of a linear equation of state of seawater was investigated to isolate the spurious mixing of the numerical model from the so-called "cabling" effects of the nonlinear equation of state of seawater. Because of the frequent change of the model configuration using different linear thermal expansion and haline contraction coefficients, the model has to be spun up to equilibrium for each change; substantial effort has to be spent on diagnosing and analyzing the model results. Investigations show that the model's spurious mixing is very sensitive to the equation of state of seawater. In all the investigations, it is found that the model's spurious mixing is, in general, too large for climate studies.

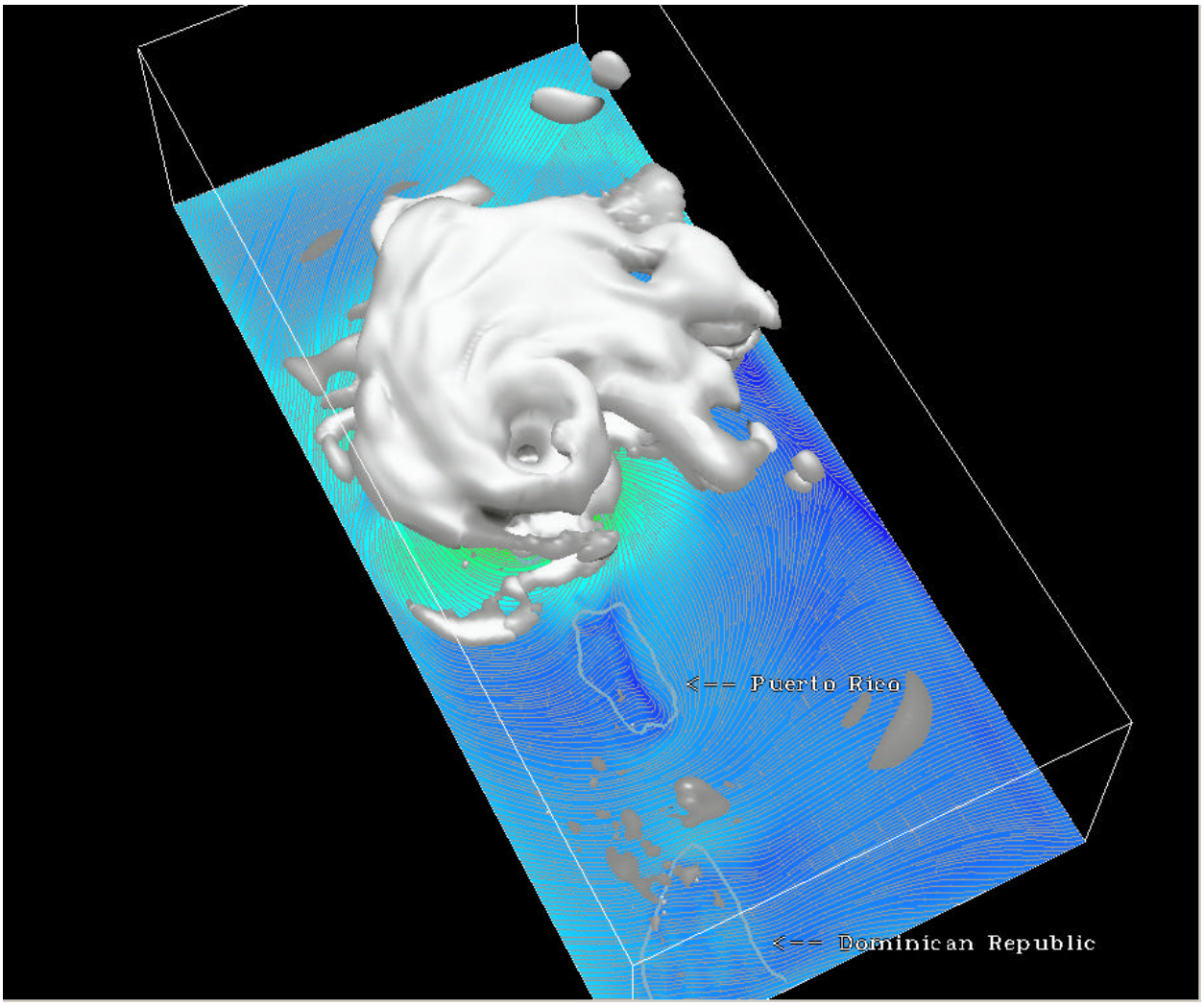
Examination of seasonal and interannual equatorial wave dynamics analyses has been finished. The reflections of the seasonal and interannual Rossby and Kelvin waves at the Pacific meridional boundaries are sometimes far from what is predicted by linear theory, suggesting strong nonlinearity in the boundary reflections. The wave reflection study is very important to the study of El Niño/Southern Oscillation (ENSO). Roles of the Kelvin and Rossby waves in ENSO evolution in the 1990s were investigated and compared with the results from linear models. The results are significantly different in some aspects,

suggesting limitations of the linear model and the importance of nonlinear simulation in investigating ENSO dynamics.

Objectives for the Coming Year

The study of wave dynamics in the nonlinear model simulation in the Atlantic and Indian oceans will continue. The detailed processes in the western boundary reflection will be explored, and diagnosis of the spurious mixing in the quasi-isopycnal model will continue, to improve model simulations for climate study.

Land Surface and Hydrology Research Group



Perspective view from the northeast of Hurricane Georges, looking toward the island of Dominica and Puerto Rico. The Regional Atmospheric Modeling System (RAMS) was used to simulate the hurricane. RAMS is a 3D primitive equation model that explicitly models relevant microphysical phenomena. The image is the result of 17 hours of integrations, using a 5-km grid spacing for the observed domain. The isosurface represents total condensate (i.e., rain, graupel, aggregates, hail, and pristine ice), while surface streamlines and pressure (color field) are also shown. Source: J. L. Eastman (GEST)

Land Surface and Hydrology Research Group

The GEST Land Surface and Hydrology Research Group integrates research into the hydrosphere with studies of the geosphere and biosphere. The group studies a wide variety of surface and near-surface processes of Earth and Mars, including surface hydrology dynamics and their interaction with climate, oceanography components and their link to climate variability, physical volcanology, and planetary geology and geophysics. Generally, the research is conducted through the context of Earth System Science, and is set 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 describing different land surface variables with land surface physical model outputs (such as soil moisture models). The integration is achieved through data assimilation methodologies; the final land surface representation can be used to initialize numerical models of global climate. By taking such a holistic approach, 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, to improve our ability to predict changes.

One common group interest area is that of biosphere-climate interactions. These interactions are studied by modeling the land surface as a lower boundary condition of the atmosphere by controlling the energy and mass fluxes from the surface to the atmosphere. Realistic representation of land surface conditions and processes is critical for both weather forecasts and climate predictions. Advances this past year continued to focus on improving the land-surface description in the Data Assimilation Office (DAO) by accounting for vegetation heat capacity and root zone hydrology, which are important in seasonal model forcing. In a related and complementary topic, studies continued on the spatial response patterns of land-surface vegetation to interannual climate variability. Efforts focused on the interannual variability of vegetation index data for Africa with a goal of determining the land-surface response patterns over Africa as a result of the change from El Niño conditions in 1997/98 to La Niña conditions in 1999/01 and the consequences of these changes to short- and long-term Rift Valley Fever (RVF) outbreak patterns and on interannual fire dynamics over Southern Africa.

Progress in our understanding of geosphere and geosphere-hydrosphere interactions has also continued this year with advances in several areas, including the effects of ambient planetary and land surface conditions—such as topography—on lava flow emplacement; how significant hydrologic events—such as flood outbursts and global volatile budgets—are expressed and reflected in martian volcanism and impact cratering; and how time-variable changes in continental water storage and in global oceanic circulation affect land surface loading and deformation and, thus, Earth's gravity field. Overlap between the solid Earth and water studies is considerable. For example, the study of deformation is also being applied to terrestrial sea ice, since sea-ice deformation is thought to have a significant effect on the ice mass balance and the surface energy balance of the polar regions. Results include the conclusion that sea ice responds to thermal forcing perturbation differently in winter than in summer, which may be an effect of sea ice's ability to adjust its surface energy balance on short time scales in winter, but not in summer.

Hydrosphere and hydrosphere-biosphere interaction research also continues to advance. A major element of this effort is in the form of land surface model (LSM) implementation at regional and continental scales. Both the North American Land Data Assimilation System (NLDAS) and its global counterpart, GLDAS, are beginning to mature. These systems use global and regional satellite and ground-based observation systems within a land surface-modeling framework, to produce optimal fields of land surface states and energy and water fluxes. A next-generation system (a Land Information System, LIS) is currently under development that uses high-performance computing to scale up the resolution in terms of both space and time discretization. The overall methodology of these LSMs has improved to the point that science studies are beginning to be conducted. For example, good progress has been made in determining the effect of the North American monsoon on land surface state predictability, a topic that can only be investigated through the use of continental-scale LSMs. Data from some of the new generation of satellite

(*e.g.*, Aqua and Terra) instruments are also starting to be examined for their utility in these modeling schemes. Soil moisture estimates from the Advanced Microwave Scanning Radiometer - EOS is being evaluated to determine its appropriateness for data assimilation into LSMs. The modeling effort, therefore, is well underway.

A second major element in the field of hydrosphere and hydrosphere-biosphere interactions research is in the utility of satellite observations from EOS satellite systems and newly developed instrument systems for the estimation of key hydrological variables. For example, progress has been made in developing methods to better estimate global snow cover and soil moisture using passive microwave instruments. In oceanic and near-shore studies, airborne lidar remote sensing is being 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 and further advances have been made to better understand the role of Arctic climate in the global climate system. Our understanding of these different variables in the global energy and water cycle systems is set to increase with this new generation of advanced technology instruments.

The overlapping science issues encountered at the land surface and hydrology interface are accompanied by common technical themes that weave through all of these studies, such as data manipulation, visualization and storage issues, remote sensing techniques, the continual need to assist with new instrument concept developments, and field campaign planning concerns. While the Land Surface and Hydrology Research Group is diverse in the span of traditional primary interest topics, these common 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 in 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 the better understanding of land surface states and possibly help predict future state variations.

Richard Kelly
Susan Sakimoto

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

GEST Investigator: C. Adam Schlosser

Collaborators: Paul Houser (PI, GSFC), D. Belvedere (UMBC/GEST), P. Morel (UMBC/GEST [retired])

Abstract

This GEST center activity 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 and NASA scientists, have been assembled. These task forces have worked to produce and to enable implementation plans that not only uphold NASA's Earth Science Enterprise (ESE) strategies, but also answer to the emergence of cross-cutting water-cycle research initiatives brought forth by interagency and government administrative science panels.

Description of Research

Spurious mixing in the Poseidon model has a Considerable attention has been given to the importance of the global water cycle (GWC) 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's response have identified the GWC as a critical research theme 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 crosscutting 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 climate-change science generally.

Accomplishments during the Reporting Period

In the past year, a document presenting the scientific foundation and roadmap for a Water and Energy Research (WatER) initiative has been completed. The WatER initiative has been presented to the NASA Earth System Science and Applications Advisory Committee and is currently under consideration by NASA program managers and ESE administrators. It is hoped that the WatER document will serve as the basis for a new water-cycle implementation strategy. A Website has been constructed (http://watercycle.gsfc .nasa.gov) to enable efficient dissemination of scientific/planning documents, solicitation of scientific and management inputs (through a web-based survey), description of NASA water-cycle science activities, and correspondence and education to scientists, educators, students, and the general public.

In conjunction with the scientific planning and coordinating activities, an analysis and synthesis effort was begun with the assistance of two summer students. This ongoing effort to quantify, balance, and characterize the global vertical fluxes of water (*i.e.*, precipitation and evaporation) uses satellite-based retrievals of ocean evaporation, model estimates of continental evaporation (based on standalone land-model simulations forced with observed atmospheric conditions), the Global Precipitation Climatology Project (GPCP) precipitation data, and multidecadal simulations from atmospheric general circulation models (AGCMs). The preliminary results indicate that our ability to characterize the general aspects of the global water cycle via satellite retrievals is encouraging, but much more attention is required to accurately quantify and balance the mean states, variability, and trends. In particular, a considerable trend exists in the Special Sensor Microwave/

Imager (SSM/I)-based ocean evaporation estimates (on the order of +1%/year), which is an order of magnitude greater than the observed precipitation and AGCM simulation. Moreover, the interannual variations in the observationally based global precipitation and evaporation estimates are not well correlated (~0.2) in comparison with the AGCM results (~0.99). The AGCM's interannual variability of the global, annual water fluxes is roughly half that of the observationally based estimates. The observationally based estimates of the relative land contribution (or conversely the ocean contribution) to the global, annual evaporation vary from 10-25%. Overall, the observationally based estimates of global, annual evaporation balance precipitation to within 10%. This imbalance, however, exceeds the degree of interannual variability seen in both observationally based estimates of global evaporation and precipitation.

Objectives for the Coming Year

In the coming year, the GEST/GSFC water-cycle support office will coordinate responses from the water and energy cycle survey, distributed to all Code 900 members. This is an important attempt to conclusively measure and assess all activities that pertain to water and energy research in the Earth Science Directorate. In addition, the final version of the WatER implementation document will be distributed to the wider scientific and management groups within NASA and other government research agencies. It is anticipated that the WatER document will serve as the basis for a new NASA Water-Cycle NASA Research Announcement (NRA) and long-term implementation strategy for NASA Headquarters (HQ) Science Division that would consist of a core project, science team members, and other NRAs that would solicit the contributions and collaborations of the community-at-large. Work will also continue to support relevant NASA HQ water-cycle program activities and potential core projects and community-based scientific collaborations that emerge from the NASA-wide water cycle initiative. The planning and coordination efforts will work in tandem with the interagency CCSP and the USGCRP elements to advance water-cycle science and prediction.

Task 921-01-018: **Coordinating and Implementing NASA Global Water Cycle Research**

GEST Investigator: Darius Mitchell

Collaborators: H. Frey (PI, GSFC), S. Sakimoto (UMBC/GEST)

Abstract

This task analyzed Martian topography data from the Mars Orbiter Laser Altimeter (MOLA) to better understand Martian surface processes and development.

Description of Research

This task creates and analyzes digital elevation maps (DEMs) of various regions of Mars. Recent work focuses on pedestal and rampart craters over many regions of Mars. Mars Orbiter Camera (MOC) imagery and MOLA topography data are used to determine what pedestal and rampart craters indicate about the depositional and erosional history of the Martian surface.

Accomplishments during the Reporting Period

Work under this task compared crater ejecta types from many locations on Mars. Pedestal craters—craters for which both ejecta blankets and cavity floors are topographically above the modern surface—may indicate regional paleosurfaces and erosional histories. Rampart craters, which exhibit fluidized ejecta blankets and—often—distal ejecta ridges are often used as indicators of Martian subsurface volatiles. These features have been compared to determine their relationship to each other. Results of this work show that pedestal craters may be eroded forms of rampart craters. MOC imagery was used to look for indications of resurfacing, such as layered terrain, in the vicinity

of pedestal craters. MOC imagery was also used to more precisely study the morphology of pedestal and small rampart craters. Analysis of these results is still underway.

Objectives for the Coming Year

As the GEST investigator is returning to graduate school, this work will be completed with the generation of a manuscript for publication.

Task 921-01-018: **Physical Volcanology, Planetary Geology, and Geophysics**

GEST Investigator: Susan Sakimoto

Collaborators: H. Frey (PI, GSFC), J. Garvin (HQ), Shauna Riedel (UMBC/GEST), Darius Mitchell (UMBC/GEST)

External Grant Collaborators: Eric Grosfils (Pomona College), James Zimbelman (Center for Earth and Planetary Studies, Smithsonian Air and Space Museum), Tracy Gregg (SUNY, Buffalo), Lori Glaze (Proxemy Research), Scott Hughes (Idaho State University), John Chadwick (Idaho State University)

Students: Jacob Bleacher (Arizona State University), Bethany Bradley (Pomona College [now at Brown University]), Shauna Reidel (Franklin and Marshal College), Devon Burr (University of Arizona), Anjani Polit (Pomona College), Zizwe Chase (Morehouse College)

Abstract

Research for this task covers a wide range of planetary geology and geophysics and terrestrial physical volcanology objectives that are important for understanding planetary surface processes.

Description of Research

Research objectives for this task include two related topics. The first is to understand terrestrial volcanic lava flow and cooling. This is done by studying channelized lava flows and small volcanic edifices on Earth and the terrestrial planets combining field, experimental, analytic, and computational studies. Since small edifices, channelized lava flows, and lava tubes are common volcanic features on the terrestrial planets, the results are widely applicable to terrestrial hazard and volcanic history studies, as well as planetary resurfacing and volcanic production estimates. The second research objective is to use topography as a constraint to understand how impact cratering and volcanic processes have played a role in Martian history and volcanic/thermal evolution. This is done with Mars Orbiter Laser Altimeter (MOLA) topography, Viking and Mars Global Surveyor (MGS) images, and models of volcanic flow and edifice construction, eruption, and impact cratering. This work is supported by MOLA mission funds and NASA grants to several PIs and Co-Is through a network of related grants.

Accomplishments during the Reporting Period

Research has gone well this year in several areas. Collaborative work addressed the geologically recent periodic flooding and volcanism of the Cerberus Rupes area on Mars, and progress was made on Martian lowlands impact basins research. NASA funding was received for initial work in the Eastern Snake River Plains, comparing volcanism there to plains volcanism on Mars, and for field work detailing Global Positioning System surveys of volcanic topography features to augment coarser digital regional topography maps. Other Martian research is still ongoing, including work on impact craters, and on some of the recent equatorial and polar deposits. Student activities included work on the equatorial Medusae Fossae Formation and polar erosion work.

In addition to guiding and participating in these numerous research activities, the GEST investigator continued a busy schedule, serving as the Geological Society of America Planetary

Geology Division's Chair from November 2001 through November 2002, participating on the Geological Society of America's Joint Technical Program Committee for the 2002 Annual Meeting, and serving on three proposal review panels for NASA's Mars Exploration Program.

Education and public outreach service included work with @discovery.ca ("At Discovery Canada") to produce a Mars Segment for a series of short items about the five naked-eye planets for television broadcast on the Canadian Discovery Channel that aired in April 2002; work with several summer interns ranging in age from high school to postdoctoral levels, teaching a graduate level spring semester course at the Johns Hopkins University for inservice teachers in their program for a Masters of Science in Education; providing the voice (and video) of "Dr. Susan" in the "Amelia the Pigeon" educational Website; and working to help win a Goddard Director's Discretionary Fund Award to investigate making three-dimensional topography models of Earth and Mars for educational use in classrooms, museums, and for visually disabled students. One set of these is now being used by the Smithsonian Air and Space Museum.

Objectives for the Coming Year

For the coming year, more time will be spent in the field measuring Idaho volcanic topography for comparison to Martian volcanic features, and collaborating with S. Hughes and T. Gregg to tie the topographic results to geochemical trends. The hope is to confirm and augment initial results that suggest some geochemical differences in volcanism can be inferred from local topographic diversity in a volcanic field. Collaboration will also continue in studies of Martian impact cratering to determine effects of target properties on crater topography. Other work will address Martian impact basins to study the relative ages of the Martian basement rocks and participation in several Martian volcanism research projects to determining magma chamber properties, lava flow characteristics, and the relative roles and timing of geologically recent lava and water flow on Mars. Several incoming summer students are expected to assist in the above research projects.

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 (PI, GSFC), Christopher O. Justice (University of Maryland, College Park), Robert Mahoney (Global Science and Technology), Kenneth Linthicum (State of California, Department of Health Services)

Abstract

This study focuses on the interannual variability of the vegetation index for Africa to determine the land surface responses across Africa as a result of changes from El Niño/Southern Oscillation (ENSO) to La Niña conditions, the consequence of these changes on short- and long-term Rift Valley Fever (RVF) outbreak patterns, and on interannual fire dynamics across southern Africa. Climate data on sea- surface temperatures (SST), outgoing long-wave radiation, and rain gauge data are used to validate the observed anomaly patterns in vegetation response and to determine SST forcings on vegetation response. Research also determines the nature of the relationship between interannual variability in vegetation and fire dynamics across southern Africa as part of the Southern African Regional Science Initiative (SAFARI) 2000 program. In general, there are reduced fire counts across southern Africa during El Niño events and an increase in fire activity during La Niña events when above-average rainfall contributes significantly to an increase in vegetation biomass, especially in grass and shrub savanna ecosystems.

Description of Research

The primary objective of this research is to better understand the spatial response patterns of land surface vegetation to interannual climate forcing. This is of critical relevance to Code 923.0 work

addressing Environmental Monitoring and Famine Early Warning in Africa, NASA's initiative on Environment and Human Health, the Department of Defense Global Emerging Infections Surveillance System (GEIS), and the Foreign Agricultural Service (FAS). The research takes an Earth system science approach, founded on an understanding of the interannual variability of tropical ocean SST and its effect on precipitation, as derived from satellite-based outgoing longwave radiation measurements, rain-gauge station data (where available), and satellite vegetation index measurements to infer the resulting impacts on the land surface.

Accomplishments during the Reporting Period

Research was carried out focusing on the interannual variability of vegetation index data for Africa to determine the pattern of land surface teleconnections over Africa as a result of the change from El Niño conditions in 1997/98 to La Niña conditions in 1999/01. Climatic data were used to validate the observed anomaly pattern in vegetation response and to determine SST forcing on vegetation response. Results across Africa show a bipolar response pattern in vegetation between East and Southern Africa. Over East Africa, during El Niño events (1997/98), there is a tendency for above normal rainfall and vegetation and below normal rainfall and drought conditions over Southern Africa. During La Niña events (1999/2000), land surface conditions were reversed between the two regions. Changes in SSTs in the Western Indian Ocean were identified to be major contributing factors to the interannual variability of land surface conditions over Eastern Africa. [Anyamba *et al.* 2001; Anyamba *et al.* 2002].

Previous research indicated the tendency for tight coupling between RVF outbreak patterns over East Africa and ENSO events. Based on analysis described above, risk maps for the likelihood of RVF outbreaks over Africa were derived [Anyamba *et al.* 2002]. The highest risk of RVF outbreak was identified for the Southern African region during the 1999/2000 and 2000/01 growing season, following persistent above-normal rainfall. Results from this research on mapping risk of RVF outbreaks over Africa are published monthly (http://www.geis.ha.osd.mil/). Over the long-term (1950 - 2000), there is no observed increase in RVF outbreaks despite a SST warming trend (consistent with global SST warming trends) over East Africa. Analysis based on over 20 years of National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) vegetation index data in concert with SST data indicates that outbreaks have occurred predominantly during warm ENSO events in East Africa, and during cold ENSO events in Southern Africa. Results provide a likely historical reconstruction of areas where RVF may have occurred during the last 20 years [Anyamba *et al.* 2002]. Currently, investigations are under way in collaboration with the World Health Organization to examine the recent (October – November 2002) outbreak in Senegal and Mauritania.

Collaborative work is investigating the role of interannual climate variability on vegetation over Southern Africa and its impacts on fire dynamics during the SAFARI 2000 campaign. During the 1999/2000 growing season, most of the region showed anomalous positive departures in vegetation—on the order of 40% above the 1981-2000 mean—especially over the shrub and grassland areas of Namibia and Botswana. This increase in biomass is related to above-normal rainfall during this period associated with the cold phase of the ENSO phenomenon, which exerts a major influence on the interannual climate dynamics of this region. An extended growing season and above-normal green biomass accumulation increased the amount of fuel available during seasonal burning between May-October 2000. There was a noted increase in the number of fires over the bushed grassland areas during this period as compared with the 1992 period, when this region received below-normal rainfall, associated with the 1991/1992 warm ENSO event. [Anyamba *et al.* 2003].

Objectives for the Coming Year

The coming year will continue the RVF monitoring work in collaboration with the GEIS and affiliated international labs. In addition, the Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation index time series will be developed for comparison with the SPOT vegetation and AVHRR vegetation index time

series. Collaborative work will begin on ecological characterization of disease vector habitat at selected sites in the continental U.S. using satellite data. The interannual variability of vegetation and its relationship to agricultural production in major agricultural regions of the world will begin with the collaboration of the FAS. Other work will include coordinating Global Inventory Modeling and Mapping Studies (GIMMS) contributions to support the application of MODIS data to agricultural assessment and forecasting by the USDA FAS. As part of this effort, the role of interannual climate variability on biomass and fuel loads over Southern Africa will be investigated. Support to the U.S. Agency for International Development (USAID)/Famine Early Warning System (FEWS) and FAS contracts will also continue.

Task 971-02-040: **Coupled Ice-Ocean Modeling**

GEST Investigator: Jinro Ukita

Collaborators: S. Häkkinen (PI, GSFC), A.K. Liu (GSFC)

Abstract

The scientific objective of this research is a better understanding of the Arctic climate system and its role in global climate by developing, testing, and implementing sea-ice data assimilation to study the Arctic climate. The past year's activity culminated at a sea-ice data assimilation workshop held in July 2002, where summary results on the progress made during the first half of the project were presented. The GEST investigator took a leading role in organizing the workshop and in producing a report that made recommendations to NASA Headquarters. Reassessment of the project goals and the general status of sea-ice data assimilation led to a new research initiative on Northern Hemisphere sea-ice variability owing to the discovery of a substantial amount of evidence linking sea-ice and North Atlantic Ocean and El Niño/Southern Oscillation (ENSO) variability.

Description of Research

Recent studies suggest that the Arctic climate has undergone significant changes on interannual-to-decadal time scales. The changes have been noted in a range of climatic parameters including sea-level pressure, sea-ice thickness and extent, surface air temperatures, and hydrographic variables [Walsh et al. 1996; Morison et al. 1998; Parkinson et al. 1999; Rothrock et al. 1999; Rigor et al. 2000]. Assessments of these changes in the context of climate variability and change require careful analyses of past records and continuous improvement of model performance and data qualities. These are addressed needs in this project data assimilation to evaluate the extent to which sea ice motion and dynamics affect the ice mass balance, thereby controlling the hydrologic cycle and the energy balance of the region.

Accomplishments during the Reporting Period

A significant part of this year's activities was devoted to organizing a workshop on sea-ice data assimilation, for which the GEST investigator was also involved in editing the workshop report [Partington et al. 2002]. A study, which resulted from research done under this task, was reported on and consisted of three parts, addressing the questions of a mechanism for ice thickening, constitutive relationships, and modification of ice momentum balance.

Results of work this past year addressed the extent to which ice thickening occurs by way of ridge and keel formations and further modifies the ice mass balance. The results, based on merged ice motion data constructed from satellite and buoy observations, suggest that the spatial pattern of the frequency of uniaxial contraction events strongly resembles that of observed ice thickness over the Arctic Ocean. Moreover, the relevant time scales for this process seem to range from months to season. These results support a key assumption used in the standard sea-ice models based on actual observations and imply the importance of dynamical process to sea-ice mass balance.

A second component of the research concerned a sea-ice constitutive relationship that has long been

debated. The observations and results from model experiments are beginning to suggest the importance of two types of the yield curve (a key component of the plastic theory), with teardrop and sine lens shapes. Within this context, relevant questions are, how these constitutive relations are related physically, and what factors control the underlying physical processes. These questions were answered by extending earlier results [Ukita 2001]. In particular there are two processes that are likely involved in the ridge formation: pressure riding and shear ridging. A model has been developed to explicitly simulate how kinetic energy is dissipated in association with these two processes, and that the relative strength of these processes has physical control on the yield curve shapes. With this knowledge, a formulation of sea-ice models becomes more robust and consistent with various kinds of observations.

In the third study, the sea-ice momentum balance was examined, with particular emphasis on how internal ice stress arising from internal friction modifies the balance. The stress clearly changes the velocity profile, thereby affecting the way in which the ice-thickening mechanism operates. Prior to this work, this problem had not been explicitly solved, which had been a source of debate and controversy. This work has derived an exact solution, as a one-to-one relationship between internal stress and the velocity for fixed currents, winds, and thickness. Since the relationship is one-to-one, it can be inverted and, with this knowledge, errors and uncertainties can be estimated for velocity or ice thickness, while fixing others parameters.

The workshop also brought a new dimension to this research. One of the key questions being addressed during the meeting was if and how sea-ice variability is directly connected to other prominent modes of climate variability, a fundamental question pertinent to data assimilation strategies. Northern Hemisphere winter-to-winter sea-ice variability has a distinct model structure characterized by a set of two modes. One mode is spatially dominant and consists of synchronous seesaws, one over the North Atlantic and the other over the North Pacific. This mode is closely linked to the North Atlantic Oscillation, with an extended influence over the North Pacific. The other mode is nearly orthogonal in the temporal sense to the first mode, and nonlinearly related to ENSO phenomena. This set of modes explains a significant part of temporal and spatial variability in Northern Hemisphere wintertime sea-ice and further suggests a direct hemispheric-scale link between the variations in sea-ice and atmospheric circulation.

Objectives for the Coming Year

The main goal for the coming year is to present these results at upcoming meetings of the American Geophysical Union/European Geophysical Society and the American Meteorological Society Polar Meteorology and Oceanography, and the International Union of Geodesy and Geophysics general assembly, and to complete three manuscripts on the subjects of sea-ice deformation, the ice momentum balance and models, and Northern Hemisphere sea-ice variability. The results from these studies will be combined to formulate both forward and adjoint sea-ice models.

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

GEST Investigator: S. Daniel Jacob

Collaborator: Chester J. Koblinsky (PI, GSFC)

Abstract

The upper ocean salt budget and its sensitivity to mixing parameterizations are investigated using a primitive equation numerical ocean model in relevance to the Aquarius sea surface salinity mission. In particular, three mixing schemes and two monthly mean forcing climatologies are used to quantify sea surface salinity (SSS) variability in a near-global configuration. Systematic SSS differences exist throughout the model domain for

the two forcing data sets with strong variability in the Bay of Bengal region. SSS variability due to mixing is persistent in the equatorial regions with large variability in the Atlantic. Using remotely sensed precipitation data, the upper ocean salt budget variability during a hurricane in the Gulf of Mexico is examined. SSS response consists of a fresher wake with lowest SSS in the right rear of the storm, which is qualitatively similar to the SST response.

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, it has also been pointed out that small changes in these parameters will cause major changes in the terrestrial water budget. SSS is representative of the surface fresh water fluxes; the upcoming NASA 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, the main objective of this study is to understand and quantify various mechanisms controlling SSS in relation to surface fresh water fluxes over interannual time scales.

The second aspect of this study deals with fresh water forcing during extreme events such as hurricanes. Such forcing has not been considered in the past due to a lack of reliable data, although rain rates of up to 17 mm/hr have been estimated from remotely sensed data. With the availability of precipitation data from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), the upper ocean heat and salt content changes and the detectability of SSS variability from space are also being investigated.

Accomplishments during the Reporting Period

The Hybrid Coordinate Ocean Model (HYCOM) is being used in this research. With the ability to combine different coordinate systems and various mixing schemes in the upper ocean, this model is ideal for investigating science issues. This model has been configured in a near-global domain with a 2°x2° horizontal resolution at the equator and 26 layers/levels in the vertical. For the reporting period, about 10 simulations were made for different mixing schemes and forcing data sets. Resulting moisture fluxes from the ocean are quantified and the range of variability in SSS is estimated. Overall, a range of ±1 psu (practical salinity unit) is found between the cases and is five times higher than the estimated accuracy of the Aquarius SSS measurement. Differences in SSS for the mixing schemes are large in the equatorial Atlantic. However, larger differences due to forcing climatologies are found in the Bay of Bengal and Indian Ocean.

The upper ocean salinity response during the passage of a hurricane is also investigated using HYCOM with 0.07° resolution in the Gulf of Mexico. The precipitation climatology derived using TRMM data set for Category-3 to -5 Atlantic hurricanes indicates an average rain rate of 14.7 mm/hr in the front right quadrant. The model forced with this climatology and wind profile from Holland (1980) produced an SSS variability of up to 0.8 psu along the right side of the track. This varies with the mixing scheme used.

Objectives for the Coming Year

The modeling work will continue in the coming year and will be refined. At present, freshwater flow due to rivers is not included in these simulations that will be taken into account. High-resolution forcing fields from reanalysis data obtained from the European Center for Medium-range Weather Forecasts (ECMWF) and Global Precipitation Climatology Project (GPCP) climatologies will also be investigated for forcing the ocean model. The main focus will be to estimate global water budget with reference to SSS. A thorough analysis of upper ocean heat and salt budgets will be carried out by examining simulated mean ocean circulation.

Additionally, a parallel version of the model is being implemented in the Goddard Compaq SC45 at varying resolutions, to quantify the roles of advection and mixing with respect to surface fresh water fluxes. Specific future research includes examination of SSS variability and ocean circulation for five mixing schemes in a 0.72° fully global HYCOM and high-resolution forcing data sets; examination of three subdomains in the near-Equatorial Atlantic, Pacific, and Indian

oceans at 0.24° resolution, with boundary conditions provided from the coarse resolution global results; and quantifying the role of air-sea fluxes in the upper-ocean salt budget and SSS variability from the nested subdomain model fields, using conservation arguments and an approach that relates transports to air-sea fluxes.

The hurricane-forced ocean model will be modified to simulate real cases to examine heat and salt budget changes and their sensitivity to upper-ocean mixing parameterizations. Detailed comparison of simulated fields with *in situ* observations will be carried out to identify the best-performing mixing scheme.. This is particularly important because of the sensitivity of hurricane intensity to surface fluxes and the upper-ocean heat budget in coupled prediction models.

Task 971-26-149: **Numerical Experiments related to Decadal Oscillations in the North Atlantic: Development of a Physical-Biological Ocean Model**

GEST Investigator: Ken-ichi Mizoguchi

Collaborators: Watson Gregg (PI, GSFC), Sirpa Häkkinen (GSFC)

Abstract

Many observational and model studies indicate that there are 12-14 year oscillations in the North Atlantic. Model studiessuggested a potential link between the thermohaline circulation and these oscillations via changes in the strength of convective activity in the Labrador Sea. A simple numerical experiment was performed that demonstrates part of the decadal oscillations is generated in the Labrador Sea and imparted in the form of the second-mode Rossby waves to the entire North Atlantic domain. As a separate project, the implementation of a biological component in an already existing coupled ice-ocean model, which provides 3-D physical variables, was attempted to support a future study of the climatic effects of the carbon cycle in the North Atlantic Ocean.

Description of Research

Results from this work suggested that observed 12-14 year oscillations propagate anomalies across the entire North Atlantic domain. The intensity of the convection changes when decadal anomalies arrive at the Labrador Sea. A numerical experiment was conducted that demonstrated the decadal propagation of the anomalies exists in the North Atlantic. This experiment was prepared with an assumption that the decadal anomalies are generated in the Labrador Sea and propagated in the form of second-mode Rossby waves. The Modular Ocean Model (MOM) 3.1 system was used to carry out this experiment, where the domain extends from 20°S to 80°N and from 100°W to 20°E with a resolution of 1°×1° After 10-20 years of the model spin-up and using the annual mean atmospheric forcings over the North Atlantic Ocean, the profile of the vertical second normal mode in both temperature and salinity was imposed over the region of deep-water formation. It was expected that the second-mode waves, produced in the Labrador Sea, would propagate across the entire North Atlantic and eventually come back to the Labrador Sea.

The biological scheme is the same as that developed and implemented by Watson Gregg on the Poseidon ocean model. The current task projects and incorporates the scheme into the coupled ice-ocean model. The physical-biological coupling occurs in only one way, by feeding the physical variables into the biological model.

Accomplishments during the Reporting Period

At present, the spun-up model needs to be improved by including the second-mode profile in the Labrador Sea. Once this has been obtained, the propagation features in the North Atlantic may be observed.

At the present preliminary stage, the physical ocean model is driven by only the climatological atmospheric forcings including the irradiance, which primarily serves as the light source that

plays an important role for the biological productivity and growth. The coupled ice-ocean model is spun up for about 10 years from the initial Levitus climatology, so that the ocean can reach a quasi-equilibrium. The biological component is then spun up for 10 years after the spin-up of the physical model.

Objectives for the Coming Year

Biological cycles at decadal timescales will be investigated with an emphasis on their possible governance by decadal oscillations in the North Atlantic, which are linked with changes in the thermohaline circulation. Also, the impact of ice dynamics on biological systems in the high-latitude oceans will be investigated.

Task 971-32-161: **Air-Sea-Ice Interaction**

GEST Investigator: Yunhe Zhao

Collaborator: Antony K. Liu (PI, GSFC)

Abstract

Sea ice motion derived from satellite data provides a natural resource for deriving ice deformation, which is responsible for the opening and closing of leads and associated ridge formation and therefore influences the sea ice mass balance. Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave Imager (SSM/I), and QuikScat data are used to derive sea ice motion for 9 winter/fall periods. Principal component analysis (PCA) has been applied to both pressure field data and derived daily sea ice motion data in the Arctic for 13 winter/fall periods, respectively, to study the effects of wind and Arctic Oscillation (AO) on sea ice motion. The results confirm that wind forcing is a major factor driving sea ice motion, and of the first two modes of PCA of sea ice motion, the mode more correlated with that of pressure field is related to and consistent with the AO index. Nonlinear internal wave models have also been applied to integrate and assimilate both synthetic aperture radar (SAR) and mooring data. Using SAR data in deep water as an initial condition, numerical simulations produce the wave evolution on the continental shelf and compared reasonably well with the mooring measurements at the downstream station.

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 and QuikScat 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

Data from several instruments (SMMR, SSM/I, and QuikScat) were used to derive sea ice motion for nine winter/fall periods, using a wavelet transform-based ice-tracking procedure. PCA has been applied to both pressure field data and derived sea ice motion data in the Arctic for 13 winter/fall periods, respectively, to study the effects of wind and Arctic Oscillation on sea ice motion. The results show that at least one of the first two modes, from PCA, of sea ice motion data is highly correlated with either mode 1 or mode 2 of a PCA of pressure field data, which confirms that wind forcing is a major factor driving sea ice motion. Moreover, the first two modes of PCA of sea ice motion consist of one transpolar mode and one circulation mode; between them, the mode more correlated with that of pressure field is transpolar mode in high AO index years, and circulation mode in the low AO index years, with only one exception, that occurring in the 1995/1996 winter/fall period. However, the circulation mode in this winter/fall period is also highly correlated with mode 2 of the pressure field.

In recent Asian Seas International Acoustics Experiment (ASIAEX), extensive moorings were deployed around the continental shelf break area in the northeast part of the South China Sea in May 2001. Simultaneous RADARSAT SAR images were collected during the field test to integrate with the *in situ* measurements from moorings, shipboard sensors, and conductivity, temperature, and depth (CTD) casts. Environmental parameters were calculated based on extensive CTD casts data near the ASIAEX area. Nonlinear internal wave models were applied to integrate and assimilate both SAR and mooring data. Using SAR data in deep water as an initial condition, numerical simulations produce the wave evolution on the continental shelf and compared reasonably well with the mooring measurements at the downstream station. The shoaling, turning, and dissipation of large internal waves on the shelf break, elevation solitons, and wave-wave interaction were studied and found to be of high importance for acoustic propagation.

Objectives for the Coming Year

With the high resolution data from Advanced Microwave Scanning Radiometer for EOS (AMSR-E) 89-GHz scan becoming available, the ice tracking algorithm will be modified to use AMSR-E data to derive sea ice motion in the Arctic and then merge the ice tracking result with those from QuikScat and SSM/I data to obtain more complete coverage of sea ice motion in the Arctic. The advantage of AMSR-E 89-GHz data is its high-resolution of 6.25 km as compared with QuikScat of 25-km resolution. This combination will allow derivation of higher resolution sea ice motion in a local area with more detailed motion pattern. Sea ice motion derived from satellite data provides a natural resource for deriving ice deformation, which is responsible for opening and closing leads and associated ridge formation, and therefore influences sea ice mass balance. Development of the algorithm for deriving reliable sea ice deformation from sea ice motion data derived from QuikScat, SSM/I, AMSR-E, and buoy data will continue, and derived ice deformation will be analyzed. The study of how the changes in atmospheric circulation (*e.g.*, Arctic Oscillation) affect the patterns of sea ice motion and deformation will continue, using the sea ice motion and deformation data derived from QuikScat, SSM/I, and AMSR-E data.

Task 972-21-143: **New Developments in Advanced Oceanic Laser Biomonitoring**

GEST Investigator: Alexander Chekalyuk

Collaborators: John Gerlach (PI, GSFC/WFF), Frank Hoge (GSFC/WFF, Code 972)

Abstract

An advanced pump-and-probe (P&P) airborne laser technology has been recently developed at GSFC. Six airborne measurement campaigns were conducted in 1999-2002 in the Chesapeake Bay, Delaware Bay, the Middle Atlantic Bight, the Gulf of Mexico, and Pamlico Sound (NC). Data on P&P validation with shipboard techniques, observations of local to regional spatial variability in photosystem II (PSII) photochemical characteristics, coastal and offshore phytoplankton blooms, physical and biological interactions, and diel photosynthetic photoregulation are currently analyzed in the framework of this program. The P&P technology may be complimented by recent developments in assessments of phytoplankton pigments and taxonomic variability from laser-induced pigment fluorescence. A laboratory prototype of the laser phytoplankton analyzer (LPA) has been recently built and successfully tested with a representative set of phytoplankton cultures and on a research cruise in the Middle Atlantic Bight, Delaware Bay, and the Delaware River. The results indicate significant potential of the new technology for improved taxonomic and pigment analysis of phytoplankton.

Description of Research

This research program focuses on two major goals: continued research on developing superactive P&P lidar technique for airborne remote sensing of phytoplankton photosynthesis in the ocean and coastal areas, and ongoing research on new technologies for phytoplankton pigment

and taxonomic analysis. The research activities include theoretical analysis, laboratory studies, instrument development, and airborne 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 the coastal areas; and spatiotemporal gaps in satellite validation/calibration over meso- and synoptic-scales.

Accomplishments during the Reporting Period

An advanced P&P airborne laser technology was developed at GSFC. The P&P system provides remote measurement of important phytoplankton photosynthetic variables along with pigment and organic matter fluorescence, downwelling and upwelling hyperspectral measurements, and surface IR temperature. Using an airplane as an observing platform provides the potential for rapid remote characterization of phytoplankton photosynthetic activity, biomass, and diversity over large aquatic areas at synoptic space/time scales.

Six airborne measurement campaigns were conducted in 1999-2002 in the Chesapeake Bay, Delaware Bay, the Middle Atlantic Bight, the Gulf of Mexico, and the Pamlico Sound (NC). Data on P&P validation with shipboard techniques, observations of local to regional spatial variability in PSII photochemical characteristics, coastal and offshore phytoplankton blooms, physical and biological interactions, and diel photosynthetic photoregulation are currently analyzed. Pathways are being evaluated to improve assessment of pigment biomass and photosynthetic rate parameters based on airborne P&P laser measurements of biophysical and bio-optical characteristics. Validation data indicate generally good agreement between satellite and lidar assessments except in areas of high concentration of dissolved organic matter. In March 2002, first 2D P&P LIDAR mapping of phytoplankton photochemical characteristics was conducted in the Delaware Bay. Annual P&P lidar surveys continued in the Chesapeake Bay and Atlantic coastal regions of the Delmarva Peninsula to characterize the bioenvironmental situation in those areas.

The P&P technology may be complimented by recent developments in assessments of phytoplankton taxonomic variability from airborne lidar measurements. This research is primarily focused on multiwavelength laser excitation of chlorophyll, phycoerythrobilin concentration (PEB), phycourobilin concentration (PUB), and phycocyanin fluorescence to remotely implement a fluorescence excitation technique. A laboratory prototype of the laser phytoplankton analyzer (LPA) has been tested and optimized with a representative set of phytoplankton cultures and their mixtures. In November 2002, the LPA was used for pigment fluorescence analysis of natural phytoplankton over a range of environmental conditions on a research cruise in the Middle Atlantic Bight, Delaware Bay, and the Delaware River. The LPA was upgraded with a Global Positioning System (GPS) capability to relate measurements to spatial coordinates and time. Valuable information about pigment abundance, phytoplankton physiological status, and their photosynthetic potential and taxonomic diversity was acquired. Initial results indicate significant potential of the new LPA technology for improved taxonomic and pigment analysis of phytoplankton.

Objectives for the Coming Year

In the coming year, development of data processing algorithms and improved LIDAR sensitivity will continue, as will the evaluation of P&P lidar potential in coastal studies, environmental surveys, and satellite validation. Work will include participating in the spring 2003 airborne field lidar measurements in the Chesapeake Bay, Delaware Bay, and the Middle Atlantic Bight, and laboratory development and field tests of optical algorithms will continue for improved taxonomic and pigment analysis of phytoplankton. An advanced fluorometer for high-resolution 2D laser excitation-emission matrix analysis will be built and tested to provide improved phytoplankton characterization.

Task 972-37-169: Data Analysis and Algorithm Refinement for TOPEX/Poseidon and Jason Altimeter Range Sea-State Bias Range Correction

GEST Investigator: Hui Feng

Collaborators: D. Vandemark (PI, GSFC/WFF), J. Campbell (University of New Hampshire), P. McCormick (Hampton University)

Abstract

Refining current altimeter range bias correction algorithms is important for improving global ocean-surface topography measurements by ocean altimetry. Strategies to optimally correct range measurement bias—termed sea-state bias (SSB)—have been proposed and implementations are in progress.

Description of Research

Most current operational SSB correction algorithms are based on the two altimeter-derived variables, the surface wind speed (Sigma0), and the ocean surface significant wave height (SWH). The residual sea surface height $\Delta_{SSH,}$ after the most current operational SSB correction is applied, still remains within the level of about 1% of SWH. It has been shown that the remaining variations of Δ_{SSH} in the domain {SWH, Sigma0} are SWH-dependent. This suggests that the SSB affected by winds has been corrected, and also indicates that there is room to refine the current SSB correction algorithm. The objective of this task is to discern some “subtle” SSB signal, which is presumably unexplained by the current SSB correction algorithm. Research towards this objective includes two main components. The first involves an analysis of global wave model data (WAM) collocated with the TOPEX/Poseidon system (T/P) and the Jason crossover data to refine SSB model work in the sense of regional or seasonal the SSB correction algorithms. The second is to develop a global analysis of the T/P and the Jason-1 radar altimeter waveforms with a goal to retrieve a new SSB signal that is skewness-related, in addition to the first order SSB signal {SWH, Sigma0}.

Accomplishments during the Reporting Period

Observations and modeling techniques for the ocean altimeter SSB correction have been reviewed. Progress has been made towards the first component of the task via the production of a global dataset from a third-generation wave model (Wave Watch III) for the Jason period, covering the years 2000-2002.

Objectives for the Coming Year

In addition to completing the generation of global WAM, coming work will focus on altimeter waveform data analysis. Specifically, this task will include assessing different parameter estimators of sea state from altimeter waveforms. These models will be intercompared to quantify the difference between the estimated parameters. Ultimately, the objective is to determine if there is a promising parameter estimator for retrieval of another parameter (skewness) from the waveforms that serve to refine the SSB.

Task 974-03-070: **(a) Global Land Data Assimilation System Project; (b) North American Monsoon's Effect on Land Surface Predictability**

GEST Investigator: Kristi R. Arsenault

Collaborators: (a) Paul Houser (PI, GSFC), M. Rodell (GSFC), J. Gottschalck (UMBC/GEST), U. Jambor (UMBC/GEST), J. Meng (UMBC/GEST); (b) Paul Houser (PI, GSFC), J. Entin (GSFC/HQ)

Abstract

Progress has been made in several key areas in the development of the Global Land Data Assimilation Systems (GLDAS) project, including the addition of several new surface-forcing datasets, testing and implementing new land surface models (LSM), and evaluating assimilation techniques. The inclusion and testing of the Noah LSM into the Land Data Assimilation System (LDAS) projects are complete; it is now being fully incorporated and parallelized into the Land Information Systems (LIS) project. Retrospective investigations of the North American Monsoon's effects on land surface predictability have led to improved understanding of the response of land surface dynamics to atmospheric variability and subsequent interactions between the land surface and the atmosphere. In addition to the work described for the two funded projects, development of applications-based research involving LDAS has begun, and collaboration with other agencies and universities is being established.

Description of Research

For the GLDAS project, the main goals include developing a global, high-resolution, near-real-time modeling scheme that makes use of various new satellite- and ground-based observation systems within a land data assimilation framework to produce optimal output fields of land surface states and fluxes. Part of this work is to include several different land surface models to compare their performance with one another to find the best land surface representation. The work involving the North American Monsoon system is a focused research effort of the North American LDAS and GLDAS projects. The goals and objectives of this research are to investigate and improve our understanding of the role of surface hydrological variables in the prediction of the monsoon and its interplay with the atmosphere on different time and spatial scales.

Accomplishments during the Reporting Period

The GLDAS project is being developed to drive multiple land surface models (LSM) globally at 0.25° and lower spatial resolutions on a sub-hourly timestep. A vegetation-based "tiling" approach is used to simulate sub-grid scale variability, with a 1-km global vegetation dataset as its basis. GLDAS runs in near-real-time, using a combination of observation-based precipitation and downward radiation fields and the best available global coupled weather forecast model output from systems, such as NASA's Goddard Earth Observing System (GEOS), NOAA's Global Data Assimilation System (GDAS), and the European Center for Medium-range Weather Forecasts' (ECMWF) operational model. Major contributions made to the these projects in the past year included integrating the Noah LSM into the LDAS driver, developing the functionality of the quality-controlled Global Telecommunications Systems (GTS) *in situ* observations for GLDAS validation and implementation, and validation studies involving North American LDAS (NLDAS) and GLDAS simulations.

The predictability of the relationship between the land surface states and precipitation patterns over the continental U.S., associated with the North American monsoon system, is being investigated within the context of both NLDAS and GLDAS. Short-term (1996-current) retrospective LDAS simulations and a 50-year retrospective model run generated at the University of Washington [Maurer *et al.* 2002] were used for this study. Research from this past year has revealed that elevation plays the main role for the land surface role in developing monsoon-type storm activity over the southwestern U.S. The mountainous

terrain acts as more than simply a boundary between moisture flows from the Gulfs of Mexico and California. Topography, vegetation type, and soil type all play crucial roles in response to atmospheric variability and the distribution of surface and ground water, but can feed back into the atmosphere as a moisture supply, ranging from diurnal to monthly timescales.

Other work has been devoted to developing an area of applications research that includes many of the projects within the GSFC Hydrological Sciences Branch and outside collaborations with the U.S. Bureau of Reclamation, the Environmental Protection Agency (EPA), and the U.S. Geological Survey (USGS). These collaborative research efforts involve applying LDAS- and LIS-generated output to these other agencies' decision support systems (DSS), which are being developed and utilized for water resource management purposes.

Objectives for the Coming Year

This coming year's objectives for the LDAS projects include further developing key parameters in the Noah LSM and implementing the Physical Space Assimilation System (PSAS) code, for use in Noah. Additional experiments involving these modifications will be made and followed with several validation studies. The Catchment Land Surface Model [Koster *et al.* 2000] will be updated and tested thoroughly in the LDAS code and driver. The North American monsoon system research will include further quantification and statistical analyses of the different land surface parameters and variables in terms of their responses to (and influences on) the overlying atmosphere. In addition, a major validation study will be undertaken to evaluate different precipitation products over Mexico and the impacts on the land surface predictability. For the application research projects, validation studies will be performed for the Columbia River and Rio Grande River basins, regarding NLDAS forcing and output and *in situ* data used by the Bureau of Reclamation, to be used as benchmarks for future work. Other pilot studies will get underway with the USGS and EPA to begin validating and investigating the use of LDAS products and other remotely sensed measurements.

Task 902-09-103: **New Developments in Advanced Oceanic Laser Biomonitoring**

GEST Investigator: Deborah Belvedere

Collaborators: Paul Houser (PI, GSFC), C. Adam Schlosser (UMBC/GEST), and P. Morel (UMBC/GEST [retired])

Abstract

This GEST center activity 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 and NASA scientists, have been assembled. These task forces have worked to produce and to enable implementation plans that not only uphold NASA's Earth Science Enterprise (ESE) strategies, but also answer to the emergence of cross-cutting water-cycle research initiatives brought forth by interagency and government administrative science panels.

Description of Research

Considerable attention has been given to the importance of the global water 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 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 crosscutting 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 climate-change science generally.

Accomplishments during the Reporting Period

In the past year, a document presenting the scientific foundation and roadmap for a Water and Energy Research (WatER) initiative has been completed. The WatER initiative has been presented to the NASA Earth System Science and Applications Advisory Committee and is currently under consideration by NASA program managers and ESE administrators. It is hoped that the WatER document will serve as the basis for a new water-cycle implementation strategy. A Website has been constructed (http://watercycle.gsfc.nasa.gov) to enable efficient dissemination of scientific/planning documents, solicitation of scientific and management inputs (through a Web-based survey), description of NASA water-cycle science activities, and general information transfer to and from scientists, educators, students, and the general public.

Information, presentations, and materials pertaining to water cycle activities at GSFC are shared with the Public Affairs Office and scientists in the community-at-large.

Objectives for the Coming Year

In the coming year, the GEST/GSFC water-cycle support office will coordinate responses from the water and energy cycle survey, distributed to all Code 900 members. This is an important attempt to conclusively measure and assess all activities that pertain to water and energy research in the Earth Science Directorate. In addition, the final version of the WatER implementation document will be distributed to the wider scientific and management groups within NASA and other government research agencies. It is anticipated that the WatER document will serve as the basis for a new NASA Water-Cycle NASA Research Announcement (NRA) and long-term implementation strategy for NASA Headquarters (HQ) Science Division that would consist of a core project, science team members, and other NRAs that would solicit the contributions and collaborations of the community-at-large. Work will also continue to support relevant NASA HQ water-cycle program activities, potential core projects, and community-based scientific collaborations that emerge from the NASA-wide water cycle initiative. The planning and coordination efforts will work in tandem with the interagency CCSP and the USGCRP elements to advance water-cycle science and prediction.

Task 974-03-070: **(a) The Relationships between Soil Moisture and Climate Over Seasonal-to-Interannual Scales; (b) The Mechanism and Modeling of Boundary Layer Development over Boreal Forests**

GEST Investigator: Jiarui Dong

Collaborators: Paul Houser (PI, GSFC), Wenge Ni-Meister (UMBC/GEST)

Abstract

Two projects are addressed under this task. One is to support the NASA Seasonal-to-Interannual Prediction Project (NSIPP) by improving seasonal-to-interannual climate predictions by investigating the relations between root-zone soil moisture and climate over seasonal to interannual scales. The other task is to examine the effects of subgrid variability of snow cover in vegetated regions on land-atmosphere interactions.

Description of Research

Work performed under this task includes investigating the relations between root-zone soil moisture and climate over seasonal to interannual scales. In a second area of research, work includes validating the planetary boundary layer (PBL) model with the atmospheric sounding and tower flux data collected during the Boreal Ecosystem-Atmosphere Study (BOREAS) field campaigns; improving land surface parameterizations by

applying these data to the Variable Infiltration Capacity (VIC) macroscale hydrological model; and coupling the non-local PBL model with the VIC model to study the effect of land surface heterogeneity on PBL development and the cloud patterns in the PBL.

Accomplishments during the Reporting Period

In situ soil moisture, monthly near-surface climate, and global land cover map were used to investigate the causal relations between soil moisture and near-surface climate at seasonal to interannual scales and the influences on these relations from vegetation types. In addition, comparisons were performed among the Scanning Multichannel Microwave Radiometer (SMMR) surface soil moisture, the output of model simulation and data assimilation systems, and field measurements to detect the sources of discrepancies in remote sensing estimates and to assess the importance and limitations for data assimilation techniques. It was found that soil moisture and precipitation averaged over the entire growing season show consistent variations on an interannual scale, but the negative relationship between near-surface temperature and soil moisture is weak. Precipitation is therefore a dominant factor in soil moisture variation over interannual scales, and temperature effects are secondary.

Investigation of soil moisture persistence—soil moisture "memory"—at seasonal scales shows that a very strong correlation exists between soil moisture in spring and precipitation in summer in Russia; the correlation in Mongolia is weak, and no correlation exists in China. Preliminary studies on the mechanism of soil moisture memory suggest that snow accumulation and snowmelt and vegetation are critical for soil moisture memory bank build-up and release. The strong correlation of snow accumulation in winter with the soil moisture in spring indicates that snow accumulation is the source of soil moisture memory bank build-up. Forest-dominant sites show long persistence in memorizing spring soil moisture from deep layers with provides a strong capability to enhance summer precipitation. Grassland sites show weak and short memory, but their soil moisture shows strong consistency of interannual variation with climate over a growing season. If the model represents the physics correctly, incorporating the relationship between soil moisture memory will improve our predictions of seasonal-to-interannual climate.

Remote sensing estimates of surface soil moisture were compared with the *in situ* measurements in China, Mongolia, and Russia. There is close agreement in surface soil moisture between remote sensing retrievals and field measurements in China, but the SMMR retrievals in Russia and Mongolia were underestimated during the growing season. The biases were attributed to the difference in definitions of the surface soil layer. The utility of SMMR data in improving the retrievals of root zone soil moisture within data assimilation system was also investigated. Although there is a large difference in surface soil moisture between SMMR data and field observations in Russia, the root zone soil moistures from thepure catchment model and data assimilation match field measurements very well because the model treats the surface layer as being only 2 cm deep.. Although few SMMR measurements were available during the winter season, data assimilation techniques still improved the root zone soil moisture retrievals. These suggest that SMMR retrievals play significant roles in data assimilation systems, and data assimilation techniques are effective ways to retrieve root zone soil moisture. This work may contribute to NSIPP activities by helping to validate model prediction over relatively longer-term periods and provide more accurate initialization of land surface moisture.

In the second project, analyses of serial upper air sounding data and tower flux data measured during BOREAS field campaigns indicate that there is a linear relation between the boundary layer (BL) development and the sensible heat forcing above boreal forests. The regression slopes on the relationship between the BL development and surface fluxes respond to the influences by the surroundings. The transient turbulence theory (TTT) model was applied in simulating the diurnal BL development at Candle Lake and Thompson release sites over boreal forests. The importance of both initial patterns and surface fluxes were estimated in controlling the modeling processes. The lake effects were emphasized by constructing

surface fluxes at the Candle Lake release site. Comparison of the model results and field measurements of the BL profiles indicates that the TTT model performs better in simulating BL development above boreal forests for clear days, rainfall days, and cloudy days.

Objectives for the Coming Year

An advanced description of canopy architecture is required for ecological and climate modeling. The leaf area index (LAI) and foliage clumping index (FCI) can be retrieved from remote sensing estimates, but they are at a coarse spatial and temporal resolution. Work during the coming year will apply data assimilation techniques to LAI and FCI predictions to create daily LAI and FCI data sets for climate modeling studies. Other research will be performed to retrieve vegetation structure parameters and aboveground biomass from airborne lidar data and scale up to large areas by linking lidar and multiangular remote sensing data.

Task 974-03-070: **A Catchment-based Global River Routing Scheme for Climate Models and Assimilation of Streamflow and Altimetry Data**

GEST Investigator: Joseph L. Eastman

Collaborators: P. Houser (PI, GSFC), J.P. Walker (University of Melbourne), M. Rodell (GSFC)

Abstract

The cycling of water through the Earth system is a fundamental phenomenon that both drives and is driven by variations in climate at all temporal scales. Its proper representation in climate models is essential to understand how the global hydrological cycle interacts with the land, ocean, atmosphere, and ice components of the Earth system.

Description of Research

One of the goals of this project will be accomplished through coupling a River Transport Model (RTM) into the Land Data Assimilation System (LDAS).

Accomplishments during the Reporting Period

Since the inception of this work late in the reporting period, the LDAS model was successfully ported to a Windows™-based PC, and a new graphical user interface was created. A prototype of the RTM was installed and is now being tested. Earlier work with the University of Puerto Rico Mayaguez (UPRM) focused on the regional impacts of landuse and rising CO_2 on the local climate and the surface physics of land falling hurricanes.

Objectives for the Coming Year

Research plans for the next year include expanding the RTM code into all land surface models embedded in the LDAS and the global version of LDAS (GLDAS). The new modeling system will be validated, and sensitivity simulations will be performed to examine the effects of rivers on regional and global surface energy budgets. The work with UPRM will continue with month-long large eddy simulations (LES) using the Regional Atmospheric Modeling System (RAMS) synchronously coupled to the General Energy and Mass Transfer Model (GEMTM). The GEMTM simulates C_3 and C_4 photosynthesis and allows the biophysical characteristics of the biome to change and provide two-way interaction between the biosphere and atmosphere. Further objectives include using the RAMS and GEMTM models in conjunction with the RTM to investigate the effects of land use change and changing CO_2 levels on regional climate.

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

GEST Investigator: Jonathan Gottschalck

Collaborators: Paul Houser (PI, GSFC), M. Rodell (GSFC), U. Jambor (UMBC/GEST), J. Meng (UMBC/GEST), K. Arsenault (UMBC/GEST

Abstract

This aspect of GLDAS-related work focuses on two main areas: improvement of leaf area index (LAI) specification in land surface models (LSM), and using satellite-based precipitation forcing. Initially in GLDAS, important vegetation parameters such as LAI have been specified based on vegetation type through the use of lookup tables. These data are spatially invariant and are not globally representative. Satellite data, however, provide better sampling in both time and space, and can be used to specify more-realistic values of LAI across the globe at all times of the year. Using 1-km LAI datasets from both the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS), an improved specification of LAI has been included in GLDAS. Initial results show that the land surface states were substantially improved with the inclusion of the satellite-derived LAI. Satellite-based precipitation datasets from a number of sources have been included in GLDAS, and evaluation of their impact on land surface states is pending.

Description of Research

GLDAS specification of LAI has been based on lookup tables, and so is likely not representative of all areas around the planet. Precipitation forcing has been based on model-derived precipitation products. These two important components of GLDAS are a focus for GLDAS improvements. The goals of this research are to more realistically specify LAI and precipitation forcing in GLDAS by incorporating satellite-based products, thereby improving understanding of land surface states.

Accomplishments during the Reporting Period

In addition to the research described earlier, significant time over the past year has been spent in further developing the GLDAS. Some development accomplishments have been to include the latest version of the Community Land Model (CLM v2.0) into the GLDAS framework, revising and improving sections of the GLDAS code, initiating and maintaining the GLDAS Website (http://ldas.gsfc.nasa.gov), and extending the capability in GLDAS to use global observed satellite precipitation data to update the model precipitation fields.

Extensive work has been performed with satellite-derived LAI data from both AVHRR and MODIS [Myneni *et al.* 1997; Myneni *et al.* 2002]. To properly include the AVHRR data into GLDAS, it was necessary to downscale it to a 1-km resolution. The approach is to use a 1-km global vegetation type dataset derived from AVHRR data by the University of Maryland. The original LAI data has a spatial resolution of 16 km, so the 1-km vegetation-type data within the 16-km region of interest is used to estimate the sub-16-km pixel variability of the LAI. To do this, calculated means for all the vegetation types were used as a function of latitude and time of the year to infer how LAI for each vegetation type relate to each other. This information is used to derive 1-km LAI that can be both less than or greater than the initial 16-km LAI value. These global 1-km LAI datasets have been derived for a twenty-year record from 1982 to 2001. The AVHRR 1-km LAI data, after being adjusted for fractional vegetation cover and scaled to the resolution of the system, are used in GLDAS and are available for use by all LSMs.

MODIS LAI data is already at the 1-km resolution. Initial results show that the land surface states were substantially improved by including the satellite-derived LAI after simulations using CLM and Mosiac LSMs, both with and without the satellite LAI. Focusing on results from North America, the largest impacts on skin temperature and soil moisture occurred across large areas of the western United States and Mexico in shrubland

and grassland areas, where the greatest differences in LAI specification were present. The satellite LAI simulation produced greater skin temperature and soil moisture when studying the monthly mean of the last month of the four months of simulation. Furthermore, the AVHRR LAI runs showed much closer agreement to Geostationary Operational Environmental Satellite (GOES) skin temperature, with the greatest impact in the western areas of the United States, indicating improved land surface states and storages.

In the area of precipitation research, functionality has been added to GLDAS to use satellite-based precipitation products from NASA [Huffman *et al.* 2002], the Naval Research Laboratory [Turk *et al.* 2000], and the University of Arizona [Hsu *et al.*1997]. These products have spatial resolutions of 1/4° with temporal resolutions ranging from one to six hours. Preliminary simulations show one of the primary impacts on the land surface states is greater runoff for most areas. These improvements in both vegetation and precipitation datasets should provide more realistic land surface states when initializing weather and climate forecast models, one of the primary goals of the GLDAS project.

Objectives for the Coming Year

Goals for the upcoming year will be to continue to help in developing the GLDAS system by including and testing additional observed global precipitation datasets into GLDAS. Such datasets include the CPC (Climate Prediction Center) Merged Analysis of Precipitation (CMAP) being developed within the National Oceanic and Atmospheric Adminstration (NOAA) at the CPC. These developmental needs are very important to progress in the GLDAS project. In addition, further investigations will take place into the impacts of AVHRR and MODIS 1-km LAI on GLDAS. Also to be explored during the next year is the inclusion of experimental albedo data from MODIS into GLDAS, and to identify its impacts on the system.

Task 974-03-070: **Global Land Data Assimilation**

GEST Investigator: Urszula Jambor

Collaborators: Paul Houser (PI, GSFC), M. Rodell (GSFC), J. Meng (UMBC/GEST), K. Arsenault (UMBC/GEST), J. Gottschalck (UMBC/GEST)

Abstract

The goal of the Global Land Data Assimilation System (GLDAS) project is to develop a global, high-resolution, near-real-time modeling scheme that makes use of various satellite- and ground-based observation systems within a land-data assimilation framework to produce optimal output fields of land-surface states and fluxes. The GLDAS framework is consistently being upgraded and expanded to accommodate more forcing data and land surface model options. Practical issues involving the maintenance of operational model simulations, the data archive, and the software itself continue to be addressed. Additionally, off-line experiments are being performed to evaluate and attain the objectives of the GLDAS project.

Description of Research

Observation and understanding atmospheric and land surface processes have been improving steadily over the past two decades, largely due to advances in satellite remote sensing and increased computing capabilities. Relying on atmospheric and land surface models (LSMs) to fill in observational gaps and incorporating observations into LSMs as forcings and constraints helps maximize our knowledge of the processes and resulting states of the Earth system. One goal of the GLDAS project is to develop a global, high-resolution, near-real-time modeling scheme that makes use of satellite- and ground-based observation systems within a land-data assimilation framework to produce optimal output fields of land-surface states and fluxes. GLDAS will improve land-surface, weather, and climate predictions by providing global fields of land-

surface energy and moisture stores for initialization. These global fields will be useful for other applications, including investigations of land-surface management issues and analysis of the relationship between model predictions and observations at various spatial and temporal scales.

Accomplishments during the Reporting Period

During the past year progress was made in the collaboration with NASA Seasonal-to-Interannual Prediction Project (NSIPP) scientists. The GLDAS framework was adapted to accommodate a land surface characterization used in the NSIPP climate modeling system. A 15-year retrospective run of the Mosaic LSM was completed, using bias-corrected reanalysis European Center for Medium-range Weather Forecasts (ECMWF) output merged with observed radiation and precipitation data as forcing. Results from this GLDAS simulation were used to improve land surface initial conditions in a study of side-by-side ensembles of seasonal forecasts performed by NSIPP researchers. The purpose of this ongoing work is to quantify the impact of realistic land surface initial conditions on such forecasts.

Another retrospective study examined the results of using observation-derived data to force a Mosaic LSM simulation. Due to a paucity of recent land surface state observations over large domains, the GLDAS simulation was evaluated against finer-resolution North American LDAS (NLDAS) results over the continental United States. The underlying assumption was that the independently forced NLDAS simulation better represented the true atmospheric and land surface states. By focusing on a region that is heavily observed and modeled, the importance of differences between the two simulations was easier to assess. In general, the use of global satellite-based forcing data yielded patterns and value ranges with scales similar to the NLDAS results. Differences in precipitation amounts between the two runs notably impacted the model outputs and indicated the need for a better-constrained precipitation product.

The day-to-day operations of GLDAS remain a significant task requiring daily data archiving, operational GLDAS runs, and software maintenance. As planned, the addition of ECMWF model output as a forcing option within GLDAS was made. Adjustments to the GLDAS software accommodated input data upgrades incorporating changes to the U.S. Air Force Weather Agency Agricultural Meteorology Model (AGRMET) model, the NASA Data Assimilation Office (DAO) Goddard Earth Observing System (GEOS)-Data Assimilation System (DAS) model, and the National Centers for Environmental Prediction (NCEP) Global DAS model. The objective of sustaining GLDAS over several computer system platforms was also tended to.

Objectives for the Coming Year

Work plans for the upcoming year include studies to evaluate and refine the GLDAS system. Currently, the GLDAS framework supports several satellite-based precipitation products. A systematic assessment of these data is planned to improve the incorporation of observed precipitation estimates within GLDAS simulations. Ongoing collaboration with NSIPP scientists includes studying the impacts of GLDAS-based land surface initializations on seasonal forecasts through additional retrospective model runs. Plans have been made to participate in the second Global Soil Wetness Project (GSWP2) by contributing results from GLDAS simulations with the Mosaic LSM and the Community Land Model (CLM). In addition, the data archives and software associated with GLDAS will continue to be tested, maintained, and improved.

Task 970-44-184: **Land Information Systems**

GEST Investigator: Sujay V. Kumar

Collaborators: Paul Houser (PI, GSFC), C. Peters Liddard (PI,GSFC)

Abstract

The research being done under this task involves implementing a Land Data Assimilation System (LDAS) globally at very high resolution. The proposed Land Information System (LIS) will have a high-resolution Global Land Data Assimilation System (GLDAS), involving several independent community land models and a Web-based user interface that accesses data mining, numerical modeling, and visualization tools.

Description of Research

The land surface and the 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 to improve models of the boundary layer and land-atmosphere coupling at all spatial and temporal scales and over heterogeneous domains. Long-term descriptions of land use and fluxes also enable accurate assessments of climate characteristics. In addition to the impact on climate modeling, land surface processes also affect the environment for growth of natural vegetation and provision of water resources. The importance of accurate land surface modeling has motivated the development of a LDAS that enables the integration of remotely sensed and model-derived data in a data assimilation framework. The LDAS system has been successful in modeling land surface processes in both real-time and at high resolution for North America. However, to accurately predict land surface initialization and climate prediction problems, the LDAS system must be implemented globally at high resolution and at near-real-time. The increased resolution of the global modeling scale of the proposed LIS significantly increases the computational requirements. As a result, this problem can be termed as a grand challenge problem.

Parallel computing has emerged as the enabling technology that help the modern computers satisfy the increasing high performance computing requirements. Building such a system that takes advantage of scalable parallel computing technologies has been proposed to facilitate global land surface modeling in a reasonable amount of time. Land surface processes have rather weak horizontal coupling on short time and large space scales, enabling highly efficient scaling across massively parallel computing platforms. The high data densities could pose limitations on the land surface modeling efficiencies, and the LIS system will explore the use of high performance technologies to eliminate this bottleneck.

In addition to the huge computational requirements, the land surface modeling process must also manipulate large amounts of data. Implementation of the LIS system in a parallel environment with a software system that uses a distributed-memory programming model could prove to be a performance bottleneck since input/output (I/O) processes could generate significant network traffic that would interfere with scaling the application. The LIS system will require daily input of approximately 280 gigabytes, and will produce 200 gigabytes of gridded output. It is clear that I/O will be a bottleneck for this system unless some type of parallel I/O method is used.

Accomplishments during the Reporting Period

LIS is one of the Round III Computational Technologies Grand Challenge projects. The project has a number of predefined milestones to be achieved at different periods during the project. The project kickoff meeting was held on March 4, 2002 at the Center For Ocean-Land-Atmosphere Studies (COLA). The meeting identified the major components of LIS. First, the heart of LIS is the LDAS land surface modeling component. The first milestone we had to achieve was to develop a software engineering plan that outlines the software development effort, which was approved in June 2002. The next milestone required

baselining a number of land surface models using LDAS on the Earth System Sciences Testbed (SGI Origin systems at NASA's Ames Research Center). The testing and validation was also conducted on various platforms at Goddard. The source code was fully documented, output datasets were provided for validation, and they were made publicly available through the Web. The baselining also included profiling the code to identify time-consuming routines in LDAS. This milestone was approved in July 2002. The second part of this milestone required the specification of a requirements document that was collected from the land surface modeling community. A software design document that provides an extensive design of various components of the system was also designed. These documents were submitted to the computational technology team at Goddard and were also approved in July 2002. During August 2002 a 200-node cluster was also constructed.

After a busy summer of meeting milestones, the next phase of the project was devoted to achieving code improvements. One of the important goals of the project is to be able to interact with other Earth system models and to be able to exchange data and information. The Earth System Modeling Framework (ESMF) is a big effort in this direction. LIS has been identified as one of the key users of ESMF.

One of the major goals of LIS is to apply the principles of software engineering to scientific programming. Object oriented programming principles were applied to LIS to convert it into a framework, which facilitates software reuse and ease of future development. The design also enables users of the system to exploit the underlying software and hardware infrastructure without the cost of developing applications from scratch. Parallel computing tools were also built into LIS during this period.

Objectives for the Coming Year

Research goals for the coming year include specifying an interoperability design for LIS, which will outline plans for interoperating with Earth system and other scientific communities. LIS will also demonstrate land surface model runs at 5-km resolution using high-performance scalable computing tools. LIS currently includes Noah and Community Land Model (CLM) land surface models. It also includes a number of ESMF utilities. In the coming year, the Variable Infiltration Capacity (VIC) land surface model and a number of ESMF interfaces and utilities will be built into the framework.

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

GEST Investigator: Jesse Meng

Collaborators: Paul Houser (PI, GSFC), M. Rodell (GSFC), U. Jambor (UMBC/GEST), J. Gottschalk (UMBC/GEST), K. Arsenault (UMBC/GEST)

Abstract

A Global Land Data Assimilation System (GLDAS) has been developed that makes use of various new satellite- and ground-based observation systems within a land surface modeling and data assimilation framework, in order to produce optimal output fields of land surface states and water and energy fluxes. Initiated in late 2000, GLDAS reached an important milestone at the beginning of 2002: the system has been successfully built with its hardware and software requirements fulfilled. GLDAS is now running daily in an operational mode. It has many user options to initialize various land surface conditions to use multiple choices of land surface models, and to be forced by various meteorological model outputs and observations. In 2002, various GLDAS experiments were produced by the GLDAS team to test and evaluate the impact of different options, including background atmospheric conditions, initial land conditions, radiation and precipitation forcing, and vegetation dynamics.

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 storage 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 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 during the Reporting Period

The primary research task for the past year was to monitor and evaluate the global land surface radiation budget from various products, and to study the impact of radiation on global land surface water and energy cycles. The observation-based radiation product from the Air Force Weather Agency (AFWA) Agricultural Meteorology (AGRMET) modeling system, using the AFWA Real-time Nephanalysis (RTNEPH) global cloud analysis derived from the Defense Meteorological Satellite Program (DMSP) and National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellite observations, and the general circulation model (GCM)-based radiation products from the NASA Data Assimilation Office (DAO) and NOAA National Centers for Climate Predictions (NCEP), were evaluated. The intercomparison between these products and validation against ground observations were made on various spatial and temporal scales. To study the sensitivity of land surface processes to surface radiation, a GLDAS experiment was performed, using altered radiation forcing. Significantly, surface temperature was shown to have a quick response (on a daily time scale) to altered radiation, and soil moisture has a slow response (on a monthly time scale) to altered radiation. This result demonstrated that GLDAS is capable of identifying and quantifying such land surface responses.

In June 2002 a new generation of global cloud analysis was published by AFWA to replace RTNEPH. In addition to polar-orbiting satellites, the new World-Wide Merged Cloud Analysis (WWMCA) adds information from the Geostationary Operational Environmental Satellite (GOES), the Geostationary Meteorological Satellite (GMS), and METEOSAT satellites to pursue higher spatial and temporal resolution. The new product has been implemented in GLDAS to generate a 24-km global, one-hourly, land surface shortwave and longwave radiation budget in near-real-time.

Objectives for the Coming Year

In addition to continuing current operations, several tasks are planned for the upcoming year. To enhance the NASA/NOAA collaboration on the GLDAS project, a parallel GLDAS system is under development at NCEP. This parallel system will allow scientists at NCEP to perform extensive GLDAS experiments and to improve their knowledge of global water and energy cycles at various time scales from daily to seasonally and annually, thereby contributing to the future development of weather and climate prediction models. Pending funding, an algorithm will be developed to retrieve surface longwave radiation budget from GOES, to investigate algorithms to retrieve land surface skin temperature from satellites, and to implement the product within the GLDAS framework.

Task 974-03-070: **(a) Optimal Land Initialization for Seasonal Climate Prediction; (b) The Effect of Subgrid Variability of Snow Cover in Vegetated Regions on Land-Atmosphere Interactions**

GEST Investigator: Wenge Ni-Meister

Collaborators: Paul Houser (PI, GSFC) Randy Koster (GSFC), Rolf Reichle (UMBC/GEST), Jeff Walker (University of Melbourne, Australia) and Jiarui Dong (UMBC/GEST)

Abstract

The one-dimensional Ensemble Kalman Filter (EnKF) has been developed and implemented in the NASA Seasonal-to-Interannual Prediction Project's (NSIPP) catchment-based land surface model (LSM) [Reichle *et al*. 2001]. During the last year, a major accomplishment was to evaluate model errors and observational errors by comparing the modeled soil moisture and remotely sensed soil moisture from the Scanning Multichannel Microwave Radiometer (SMMR) with *in situ* measurements in Eurasia. The data assimilation algorithm was also evaluated. How land surface heterogeneity influences boundary layer development was investigated in boreal forests, where snow exists for half of the year.

Description of Research

Subsurface moisture and temperature stores exhibit persistence on seasonal-to-interannual time scales; together with external forcing and internal land surface dynamics, this persistence has important implications for the extended prediction of climatic and hydrologic extremes. Accurate initialization of land surface moisture and energy stores in fully coupled climate system models is critical for seasonal-to-interannual climatological and hydrological prediction Thus, to improve the initialization of land surface states, a central research activity within NSIPP is to constrain the NSIPP land model with remotely sensed soil moisture measurements and other land surface variables using a Kalman filter-based data assimilation strategy.

The second subtask addressed general circulation model (GCM) sub-grid variability of snow cover, which has a significant impact on land-atmosphere interactions due to the high albedo, low thermal conductivity, and melting processes of snow. In highly vegetated mid- and high-latitude regions, where the snow is often found below and between plant canopies, land surface heterogeneity is even more complex, and it is difficult to predict its influence on the atmosphere. A better land surface parameterization scheme to account for sub-grid variability in vegetated regions is necessary to study land-atmosphere interactions in regional and global climate and weather prediction models.

One goal of the project is to develop a hybrid modelto characterize GCM sub-grid variability of snow cover in vegetated regions . Another goal is to develop an improved coupled land-atmosphere model for snow-covered and vegetated regions to study the interrelationships and feedbacks among clouds, precipitation, and boundary layer and land surface processes. The hybrid scheme is developed by incorporating the well-developed Geometric Optical Radiative Transfer (GORT) canopy radiation model to characterize the variations of radiation regime at forest stand or smaller scales, into the Variable Infiltration Capacity (VIC) macro-scale process-based land surface model. This hybrid scheme will be coupled with a non-local PBL model. This coupled land-atmosphere model will be used to study the influences of snow cover heterogeneity in vegetated regions on land surface hydrological processes, surface energy and water balances, and atmospheric dynamics, such as turbulent boundary layer development and cloud and precipitation patterns.

Accomplishments during the Reporting Period

For the first subtask, the one-dimensional EnKF has been developed and implemented in the NASA Seasonal-to-Interannual Prediction Project's (NSIPP) catchment-based LSM [Reichle *et al.* 2001]. During the last year, a major accomplishment was to evaluate model errors and

observational errors by comparing the modeled soil moisture and the Scanning Multichannel Microwave Radiometer (SMMR) data with *in situ* long-period measurements of soil moisture in Eurasia. The data assimilation algorithm was also evaluated at the continental scale .

In the second subtask, during the last year the turbulent boundary layer was evaluated using the data collected in boreal forest in Central Canada. An algorithm was also developed to study the effect of heterogeneous conifer forests on snowmelt in boreal forest, and implementing the algorithm in a land surface processes model.

Objectives for the Coming Year

Work in the coming year for the first subtask will continue exploring the optimal initialization approaches of the land system in NSIPP.The soil moisture data derived from SMMR will be rescaled so that they are within the same range as modeled soil moisture values. One option is to assimilate the soil moisture index; the other option is to rescale SMMR-derived soil moisture so that the mean SMMR value will be the same as the modeled mean soil moisture values. Another possibility is to explore some other innovative approach, such as assimilating the soil moisture difference. The goal is to pursue the best operational approach to assimilate SMMR data into the catchment-based LSM for to best initialize soil moisture in NSIPP seasonal climate models. In the second subtask, the algorithm to study the effects of the land surface heterogeneity on the estimates of surface energy and water balance and surface hydrology parameters over boreal forest will be finished . It will be coupled with a turbulent boundary layer model to study the effect of land surface heterogeneity on boundary layer development over different seasons.

Task 974-03-070: **Assimilation of Remotely Sensed Snow Observations into the NSIPP Land Surface Model**

GEST Investigator: Chaojiao Sun

Collaborators: Paul Houser (PI, GSFC), J. Walker (University of Melbourne), J. Foster (GSFC), M. Stieglitz (Columbia University), R. Koster (GSFC)

Abstract

A sequential data assimilation scheme has been developed to assimilate remotely sensed snow water equivalent into the catchment-based land surface model (LSM) used by the NASA Seasonal-to-Interannual Prediction Project (NSIPP). This scheme successfully recovers the true snow states over North America in the context of identical twin experiments. Preliminary results show that assimilation of remotely sensed snow observation from the Scanning Multichannel Microwave Radiometer (SMMR) improves the model prediction of snowfields. The work of quantifying uncertainty in passive microwave snow water equivalent observations is currently underway.

Description of Research

The primary aim of this research is to develop a framework to assimilate remotely sensed snow observation products into the NSIPP LSM. The specific objectives are to develop a Kalman filter-based snow assimilation strategy; to investigate the utility of novel snow observation products, such as snow melt signature and fractional snow cover; to provide a basis for global implementation of an assimilation scheme for snow observations, both for near-real-time forecasting and to accurately initialize seasonal-to-interannual predictions in the NSIPP fully coupled GCM; and to quantify the error statistics of passive microwave snow data from satellites and to provide observational statistics for data assimilation schemes.

Accomplishments during the Reporting Period

It is important to accurately forecast snow cover and its mass in climate and numerical weather prediction models, because snow cover impacts heat flux between the land and atmosphere. However, it is difficult to forecast snow accurately because of its sub-grid scale variability and

forcing errors from models. Data assimilation methods seek to combine imperfect observations with imperfect model simulations in an optimal way to provide a best analysis of these phenomena. Remotely sensed observations provide a consistent picture of the snow cover and snow depth, but vegetation cover and other factors cause errors in measurement; boreal forest cover particularly causes the passive microwave radiometer to consistently underestimate snow depth. To produce optimal estimates of snow cover, the statistics of the observation error and model error must be known. With knowledge of these errors, data assimilation techniques can be used to generate more accurate initial conditions for global climate models (GCM) than what is obtained from a LSM snow initialization based on model spin-up.

An Extended Kalman Filter (EKF) was used to sequentially update model states and model error covariances. Identical twin experiments were conducted in which both true states (the natural state) and observations were generated by the model. Under these conditions, the statistics of observational errors and model forecast errors are known. In reality, these error statistics are hard to quantify. In twin experiments the assimilation scheme can be tested and verified before it is applied to the real world.

To mimic the remotely sensed snow products, snow water equivalent (SWE) of the snow pack was chosen as the synthetic observation in the twin experiments. SWE is highly desirable as compared to snow extent because snow mass is very important in albedo calculations and for water balance considerations. However, snow state is not fully described by the SWE alone, since it does not have information on density and temperature of the snow pack. The strategy is to update the SWE variables for each layer using the Kalman filter, and to update other state variables by using updated SWEs and model-predicted density and temperature.

The focus of these studies was a retrospective study of snow cover in North America over the past twenty years. Remotely sensed snow water equivalent (SWE) from passive microwave radiometers on satellites will be assimilated. North America was chosen because high-quality ground-based and airborne data are available that are spatially and temporally extensive; . In particular, data from SMMR (from 1979 to 1987) and the Special Sensor Microwave/Imager (SSM/I) (1987 to present) will be assimilated. The forcing data come from the European Center for Medium-range Weather Forecasts (ECMWF), which are further processed to remove precipitation bias.

This scheme is robust and effective in recovering the true states from erroneous initial conditions. It can be easily applied to a global analysis. Preliminary results from assimilating SMMR data show that the assimilation improves model prediction of snow states. In the future, multivariate assimilation will be implemented to include other types of observations, such as snow depth and snow cover, obtained from instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E)..

Objectives for the Coming Year

Work in the coming year will focus on applying the newly developed assimilation scheme to assimilating remotely sensed real snow observations, particularly SWE and snow cover observations measured by passive microwave radiometers from SMMR and SSM/I. Work will continue on validating error estimates in passive microwave snow observations. In addition, pending funding, an assimilation scheme for the Common Land Model (CLM) will be developed to enable the Data Assimilation Office (DAO) forecast system to assimilate real-time snow observations from SSM/I and AMSR-E, and to enable the land modeling community to use the scheme to assimilate snow in their studies. The challenging problem of temperature bias correction through assimilation of snow observations will be tackled, and the effect of bias correction will be evaluated. The usefulness of novel snow observation products, such as snowmelt signature and fractional snow cover, will be investigated. The potential of assimilating different types of snow observations simultaneously will be studied.

Task 974-44-184: **Land Information System: Building a Beowulf Cluster**

GEST Investigator: Yudong Tian

Collaborators: Paul Houser (PI, GSFC), C. Peters-Lidard (Co-PI, GSFC)

Abstract

The Land Information System (LIS) is an effort to develop a cutting-edge land surface simulation and data assimilation system with a spatial resolution up to 1 km on a global scale. The engine that provides the required high-performance computing power is a Beowulf cluster. The cluster was designed, constructed, and tested successfully during the past year and is now actively serving further development of the LIS.

Description of Research

The LIS project, sponsored by NASA's Earth Science Technology Office (ESTO) Computational Technologies (CT), is an ambitious effort to develop a leading-edge land surface modeling and data assimilation system (DAS), to support broad land surface research and application activities, to help define Earth system modeling interoperability standards, and to lead the effective application of Internet technology and cost-effective parallel processing to high-resolution, real-time Earth system studies.

Accomplishments during the Reporting Period

In the first year of the LIS project, all four planned milestones have been reached, including completing the software engineering plan, baselining the Global Land Data Assimilation System (GLDAS) code, installing a 200-node Beowulf cluster at NASA, and submitting the FY 02 annual report.

The critical infrastructure for the high-performance computing of LIS is a 200-node Beowulf cluster. Requirements analysis was performed, as were system, network, storage and security design, hardware procurement, node assembly, and final construction of the cluster. Several challenges were overcome in the process, such as hardware debugging, power density, and temperature control. The software environment for the cluster was also established, tested, and tuned. A series of performance benchmark tests was carried out, which demonstrated that the design goal was amply achieved. The cluster is now fully operational, and is playing a critical role in the further development of the LIS.

An effective software package, C-RPM], was developed to monitor, in real-time, the status and hardware health of the cluster nodes via a Web browser. Compared with other third-party systems we have tested, this system has a cleaner, easier-to-understand graphical user interface and imposes much less overhead to the cluster.

Objectives for the Coming Year

More challenges will be addressed in the coming year. For example, it must be demonstrated that the performance of the improved LIS software meets the milestone requirements. Also, as the spatial resolution of the LIS is getting higher and higher, the data volume is increasing explosively, and innovative approaches to handle the huge end-to-end data flow are being investigated. In addition, the parallel computing and data throughput on the LIS Beowulf cluster will undergo more tests, and further development will be performed on the cluster to set the stage for the eventual 1-km-resolution runs.

Task 970-44-183: **Quantifying the Relation between Remotely-Sensed and Modeled Soil Moisture [NASA Research Grant NAG5-8658**

GEST Investigator: Yihua Wu

Collaborators: C. D. Peters-Lidard (PI, GSFC), D.R. Webster (GTRC), Feifei Pan (GTRC), Paul Houser (GSFC), P.E. O'Neill (GSFC), Ann Hsu (GSFC), Mike Tischler (SSAI)

Abstract

Accurately assessing the spatiotemporal variation of soil moisture is essential for addressing many questions pertaining to land-atmospheric interactions. Soil moisture is a basic link between the water and energy budgets of land surfaces through its regulation of the partitioning of latent and sensible heat fluxes, its proportioning of rainfall into infiltration and runoff, its primary control on vegetation development via photosynthesis, and its impacts on gaseous exchanges between the atmosphere and biosphere by regulating the leave stomata opening. Attempts to routinely estimate soil moisture over regional areas using only one source of information (*e.g.*, point measurements, remote sensing, or modeling) have been relatively unsuccessful. Recent work has shown that remote sensing combined with water and energy balance modeling in a four-dimensional data assimilation (4DDA) framework provides superior estimates of distributed soil moisture. However, there are still significant differences between the model predictions and remotely sensed observations of soil moisture that must be fully characterized to allow their successful integration.

Description of Research

The primary objective of this project is to assess, understand, and predict the relationship between remotely sensed and modeled soil moisture, a necessary prerequisite to successfully integrating remotely sensed soil moisture observations with models of the land surface water and energy balance, including Soil-Vegetation-Atmosphere Transfer Schemes (SVATS). This will be done through a rigorous intercomparison of soil moisture predictions made by several fundamentally different SVATS models and remotely sensed passive microwave soil moisture observations at several different scales, climates, and seasonal regimes. The SVATS models represent a hierarchy of complexity in the representation of spatial heterogeneity. Several of these models will be used to make soil moisture predictions at spatial resolutions compatible to microwave soil moisture remote-sensing observations available at the Walnut Gulch Watershed in Arizona, the Little Washita Watershed in Oklahoma, and the Southern Great Plains (SGP) 1997 experiment. The relationships between modeled and observed soil moisture at different scales and climates using different SVATS will be examined using summary statistics, correlation analysis, spatial covariance modeling, and SVATS structural analysis to understand mechanisms that may aid in the prediction of these relationships. It is expected that the proposed strategies will contribute to NASA's Earth Science Enterprise (ESE) science goals by improving our understanding and ability to observe and predict soil moisture, by improving modeled land surface dynamics and spatial heterogeneity, and by ameliorating the land surface data assimilation effort.

Accomplishments during the Reporting Period

The National Centers for Environmental Prediction (NCEP) Oregon State University, Air Force, and Hydrologic Research Lab (NOAH) driver was modified for the full two-dimensional version of NOAH over the SGP97 and Monsoon90 test regions. Several runs for each test region were conducted. Model outputs and Pushbroom Microwave Radiometer (PBMR) data were analyzed, and a time series of rainfall, modeled soil moisture for the same area of PBMR data, and measured soil were also analyzed. Several statistical parameters were computed for comparisons between model outputs and observations. Generally, the model overestimated soil moisture, shown by the positive bias between the modeled and PBMR soil moisture and larger variance of model outputs. The variance of model

outputs is larger than those for PBMR and for observations from the eight flux sites. The SVAT model has a positive (wet) bias, which persists throughout both the SGP97 and the Monsoon90 period. Causes for this bias are likely due to underestimation of several parameters. The model works better in wet periods than in dry periods. Precipitation is the most important input in the model simulation. The distribution patterns of the modeled soil moisture on the six days in the 15 runs are very similar to the distribution patterns of the accumulated rainfall in previous hours. The time series of rainfall, modeled, and observed soil moisture show that both modeled and observed soil moisture increase during raining period and decrease in dry periods. Soil parameters (*e.g.*, saturated hydraulic conductivity, porosity) and plant-related parameters (*e.g.*, vegetation type, leaf area index (LAI), and minimum stomatal resistance) are important for model simulations, as shown by the comparisons of variances, bias, skewness, and kurtosis parameters among all runs. The higher the resolutions of these parameters, the better the model simulations. In all runs, the run with the best parameter images available yields the best results. Performing soil moisture difference analysis by taking differences between subsequent days of modeled and measured soil moisture allows assessment of the accuracy of soil hydraulic parameters, precipitation input, and land cover parameters.

In the second research, the 1D NOAH model was coupled with the multi-layer biochemical (MLBC) dry deposition model developed by the GEST investigator in the U.S. Environmental Protection Agency (EPA). Two numerical experiments were conducted. In experiment one, CO_2, O_3, SO_2, and H_2O (latent heat) fluxes were simulated under wet, dry, and optimal soil moisture conditions. In experiment two, these fluxes were simulated with the same soil moisture content for 8 soil types. Analysis shows that soil moisture and soil types have the mostly impact on the amplitudes of seasonal and diurnal variations of the exchange flux of each gas species, but little effect on phases of the model-simulated seasonal and diurnal cycles of the exchange flux of each gas species. The effects of soil moisture and soil types on the amplitudes of the model-simulated seasonal and diurnal cycles are larger during summer and noontime. These results were presented at the 83rd American Meteorological Society (AMS) meeting on February 10 at Long Beach, California.

Objectives for the Coming Year

Future activities include modifying the driver program for the NOAH model; running the NOAH model over Monsoon90 and Washita92 experiments; running the NOAH model with features of several SVATS over Monsoon90, Washita92, and SGP97 data; further validating modeled soil moisture against observations; and investigating vegetation type effects.

Task 974-03-070: **Global Validation of EOS Aqua Land Surface Dynamics Using Data Assimilation**

GEST Investigator: Xiwu Zhan

Collaborators: P. Houser (PI, GSFC), P. O'Neill (GSFC)

Abstract

Work on the Aqua Land Product Validation project during the last year included implementing an Extended Kalman Filter (EKF) data assimilation scheme in the Land Data Assimilation System (LDAS); completing a series of numerical experiments with the EKF-LDAS to examine the feasibility and benefits of EKF assimilation of soil moisture data sets; performing a study on improving plant canopy photosynthesis parameterization for carbon cycle models; participating in the Soil Moisture Experiments (SMEX02) international field experiment on soil moisture observations in Ames, Iowa; and assisting in field observations for the Optimizing Production Inputs for Economic and Environmental Enhancement (OPE3) at the USDA Beltsville Agricultural Research Center site.

Description of Research

The Advanced Microwave Scanning Radiometer for EOS (AMSR-E) soil moisture product validation project is designed to determine the nature and variability of uncertainties in selected global soil moisture and snow products measured by the 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, innovative land surface data assimilation techniques are being used to check the quality control, physical consistency, and systematic realism of global EOS Aqua land observations in the context of the collaborative, real-time LDAS project.

Accomplishments during the Reporting Period

For the AMSR-E soil moisture validation project, an extended Kalman Filter data assimilation algorithm was implemented in the land surface data assimilation system. Before a calibrated AMSR-E soil moisture data product will be available, assimilation of the remote sensing data from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) has been explored. The results of these explorations were presented at the spring and fall meetings of the American Geophysical Union. The Extended Kalman Filter was found to be superior in comparison with other data assimilation methods (*e.g.*, direct insertion) in terms of getting soil moisture simulation results with values that are close to observations. Task work also included participating in an international, large-scale field experiment, held in Ames, Iowa from June 25 to July 15, 2002, to obtain *in situ* field measurements to validate results from remote sensing and land surface hydrological models. The measurement data have been processed and will be published on the NASA DAAC website and, eventually, in a peer-reviewed manuscript.

Objectives for the Coming Year

The goal for the coming year will be to develop a near-real-time operational land data assimilation system that will monitor the spatiotemporal AMSR-E soil moisture and snow observation quality to provide feedback to mission operators concerning possible observational problems. This system will also extend AMSR-E products in time and space to produce consistent data assimilation land surface fields that will be valuable for use in subsequent analysis and application. Finally, selected *in situ* and airborne land surface observations will be used as a secondary test of data integrity. The proposed innovative validation strategies will feed back to improve the calibration and accuracy of EOS land-surface observations. These improvements will lead to enhanced characterization of the spatial and temporal dynamics of uncertainty in these critical land surface quantities and will benefit climate and weather prediction efforts.

Task 974-05-086: **Development, Calibration, and Validation of Algorithms for Retrieving Snowpack Parameters at Global-to-Local Scales Using NASA's Aqua Satellite Remote Sensing Instruments**

GEST Investigator: Richard E. J. Kelly

Collaborator: A.T.C. Chang (PI, 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 areal extent and snow water equivalent will improve global climate modellers' simulations and predictions of climate behavior. In addition, resource managers will be able to more effectively manage demands for water supply and to avoid hazardous flooding events caused by melting snow. This research effort is designed to develop, apply, and validate a snow area mapping and snow-water-equivalent algorithm that will use data from NASA's Aqua satellite, launched in 2002. Snow-water-equivalent values have been retrieved from Earth observation satellite instruments for several years but, with Aqua, the spatial resolution

and error of snowpack estimation will be improved.

Description of Research

Producing a reliable and well-defined algorithm to monitor snow cover at various time and space scales is of great importance to the research community (*e.g.*, climate modellers) and the environmental management community (*e.g.*, water resource managers). Monitoring and mapping snowpack resources within specified ranges of accuracy is essential to better explain—and perhaps improve—predictions of climate change. Global snow cover is a highly variable environmental parameter in both space and time. Significant efforts are underway to map daily snow area at local and global scales using the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra satellite. With the successful launch of Aqua in 2002 the potential availability of microwave data from the Advanced Microwave Scanning Radiometer - EOS (AMSR-E) is providing an exciting possibility to map snow water equivalent (SWE) at spatial scales that are half of what are currently available. Furthermore, the addition of two lower-frequency microwave channels on AMSR-E should greatly improve our ability to successfully map snowpacks in a variety of states (*e.g.*, wet snow, dry snow, layered snow). The research being pursued here focuses on developing, calibrating, and testing algorithms to effectively map SWE using passive microwave data from AMSR-E.

Accomplishments during the Reporting Period

In the past year, research continued to focus on developing and verifying SWE estimation algorithms for AMSR-E image data. Using data from the Special Sensor Microwave Imager (SSM/I), two approaches have been successfully developed as improvements on long-standing methodologies. One algorithm was parameterized spatially using long-term snow depth records; the other approach coupled a simple hydrological model with a dense-media radiative transfer model to produce a spatially and temporally parameterized dynamic algorithm. The lineage of both approaches is predicated on SWE monitoring using passive microwave instruments dating back to the 1980s; naturally emitted microwave radiation from the Earth surface was observed to be substantially attenuated by dry snow. The strength of this attenuation can be directly related to the SWE of the snowpack. However, to complicate matters, the size distribution of ice grains in the pack, the amount of liquid water in the pack, the snowpack stratigraphy, and the geographical location of the snowpack (especially whether or not it is located in a forested area) also control microwave attenuation by the snow. In the absence of detailed and widespread information about the physical "state" of a snowpack (*e.g.*, grain size, wetness, surface roughness, etc.), the research effort has combined generic snow "state" factors in an attempt to quantify their space and time variability on a statistical basis.

To test some of these algorithm improvements, the research has also focused on field experimentation, particularly through the large-scale Cold Lands Processes Field Experiment (CLPX) funded by NASA's Land Surface Hydrology Program. Field work was conducted in February and March 2002 and will continue during the same months in 2003. This experiment has collected unprecedented volumes of field snow measurements, including snow depth, density, stratigraphy, etc., which will help further refine algorithms for global snow depth and SWE estimation.

Objectives for the Coming Year

The overall goals for the coming year are to mature the AMSR-E snow monitoring algorithm (especially the snowpack description component), and to start validating the algorithm using the snow data from the CLPX (*i.e.*, Colorado snow packs) and from other global sites (*e.g.*, the Ob River in Russia). Data from the CLPX 2002 season are available and are currently under investigation. Since Aqua's launch in 2002, AMSR-E data are beginning to become available, and the research will seek to implement and test our "baseline" snow depth and SWE products. Furthermore, the CLPX data are being used to provide a benchmark data set, against which we are developing instrument concepts and configurations for a dedicated snow hydrology measurement program. This is being undertaken with colleagues at the snow research community level.

Climate and Trace Species Research Group

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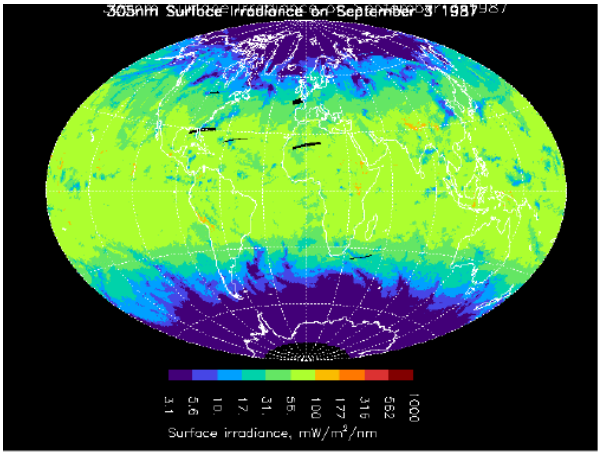

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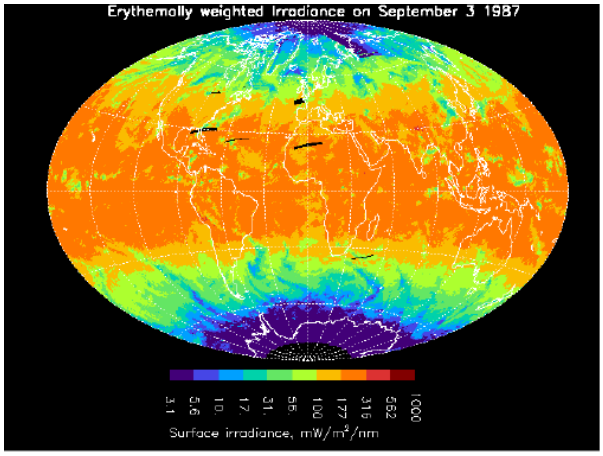
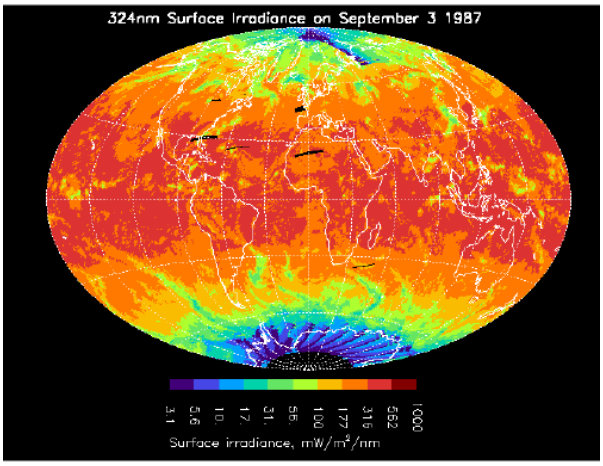
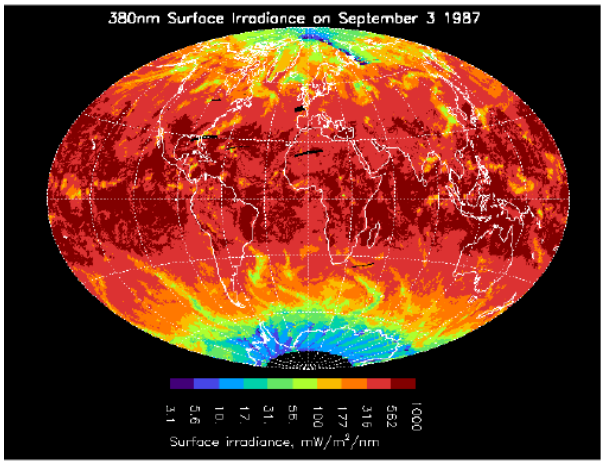


324 nm



380 nm



Increases in the abundance of chlorine from anthropogenic sources (mostly chlorofluorocarbons) lead to decreases in stratospheric ozone concentrations. This leads to global increases in surface ultraviolet (especially UV-B) radiative fluxes, which may strongly affect human health and terrestrial and aquatic ecosystems. Human-induced ozone loss thus remains an issue of public concern, as it has been for the past 20 years. Understanding the extent of the changes in UV requires careful analysis of surface and space-based ozone and radiation observations, alongside the application of models to understand the impacts of ozone change on surface UV fluxes.

A surface UV irradiance algorithm has been developed for Ozone Monitoring Instrument (OMI) to be launched on EOS/Aura satellite. Although the same UV algorithm is used as for the current Total Ozone Mapping Spectrometer (TOMS) and Global Ozone Measurement Experiment (GOME) instruments, the OMI UV product will benefit from the higher spatial resolution of the measurements.

The figure shows simulated OMI surface UV irradiance products: spectral surface irradiance at 305, 324, and 380 nm, and erythemally weighted UV irradiance (UV Index). The products were simulated using TOMS Level-2 radiances measured on September 3, 1987.

Climate and Trace Species Research Group

Members of the Climate and Trace Species Research Group address studies of atmospheric circulation on all timescales, investigations of atmospheric distributions of trace gases and aerosols, and examinations of the spectral and geographical distributions of the incident and emitted radiation fields along with their impacts on physical and biological environmental components. Activities of group members span measurement and retrieval processes, data analysis, and modeling, and combine such activities in support of data assimilation.

Space-based data describe the incident solar irradiance and allow estimates of its absorption in the atmosphere and at the surface. Judit Pap's studies of the spectral structure of the incident solar radiation field improves understanding of the primary forcing mechanism for the Earth system, central to studies of climate, aeronomy and remote sounding. Pap is also reconstructing historical records of solar irradiance and variability, for understanding past climate forcing.

Several existing and planned space-based instruments measure components of the solar spectrum to obtain information about the Earth's atmospheric composition. These include the Total Ozone Monitoring Spectrometers (TOMS), the Global Ozone Monitoring Experiment (GOME), and the planned Ozone Monitoring Instrument (OMI), all of which measure portions of the ultraviolet spectrum. Information about aerosol distributions and other trace gases also can be obtained from these measurements. Nickolay Krotkov uses TOMS data to infer the distributions of aerosols and sulfur dioxide; OMI measurements will also be used. Eric Buscela infers nitrogen dioxide distributions from GOME and OMI measurements.

Krotkov is developing algorithms to infer the spatial distribution of UV radiation at the surface from TOMS data. Sensors such as the Solar-Backscattered Ultraviolet (SBUV) allow measurements of the vertical distribution of ozone. Ozone data assimilation, combining modeled and measured fields, extends along-track coarse-resolution space-based to high-frequency, 3D global fields. Hiroo Hayashi's tropospheric ozone assimilation work has shown the importance of the transport scheme in prediction models.

While ground- and space-based measurements give information about the distribution of aerosols, understanding their sources requires model studies. Paul Ginoux has modeled their distribution using the 3D Global Aerosol Chemistry-Aerosol Radiation-Transport (GOCART) model. Rigorous analysis of observations has led to implementation of an aeolian module to help understand dust distributions. Simulated profiles have fed back into the development of the TOMS aerosol retrieval algorithms. Joan Rosenfield used a zonally symmetric model to investigate the links between volcanic aerosol and ozone, showing increased ozone depletion in the polar vortices for up to five years after the eruption of a major volcano, which deposited aerosol into the tropical stratosphere.

Aerosol must also be accounted for when retrieving space-based estimates of temperature. Clark Weaver's research has focused on the impacts of aerosols on the measurements from the Tiros Operational Vertical Sounder/High-Resolution Infrared Radiation Sensors (TOVS/HIRS) instruments. His work shows that improvements in space-based estimates of surface and lower-tropospheric temperature arise by accounting for moderate dust loading in the tropical Atlantic.

Modeling of meteorology and climate involves the use of state-of-the-art representations of both large-scale dynamics and parameterized physical processes in the general circulation model (GCM). Research in state of the art numerical methods includes relaxations of the hydrostatic assumption included in most models, still using sophisticated model grids that give a uniform spatial coverage. Kevin Yeh's research has developed a general framework for the global shallow-water equation model on a geodesic grid, including computing algorithms for conservative and monotonic transport. Jiun-Dar Chern studied the impacts of physical parameterizations in the GCM used by the Data Assimilation Office; a new prognostic cloud-water parameterization has been added, as have detailed improvements to the radiation

code and cloud-radiation interactions. The GCM performs very well in medium-range forecasting and for climate integrations.

Oreste Reale has investigated the meteorological conditions causing the formation of explosive cyclones over France in 1999. Two tropical cyclones that impinged on the mainland U.S. have been studied, and theoretical developments made for the theme of Mediterranean cyclogenesis. Yehui Chang has studied extreme precipitation events over the U.S using a 50-year model integration. Two dominant patterns that lead to extreme rainfall have been identified. Baode Chen is modeling the Intertropical Convergence Zone (ITCZ), using a mesoscale model to examine the changes in this system as greenhouse gases increase and change the radiation balance of the atmosphere.

Assimilation techniques are being developed. Lars-Peter Riishojgaard leads an effort to assimilate temperature instead of geopotential height, as well as examining the impact of assimilating wind data in polar regions, derived from the Moderate Resolution Imaging Spectrometer (MODIS). A new project, led by Ronald Errico, will study many aspects of the assimilation system, including the use of adjoint techniques to determine the relative importance of different observations. Shuhua Li and Steven Pawson are assimilating data to examine the atmospheric structure and transport for the period 1991-1995, when observations from the Upper Atmosphere Research Satellite (UARS) are available. Sensitivity studies reveal a strong dependence of polar temperatures to the GCM's gravity wave drag formulation. These new products are superior to older ones when used to drive chemistry-transport models (CTMs). Susan Strahan is using the Global Modeling Initiative (GMI) CTM to study long-term changes in ozone, arising as the atmospheric halogen loading decreases and other gases increase. Her calculations reveal that the transport circulation is much stronger with assimilated winds than with model-generated winds. Joan Rosenfield's transport studies reveal that the most realistic results are obtained with vertical velocities derived from radiative heating rates.

Song Yang is working on the algorithm for the TRMM Microwave Imager (TMI) rainfall rate data, demonstrating recent improvements in comparison to ground-based products. Estimates of latent heating are also being examined, with thorough validation against independent data. Prasun Kundu is extracting from TRMM data the details of rainfall over the Pacific region. Kundu is also examining the statistical distributions of rainfall in the TOGA-COARE dataset. Extreme rainfall events are often associated with thunderstorms, which (through electrification processes) lead to the formation of red sprites, which are the subject of examinations by Buscela.

Because of the nature of the areas of study, the work of the Climate and Trace Species group is having significant impact on research across the broad range of topics that are addressed by NASA's Earth Science Enterprise, and other Earth system science research generally.

Steven Pawson

Task 910-00-012: **Synoptic-Dynamic Evaluation and Improvement of the Data Assimilation Office Finite Volume Data Assimilation System**

GEST Investigator: Oreste Reale

Collaborator: Robert Atlas (PI, GSFC)

Abstract

This task focuses primarily on synoptic evaluation of various aspects of the finite volume atmospheric model and data assimilation system (fvDAS), developed in the Data Assimilation Office (DAO). The research investigates and improves the representation of individual weather systems in the fvDAS, through a deeper understanding of their dynamics. During the past year, particular emphasis was made on studying two exceptional storms that affected Europe in 1999. Research was also performed on Mediterranean cyclones and on two tropical cyclones that affected the U.S. mainland. The work developed on the European storms was acknowledged with the 2002 NASA-DAO Outstanding Performance Award.

Description of Research

The main goal of this task is to evaluate the potential of the fvDAS in simulating weather events at spatial and temporal scales near the limits imposed by model resolution, or events (such as rapidly-developing cyclones) that generally represent a challenge from the data assimilation perspective. The research explores the sensitivity of the analysis to the formulation of the forecast error correlation, and the impact of different data types (*e.g.*, satellite-derived wind data) in particular synoptic situations, in which the impact of additional data is critical.

In the past, scientific communities studying weather and climate were distinct, because models designed for climate simulation were generally not designed to simulate weather events with a high level of accuracy. Defining as “weather” the sequence of instantaneous values taken by a generic atmospheric variable, and as “climate” its long-term mean, with an averaging time chosen to be much larger than the time scales of the weather-induced fluctuations (the so-called synoptic-scale variability); it was generally accepted that to reproduce synoptic-scale events within a climate-oriented model was not feasible. In recent years, however, there has been growing attention in the climate community on the importance of so-called extreme events. Many extreme events occur on weather (synoptic) time-scales; nonetheless, they can have a powerful impact on the mean state of the atmosphere at time scales much longer than the events themselves. Therefore, the need to reproduce a realistic synoptic variability has become a goal in the climate community.

The fvDAS system is one of the first models that has been designed to challenge both the domains of climate and weather. The research developed under this particular task is explicitly devoted to analyzing the performance of fvDAS with respect to individual, extreme, weather systems.

Accomplishments during the Reporting Period

So-called explosively developing cyclones, *i.e.*, cyclones that have a central pressure deepening rate greater than a certain latitude-normalized threshold, are examples of extreme events. They are a major challenge for any numerical weather system because of their high propagation speeds and rapid internal structure changes.

Two cases, study of which began in the previous year, have continued to be the target of analyses and experiments during the past year. These events are two explosive cyclones that hit northwestern France and most of western Europe between December 26-28, 1999, producing winds up to 150 mph. Operational forecasting centers performed very poorly in this occasion because of the exceptional deepening rates of these two cyclones, which therefore represent a very important test for any numerical model or data assimilation technique.

Under this task, the dynamics of these storms were analyzed, and some unusual facts were identified, namely, a synergistic interaction between a low-level jet and an upper-level anomalously strong jet stream. From dynamical considerations, it was initially hypothesized that the representation of these two jets in the fvDAS system was crucial for correct analysis and prediction of the storms. Therefore, a large number of assimilation experiments were performed, focusing on the impact of two satellite products: wind vectors derived from the European Meteosat and NASA QuikSCAT satellites. Both these products have the possibility of improving the wind information respectively at the jet-stream level and in the lowest levels. When assimilating these wind data sets, the radius of influence of observations and their weight was perturbed. The results show that the analyses produced by fvDAS are very sensitive to the representation of the two aforementioned jets, thus confirming the initial working hypothesis. Some new dynamical aspects of rapidly developing cyclones were outlined, and advancement towards the predictability of these events has been made under this task. This research was acknowledged with receipt of the DAO Outstanding Performance Award.

Some new theoretical aspects of Mediterranean cyclogenesis have been investigated, particularly, the incidence in the Mediterranean region of cyclones resembling tropical cyclones and polar lows. These rare, intense, and small-scale cyclones have generally been neglected in earlier studies. Research in the past year, developed a new, dynamically-based classification of Mediterranean cyclones; the first to take into account sub-synoptic scale cyclones.

Finally, research was also conducted on two tropical storms, Bonnie and Floyd, in collaboration with other DAO scientists.

Objectives for the Coming Year

The main goal for this task will continue to be to evaluate the potential of the fvDAS in simulating weather events at spatial and temporal scales near the limits imposed by model resolution. The research will also continue to explore the sensitivity of the analysis to formulation of forecast error correlation and the impact of different data types (*e.g.*, satellite-derived wind data) in synoptic situations, which can represent a substantial and challenging test for the fvDAS system. Research will also be conducted to investigate any new, fundamental, aspect pertinent to synoptic and dynamic meteorology that might arise during fvDAS evaluation.

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

GEST Investigator: Steven Pawson

Collaborators: Arthur Hou (PI, GSFC), Mark Schoeberl (GSFC), Anne Douglass (GSFC), Ivanka Štajner (SAIC), David Crisp (JPL), Takeshi Horinouchi (University of Kyoto), Gloria Manney (JPL), Wei Tan (SAIC), Joan Alexander (Colorado Research Associates)

Abstract

Research has led to improvements of our understanding of the impact of data assimilation on transport and the formation of analysis techniques to quantify the causes of such impacts. Studies have established the quality of simulated and analyzed water vapor in the tropopause region and the impacts of assumptions in the model. Tropical convection has been shown to have a substantial impact on upward-propagating gravity waves that varies substantially among models. Parameterized gravity wave drag has been shown to have a large impact on assimilation and simulation. A strategy is being developed to develop a carbon species modeling and assimilation system.

Description of Research

The first major effort under this task is stratospheric research, which involves continual diagnosis of operational and research products, validating and analyzing model integrations and assimilation experiments, and improving the model and analysis system in the stratosphere. The Reanalysis for Stratospheric Trace Gas Studies (ReSTS) project was funded to produce analyses of the period 1991-1995, including aspects of sensitivity to various forcing mechanisms. Recent foci of this work have been on the impacts of the model formulation on the analyses in the middle atmosphere and on the sensitivity of transport processes to the assimilation process. The second major effort under this task involves the constituent assimilation group, which is evolving from the ozone assimilation system. This effort is expanding to include many different types of data, especially tropospheric trace gases. This group will contribute to analyses of data from the EOS/Aura platform and other satellites. It also involves planning for the development of an atmosphere-land-ocean assimilation system for carbon.

Accomplishments during the Reporting Period

Stratospheric research has involved the continual analysis of the Data Assimilation Office's (DAO) Goddard Earth Observing System (GEOS)-3 and GEOS-4 assimilation systems. While GEOS-4 offers clear reduction in noise in the middle atmosphere, the assimilated winds show strong divergent components that lead to anomalous transport. One GOES-4 analysis [Schoeberl *et al.* 2003] used trajectory analyses to investigate the transport of air masses, revealing quite clearly that the assimilation process leads to excessive dispersion. Another GOES-4 analysis [Douglass *et al.* 2003] reveals improvements in tropical transport between GEOS-3 and GEOS-4. These two studies suggest that fundamental processes must be investigated, an activity which is ongoing in collaboration with a postdoctoral scientist in the DAO. Alongside the large-scale, slowly varying estimates of transport (which affect the distributions of long-lived trace gases), colleagues have identified localized structure in the assimilated ozone fields, which are a consequence of noise in the divergent wind component of the assimilation system. An effort is underway to isolate the causes; results to-date suggest that while a reduction in the divergence damping of the parent model led to a growth in the noise level, it is the data insertion process that causes the noise. Present research, controlling both the types of data that are assimilated and the regions of the atmosphere where data are inserted, is directed at examining causes of this problem. Initial analysis suggests that deficient assumptions about the mass-wind balance are central to the problem.

Considerable effort in the group has been devoted to the impact of parameterized gravity waves in the model on the quality of the analyses. One component of this work has been performed in collaboration with Shuhua Li (GEST) and is described elsewhere in this volume. The second effort is performed in collaboration with Wei Tan (SAIC) and Joan Alexander in Boulder, Colorado. This effort is directed primarily at improving simulations of the tropical quasibiennial oscillation using a spectral parameterization of gravity wave drag. This should remove bias from the model in the assimilation procedure and lead to the inclusion of an important forcing mechanism for the interannual variability of ozone in multi-annual model simulations. A background for this work includes the paper by Horinouchi *et al.* [2003] that demonstrates quite clearly the impact of convection schemes on the resolved gravity wave spectrum in general circulation models (GCMs), with the DAO's model having a very weak spectrum. Task work contributed to the interpretation of the analyses in that publication, which arose from the GCM-Reality Intercomparison Project for SPARC (GRIPS) model assessment.

A considerable amount of time has been devoted to the formulation of an interdisciplinary team for assimilating carbon species data. This work involves scientists from GSFC as well as other institutions, and the planning and proposal is presently underway. Contributions were made to two major GSFC carbon cycle planning documents, and a workshop on Carbon Data Assimilation, held in October 2002 was co-hosted. Other task-related work includes membership on the Orbiting Carbon Observatory science team. This is the Earth System Science Pathfinder

project scheduled for launch in 2007. Other work on trace gases has focused on water vapor in the upper troposphere and lower stratosphere and on the ozone. Work on simulated and analyzed water is funded through the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL-FACE) Science Team, and special products are being made for the that mission. Collaboration with members of the DAO on ozone assimilation is performed in the DAO.

Objectives for the Coming Year

The first of two major foci for the coming year is to complete the development of an infrastructure for the assimilation of carbon species in the context of existing observations, expected future observations, and forthcoming national and international field experiments. The assimilation system, including modeling, will include a substantial collaborative component with atmospheric scientists, land process experts, and oceanographers, representing an interdisciplinary activity undertaken in GSFC's new office for modeling and data assimilation. The second major activity will be to coordinate real-time and reanalysis activities with EOS satellites, especially EOS/Aura, which will be launched in January 2004. A number of ongoing activities include the GRIPS model assessment and SPARC-related research, continued evaluation and analysis of the transport circulation in fvDAS, and studies of the interannual variability of the atmospheric circulation.

Building the carbon species assimilation capabilities at NASA will continue, as will participation in national, interagency efforts, including co-convening a status meeting in June 2002.

Task 910-01-010: **Data Assimilation Office Analysis Group Leadership**

GEST Investigator: Lars Peter Riishojgaard

Collaborator: Robert Atlas (PI, GSFC)

Abstract

In addition to leading the Analysis Group in the Data Assimilation Office (DAO). Research has focused on two main areas. The first has been a major project with substantial progress, in which the analyzed mass field is being changed from geopotential height to temperature. The second has been to study the impact of various wind datasets on the DAO's analyses, as a result of which Moderate Resolution Imaging Spectroradiometer (MODIS)-derived winds have been shown to have a potential beneficial impact on the analyses at high latitudes. Improvements have been introduced into the data selection criteria for cloud-track winds.

Description of Research

The main activity performed under this task is to lead the research and development efforts in the Analysis Group of the DAO. This group currently consists of about 15 individuals, including one civil servant, GEST and JCET faculty, and private contractors. The group is responsible for algorithmic, as well as computational aspects of the core analysis algorithm employed by the DAO, the so-called Physical-Space Statistical Analysis System (PSAS). In addition, research and development is carried out to assess and improve the performance of the analysis and the overall data assimilation system. This work consists of designing, running, and evaluating experiments to determine the impact of various assumptions built into the analysis and of the various observation types used. The incumbent of this position is also the NASA Deputy Director of the NASA/NOAA Joint Center for Satellite Data Assimilation (JCSDA).

Accomplishments during the Reporting Period

The work in the analysis falls into two main categories: algorithm analysis and software development; and observation preprocessing, monitoring, and impact studies.

In the former category, substantial progress has been made toward effecting a change in analysis variables for the mass field from geopotential height to temperature. There are two main reasons for deciding to make this change. First, the vertical structure of the background error correlations are easier to understand and model when formulated in terms of a local variable such as temperature than when using a vertically integrated variable such as height. Second, single-level temperature observations, *e.g.*, from aircraft, cannot readily be assimilated into a height-based analysis system. The same problem also affects the assimilation of infrared and microwave satellite soundings, albeit to a lesser extent. Satellite soundings carry information about temperatures at individual levels, whereas the information required for extracting a column of geopotential heights is missing or incomplete. A new version of the PSAS code using the Message Passing Interface (MPI) library was released. In addition to improving the scaling of the algorithm on massively parallel machines, this has enabled the DAO to run experiments using a much larger number of observations than were hitherto possible. To further increase the number of observations analyzed and to further improve the throughput, extensive experimentation was carried out with a new method ("Reduced PSAS") to localize the impact of the observations without modifying the basic assumptions of the covariance model. The results from this work are very promising, allowing for substantial improvements in computational performance without penalizing the scientific performance of the system.

Concerning the data impact studies, winds from the MODIS instrument are now assimilated in preoperational mode, and the results still indicate a substantial potential for assimilation of this type of observations in high latitudes. Further refinements in the data selection for geostationary winds have been implemented based on experimental results. Work on testing winds from the Multiangle Imaging Spectrometer (MISR) instrument progressed at a slower than anticipated rate due to persistent problems with the quality of the data. With the release of Version 1.4 of the finite volume Data Assimilation System (fvDAS), important parts of the observation and forecast error covariance models were retuned, and a complete series of Observing System Experiments were therefore carried out. The results are still being analyzed, but overall the findings appear to be in line with what other centers are seeing in terms of data impacts. Good progress has been made toward initial testing of a prototype state-dependent data selection algorithm. This work is also strongly supported by the JCSDA.

Objectives for the Coming Year

With the transition to the Goddard Earth Observing System (GEOS)-4 system now having been completed, the upcoming major task for the Analysis Group in the DAO will be to complete the change in analysis variable from geopotential height to temperature. Through the experimentation mentioned above, a substantial amount of anecdotal and quantitative evidence has been collected that supports the hypothesis that wind-mass coupling in the analysis is flawed. The implementation of temperature analysis provides an opportunity to reevaluate many basic assumptions on which the background error covariance model is built, and formulation of the wind-mass balance is thus one of several areas that will be given increased attention over the next year. The JCSDA is now taking on a more definite shape and is emerging as the primary vehicle to transfer knowledge and technology from NASA into NOAA operations in the area of satellite data processing and assimilation. It will be a major challenge for GSFC participants in the JCSDA to try to steer the relevant work carried out within the DAO, in particular, in a direction where it feeds into the goals of the JCSDA without jeopardizing the scientific independence and integrity of the research.

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

GEST Investigator: Joan E. Rosenfield

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

Abstract

The effects of the stratospheric sulfate aerosol layer associated with future volcanic eruptions on the recovery of the ozone layer were studied with a zonally symmetric model of stratospheric photochemistry and transport. Compared to a control run using background aerosol loading, transient reductions of globally averaged column ozone of 1.7-2.8% were computed as a result of future eruptions, with the ozone recovering to levels computed for the nonvolcanic case in about five years. Springtime Arctic column ozone losses of 9-17% also recovered to the nonvolcanic case within five years. These results suggested that the long-term recovery of ozone would not be strongly affected by infrequent large volcanic eruptions. In other work, parcel trajectory calculations using United Kingdom Meteorological Office (UKMO)-analyzed vertical velocities exhibited excessive mixing compared with calculations, in which computed heating rates were used to determine vertical motion.

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 analyzed temperature fields. These heating rates are being used in calculations of diabatic parcel trajectories in the stratosphere. The radiative transfer model also constitutes a module in the GSFC zonally symmetric 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

Parcel trajectory computations were carried out to further characterize the diabatic descent of air in the stratospheric polar vortex. Comparisons were made between diabatic and kinematic trajectories. In the diabatic trajectories, parcel vertical motion was obtained from heating rates computed with the radiative transfer code, while in the kinematic trajectories, vertical motion was prescribed from the vertical velocities determined by an analysis model. The kinematic descent computed with UKMO-analyzed vertical velocity fields was much less than the diabatic descent computed with heating rates determined from UKMO temperatures. The UKMO kinematic trajectories showed excessive mixing of mid-latitude with polar air. Kinematic trajectories computed with vertical velocities from the GSFC finite volume general circulation model (fvGCM) showed a much more realistic distribution of parcels. Springtime values of the tracers CH_4 and HF were reconstructed using the back trajectory spring-to-fall computations, together with fall values of the tracers from the Halogen Occultation Experiment (HALOE) instrument on the Upper Atmosphere Research Satellite (UARS). The reconstructed spring HF agreed very well with HALOE data, while agreement for CH_4 was not quite as good.

Volcanic effects on the recovery of the ozone layer were studied with the coupled zonally symmetric model of stratospheric photochemistry and transport, using stratospheric sulfate aerosol anomalies associated with the eruption of the Mt. Pinatubo volcano and with future volcanic eruptions. Model runs from 1980 out to the year 2050 were carried out, in which volcanoes having the characteristics of the Mt. Pinatubo volcano were caused to erupt at ten-year intervals, starting in the year 2010. Both the time-varying chlorine loading and the stratospheric cooling due to increasing carbon dioxide were taken into account. Computed ozone and temperature perturbations during the actual Mt. Pinatubo eruption period agreed well with observations. Compared to a control run using background aerosol loading, transient future reductions of globally averaged

column ozone of 1.7-2.8% were computed as a result of each of these eruptions, with the ozone recovering to that computed for the nonvolcanic case in about five years after the eruption. Springtime Arctic column ozone losses of 9-17% also recovered to the nonvolcanic case within five years. These results, and studies exploring the sensitivity to temperature and aerosol loading, suggested that long-term recovery of ozone would not be strongly affected by infrequent large volcanic eruptions. In addition, in order to simulate situations in which frequent smaller volcanic eruptions result in increasing the background sulfate loading, runs in which the background aerosol was increased by reasonable amounts were also carried out. These resulted in delays in ozone recovery of two to five years.

Work has begun on comparing computed ozone profile trends with observations. Ozone profile trends as a function of latitude and height are being computed for the period 1980-2001, using output from the zonally symmetric photochemical model and a statistical time series analysis. The observations are from the Solar Backscatter Ultraviolet (SBUV and SBUV/2) instruments. The observational dataset is a new SBUV merged data set in which observations from the SBUV instruments on various satellites have been combined, using a time dependent calibration adjustment based on comparisons with Stratospheric Aerosol and Gas Experiment (SAGE) II profiles. The resulting internally consistent ozone profile data set is suitable for trend analysis. Annual mean and seasonal trends will be compared. Preliminary results show that the maximum upper stratospheric negative trends at 45°N are largest in the winter season and smallest in the summer season, for both the model and the data. This work is being done in collaboration with R. Stolarski (GSFC).

Objectives for the Coming Year

The ozone profile trend analysis will continue, comparing model with observed trends. The underlying reasons for computed differences in seasonal trends will be examined. Model output will be compared with that from a run with fixed temperature and circulation to understand the roles that changing dynamics may play in computed trends. In addition, more improvements in the radiative transfer model are planned. The radiation model does not include infrared heating due to the greenhouse gases methane and nitrous oxide. A parameterization for the absorption and emission by these gases will be developed or adopted.

Task 910-04-074: **Observational and Modeling Studies of Stratospheric Chemistry and Dynamics**

GEST Investigator: Susan Strahan

Collaborator: Anne Douglass (PI, GSFC)

Abstract

A study of the influence of transport on Arctic ozone using satellite ozone observations was completed. The NASA Global Modeling Initiative (GMI) integrated two, 35-year simulations of a decreasing chlorine scenario to assess future changes in stratospheric ozone. The two simulations, driven by different meteorological fields, show similar patterns of ozone recovery. Output from these simulations is being analyzed to understand the roles of chemistry and transport in ozone recovery.

Description of Research

This research focuses on analyzing and interpreting satellite and aircraft observations of stratospheric trace gases, and on three-dimensional atmospheric modeling. The goal of the data analyses is to better understand the balances between photochemistry and transport on stratospheric ozone and various long-lived trace gases. The data analyses are also used to evaluate the performance of models, in particular, the Goddard 3D Chemistry and Transport Model (CTM) and the NASA Global Modeling Initiative CTM. These models are used to investigate

anthropogenic influences on the stratosphere and to estimate their effects in the future.

Accomplishments During the Reporting Period

A study using a three-year time series of satellite ozone data from the Polar Ozone and Aerosol Measurement (POAM) III instrument was completed. The analysis of POAM data in the middle and lower stratosphere demonstrated how unusually strong transport during a warmer than normal Arctic winter resulted in unusually high O_3 in the lower stratospheric vortex by the end of winter. The levels were higher than what would be expected even in the absence of polar stratospheric cloud (PSC) activity.

The main research activities this year involved the NASA-funded investigation on stratospheric process studies for the GMI. The GMI project has developed a state-of-the-art, modular, full-chemistry 3D CTM to assess the affects of various perturbations on the troposphere and stratosphere. Last year, plans were made to integrate long-term calculations using different meteorological fields with known different circulations. The purpose of these simulations is not only to assess the recovery of stratospheric ozone in the 21st Century as chlorine levels decrease, but also to obtain an estimate of how the recovery depends on the transport and circulation of the meteorological fields used.

Winds from NASA's finite volume General Circulation Model (fvGCM) and the finite volume Data Assimilation System (fvDAS) were each used to integrate a simulation for 1995-2030 using boundary conditions of decreasing halogens and increasing N_2O and CH_4. Although the circulation in the fvDAS is known to be much stronger than the fvGCM, the amount and spatial distribution of ozone recovery was nearly the same for the two simulations. Previous tests of transport and temperature (developed several years earlier for GMI) were applied to simulations and showed many aspects of transport to be realistic and better than previous GMI simulations. In the Antarctic, where there is a significant recovery in lower stratospheric ozone, differences in model mixing between the mid and high latitudes are seen to have a large impact on the overall recovery of the southern hemisphere. However, in the northern hemisphere similar differences exist, yet do not produce significant differences in ozone recovery. In addition, while ozone is controlled by rapid photochemistry in the middle and upper stratosphere, transport still plays a role in recovery, because it controls the abundances of long-lived trace gas families whose reactive members are important in regulating ozone.

Objectives for the Coming Year

The first objective is to complete the current analysis of the effects of transport on ozone recovery. Following that, two projects are planned for the coming year that will address various aspects of stratospheric ozone in a changing atmosphere. The first is a 50-year run using the Goddard CTM that will be both a "hindcast" and a forecast, beginning in 1973. The simulation will be integrated with 50 continuous years of fvGCM winds; these winds show considerable interannual variability.

The second project will be one or more multidecadal simulations with the GMI CTM to further explore how future changes in stratospheric conditions may affect ozone. Simulations will try to bracket the range of possible ozone changes by simulating a series of warm stratospheric years and a series of cold ones. These simulations may be complementary to the 50-year GSFC run, which, unlike these runs, has significant interannual variation.

Task 910-04-074: **Assimilation Studies**

GEST Investigator: Clark Weaver

Collaborators: Arlindo da Silva (PI, GSFC), Mian Chin (GA Tech), Joanna Joiner (GSFC), Paul Ginoux (UMBC/GEST)

Abstract

Since mineral aerosols absorb significant amounts of infrared radiation, they may contribute to errors in the retrievals of atmospheric and surface parameters from the TIROS Vertical Sounder (TOVS) High-resolution Infrared Radiation (HIRS) instrument if the atmosphere is assumed clear. HIRS channels that are sensitive to the surface temperature, lower tropospheric temperature, and moisture are subject to a 0.5 K or more reduction in the brightness temperature during heavy dust loading conditions. A dust-clearing algorithm has been developed that accounts for dust absorption in the TOVS temperature and moisture retrievals. Accounting for dust absorption in the retrieval system yields warmer surface temperatures (0.4 K) and warmer lower tropospheric temperatures in regions of moderate dust loading over the tropical Atlantic. An offline aerosol assimilation using Moderate Resolution Imaging Spectroradiometer (MODIS) retrieved optical depths is currently under development.

Description of Research

The two main research topics addressed under this task are to develop an aerosol assimilation system using MODIS-retrieved optical depths and to improve a temperature and moisture retrieval system for TOVS radiances that accounts for dust absorption.

Accomplishments during the Reporting Period

Mineral aerosols can absorb significant radiation in the infrared spectrum. Consequently, there may be errors in TOVS retrieved temperature and moisture profiles in regions of heavy dust loading. This task had developed a temperature and moisture retrieval system for nighttime conditions over oceans that accounts for dust absorption in the infrared. Information on the dust concentrations and size distribution is from the Goddard Chemistry Aerosol Transport model (GOCART). The observed minus the forecast (O-F) brightness temperature at each TOVS channel is a measure of the accuracy of the retrieval, with smaller values preferred. For each TOVS channel, there is a clear dependence between the amount of dust loading shown in the GOCART model and the O-F brightness temperature difference. When the radiative transfer model used in the retrieval system is modified to account for the radiative effects of dust, the dependence between dust loading and O-F brightness temperatures is reduced, and for some channels the dependence is removed. Accounting for dust absorption in the retrieval system yields warmer surface temperatures (0.4 K) and warmer lower tropospheric temperatures in regions of moderate dust loading over the tropical Atlantic [Weaver *et al.* 2003].

An off-line assimilation system for MODIS-retrieved optical depths has been developed. Given aerosol spatial distributions from the GOCART model, a forward model produces optical depths like those retrieved by MODIS. The differences between the GOCART optical depths and those retrieved from MODIS are used to modify the GOCART aerosol concentrations, so that they are in more close agreement with the MODIS retrievals. A Version 1 MODIS assimilation system has been developed; however, much more work needs to be done on the forward model.

Objectives for the Coming Year

The Version 1 aerosol assimilation only uses the optical depth at one MODIS channel (550 nm). Moreover, the optical parameters of the aerosols used in the forward model are different than those assumed in the MODIS retrievals. The task's future research, then, involves improving the forward model of the aerosol assimilation so that it uses all seven channels of the MODIS observations and optical parameters consistent with those used in the MODIS optical depth retrievals.

Task 910-05-082: **Reanalysis for Stratospheric Trace Gas Studies**

GEST Investigator: Shuhua Li

Collaborators: Steven Pawson (PI, GEST), Arlindo da Silva (GSFC), Shian-Jiann Lin (GSFC)

Abstract

Work performed under this task involves assessing the sensitivity of middle-atmospheric analysis to formulating the data assimilation system developed at GSFC. A number of experiments have performed to investigate the sensitivity to gravity wave drag parameters, concluding that traveling gravity waves are important to analysis of and model forecasts for the middle atmosphere. The GSFC data assimilation system has been applied to a multi-year reanalysis of meteorological fields and trace species in the middle atmosphere.

Description of Research

This work involves reanalysis of meteorological fields and trace species in the middle atmosphere, over the period 1991 to 1995. Part of the work is to investigate the sensitivity of middle atmospheric analyses to the formulation of the general circulation model (GCM). A major uncertainty in middle atmospheric models is the representation of sub-grid scale gravity waves (GWDs). Based on the finite-volume Data Assimilation System (fvDAS) developed at the Data Assimilation Office (DAO), the main objective of this project is to produce a validated, well-documented, four-year (1991-1995) dataset for use by the atmospheric science community. This work involves analysis of that dataset, along with studies of the sensitivity of the analyses to gravity wave drag and other aspects of the analysis system.

Accomplishments during the Reporting Period

One of the major accomplishments during the past year was achieved in a series of assimilation and forecast experiments by modifying parameters within the GWD scheme. This parameterization scheme allows for multiple-wave forcing induced by convection in the troposphere and the presence of stationary waves due to orography. The results indicate that the effects of gravity wave forcing are predominantly significant in the winter hemisphere at high latitudes in the mid-to-upper stratosphere and mesosphere. Compared to multiple-wave forcing, a single stationary wave has a much smaller impact. Traveling gravity waves are very important for both forecast and analysis, especially in the middle atmosphere. As a statistical quantity, analysis of observation minus forecast (O-F) data reflecting geopotential height indicates that traveling gravity waves make a significant contribution to improving the analysis, while stationary waves have little impact in the upper stratosphere.

Another aspect is monitoring and analyzing the reanalysis data from experiments over the period 1991-1994. (Due to data input problems, the experiments terminated in late 1994.) Some general features were investigated, such as temperature and zonal wind in the stratosphere, the residual mean circulation, etc. . A comprehensive study of the reanalysis products is still underway.

In addition, a number of assimilation experiments were repeated using different versions of the DAO assimilation system. The purpose was to examine the divergence field, which is critical to vertical transport in the atmosphere. In particular, the height-dependent divergence-damping scheme employed in the GCM has been modified; this corresponds to a different divergence field, especially in the upper stratosphere. The divergence damping needs to be updated to reduce biases and noise in the analyzed divergence field.

Objectives for the Coming Year

In the coming year, the multi-year reanalysis will be rerun, and the products will be documented. Quantitative comparison will be made with other reanalysis products. Another important task is to incorporate volcanic aerosols into the assimilation system. The Mt. Pinatubo eruption in 1991 is expected to have significant impacts on the assimilation fields. These experiments will lead to quantitative assessment of the effects due to the Pinatubo eruption over seasonal-to-multi-year time scales.

Task 910-08-099: **Improvement of the Physical Parameterizations in the Finite-Volume General Circulation Model**

GEST Investigator: Jiun-Dar Chern

Collaborator: Shian-Jiann Lin (PI, GSFC)

Abstract

In recent years, the Data Assimilation Office (DAO) at GSFC has collaborated with the National Center for Atmospheric Research (NCAR) to develop the NASA/NCAR finite-volume General Circulation Model (fvGCM) for data assimilation, numerical weather prediction, atmospheric chemistry transport, and climate study. The fvGCM has employed a unique finite-volume dynamic core developed at the DAO and adopted the physics package from the NCAR Community Climate Model CCM3, which represents a well-balanced set of processes with a long history of development and documentationDuring this past year, the model's diagnostics have been improved, and the interface between the fvGCM and the finite-volume Data Assimilation System (fvDAS) was modified to meet DAO's mission requirements. The medium range weather prediction capabilities of the high-resolution fvGCM have been established with initial and boundary conditions directly from the National Oceanic and Atmospheric Administration (NOAA) and the National Centers for Environmental Prediction (NCEP). Many physical parameterizations in the fvGCM have been improved, including a new prognostic cloud water parameterization, an improved long-wave radiation scheme, a cloud-overlap specification, a gravity wave drag scheme, and a new land surface model. These parameterizations are undergoing extensive testing and validation.

Description of Research

The fvGCM is a NASA core model for data assimilation, numerical weather prediction, atmospheric chemistry transport, and climate study. Research objectives for this task are: to maintain a state-of-the-art modeling system by improving the physical parameterizations of the model; to improve the interface between the model and the data assimilation system, as well as the analysis to meet the mission requirements of instrument teams; to investigate the forecast capability of the fvGCM; and to modify the model to support data assimilation of new space-based observations and to study the impact of these data on the forecasting skills and the quality of analysis.

Accomplishments during the Reporting Period

One of the major goals of the DAO is to advance the state-of-the-art of data assimilation and to produce research-quality assimilated global data sets to advance our understanding of the Earth system and climate change. The fvDAS is one of the key components to achieve these goals. The fvGCM has been successfully integrated into the fvDAS that became operational in October 2002. The original model diagnostics are very limited for validation, data assimilation, numerical weather prediction, and other applications. Many new diagnostics have been added to the fvGCM to meet the needs for data assimilation, numerical weather prediction, chemistry transport, and climate study. For example, detrainment and entrainment rates of convective clouds are crucial model diagnostics for chemistry transport. The thickness of the 500 hPa to 1000 hPa layer, precipitation amount and type, and the total accumulated snow depth are all important diagnostics for numerical weather prediction of winter storms. Detailed water budget diagnostics from land models are important for global water cycle study.

Many new physical parameterizations from the Community Atmosphere Model Version 2 (CAM2) have been integrated into the fvGCM, including a new prognostic cloud water parameterization, an improved radiation parameterization, a cloud overlap specification, and a gravity wave drag parameterization. The parameterization of non-convective cloud

processes has two components: a macroscale component that describes the exchange of water substance between the condensate and the vapor phase, and the associated temperature change arising from that phase change [Zhang *et al.* 2003]; and a bulk microphysical component that controls the conversion from condensate to precipitate [Rasch and Kristjansson 1998]. The solar spectrum in CAM2 is divided into 19 discrete spectral intervals (7 for ozone, 1 for the visible region, 7 for H_2O, 3 for CO_2, and 1 for the near-infrared) [Collins 1998]. The original longwave radiation parameterization for water vapor absorptivities and emissivities in CCM3 has been replaced by a new formulation in CAM2 [Collins *et al.* 2001]. The new formulation uses the line-by-line radiative transfer model GENLN2 Version 4 to generate the absorptivities and emissivities. The major difference between the shortwave parameterizations in CCM3 and CAM2 is the new treatment of cloud vertical overlap [Collins 2001]. The overlap parameterization is designed to reproduce calculations based upon the independent column approximation. The new parameterizations can treat random, maximum, or an arbitrary combination of maximum and random overlap between clouds. The new gravity wave drag scheme incorporates a fairly general spectrum of monochromatic waves and a single stationary wave generated by flow over orography following McFarlane [1987]. The impact of these new parameterizations on numerical weather prediction and climate study is presently undergoing extensive study.

The recently developed state-of-the-art Community Land Model (CLM) Version 2.0 [Bonan *et al.* 2002] has been was successfully integrated into the fvGCM. The CLM2 was developed collaboratively by an open interagency/university group of scientists; it provides a comprehensive physical representation of soil/snow hydrology, thermal dynamics, and biogeophysics. With the improvements of the biogeophysics in CLM2 by the DAO land modeling group, it has been demonstrated that CLM2 is superior to the land surface model in CCM3 in both climate study and the numerical weather prediction skills. Plans are to incorporate the CLM2 into the fvDAS system in the very near future.

The medium range weather prediction capabilities of the high-resolution fvGCM have been established with initial and boundary conditions directly from NOAA/NCEP. Currently, the fvGCM provides routine 10-day weather forecasting. Even with some initial spin-up problems with NCEP initial conditions, the forecast skills from fvGCM are very competitive. The fvGCM is superior to the medium-range forecast during the winter. The model predictions of severe winter storm, hurricane track, and landfall have been analyzed for one season. The results showed that very promising forecast skill can be achieved by using the fvGCM at very high horizontal resolution. The numerical weather prediction is also an important testing tool for evaluating any new physical parameterization.

Objectives for the Coming Year

The impacts of the new CAM2 physical parameterizations on weather prediction, data assimilation, and climate study will be explored. A new planetary boundary layer turbulent parameterization will be developed, based on the finite volume floating vertical Lagrangian coordinate. A new land specification dataset will be implemented, including Advanced Very High Resolution Radiometer (AVHRR) leaf area index and Moderate Resolution Imaging Spectroradiometer (MODIS) land cover that are much better than the default NCAR data. The cold-lake temperature problem in the CLM2 will be corrected.

Task 910-14-123: **The Characteristics of Wintertime Extreme Precipitation Events over the Contiguous U.S.**

GEST Investigator: Yehui Chang

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

Abstract

Extreme weather events have a major impact on our lives. It is important to understand the link between such extreme events, climate variability, and climate change. This work studies the differences in the regional and seasonal characteristics of extreme precipitation events over the U.S. The impacts of El Niño/Southern Oscillation (ENSO) on extreme events are examined using observed and assimilated data and how well the NASA Seasonal-to-Interannual Prediction (NSIPP) atmospheric-land general circulation model (AGCM) produces realistic extreme events and related statistics.

Description of Research

The ENSO has a major impact on the winter mean climate of the U.S. During a moderate to strong El Niño event, the Pacific subtropical jet extends southward and eastward across northern Mexico, the northern Gulf of Mexico, and Florida. Conditions tend to be wetter and cooler than normal across the southern tier of states, warmer than normal over a large region extending from Alaska across the northern states to the Great Lakes, and drier than normal over parts of the Midwest. La Niña events are characterized by a variable polar jet, and a retracted and northward displaced (and more variable) subtropical jet. The anomalies over North America show the opposite response to those for El Niño conditions, although exceptions to that rule include wetter than normal conditions over the Pacific Northwest, and various details of the spatial coverage of the anomalies. This work seeks to better understand how ENSO impacts the characteristics of weather over the U.S., both through changes in the base state and through changes in the low frequency transients. Another important aspect of the work is to evaluate the ability of the NSIPP AGCM to simulate realistic precipitation extremes. Existing long simulations were used to address this issue, and reanalyses and other observational datasets are used to help verify the results and to validate the model.

Accomplishments during the Reporting Period

In this study, the characteristics of extreme wintertime precipitation events over the continental U.S. were examined using 50 years' worth (1949-1998) of daily, gridded precipitation observations and National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalyses. The approach consists of expanding the daily precipitation data in rotated empirical orthogonal functions (EOFs) and compositing various fields for those days when the amplitude of the leading precipitation principal components (PCs) exceeds a predetermined large value. Two dominant winter (December through February) weather patterns were identified that are major contributors to precipitation maxima over the continental U.S. The leading pattern—the western extreme precipitation (WEP) pattern—is a slow-moving west coast storm system that is associated with major flooding over California; it appears to be linked to the 22-day oscillatory mode. The second pattern—the eastern extreme precipitation (EEP) pattern —is an extratropical cyclone that apparently develops in the Gulf of Mexico and moves to the northeast, producing large amounts of precipitation over much of the eastern U.S. The WEP pattern tends to be active (suppressed) during "large-scale" atmospheric conditions associated with El Niño (La Niña), and the positive (negative) phase of the North American pattern (NAP). The latter is a dominant pattern of monthly variability of the global 300mb height field. A precursor to the WEP weather system can be found almost two weeks in advance of the maximum rainfall over California, consisting of a suppressed local Hadley cell over the tropical western Pacific and Indian Oceans. The EEP pattern shows a tendency to be active during winters in which the entire tropic/subtropics is

warmer and the middle latitudes are cooler than normal. Suppression of EEP pattern tends to occur during winters that have a "La Niña type" anomaly pattern that includes enhanced upper tropospheric heights across the southern U.S.

Understanding how ENSO affects weather is central to understanding and predicting ENSO's impact on the climate of the U.S.. The robustness of the ENSO-weather connection clearly depends on a number of different processes, including the large-scale seasonal mean response of atmospheric to tropical Pacific sea-surface temperature (SST) anomalies and potential attendant changes in various subseasonal low-frequency variations, such as the Pacific-North American (PNA) and blocking. These linkages are complicated by potential nonlinearities that result in the interactions between the various temporal and spatial scales.

Objectives for the Coming Year
Existing multi-year (1949-2000) simulations forced by observed SST will be used to help evaluate the ability of the NSIPP model to simulate winter storm systems and extreme events at the current production medium resolution (2° x 2.5°). In the second track, work will focus on a few winters (*e.g.*, in El Niño, La Niña, and neutral years) and carry out large (approximately 100-member) ensemble integrations at both medium and high resolutions (1° x 1.25°) to assess the impact of resolution on characteristics of the weather systems, including changes in the point distribution function and extreme events. A number of global and regional data sets will be used for validation including NCEP/NCAR and the anticipated new NASA/Data Assimilation Office (DAO) global renanalyses, NCEP regional reanalyses, and several *in situ* and satellite-based estimates of precipitation.

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

GEST Investigator: Kevin Yeh

Collaborator: Shian-Jiann Lin (PI, GSFC)

Abstract
The framework for a global shallow-water model on geodesic grids has been established, including the geodesic-grid generator with appropriate modifications. Formulations of new transport algorithms have been derived, for which the preliminary results indicate desired numerical properties.

Description of Research
The goal of this project is to develop a next-generation dynamical core with the finite volume method on geodesic grids. This potential dynamical core is intended for future application in the NASA/NCAR finite volume General Circulation Model (fvGCM) as a major component for global high-resolution modeling. While the quasi-uniform geodesic grids provide a good foundation to achieve great efficiency for the enormous amount of computation required by global high-resolution, the major effort is to overcome the scientific difficulty of developing sufficiently accurate finite volume algorithms for unstructured grids.

Accomplishments during the Reporting Period
The framework for a global shallow-water model on geodesic grids has been established, including the geodesic-grid generator with appropriate modifications to provide a smooth and quasi-uniform grid system for consistent truncation of numerical approximations to the dynamics system.

General formulations of new computing algorithms have been derived for conservative and monotonic transport on an arbitrary grid system. Numerical experiments have been designed to test these new algorithms; the preliminary results indicate desired numerical properties.

Objectives for the Coming Year
Further numerical experiments are to be conducted for the transport algorithms on geodesic-grids. Refinements of the transport algorithms are

expected to improve both accuracy and efficiency. Shallow-water dynamics are to be investigated after the design of the transport algorithms has been completed.

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

GEST Investigator: Hiroo Hayashi

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

Abstract

Tropical tropospheric ozone in the satellite ozone assimilation system developed in NASA's Data Assimilation Office (DAO) is being investigated by comparing independent observations from the Southern Hemispheric Additional Ozonesondes (SHADOZ) network. Studies over the past year show that assimilated ozone distribution in the troposphere is sensitive to the meteorological field used in the transport model in the assimilation system, and winds analyzed in the latest version of the Goddard Earth Observing System data assimilation system (GEOS-4) are realistic. Assimilation of Total Ozone Mapping Spectrometer (TOMS) data has a negative impact on reproducing the tropical tropospheric ozone field. Incorporating parameterized chemistry from Harvard's GEOS-CHEM model improves assimilated lower tropospheric ozone profiles, confirming the importance of the tropospheric chemistry.

Description of Research

Tropospheric ozone is environmentally important because it acts as a strong oxidant to control the concentrations of many reduced gases (*e.g.*, methane and carbon monoxide); its radiative forcing plays a significant role in the greenhouse effect, and direct contact with ozone is harmful to human health. The main goal of this research is to provide better estimates of tropospheric ozone distribution by assimilating satellite ozone measurements. Many experiments in the satellite ozone assimilation system in the DAO have been being performed and compared with independent observations from SHADOZ to improve the assimilation system. These studies will also lead to better understanding of the mechanisms that determine ozone distribution in the atmosphere.

Accomplishments during the Reporting Period

The ozone assimilation system in the DAO includes a chemistry-transport model that uses analyzed winds from the Goddard Earth Observing System (GEOS) data assimilation system. Two experiments with different wind fields were performed: one is from a previous system (GEOS-2), and the other is from the latest system (GEOS-4). While the two meteorological data assimilation systems utilize the same Physical-space Statistical Analysis System (PSAS) and use comparable observations, they use entirely different general circulation models. The experiments demonstrated that the shape of annual mean vertical profile is sensitive to the meteorological analyses with the GEOS-4-based ozone being closest to the SHADOZ observations. This means that the resolved transport in GEOS-4 is more realistic than in GEOS-2. Remaining uncertainties include quantification of the representation of sub-grid scale processes in the transport calculations, which plays an important role in the locations and seasons where convection dominates transport.

While the data from the Solar Backscatter UltraViolet/2 (SBUV/2) instrument are assimilated in the DAO ozone assimilation system, high-resolution total column ozone data from the TOMS were included in some experiments to examine its impact on the system. Comparisons with SHADOZ profiles revealed a negative impact of TOMS data on the assimilated tropical tropospheric ozone. This implies that the TOMS instrument overestimates the total column ozone.

To investigate influence of tropospheric chemistry, efforts to incorporate ozone production, loss, and dry deposition rates calculated in the Harvard GEOS-CHEM model into the DAO ozone assimilation system have been made. Preliminary results showed that the parameterized chemistry improves the lower tropospheric ozone profile.

Objectives for the Coming Year

The impact of changing model resolution will be investigated. Increasing the vertical resolution is expected to have a beneficial influence on the tropospheric ozone distribution. Future efforts will be devoted to developing an online transport model in which sub-grid scale convective transport, which is especially important in the Tropics, should be included.

Task 910-20-138: **Analysis of Aerosols Distribution and Optical Properties**

GEST Investigator: Paul Ginoux

Collaborators: Arlindo da Silva (PI, GSFC), Steven Pawson (GEST/UMBC), Omar Torres (JCET/UMBC), Oleg Dubovik (GEST/UMBC), Mian Chin (GA Tech)

Abstract

An original dust source inventory has been established for the Global Ozone, Chemistry, Aerosol, and Radiative Transport (GOCART) model; the inventory is based on geomorphological characteristics of ephemeral lakes. The simulation of the global distribution of dust has been compared with ground-based and satellite data. An original empirical formula to calculate an aerosol index as an explicit function of the single-scattering albedo, optical thickness, and centroid of mass has been established and applied for model validation and dust source characterization. The effects of dust distribution on ozone chemistry (through reduction of the photolysis rates and catalysis of heterogeneous reactions); ocean primary production (by providing Fe nutrients for phytoplankton blooming); radiative forcing; and intercontinental transport of dust particles have been studied, and their results published. Also, the effects of non-sphericity on dust modeling have been analyzed and published. Some progress has been made in implementing the GOCART aerosol physics in the finite volume General Circulation Model (fvGCM).

Description of Research

The objective of this research is to better understand the factors controlling the variability of aerosols in the atmosphere and their impact on radiation, tropospheric chemistry, and ocean biogeochemistry. To reach such objectives, model results are compared with observations to assess our correct understanding of the processes controlling the variability of aerosol distribution. This work has two main parts: Analysis of the variability of the aerosol distribution and optical properties using the GOCART model and ground-based and remote sensing data; and implementing the GOCART aerosol package in the Data Assimilation Office's (DAO) fvGCM and finite volume Data Assimilation System (fvDAS).

Accomplishments during the Reporting Period

The global distribution of aeolian dust has been simulated for 20 years with the GOCART model and compared with *in situ* measurements at different locations and using satellite data [Ginoux *et al.* 2003]. The originality of the GOCART dust model is that the dust sources are located in topographic depression and is based on rigorous comparison with the Total Ozone Mapping Spectrometer (TOMS) aerosol index [Prospero *et al.* 2002]. The optical effect of dust and other aerosols has been analyzed with GOCART by comparing the calculated optical thickness with ground-based and satellite measurements [Chin *et al.* 2002]. The GOCART dust vertical distribution has been used to retrieve optical properties from the TOMS radiances [Torres *et al.* 2002]. The GOCART aerosol components have been compared with other transport models [Penner *et al.* 2002; Kinne *et al.* 2003]. A new technique has been developed to allow direct comparison with the TOMS aerosol index [Ginoux *et al.* 2003]. Such a technique has been further developed, and

an empirical TOMS aerosol index has been proposed to simplify the calculations [Ginoux and Torres 2003]. The comparisons show that GOCART dust distribution can correctly reproduce the interannual, seasonal, and daily variability in dusty regions; however, it underestimates the fraction of particles larger than 5 µm. This problem has been investigated and does not seem to be due to the nonspherical shape of dust particles, but rather to the choice of a numerical algorithm to solve gravitational settling [Ginoux 2003]. Because GOCART is an off-line transport model, the implementation of the GOCART aerosol package into the fvDAS should further improve the simulated aerosol distribution. Unfortunately, this implementation has proceeded much more slowly than expected, due to the complexity of the fvDAS architecture. Meanwhile, the GOCART results have be applied to study the effects of dust on the different components of the Earth system.

The first application has been to study the effects of dust on satellite retrieval used in fvDAS [Weaver *et al.* 2003]. The second application was to study the effects of dust absorption on ozone photochemistry [Martin *et al.* 2002], and the reduction of the oxidizing capacity of the atmosphere by heterogeneous reactions [Martin *et al.* 2003]. The third application has been to study the importance of Aeolian dust deposition of the ocean surface to the primary production (Gregg *et al.* 2003a; Gregg *et al.* 2003b). Finally, the GOCART simulation was helpful to provide evidence of inter-continental transport of Asian dust [Grousset *et al.* 2003].

Long-term simulation of atmospheric dust has been compared with observational data and applied to different atmospheric and oceanographic research fields. The first test of dust simulation in the fvDAS has taken place.

Objectives for the Coming Year

The first objective for the coming year is to pursue the analysis of aerosol variability to quantify the contribution of each transport and removal process. The second objective is to improve the definition of dust sources based on the location of dry lakes validated with Moderate Resolution Imaging Spectroradiometer (MODIS) data. Interdisciplinary collaborations with oceanographers will continue, to improve our understanding of ocean primary productivity. The implementation of the GOCART aerosol model in fvDAS will be completed.

Task 910-31-155: **Data Assimilation and Numerical Weather Prediction**

GEST Investigator: Ronald Errico

Collaborator: Ronald Gelaro (PI, GSFC)

Abstract

The work performed under this task supports the GSFC Data Assimilation Office, with activities in adjoint model and ensemble applications in addition to data assimilation. During this first year of the tast the primary effort is devoted to developing the software necessary for the application of new diagnostic tools to the fvGCM and fvDAS. These tools will include corresponding adjoints of the fvGCM and fvDAS and software for singular vector and normal mode analysis of the fvGCM.

Description of Research

The scope of this project is very broad within the contexts of data assimilation and numerical weather prediction. Objectives include investigating the effects of dynamic imbalances on data assimilation procedures (one of the current problems with the finite volume Data Assimilation System (fvDAS)); applying adjoint model diagnostics to measure the relative importance of observations and to detail the mechanisms of forecast-error generation; and examining the use of Monte Carlo techniques to determine flow-dependent background-error statistics. Much of the work in the first two years of this project will deal

with developing required software and validating the developed techniques.

Accomplishments during the Reporting Period

The main activities in the early part of the past yearinvolved developing and validating software performance sensitivity analyses based on tangent linear and adjoint model versions of the DAO finite volume general circulation model (fvGCM). This includes the ability to compute singular vectors of short-term weather forecasts. In support of the latter, an appropriate operator was developed to compute the total energy L-2 norm on the fvGCM grid along with its inverse square root and adjoint inverse square root operators. These have been validated using the standard tests that had been developed for use with the Mesoscale Adjoint Modeling System. The tangent linear and adjoint versions of the dynamic core of the fvGCM have failed these tests, however, an effort to get these corrected and re-validated will be undertaken.

An investigation of singular vectors was completed using moisture measure norms in the previously developed Mesoscale Adjoint Modeling System, the only adjoint modeling system with demonstrated utility for such purposes. Results show that initial errors in moisture can create almost the same magnitude of forecast errors as initial errors in temperature or wind. In some cases, the initial moisture errors that cause the greatest growth have a similar structure and occur in the same location as the most rapidly growing initial temperature structures. At other times, the growth arising from the two initial fields are clearly unrelated. Similarly, for some cases, the maximum errors in precipitation rate and total energy are clearly related but other times, not. Therefore, the characteristics of maximum error growth vary greatly as different weather patterns are considered.

An implication of this moist singular vector work is that as much attention must be paid to estimating the effects of initial errors in moisture as those for temperature and wind fields. Furthermore, the effort to reduce initial moisture errors through data assimilation should not receive less attention than that to reduce errors in dry fields. When attempting to correct precipitation forecasts, adjustments to initial conditions of both temperature and precipitation should be simultaneously considered. The study also shows that the use of singular vectors as a diagnostic tool can be broadened to include new measures of error growth, such as involving precipitation rate and the effects of initial moisture errors.

Another task has been the examination of the use of Monte-Carlo techniques to perform data assimilation, to efficiently estimate background error statistics that are flow-dependent. This task began by organizing an ensemble Kalman filter reading group within the DAO. Simple simulation tools have been developed to examine some basic behaviors of ensemble-based data assimilation techniques.

Task work has included assisting colleagues, at the Marine Division of the Naval Research Laboratory (NRL) in Monterey, California, in developing an ensemble forecast system based on drawing random perturbations from a distribution designed to reflect estimates of analysis error statistics. For each field, the initial error variances are three-dimensionally varying, but the vertical and horizontal correlations are homogeneous and isotropic. The scheme is now undergoing tests at NRL.

Objectives for the Coming Year

Objectives for the coming year deal with separate but related aspects of generating background errors in data assimilation and the generation of 6-to-72-hour weather forecast errors. In particular, procedures will be developed to determine the effects of nonmodal error growth. This determination, which will include consideration of Monte Carlo (ensemble) techniques, will be critical to lay the foundation for a next-generation data assimilation scheme to be developed at the DAO.

Task 912-23-147: **Global Precipitation Measurement**

GEST Investigator: Song Yang

Collaborators: Jim Smith (PI, GSFC), William S. Olson (UMBC/GEST), Arthur Hou (GSFC)

Abstract

This focus of this project is mainly to demonstrate recent improvements of the Tropical Rainfall Measuring Mission (TRMM) Microwave imager (TMI) rain algorithm (Version 6). Another important effort is to compare latent heating retrieved from satellite measurements with independent latent heating estimated from ground radar observations over TRMM field campaign sites. Comparisons of different TRMM satellite precipitation algorithms were completed. Initial results on heating comparison are promising. Work related to the Global Water and Energy Cycle (GWEC) is in progress. Activities associated with the Global Precipitation Measurement (GPM) project are helping the GPM science implementations.

Description of Research

The rainfall retrieval algorithm that uses passive microwave measurements from TMI is one of the key TRMM facility rain algorithms. Current primary efforts are to update the TMI rain algorithm into Version 6. The latent heating product has also been added to the improved TMI rain algorithm. The rainfall measured from ground radar and latent heating from dual-Doppler radar analysis over TRMM field campaign sites serve as alternative measurements to compare rain and latent heating from satellite measurements. Results from these comparisons will demonstrate the improvement of TRMM rain retrieval algorithms. In addition, latent heating is introduced to the TRMM TMI/PR (precipitation radar) combined rain algorithm. Investigations on latent heating products will show reliability of the heating retrievals. Activities associated with the GWEC project focus on studying the impacts of TRMM rain/latent heating products on GSFC general circulation model simulations. Since the GPM project is still in its early stage, efforts are now focused on how to advance the GPM project and to plan its science implementation, and to transfer/improve TRMM rain/latent heating products into future GPM products.

Accomplishments during the Reporting Period

The upgrade of TMI rain algorithm into Version 6 is almost completed. Comparisons of surface rainfall from the new version TMI rain algorithm, current TRMM facility rain algorithms, and ground radar measurements over the Kwajalein Island site demonstrate the improvement of the TMI rain algorithm. One key output added to Version 6 of the TMI rain algorithm is the latent heating product. Dual-Doppler analysis for selected cases over the Kwajalein site have been finished, and estimates of latent heating are used to validate the retrieved latent heating profiles and to study the credibility of the retrieved heating field.

TRMM rain data collections for the GWEC project are in progress. New simulations for the GSFC general circulation model are designed for data from the summer of 1998 to test the impacts of TRMM rain products on this model. In addition, initial error analyses of rain and heating products are prepared for investigating their roles in the data assimilation at GSFC.

Activities associated with the GPM project focus mainly on its science implementation. Some efforts are being made to determine how the current TRMM rain and latent heating products can be improved for use in generating future GPM products.

Objectives for the Coming Year

Further investigation is needed to show the improvements on TMI and TMI/PR rain algorithms. More detailed comparisons of latent heating from TMI and TMI/PR rain algorithms and TRMM field campaigns, the South China Sea Monsoon Experiment (SCSMEX) and the Kwajalein Experiment (KWAJEX) will be conducted in the upcoming year. Results from

these studies will demonstrate the reliability and confidence of the improvements on TRMM facility rain algorithms. TRMM rain products and GSFC model simulations for the summer of 1998 will be analyzed. Finally, more effort will be made to support the GPM.

Task 913-02-035: **Large-scale Tropical Circulation**

GEST Investigator: Baode Chen

Collaborator: Winston C. Chao (PI, GSFC)

Abstract

A regional climate model study has been performed to examine enhanced climate warming in the Tibetan Plateau (TP) due to doubling CO_2 levels. The results indicate that a strong ground warming occurs in the TP when CO_2 is doubled; the largest warming is located at two regions in the eastern TP and along the southwestern and western slopes. Most significantly, the ground warming shows an altitude dependence, with the warming at high elevations being more pronounced than that at low elevations. Through an analysis of the surface energy budget, it was found that cloud-radiation interactions and snow-albedo feedback mechanisms play the most essential roles in the characteristics of ground warming in the TP.

Description of Research

The structure of the Intertropical Convection Zone (ITCZ) under the settings of an aqua-planet with uniform sea-surface temperature (SST) and solar angle has been studied. Such simplified settings isolate the more essential characteristics and test our basic understanding of the ITCZ. The basic understanding obtained from this study can serve as a cornerstone for further understanding of the ITCZ under more complicated settings.

Previous work under this task showed the existence of multiple quasi-equilibria for the ITCZ and indicated that monsoon onset could be interpreted as an abrupt transition between the quasi-equilibria of the ITCZ. In the past year, task research attempted to give a theoretical interpretation for the decade-old general circulation model (GCM), finding that the ITCZ structure in an aqua-planet model with globally uniform SST and solar angle can switch between a single ITCZ over the Equator and a double ITCZ, straddling the Equator when the cumulus parameterization scheme is changed.

The National Center for Atmospheric Research (NCAR) regional climate model (RegCM2), together with initial conditions and time-dependent lateral boundary conditions provided by a 130-year transient increasing CO_2 simulation of the NCAR Climate System Model (CSM), has been used to investigate the mechanism of surface warming over the TP. Two runs, one with current CO_2 and another with doubling CO_2, have been integrated for three years and four months. An analysis of the surface energy budget has been made to demonstrate the roles of various surface energy exchanges in the local ground temperature response to doubling CO_2.

Accomplishments during the Reporting Period

It has been known for more than a decade that an aqua-planet model with globally uniform SST and solar insolation angle can generate an ITCZ. Previous studies have shown that the ITCZ structure under such model settings can be changed between a single ITCZ over the Equator and a double ITCZ straddling the Equator through one of several measures. These measures include switching to a different cumulus parameterization scheme, changes within the cumulus parameterization scheme, and changes in other aspects of the model design such as horizontal resolution. In this study, an interpretation for these findings is offered. Under the aforementioned model settings, the latitudinal location of the ITCZ is the latitude where the balance of two types of attraction on the ITCZ, both due to Earth's rotation, exists. The first type is toward the Equator, and is directly related to the Earth's rotation and thus is not sensitive to model design changes. The second type is poleward, and is

related to the convective circulation and thus is sensitive to model design changes. Due to the shape of the attractors, the balance of the two types of attractions is reached either at the Equator or more than 10º away from it. The former case results in a single ITCZ over the Equator, and the latter case is a double ITCZ, straddling the Equator.

The regional climate model (RegCM2), together with initial conditions and time-dependent lateral boundary conditions provided by a 130-year transient increasing CO_2 simulation of the NCAR CSM, has been used to investigate the mechanism of surface warming over the TP. The model results show that when CO_2 in the atmosphere is doubled, a strong surface warming occurs in the TP. Two regions within it with the largest warming are in the eastern TP (Region I) and along the southwestern and western slopes (Region II). A strong elevation dependence of ground warming is found in Region I for the winter half-year, and in Region II for both winter and summer half-years at elevations below 5 km. In addition, the ground warming does not show elevation dependency in Region I for the summer half-year. The simulated characteristics of ground warming in the TP are consistent with the observations. In Region I, when CO_2 is doubled, the cloud amount increases at lower elevations and decreases at higher elevation for the winter half-year. As a consequence, at lower elevations the shortwave solar radiation absorbed at the surface declines, and the downward longwave flux reaching the surface is enhanced. On the other hand, at higher elevations the surface solar radiation flux increases and the surface infrared radiation flux shows a more uniform increase. The net effect of the changes in both radiation fluxes is an enhanced surface warming at higher elevations, which is the primary cause of the elevation dependency in the surface warming. In the summer, half-year cloud amounts are reduced as a result of doubling CO_2 in Region I for all elevations, and there is no elevation dependence detected in ground warming. Moreover, there is little snow in Region I for both summer and winter half-years, and the impact of snow-albedo feedback is not significant. In Region II, although the changes in the cloud amount bear a resemblance to those in Region I, the most significant factor affecting the surface energy budget is the depletion of the snow cover at higher elevations, which leads to a reduction of the surface albedo. This reduction, in turn, leads to an enhancement in the solar radiation absorbed in the surface. The snow-albedo feedback mechanism is the most essential component in the elevation dependence in surface warming for Region II.

Objectives for the Coming Year

In the coming fiscal year task work will expand to explain the longitudinal distribution of precipitation. In addition, the work will continue to further understand the finite-amplitude nature of tropical cyclogenesis by using the axisymmetric version of Goddard Cloud Ensemble (GCE) model.

Task 913-18-130: **Modeling of Rainfall Statistics from Satellite- and Ground-based Remote Sensing Measurements**

GEST Investigator: Prasun K. Kundu

Collaborator: Thomas L. Bell (PI, GSFC)

Abstract

Research efforts under this task involved a detailed study of various aspects of the statistics of gridded, monthly averaged rainfall data from the Tropical Rainfall Measuring Mission (TRMM) over the equatorial Pacific, and estimating the sampling error using a previously developed theoretical approach and applying a spectral model of rain to describe the spatial statistics of area-averaged rainfall data obtained from the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE). The model successfully describes various features of the rain statistics, including the power-law scaling behavior at small spatial scales. Current work focuses on applying the model to

describe the statistics of time-averaged rain gauge data collected at the various TRMM ground validation sites as part of a study of the intercomparison of gauge and satellite precipitation estimates.

Description of Research

There are four major goals of research performed under this task, which include developing mathematical models of rainfall statistics; applying these models to describe statistical behavior of precipitation data sets from a variety of sources, including satellite- and ground-based remote sensing measurements and rain gauge networks; a detailed study of the statistics of precipitation data obtained from low-Earth-orbiting satellites, such as TRMM and Special Sensor Microwave/Imager (SSM/I) data and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) on the EOS Aqua platform; and providing sampling error estimates of gridded monthly rainfall averages obtained from these global satellite data sets using a theoretical formula based on previous studies of actual satellite rain data [Bell *et al.* 2001] and numerical simulation of the satellite sampling pattern using realistic orbital dynamics combined with modeled rainfall statistics [Bell and Kundu 1996].

Accomplishments during the Reporting Period

Work continued on a number of applications of the stochastic dynamical model of rain originally developed for describing the statistics of precipitation during Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE). The model was found to successfully describe various aspects of the spatial statistics of the gridded rainfall data collected during the TOGA-COARE campaign. The four parameters of the model spectrum—an overall strength parameter, a characteristic length separating the long and short wavelength regimes, a characteristic relaxation time for decay of the autocorrelation of the instantaneous local rain rate, and a certain “fractal” power law exponent—were tuned to the statistics of rain-rate data spatially averaged on a square grid. The model is approximately scale invariant at small spatial scales and naturally predicts power-law scaling behavior for a number of rain statistics. Moreover, the scaling exponents are all simply expressed in terms of the single fractional index appearing as a model parameter in the spectrum. The fractal behavior predicted by the model at small scales agrees well with observations.

The spectral model was also applied to the intercomparison problem of rain gauge and satellite estimates over an area surrounding the gauges. The model predicts that there is an optimal averaging time for gauge data when gauge averages are compared to the satellite averages in the sense that it minimizes the RMS difference between the two estimates [Bell and Kundu 2003]. The optimal averaging time decreases as more gauges are added within the area viewed by the satellite. Current work involves applying the spectral model to describe the statistical behavior of time-averaged precipitation data from the multi-year time series of rainfall collected at several TRMM ground validation sites. In addition to the work on models of rain statistics, work continued on estimating the sampling errors for TRMM data using previously developed error models. An extensive effort to gather rain statistics form the entire available TRMM Microwave Imager (TMI) data has been initiated as a part of a collective TRMM data mining operation.

Objectives for the Coming Year

In the coming year, the immediate goal is to investigate the statistics of time-averaged precipitation data from rain gauge networks, looking for evidence of scaling behavior that would test—and hopefully validate—the spectral model in a broader regime. New theoretical work will explore the idea of applying renormalization group methods to explain the scale-invariant properties of rain statistics without recourse to detailed model dynamics. The original program of studying various aspects TRMM rainfall statistics will continue as the data mining operation progresses.

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), S. Randolph Kawa (GSFC)

Abstract

Research efforts under this task involved a detailed study of long-range and sub-scale transport including the interhemispheric exchange of atmospheric tracers such as CFC-12 and radon. This study was carried out using the GSFC parameterized chemical transport model (PCTM) that employed meteorological input from the GSFC finite volume General Circulation Model (fvGCM) and the finite volume Data Assimilation System (fvDAS) models. Effects of meteorological input on the tracer transport are studied by using meteorological fields from different model year simulations. In addition, this study also concentrated on quantifying the contributions from regional emissions on the atmospheric loading of radon at various receptor locations.

Description of Research

One of the major goals of the atmospheric modeling in GSFC Code 916 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 and mutual interactions of global air quality with the climate system. There is an ongoing project to couple the atmospheric (both tropospheric and stratospheric components) chemistry models with the GSFC Data Assimilation Office (DAO) atmospheric general circulation model (AGCM). Modeling tools developed under this task will be used to examine the important scientific issues such as future recovery of stratospheric ozone and atmospheric chemical-climate interactions.

Accomplishments during the Reporting Period

Based on the specific stratospheric research objectives, the GSFC Chemical Transport Model (CTM) has employed the observed mixing ratios of atmospheric trace gases as their lower boundary conditions in the upper troposphere. However, to address scientific questions addressing future atmospheric behavior, these lower boundary conditions must be replaced by the projected future surface emission fluxes. Given the spatial and temporal inhomogeneities in the surface emissions, trace gases undergo sub- and large-scale transport (*e.g.*, interhemispheric exchange) before they reach the stratosphere. To study the stated transport features of the AGCM's meteorology, several atmospheric simulations of CFC-12 (a long-lived, man-made chemical often used to diagnose large-scale transport) and radon (a short-lived, radioactive tracer for subscale and intercontinental transport studies) were performed using the meteorological fields from the DAO's fvGCM and fvDAS. Modeled trends in CFC-12 surface mixing ratios and their interhemispheric gradient were compared to observed values. Given the importance of intercontinental transport in the context of regional air quality and its interaction with the climate, source-receptor relationships for radon are examined on a global scale using regionally tagged emissions. Emphasis was placed on the sensitivity of model results with respect to the different meteorological input.

Objectives for the Coming Year

After examining the characteristic features of tracer transport, the next step would be to couple the chemistry component of GSFC CTM with the DAO fvGCM, which will be followed by testing and validating the coupled model. Presently, the GSFC CTM has a provision for parameterized tropospheric ozone chemistry to address the ozone flux exchange across the tropopause and to model the ozone in the upper troposphere. This parameterized tropospheric ozone chemistry will be replaced by the interactive chemical scheme responsible for chemical balance of the natural

troposphere. Also, presently prescribed lower boundary conditions for the long-lived species in terms of mixing rations will be replaced by the corresponding surface emissions. Both of these modifications to the CTM would help to properly address the issues of stratospheric ozone and to interpret the residual tropospheric ozone derived from space-based column ozone observations.

Task 916-04-076: **Surface UV Irradiance and Volcanic Emissions Remote Sensing**

GEST Investigator: Nickolay A. Krotkov

Collaborators: Jay Herman (PI, GSFC), Arlin J. Krueger (UMBC/JCET)

Abstract

Support was provided to develop applications for satellite data, such as ultraviolet (UV) irradiance estimation at the Earth's surface and generation of volcanic emissions data products from the Total Ozone Mapping Spectrometer (TOMS) missions. This work includes developing algorithms, case studies, validating products, and developing new proposals for satellite flights to improve existing products. New algorithms were proposed to retrieve sulfur dioxide (SO_2) and UV irradiance from hyperspectral satellite instruments, such as Ozone Monitoring Instrument (OMI) on the EOS/Aura satellite.

Description of Research

Increases in UV-B fluxes from decreasing amounts of stratospheric ozone caused by anthropogenic chlorine-releasing gases (primarily chlorofluorocarbons) have been an issue of public concern for the past 20 years, due to their direct effect on human health and terrestrial and aquatic ecosystems. Other atmospheric constituents, such as aerosols, clouds, and gases (*e.g.*, SO_2) also cause changes in UV fluxes at the Earth's surface. Satellite data on ozone, SO_2, aerosols, and clouds were used as input to radiative transfer models to map surface UV fluxes on a global scale. Because of daily global coverage and the availability of a long (since 1978) record, the data from TOMS instruments are vital for global daily mapping and estimating global trends in surface UV irradiance. The daily TOMS UV data can be found on the TOMS Web page, http://toms.gsfc.nasa.gov and on the Earth Observatory Web page, http://earthobservatory.nasa.gov/.

Other task work addresses volcanic eruptions, which are one of the primary forcings for the Earth system. The extreme interannual variability of eruptions makes the availability of a long time series very important to climate prediction. This task analyses information on volcanic eruptions derived from satellite-based UV Earth radiance data. The SO_2 content of volcanic clouds was first measured with the TOMS on the Nimbus-7 satellite, launched in 1978. The 14-year life of this instrument led to the first statistics for the volcanic sulfur budget from large eruptions that can impact climate. Successive TOMS missions have extended this time series to over 25 years. Case studies of all detected eruptions to date are summarized on the TOMS volcanic Web page (http://skye.gsfc.nasa.gov). A continuing series of UV instruments is important to climate and solid Earth studies. This work will maintain the integrity of satellite-based global volcanic sulfur budget estimates and assure continuity in the eruption time series.

Accomplishments during the Reporting Period

The algorithm for surface UV irradiance estimation using TOMS data was validated against ground-based UV measurements worldwide. These validation studies have shown that TOMS estimates can successfully reproduce long-term and major short-term UV variations. However, some systematic differences remain in the absolute values of UV irradiance.

The bias is different at different locations and was close to zero for sites with clean air (*e.g.*, New Zealand; Saturna Island, Canada). Further validation studies are needed to quantify the bias at different locations and for different conditions. The TOMS algorithm for surface UV irradiance is being passed to the OMI processing system by collaboration with the Finnish Meteorological

Institute (FMI). The OMI UV algorithm theoretical basis document (ATBD) was peer-reviewed and submitted to NASA's EOS office in July 2002.

Ongoing support was provided for algorithm maintenance and analysis of the TOMS data for volcanic emissions (SO_2 and ash) and new SO_2 algorithm development for OMI on the EOS/Aura satellite. Currently, the Earth Probe TOMS is degrading, but continues to produce data in its 7th year of operation. Case studies of all detected eruptions are summarized on the TOMS volcanic Web page (http://skye.gsfc.nasa.gov). Work continued on software development for retrieval of sulfur dioxide from UV radiances measured by OMI on the EOS/Aura satellite. Scheduled for launch in 2004, the OMI will continue the TOMS UV record of volcanic emissions.

Knowing aerosol absorption characteristics in the near-UV is of interest to tropospheric chemistry studies, because it changes the rate of photochemical reactions and smog production and penetration of biologically harmful UV radiation to the surface. To support the need for such data, a proposal was submitted to NASA to extend ground-based sun and sky photometer measurements from the Aerosol Robotic Network (AERONET) of sky radiances and inversions of column aerosol absorption to UVA wavelengths (340 nm and 380 nm), develop and manufacture a portable UV-VIS sun/sky spectrometer, and conduct unique measurements of aerosol absorption vertical profiles using GSFC Scanning Raman Lidar (SRL) data.

Objectives for the Coming Year

The current Earth Probe (EP)/TOMS is the last instrument in the TOMS series. It will be turned off after the launch and checkout of Aura, sometime late in 2004. The UV and SO_2 algorithms will be modified for the new generation of nadir-viewing instruments, via the Dutch-provided OMI instrument on the EOS/Aura satellite, and the recently approved Ozone Mapping and Profiler Suite (OMPS) instrument on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) satellite in 2007. In the coming year, the work will focus on quantifying UV-absorbing aerosol properties and on aerosol forcing of UV irradiance and photolysis rates. Upon acceptance of the submitted proposal, different retrieval techniques will be tested and compared using new UV measurements. The newly proposed aerosol absorption techniques will be cross-validated by ancillary UV measurements from other instruments currently available at GSFC. Accurate vector radiative transfer forward modeling will be used to combine and cross-validate different methods of measuring aerosol absorption, and to ensure consistent aerosol retrievals derived from different methods and between UV and visible wavelengths.

Task 916-13-121: **Global Ozone Monitoring Experiment Analysis**

GEST Investigator: Eric Bucsela

Collaborators: James Gleason (PI, GSFC), Edward Celarier (SGT), Joanna Joiner (GSFC), P.K. Bhartia (GSFC), Folkert Boersma (KNMI), Ellen Brinksma (KNMI), Ernest Hilsenrath (GSFC), Scott Janz (GSFC), George Mount (NOAA)

Abstract

During the past year, work was done in the areas of Ozone Monitoring Instrument (OMI) algorithm development, nitrogen dioxide (NO_2) ground-based measurements, and analysis of sprite observations. Specific challenges involving the computation of air mass factors were resolved by analyzing output from radiative transfer models including the Doubling-Adding KNMI (DAK) model, developed at the Koninklijk Nederlands Meteorologisch Instituut (KNMI), and the TOMRAD radiation code, which has been used in NASA's Total Ozone Mapping Spectrometer (TOMS) program. These models were compared

for use in developing look-up tables in the OMI NO_2 algorithm. Ground-based spectroscopic retrieval of NO_2 using a Differential Optical Absorption Spectrometer (DOAS) technique was explored as part of a joint project with Washington State University. Spectroscopic studies of thunderstorm electrification phenomena—specifically, red sprites—were also performed, the results of which helped confirm the existence of ionization in sprites.

Description of Research

The past year's research supported trace-gas-retrieval algorithm development as applied to OMI NO_2 measurements. The goal was to build on feasibility studies from the previous year that looked at issues including air mass factor estimations, temperature sensitivity, cloud cover, and signal-to-noise ratios. This work was to be implemented in the code written to process actual OMI data, as well as existing data sets from the Global Ozone Monitoring Experiment (GOME) instrument. The air mass factor studies were also useful in the investigation of ground-based Aura validation studies of NO_2 that will be undertaken after OMI deployment early in 2004. A separate area of research was aimed at understanding the excitation and ionization of molecular nitrogen in sprites and related phenomena. This work was carried out in association with the U.S. Naval Research Laboratory and the University of Alaska, using data from 1996 and 1998 aircraft campaigns.

Accomplishments during the Reporting Period

During the past year, significant progress was made in preparation for the upcoming deployment of the EOS Aura satellite in 2004. The work described here focuses on the OMI, which, in addition to measuring ozone, will be able to measure column amounts of NO_2. Work on the OMI instrument is being carried out at NASA as part of a joint venture with KNMI in the Netherlands. The culmination of the year's work was the delivery of version 0.9 of the NO_2 algorithm to be run on the Science Investigator-led Processing Systems (SIPS) at GSFC.

Research continues on NO_2 air mass factors (AMFs). Air mass factors were calculated using both DAK and TOMRAD radiative transfer codes. Computed AMFs were compared and used to correct a minor error in TOMRAD. In general, TOMRAD was determined to be the more rigorous of the two algorithms for the purpose of computing NO_2 AMFs to process OMI data. A method was designed and used to compute differential air mass factors (dAMFs), the effective AMFs for infinitesimally thin layers from the total air mass factors that TOMRAD generates. This method works by inverting a set of total AMFs, each associated with a narrow NO_2 layer of finite thickness, peaking at a specific altitude. The inversion produces dAMFs used directly in the OMI NO_2 algorithm. The dependences of the dAMFs on surface height and albedo, and on the absolute NO_2 number densities, were investigated and quantified. Progress was also made in estimating the uncertainties in the AMF calculations. These uncertainties are the primary component of the error budget in the OMI NO_2 retrieval process.

The work on NO_2 slant column retrievals and their conversion to vertical column amounts was also applied in the study for a proposed OMI validation experiment. Development of a ground-based spectrometer, the Multi-Axis DOAS (MAXDOAS), was proposed to measure NO_2 column densities at a specific site and to compare them with concurrent OMI measurements from the Aura satellite. The method will involve DOAS-type spectral retrievals at several viewing geometries; comparison of slant columns at low and high ground-based viewing zenith angles will identify the tropospheric component of the NO_2 vertical column density. The sensitivity of the total NO_2 vertical column, *i.e.*, the quantity retrieved by OMI, to the particular vertical distribution of NO_2 was determined. It was shown that the tropospheric column can indeed be measured independently of the vertical profile through judicious choice of viewing geometries.

Studies involving red sprites—the atmospheric discharges sometimes seen over large thunderstorms—were also undertaken. Broad- and narrow-band images of a sprite from a 1998 aircraft observation were obtained, which revealed the faint but distinct signature of an N_2^+ first negative emission. From this observation, electron energies between 1.2 and 2.2 eV were estimated. Other work involved the analysis of two spectra

observed at different altitudes on the same sprite during a 1996 campaign. The spectra have distinct characteristics and suggest a variety of excitation processes for the vibrational levels of the N_2 B-electronic state. The higher altitude spectrum also indicates the probable presence of N_2^+ Meinel emission. Together, these studies provide strong evidence for the existence of ionization in sprites, and imply relatively high-energy incident electrons.

Objectives for the Coming Year

Work in the upcoming year will involve continued development of trace gas retrieval algorithms in preparation for the launch of the EOS Aura satellite in early 2004, as the OMI will measure NO_2 column densities. Aspects of the existing algorithm used to process the OMI measurements will be tested and refined. Specifically, we plan to study NO_2 profiles to be used for computation of air mass factors. The studies will be based on atmospheric chemical models as well as climatological stratospheric profiles from existing satellite observations. The NO_2 algorithm will be tested extensively on data from the GOME instrument on the European ERS-2 satellite. Version 1.0 of the NO_2 algorithm will be readied by year's end. Also, if additional funding becomes available, work will continue on ground-based validation of NO_2 measurements, as well as further investigations of sprites and related phenomena.

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

GEST Investigator: Mark A. Olsen

Collaborator: Anne R. Douglass (PI, GSFC)

Abstract

The exchange of air and chemical species across the tropopause has implications for studies of 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 is concerned with the development and application of diagnostics for STE in global atmospheric data sets and output from global atmospheric models.

Description of Research

This task focuses on the analysis of STE in global atmospheric data sets and model output. Science issues that will be addressed include ozone trends in the upper-troposphere/lower-stratosphere, seasonal and interannual trends in STE of total air mass and ozone mass, and the importance of STE to climate change.

Accomplishments during the Reporting Period

The initial work under this new task has been to refine a new ozone and mass STE diagnostic to be used with various data assimilation systems, such as the finite volume General Circulation Model (fvGCM), and the Goddard Chemistry and Transport Model (GCTM). The role of the Asian monsoon in transporting water to the stratosphere is also currently being investigated.

Objectives for the Coming Year

Task work for the coming year will include diagnosing mass and ozone STE for GCTM simulations using a single year’s winds with differing boundary conditions. This will provide information used to determine the relative importance of composition and dynamics to any trend in STE. The seasonal and interannual trends and the variability of STE will be examined in detail as results from a fifty-year run of the GCTM become available. In addition, a global and seasonal climatology of the preferred locations and local magnitude of STE will be determined. The work on the transport of water to the stratosphere from the Asian monsoon will also be continued during this time period.

UMBC Grant (05-5-25957): **Solar Irradiance Variability and Climate Implications**

GEST Investigator: Judit M. Pap, PI

Collaborators: Stuart Jordan (GSFC), Charles Jackman (GSFC), Doug Rabin (GSFC), Harry Jones (GSFC)

Abstract

Within the last year, work continued to study the relationship between variations in solar irradiance (both bolometric and at various UV and EUV wavelengths) and the magnetic fields of active regions (sunspots and faculae) as measured by the Solar and Heliospheric Observatory (SOHO)/ Michelson Doppler Imager (MDI) experiment and the full-disk magnetic field strength data as measured at the Kitt Peak Solar Observatory. The motivation and goal of these studies are to better understand the underlying physical mechanism of solar irradiance variability and to improve irradiance models for climate studies. One of the most important results is that the relation between the amplitude of the sunspot cycle as defined by the sunspot number and/or the magnetic field strength is not linear: both total and UV irradiances were higher during the weak Solar Cycle 23 than the magnetic indices. The reason for this discrepancy is being further investigated as part of our SOHO/Guest Investigator program. The Upper Atmosphere Research Satellite (UARS)/Active Cavity Radiometer Irradiance Monitor (ACRIM) II total solar irradiance measurements have also been reprocessed, and currently these data are being validated and integrated into the long-term NASA irradiance database.

Description of Research

The research studies variations in solar output using observations from various surface and space-based sources. Results serve to both characterize the variations in solar output, examining the links between different indices, and to understand the reasons for the variations. The work includes leading several international efforts and collaborations with a number of scientists in different institutions.

Accomplishments during the Reporting Period

During the last year, task work continued to study the origin of solar irradiance variations. Results show that both total irradiance (integrated over the entire solar spectrum) and UV irradiance increased more during the weak Solar Cycle 23 than the rest of the magnetic indices. The reason for this discrepancy is not understood. In case of total irradiance, the less and smaller sunspots during cycle 23 may be less effective to diminish solar irradiance. In case of UV irradiance, sunspots do not play significant roles, so one can assume that during weaker cycles the magnetic fields are spread over larger areas rather than concentrating in bright features. These results may have climatology significance, since current irradiance models used in climate studies assume that there is a linear relation between irradiance variations and magnetic activity.

These results were confirmed by studying the MDI images, as a collaborative effort with Michael Turmon (JPL) and Harrison Jones (GSFC/Southwestern Station). Various features were compared, as deduced from the MDI and Kitt Peak images and using the Hungarian high-resolution sunspot observations. The MDI sunspots were found to be larger than the Hungarian and Kitt Peak sunspots, while the MDI faculae were smaller and correlated better with UV indices.

The PI chaired the Solar Variability and Climate Change session (D2.3/E3.3 event) of the Committee on Space Research (COSPAR) Assembly held in Houston, October 10-18, and to chair Working Group 1 of the International Solar Cycle Studies, working under the auspices of the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP).

The PI was also the chief editor of the AGU Monograph Series, *Solar Variability and Its Effect on the Earth's Atmosphere and Climate.*

Objectives for the Coming Year

The key objective for the coming year is to study why both solar UV and total irradiance is high for the relatively weak solar cycle 23 when fewer and smaller sunspots and faculae occurred on the Sun. For this purpose, analysis of the highest resolution MDI images has begun to see whether small, weak magnetic elements are hidden in the normal 1000x1000 pixel images, and to establish the role of weak fields in irradiance variations. An additional goal, in collaboration with scientists from the Jet Propulsion Laboratory, National Solar Observatory at Kitt Peak, California State University and the Heliosphysical Observatory at Debrecen, is to directly compare solar feature classification to make sure that a uniform classification system is developed. Part of this research is study the evolution of sunspots and their relation to irradiance changes, and to develop a system based on the structural changes of sunspots to predict eruptive events of the Sun. These studies are important for both climate modelling and space weather. These studies have currently been funded by NASA through the PI's LWS proposal for a three-year period. Finally, improvements continue in both image and time series analysis techniques that will be provided to the Virtual Solar Observatory and will be a pipeline for the SDO/HMI experiment irradiance modeling task. The PI will also continue to lead the ISCS WG1 activities during its last year and to prepare the approved Sun-climate session for the 35th COSPAR General Assembly, chaired by the PI.

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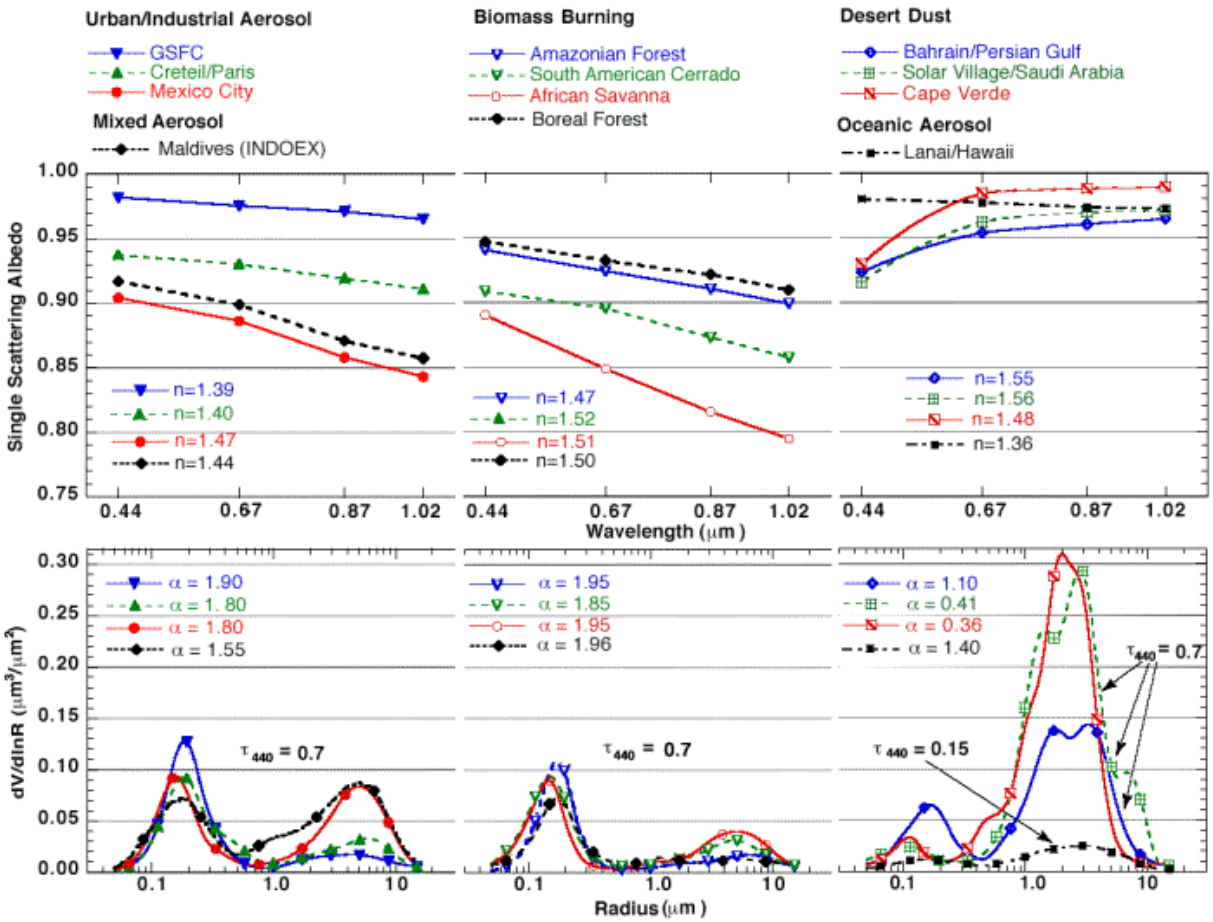
Aerosols and Lidar Research Group



The averaged optical properties of different types of tropospheric aerosols retrieved from the worldwide AERONET network of ground-based radiometers.

Aerosols and Lidar Research Group

GEST Center scientists conduct multi-disciplinary research in many areas related to climate change and weather forecasting. Aerosols, cirrus clouds, ozone, and water vapor play major roles in the Earth's radiation budget, directly and indirectly affecting the Earth's radiant energy balance. GEST Center scientists are collaborating with NASA and other researchers in developing retrieval algorithms for data interpretation, modeling techniques to represent physical processes, assimilation methods used to combine observations and models, and new instruments.

The research in the framework of the globally distributed Aerosol Robotic Network (AERONET) is centered on the analysis of measurements made by automatic sun-sky scanning radiometers. The main effort was focused on the development of the improved inversion code for the AERONET data (Dubovik). Multi–site, multi-year aerosol optical depth data from AERONET provided a unique opportunity for a comprehensive analysis of diurnal aerosol variations according to aerosol types and landscapes (Smirnov). The interannual variability of the aerosol optical depth in the southern Amazon basin and the relationship between the satellite-detected fire counts and the smoke aerosol optical depth was investigated (Eck). Also, the analysis of AERONET data showed that there is no unknown absorption of sunlight in the atmospheric windows covered by AERONET (Dubovik, Smirnov). Large dynamics in both size distributions and spectral single-scattering albedo of the dust aerosol were quantified in both the fine and coarse mode aerosol components, based on data from the ACE-Asia campaign (Eck). A simple model of the maritime aerosol component, derived using AERONET data from island locations in the Atlantic, Pacific, and Indian Oceans, was developed (Smirnov, Dubovik, Eck).

The Micro-Pulse Lidar Network (MPLNET) is comprised of lidars stationed to provide measurements and automated processing of aerosol and cloud vertical structure at sites around the world, including vertical distribution of cloud and aerosol layer heights, optical depths, and extinction profiles (Welton, Berkoff). Accomplishments this year include development and demonstration of a new prototype version of the Micro-Pulse Lidar (MPL) instrument, implementation of new fiber-coupled laser-diode pumps to improve laser system performance, and investigation of instrument overlap correction methods.

The most recent theoretical studies showed that three-dimensional radiation effects caused by surface inhomogeneities play an important role in the optical remote sensing of atmospheric aerosol and land surface reflectance. These effects may contribute to the error budget of retrievals over a broad range of sensor resolutions, thus making the development of accurate atmospheric algorithms for the EOS instruments MODIS and MISR, and Landsat ETM+ imager of crucial importance. Initial validation showed that a new 3-D method of aerosol retrievals from ETM+ data over land effectively removes biases in the aerosol optical thickness caused by the use of 1-D theory in current algorithms (Lyapustin, Yujie Wang).

Surface angular and spectral properties were analyzed using the Cloud Absorption Radiometer (CAR) data obtained during two major field experiments: The Southern African Regional Science Initiative 2000 (SAFARI 2000) and Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS). Results from analysis of SAFARI 2000 measurements show complete spectral bidirectional reflectance functions for African savanna, saltpans in southern Africa, and marine stratocumulus clouds off the coast of Namibia. Preliminary results from CLAMS show complete spectral BRDF of the ocean for different sun angles (Gatebe).

Using satellite-derived data from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) and Meteosat, the direct radiative forcing of Saharan and Asian dust has been calculated by Hsu, who continued to improve new algorithms for retrieving aerosol properties such as optical depth and the Angstrom exponent from the satellite data. The long-term temporal changes in airborne Asian dust were also studied using 20 years' of Total Ozone Mapping Spectrometer (TOMS) data.

The first version of the Forecast of Atmospheric Radiative and Optical Properties (FAROP) model was successfully designed. The model uses the outputs of a Navy global aerosol dispersion model and simulates the radiance reaching a detector for user defined viewing geometries. The model is very fast (~10-20 sec), making it an ideal tool for real time model predictions (Gassó). Work on modeling the transport and deposition of Saharan dust over the North Atlantic Ocean has continued, as has collaboration with investigators from the Puerto Rico Dust Experiment (PRIDE) field program. A similar investigation of simulating dust, smoke, and sea salt aerosols over the Caribbean and Florida during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL/FACE) experiment is underway (Colarco). A study is underway to assess the utility of remote sensing of environmental parameters as indicators of the potential threats to human health in contaminated Arctic areas (Yurchak).

A method (based on Raman lidar measurements) was developed to estimate aerosol parameters at various altitudes (Veselovskii). The lidar provides three backscattering (at wavelengths 355, 532, 1064 nm) and two extinction (355, 532 nm) coefficients, making possible the estimation of aerosol parameters in the 0.1-10 μm radius range.

To estimate possible effect of thin cirrus clouds on the retrievals of water vapor (using IR sensors such as Advanced Infrared Sounder (AIRS) and the Geostationary Observational Environmental Satellite (GOES), sub-tropical cirrus properties measured by the GSFC Scanning Raman Lidar (SRL) were analyzed. Comparison of water profiles between AIRS retrievals and SRL measurements provides an important validation element (Zhien Wang).

The development of high-quality Fabry-Perot etalon filters is critical to the advancement of lidar technology and to the success of spaceborne atmospheric lidar missions. Recent activities include development of the Fabry-Perot etalon filter included in the Geoscience Laser Altimeter System (GLAS) (Lancaster).

Continuing this past year was development and maintenance of the current NASA tropical data set of tropospheric column ozone (TCO) and stratospheric column ozone (SCO) derived from the TOMS measurements using the Convective Cloud Differential (CCD) method. The CCD, TCO, and SCO data are updated monthly and made available to the world science community via the Internet. A new algorithm, based on a technique called “cloud slicing,” derives tropospheric ozone profile information, and the cross-calibration method (which uses CCD and SCO) provides daily global columnar tropospheric ozone measurements (Ziemke).

It should be clear from this brief summary and the following detailed reports that the GEST Aerosols and Lidars Research Group is at the forefront of research activities in these important areas, with results from these investigations making their way into the literature and research underway at other institutions, to the benefit of all.

Alexander Smirnov

Task 900-03-041: **Cloud Absorption Radiometer**

GEST Investigator: Charles K. Gatebe

Collaborators: Michael D. King (PI, GSFC), Oleg Dubovik (GEST), Si-Chee Tsay (GSFC)

Abstract

Major efforts over the past year involved analysis of Cloud Absorption Radiometer (CAR) data obtained during two major field experiments: Southern African Regional Science Initiative, 2000 (SAFARI 2000) and Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS). Results from analysis of SAFARI 2000 measurements show complete spectral bidirectional reflectance functions for African savanna, salt pans in southern Africa, and marine stratocumulus clouds off the coast of Namibia. Preliminary results from CLAMS show complete spectral BRDF of the ocean for different sun angles.

Description of Research

With the use of related airborne instrumentation, such as CAR, the primary objective is to develop a new inversion scheme to simultaneously retrieve aerosol optical properties and surface bidirectional reflectance distribution function (BRDF) using radiation measurements from CAR obtained over several regional types including: cerrado (Smoke, Clouds, and Radiation Experiment - Brazil; SCAR-B); ocean (Persian Gulf and Atlantic Ocean; Kuwait oil fire smoke experiment; Tropospheric Aerosol Radiative Forcing Observational Experiment, TARFOX; and CLAMS); Mopane and Miombo woodlands of southern Africa (Botswana, South Africa, and Zambia; SAFARI 2000); pans of Botswana and Namibia (SAFARI 2000); the Great Dismal Swamp (Sulfates, Clouds, And Radiation – Atlantic, SCAR-A; TARFOX; and CLAMS); and desert (Saudi Arabian Kuwait Oil Fire Smoke Experiment). The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties inferred from airborne directional radiance measurements.

Accomplishments During the Reporting Period

Several activities involving analysis of CAR measurements of BRDF during SAFARI 2000 and CLAMS have been accomplished. Results from analysis of SAFARI 2000 measurements show complete spectral bidirectional reflectance functions for African savanna, salt pans in Southern Africa, and marine stratocumulus clouds off the coast of Namibia. Preliminary results from CLAMS show complete spectral BRDF of the ocean for different sun angles.

Meetings attended this year include the CLAMS data workshop held in Lanham, Maryland, February 27-28, 2002; the Spring American Geophysical Union Meeting, Washington, D.C., 28-31, 2002; the Third International Workshop on Multiangular Measurements and Models (IWMMM-3), Steamboat Springs, Colorado, 10-12 June 2002; the Kenya Chemical Society Workshop, Egerton, Kenya, 22-23 August, 2002; MODIS Workshop on Land Surface Radiation Budget Variables and Snow and Ice Products, Boston University, October 21-22, 2002; Committee on Earth Observation Satellites (CEOS)/Working Group on Calibration and Validation (WGCV)/Land Product Validation Workshop on Albedo, Boston University on October 22-24, 2002; and community outreach activities on remote sensing applications, Nairobi, Kenya 18 July to 28 August, 2002.

Objectives for FY 02-03

Work in the coming year will include continuing development of a new inversion scheme to simultaneously retrieve aerosol optical properties and surface BRDF using radiation measurements from CAR obtained over several regions, including cerrado (Brazil; SCAR-B), ocean (Persian Gulf and Atlantic Ocean; Kuwait oil fire smoke experiment, TARFOX, and CLAMS), Mopane and Miombo woodlands of southern

Africa (Botswana, South Africa, and Zambia; SAFARI 2000), pans of Botswana and Namibia (SAFARI 2000), the Great Dismal Swamp (SCAR-A, TARFOX, and CLAMS), and desert (Saudi Arabian Kuwait Oil Fire Smoke Experiment). The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties inferred from airborne directional radiance measurements.

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), Rita L. Aissi-Wespi (DSTI)

Abstract

Remote sensing and observation are providing powerful new tools for retrieving information concerning the human health aspects of sustainability by improving our understanding of the linkages between health-related environmental and ecological parameters. The subject of this study involves a unique environment: the Arctic. The ecology and environment of the Arctic are very sensitive to both anthropogenic pollution and climate change. A unique aspect of the Russian Arctic specifically is the relationship between the environment and indigenous humans involved in reindeer husbandry. The socioeconomic wellbeing and health of these people are dependent upon the ecological conditions of the land they live on and the well being of the reindeer with which they work. The main objective of this task has been to assess the utility of Earth remote sensing of Arctic environmental parameters as indicators of potential threats to human health in the Arctic, with emphasis on environmental contamination and the ecological situation related to the state of reindeer husbandry. The first step in this analysis was the preparation of a review of the present state of Earth remote sensing capabilities for contaminant detection and monitoring within the Arctic region. A study is now under way to determine what remote sensing technologies and derived information could best support reindeer husbandry.

Description of Research

The Russian Arctic was chosen as an area of interest for several reasons. The vast expanse of land in the Russian Arctic is most easily observed through remote sensing due to the sheer size of the area of interest. It is also well known that current climate changes and contaminant transport to and within the Arctic are having clear impacts on both humans and the environment, as documented through the Arctic Monitoring and Assessment Program. Finally, Russian socioeconomic impacts caused by the dissolution of the Soviet Union have initiated catastrophic changes in Russian reindeer husbandry practices and, as a consequence, the health of the indigenous people associated with such activities. It has been shown that anthropogenic factors such as pollution and the state of the reindeer husbandry industry are two of the main factors influencing the health of indigenous peoples in the Russian Arctic.

The prospect of utilizing information from remote sensing to support early warning and decision-making about the health of indigenous people in the Arctic regions was evaluated first. A review was written to summarize the present capability of remote sensing technologies to determine the best methods to detect and monitor Arctic pollutants and that might be most useful in implementing decision support systems addressing activities impacting health in the Arctic. A matrix for classifying remote sensing methodologies applicable to these purposes was formulated, and the results of an analysis of remote sensing applications relevant to reindeer husbandry, which take place in Scandinavia, Canada, and the U.S., were prepared.

The next step is to test the suitability of selected remote sensing data products and observations for studying specific aspects of the task's goals. Currently, research is being carried out to find all appropriate data sources, products, and ways to access that information.

Accomplishments during the Reporting Period

A review of remote sensing applications for pollution detection and monitoring in the Arctic has been completed; it is the information base for research currently being conducted for the project. It has become clear that the health of the indigenous peoples in the Russian Arctic who are associated with reindeer herding is directly correlated with reindeer husbandry. The corresponding link between human health and reindeer activities and their environment and the use of remote sensing are included in the analysis.

Objectives for the Coming Year

Activities for the coming year will focus on testing selected remote sensing methodologies for retrieving required health-related information about environmental and contaminant impacts in specific test cases in the Arctic. One of the main objectives will be to select and test chosen methodologies at a minimum of one field site in the Russian Arctic. Another objective is to form technical partnerships for information sharing with members of the indigenous Russian community involved in reindeer herding in the area of the field site, and with appropriate members of the Russian scientific community.

Task 912-01-011: **The Micropulse Lidar Worldwide Observational Network (MPLNET)**

GEST Investigator: Timothy A. Berkoff

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

Abstract

The Micro-Pulse Lidar Network (MPLNET) is comprised of lidars stationed around the globe to provide measurements of aerosol and cloud vertical distributions on a continuous basis. Reliable and accurate instrumentation performance in the field is essential to assure the generation of high-quality data from remote sites. Investigation of technology issues in relation to network operational activities is a key component in the success of MPLNET. Accomplishments this year include development and demonstration of a new prototype version of the Micro-Pulse Lidar (MPL) instrument, implementation of new fiber-coupled laser-diode pumps to improve laser system performance, and investigation of instrument overlap correction methods. In addition, engineering improvements were applied to a number of lidar systems in the network.

Description of Research

Each lidar in the network consists of a telescope, laser, receiver optics, detector, and data collection system. These lidar systems are novel in that they are portable and eye-safe, and therefore present a unique set of technology challenges different from traditional lidar systems. In this effort, investigations are primarily focused on improving instrument optical stability, developing new measurement techniques to monitor and maintain data quality in the field, and development and commercialization of a new optimized instrument tailored to MPLNET. This is accomplished through analytical and numerical analysis of instrument characteristics to address known measurement and operational issues. Engineering upgrades and improvements are first demonstrated at the prototype level in the lab, and then applied to MPLNET instruments to be deployed into the field.

Accomplishments during the Reporting Period

For the first time, MPL prototype systems called "Type 4" were constructed and tested. Technical guidance and oversight was provided for the development and fabrication of each of the main subassemblies for the new system, which were contracted out to various vendors. Delivered subassemblies were characterized and successfully integrated into completed prototype systems. Two prototype systems were constructed, and results obtained from these systems demonstrated a significant improvement in signal-to-noise performance, with enhanced operational characteristics tailored to MPLNET activities. As a result, the new "Type 4" system is the preferred

version of the instrument, and arrangements to replicate these prototypes through a commercial vendor are underway.

During this reporting period, progress was also accomplished in demonstrating an alternative method to obtain the instrument "overlap" correction. Traditional procedures to obtain this data correction require a horizontal 10-15 km clear line-of-sight and homogenous atmospheric conditions, both limiting the location and ease in which lidars can be successfully used. During this year, preliminary results were obtained using a small-diameter, wide-field secondary receiver to obtain the MPL overlap corrections in a vertical path at night, then transferring this correction to daytime measurements. This approach has a significant benefit in that overlap corrections can be obtained without the need for horizontal measurements. Preliminary results of this approach and a discussion on the impact on reducing uncertainty and bias errors in MPLNET aerosol profiles will be presented at the International Geoscience and Remote Sensing Symposium (IGARSS) conference in Toulouse, France.

For the first time in MPLNET activities, an alternative laser diode pump has been used to increase laser power and potential lifetime, while enabling in-field laser repairs. Past MPL laser systems have used discontinued bulk-optic diode lasers that were limited in power, routinely failed within eight months of operation, and expensive to replace. Use of an alternative diode pump was investigated; a vendor was selected to obtain diodes with the desired spectral and fiber coupling characteristics, to successfully pump the MPL Nd:YLF laser medium. The MPLs at GSFC and South Pole Station were successfully upgraded to this new style laser diode pump; future replacements at other sites are anticipated.

More than six existing MPLs were upgraded with a variety of engineering improvements, benefiting a number of research sites and activities around the globe. This includes working with National Oceanic and Atmospheric Administration (NOAA) personnel to implement laser modifications at the Amundsen-Scott South Pole station, upgrade of a system at Rabben Station in Svalbard, Norway, MPL equipment deployment to White Sands New Mexico for Ice, Cloud, and Land Elevation Satellite (ICESat)/Geoscience Laser Altimeter System (GLAS) calibration validation activities, support to the Cirrus Regional Study of Tropical Anvils and Cirrus Layers (CRYSTAL) field campaign in Florida, the Smoke Aerosols, Clouds, Rainfall and Climate (SMOCC) field campaign in Brazil, the Naval Research Laboratory at Monterey California, and upgrade of the Scripps Institute lidar.

Objectives for the Coming Year

During the next reporting period, the new "Type 4" MPL system should become available through a commercial vendor to provide a new avenue for research groups interested in long-term studies of aerosol and cloud properties to participate in MPLNET. Technology improvements in existing systems within the network will also continue. This will include further development and refinement of overlap correction techniques, site implementation, and investigations of instrument stability. In addition, construction of a Small Lidar Advanced Measurement (SLAM) facility to improve MPLNET calibration and validation activities should occur.

Task 912-01-011: **(a) The Micro-pulse Lidar Worldwide Observational Network (MPLNET); (b) The Geo-Science Laser Altimeter System (GLAS) Satellite Lidar Project**

GEST Investigator: Ellsworth Judd Welton

Collaborators: James Spinhirne (PI, GSFC)

Abstract

The investigator serves as the project scientist and manager for the micro-pulse lidar (MPL) worldwide observational network, MPLNET, which began operation in 2000. MPLNET activities include continuous measurements of

aerosol and cloud vertical structure at sites around the world. Measurements are also made during various field experiments and ocean cruises. The vertical distribution of cloud and aerosol layer heights, optical depths, and extinction profiles are determined for all MPL deployments. Automated processing algorithms have been developed to process the MPLNET data and distribute it through the MPL Website (provided below). In addition, work has been completed on the Geoscience Laser Altimeter System (GLAS) satellite lidar project, launched in January 2003. In particular, improvements to the GLAS cloud and aerosol layer processing algorithms and calibration techniques have been performed, and validation efforts have been organized using sites in the MPLNET project.

Description of Research

Measurements of cloud and aerosol physical and optical properties are needed for calibration/validation efforts by EOS satellite projects, as data sets for a variety of modeling efforts, and for studies aimed at better understanding the role these atmospheric particles play in the global climate. There are many instruments capable of providing key data products on cloud and aerosol properties. However, one key required data product has been unavailable: long-term measurements of the vertical distribution of cloud and aerosol layers at key sites around the world. In particular, the vertical profile of cloud and aerosol layer heights and optical depths are required.

One instrument capable of providing this information is a lidar, which uses pulses of laser light to profile the vertical distribution of cloud and aerosol layers in the atmosphere. Despite this need, lidar systems prior to the mid-1990s were large, expensive, and not eye-safe, which made them unsuitable for long-term worldwide deployments. During the 1990s, the first small, autonomous, and eye-safe lidar system became available: the micro-pulse lidar system(MPL). The MPL has since been used successfully at a long-term site run by the Atmospheric Radiation Measurement (ARM) program and in several independent field experiments around the world. In 2000, the EOS program agreed to fund the creation of a worldwide network of MPL systems to provide long-term measurements of cloud and aerosol vertical properties at sites around the world. The network is called MPLNET. MPLNET sites are co-located with Aerosol Robotic Network (AERONET) sunphotometers. In addition, the EOS funding provides support for MPL deployments to field experiments. The NASA Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) project has also provided funding to perform MPL measurements during ocean cruises. This provides an opportunity to study aerosols and clouds over remote ocean areas that would otherwise be overlooked. MPLNET has been in successful operation since the beginning of 2000. However, the best platform for measuring the long-term distribution of cloud and aerosol layers worldwide is from a satellite based lidar. The Geoscience Laser Altimeter System (GLAS) is the first such satellite lidar project and was launched on January 12, 2003.

Accomplishments during the Reporting Period

Work on the MPLNET project was accomplished during 2002. Measurements continued at the GSFC and South Pole MPLNET sites, and at our two Japanese National Institute of Polar Research-funded sites on the coast of Antarctica and in Norway. Final preparations were completed to begin operations at a new site at the Naval Research Lab in Monterey, California.
New, automated data processing algorithms are under development to analyze data from all MPLNET sites and field experiments. The data are available from the MPLNET Website (http://mplnet.gsfc.nasa.gov/). Data products include profiles of the MPL signal, aerosol and cloud layer heights, aerosol extinction profiles, and associated parameters. The data are collected jointly with co-located AERONET sunphotometers, and both data sets are correlated in the MPLNET data files. Construction was completed on a new MPL prototype that incorporates an improved optical and mechanical design. This work is discussed in more detail by Berkoff, elsewhere in this report.

Work on the GLAS satellite project was completed this year. Planning for GLAS calibration/validation work using MPLNET sites led to the installation of an MPL at the primary GLAS ground site at White Sands, New Mexico. In addition, the new MPLNET site at the NRL in Monterey will be used for GLAS calibration/ validation work. The ground MPLNET sites are being used for the GLAS calibration/validation period, currently scheduled to end in early summer 2003.

Objectives for the Coming Year

Because the investigator left GEST at the end of 2002, there are no objectives listed for the coming year.

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

GEST Investigator: Redgie S. Lancaster

Collaborator: James D. Spinhirne, (PI, GSFC)

Abstract

This research activity focuses upon developing advanced electro-optic instrumentation and technologies for use in satellite remote sensing. Recent activities include development of the Fabry-Perot etalon filter included in the Geoscience Laser Altimeter System (GLAS), the scientific payload of the Ice, Cloud, and Land Elevation Satellite (ICESat).

Description of Research

Developing high-quality Fabry-Perot etalon filters is critical to the advancement of lidar technology and to the success of spaceborne atmospheric lidar missions. This is especially true in the case of daytime lidar measurements, where faint laser return signals must be detected against the contamination of strong solar background emissions. The requisite background rejection cannot be achieved using interference filters; a Fabry-Perot etalon filter is required. The GLAS instrument onboard ICESat spacecraft is a case-in-point. The ICESat mission is designed to quantify ice sheet mass balance and to enable a better understanding of many aspects of the Earth's climate system, ranging from climate change to variations in sea level. ICESat also measures global distributions of clouds and aerosols for studies of their effects on atmospheric processes and global change, and land topography, sea ice, and vegetation cover.

Accomplishments during the Reporting Period

ICESat was successfully launched from the Vandenberg Air Force Base in January 2003. Prior to launch, activities centered on developing, testing, and characterizing the Fabry-Perot etalon filter critical to the performance of the 532-nm-channel receiver. In this last year efforts focused on developing the active control loop that allows the etalon filter to maintain high performance under a wide variety of changing instrument and space environment conditions. This required developing several optional control systems to counter a number of contingencies that could be encountered once ICESat was inserted into orbit. Several technical challenges were overcome to arrive at an actively controlled filter that is truly unique among space systems.

Objectives for the Coming Year

Developing the etalon filter does not end with the launch of ICESat. Testing, characterizing, and verifying the filter and instrument performance continues, using data acquired while in orbit.

Task 912-31-157: **Inversion of Multiwavelength Lidar Data for Retrieval of Aerosol Size Distribution Parameters**

GEST Investigator: Igor Veselovskii

Collaborator: David N. Whiteman (PI, GSFC)

Abstract

Aerosols are key atmospheric constituents influencing the Earth's radiation balance. Lack of knowledge of related optical parameters results in uncertainty in modeling the planet's radiative forcing. The goal of this project is to develop lidar methods to estimate aerosol parameters over a wide range of particle sizes. The effective radius, number, surface, volume concentration, and complex refractive index of aerosols at different altitudes are obtained by using Raman lidar based on a tripled Nd:YAG laser. This lidar provides three aerosol backscattering (355, 532, 1064 nm) and two extinction (355, 532 nm) coefficients, which makes possible the estimation of aerosol parameters in the radius range of 0.1-10 μm using the inversion with regularization procedure. In contrast to the classical Tikhonov method, which only accepts that solution for which the discrepancy reaches its global minimum, in the algorithm being used in this work, the averaging of solutions in the vicinity of this minimum is performed. This averaging stabilizes the underlying ill-posed inverse problem. Simulation studies demonstrate that the data set from this lidar is sufficient to estimate parameters for a bimodal aerosol size distribution.

Description of Research

The focus of this program is to improve the accuracy of aerosol and cloud parameter retrieval using a multi-wavelength Raman lidar based on a tripled Nd:YAG laser, and to study the influence of aerosols on cloud parameters. Aerosol size distribution (ASD) at different heights is obtained with multiwavelength Raman lidar. The prototype of this lidar was built in 2001-2002 in GSFC's Laboratory for Raman Lidar. It includes a Continuum Precision II tripled Nd:YAG laser and a 16-inch receiving telescope. The receiving module is designed to measure eight signals: elastic scattering at 355, 532, and 1064 nm; nitrogen Raman scattering at 387 and 607 nm; the water vapor Raman signal at 408 nm; the liquid water Raman signal at 402 nm; and the depolarized signal of elastic scattering at 355 nm. The lidar provides three aerosol backscattering and two extinction coefficients. Preliminary simulations demonstrate that this $3\beta+2\alpha$ set is sufficient to estimate bimodal size distribution parameters even with optical data errors up to 20%. The previously developed inversion algorithm has been significantly improved. In retrieving bimodal aerosol size distribution aerosol radii up to 30 μm are considered, so Mie computations become extremely time consuming. To speed up the calculations, databases for Mie functions and corresponding matrix elements used in the retrieval were created and implemented. To maximize the stability of the algorithmic inversion scheme, different kernels and base functions were tested.

Accomplishments during the Reporting Period

The lifetime of tropospheric aerosols is on the order of a week, so continuous global monitoring is required to observe aerosol emission and transport. Multiwavelength lidar is a tool that is—in principle—capable of providing comprehensive information about height-resolved aerosol properties. The necessity for global monitoring dictates combining lidars in a network. The first attempt of such network operation was made in 2000-2001 in the context of the European Aerosol Research Lidar Network (EARLINET) program. The operation of more than 20 lidars across Europe provided information about aerosol extinction and backscattering height profiles. The next step in the framework of such a network would be to extend the retrieved data to include aerosol parameters such as single-scattering albedo, concentration, effective radius, and complex refractive index. It would be desirable to obtain this information from a simplified version of the multiwavelength lidar based on a tripled Nd:YAG laser, which is available for other

research. Such lidar monitors elastic (355, 532, 1064 nm) and nitrogen Raman (387, 607 nm) scattering, so three aerosol backscattering and two extinction coefficients (a $3\beta+2\alpha$ data set) are available.

In a recent publication [Veselovskii *et al.* 2002], the description of the modified Tikhonov algorithm was presented for retrieval of ASD. In contrast to the classical Tikhonov method, which only accepts that solution for which the discrepancy reaches a global minimum, in the algorithm described here average solutions in the vicinity of this minimum are calculated. This averaging stabilizes the underlying ill-posed inverse problem. The classical Tikhonov method demands also an *a priori* knowledge of optical data errors to estimate the stabilizing penalty term. The application of a modified discrepancy in this algorithm eliminates the necessity of including such information. The comparison of results obtained from $3\beta+2\alpha$ lidar data sets with simultaneous aircraft *in situ* measurements shows reasonably good agreement, so the simplified multi-wavelength Raman lidar has good potential for use in a lidar network.

The developed algorithm does not use any preliminary assumption about ASD; hence it may be applied to any kind of size distribution. Normally, aerosol distribution presents two modes—fine and coarse—so the ability of lidar to reproduce both modes becomes essential. A problem arises because the coarse mode may include particles as large as ~10 μm, while the longest wavelength available is 1.064 μm, so the corresponding kernel functions are not very sensitive to size variations of such large particles. In this study, several questions were addressed: Can the coarse mode of the ASD be estimated from Nd:YAG laser-based lidar, and what are the expected errors? Numerical simulation of retrieval of bimodal ASD from lidar data for different types of aerosols (urban industrial, biomass burning, desert dust, and oceanic) were performed and characterized by various relationships between particle concentrations in fine and coarse modes. The results of these simulations demonstrate that the volume of particles in coarse mode for all types of aerosols may be estimated with accuracy better than 50%.

Objectives for the Coming Year:

Because the investigator left GEST at the end of 2002, there are no objectives listed for the coming year.

Task 913-13-120: **Characterization of Aerosol and Atmospheric Parameters from Spaceborne and Surface-based Remote Sensing**

GEST Investigator: Santiago Gassó

Collaborator: Si-Chee Tsay (PI, GSFC)

Abstract

The main goal for the past fiscal year was achieved with the successful design of the first version of the Forecast of Atmospheric Radiative and Optical Properties (FAROP) model. The model uses the outputs of a Navy global aerosol dispersion model and simulates the radiance reaching a detector for user-defined viewing geometries at each grid point. The model uses the single-scattering approximation and simple parameterizations of water absorption. As a result, the model is very fast (~10-20 secs) making it an ideal tool for real-time model predictions. The motivation for such design was the operational need by the Navy to establish visibility conditions for detectors with different spectral responses.

Description of Research

The main objective for the past year was to make use of the aerosol mass concentrations predicted by an existing aerosol dispersion model, the Navy Aerosol Analysis and Prediction System (NAAPS), and to model the signal measured by different detectors for hypothetical viewing conditions commonly found in the environment. The main constraint for the model was

computational speed, as there was a need to have the simulated signals available in a timely fashion to support field and deployment decisions.

Accomplishments during the Reporting Period

A fast computer code, FAROP, that fulfills the design specification, was developed.
The code computes radiances measured by a hypothetical detector with 3 bands (visible, near-IR, and IR) for several viewing geometries. The detector is assumed to be mounted on an aircraft flying at 20,000 feet, looking at a target located at five different locations with respect to the plane. In two positions, the target is 10 km ahead and behind in the same layer as the sensor. In the other three, the target is on the ground, straight down; ahead, 60 degrees down with respect to the direction of motion of the aircraft; and away from the sun, behind the aircraft. Typical run time is on the order of 10 seconds for a region of the size of North America. The high speed is accomplished through the use of the single scattering approximation, a simple parameterization of the water vapor absorption and the use of the Henyey-Grenstein phase function. In addition, a new module has been created that computes top-of-atmosphere (TOA) and surface fluxes using the Fu-Liou radiative transfer code. With this capability, the code is able to compute aerosol radiative forcing. During FY 02, task work included a presentation at the Puerto Rico Dust Experiment (PRIDE) workshop in Miami, and participation in the Cirrus Regional Study of Tropical Anvils and Cirrus Layers (CRYSTAL) field experiment in Miami.

Objectives for the Coming Year

Research objectives for the next fiscal year include modeling the instantaneous aerosol direct forcing from the outputs of the NAAPS and comparison with ground-based measurements of aerosol forcing; and improving and expanding the method for retrieving aerosol mass concentration from space developed by Gassó and Hegg [2003].

Task 916-08-101: **Calculation of Radiative Forcing of Aerosols and Clouds Using Satellite and *In Situ* Measurements**

GEST Investigator: Nai-Yung Christina Hsu

Collaborator: Jay R. Herman (PI, GSFC)

Abstract

During this time period, there was continued improvement of new algorithms to retrieve aerosol properties (such as optical depth and Angstrom exponent) from data obtained with the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) and Meteosat. Using the information from these satellite data, the direct radiative forcing of Saharan and Asian dust has been calculated. The direct forcing of Saharan and Asian dust has been isolated by applying a regression technique to the collocated data sets obtained from the Total Ozone Mapping Spectrometer (TOMS)/Clouds and the Earth's Radiant Energy System (CERES) instruments. The long-term temporal change of airborne Asian dust was also studied using 20 years' worth of the TOMS data. Participation in the Aerosol Characterization Experiment (ACE)-Asia Phase 2 campaign also took place.

Description of Research

Part of this task is to develop data sets from various satellite-based instruments to address aerosols, water vapor, and other products suitable for the estimation of radiative forcing due to tropospheric aerosols and clouds. Top-of-atmosphere and bottom-of-atmosphere radiative flux measurements observed by satellite and ground instruments are also simulated using radiative transfer codes under various conditions.

Accomplishments during the Reporting Period

During this period, progress was made in applying research towards understanding the significant atmospheric processes that drive climate response.

Task work included participation in Phase 2 of the ACE-Asia campaign, which was organized on a grass roots basis by scientists at GSFC and in Asia

to make *in situ* and ground-based remote sensing measurements of Asian mineral dust during March-May 2002. To support the field experiments near-real time images of aerosol optical depth and Angstrom exponent from this algorithm were provided through a Website hosted at Code 916, http://code916.gsfc.nasa.gov/Missions/ACEASIA/satellite/index.html.

Images of aerosol index from TOMS and RGB images from SeaWiFS were also provided. These images were widely used by scientists based in Korea, Japan, and China for model validation and closure experiments. Results from task work led directly to a proposal from GSFC's Cloud and Radiation Branch (Code 913) to continue this important set of measurements.

A major new initiative was undertaken to study the direct and indirect effects on the climate due to smoke aerosols generated from biomass burning activities in Southeast Asia. Narrowband radiance measurements from ultraviolet to near-infrared wavelengths (obtained from, *e.g.*, SeaWiFS and TOMS) were combined with broadband irradiance measurements (*e.g.*, from CERES) to quantify how smoke aerosols modulate cloud radiative forcing. Results revealed that smoke is frequently present over large areas of cloud-covered regions in Southeast Asia during boreal spring. Depending on the loading of smoke aerosols, the reflected solar (emitted thermal) radiation from clouds can be reduced (enhanced) by as much as 100 (20) Wm^{-2} over the month of March 2000. A critical discovery was made that the reduction in cloud spectral reflectance at 670 nm is large enough to lead to significant errors in retrieving cloud properties, such as optical thickness and effective radius, from current satellite measurements, using instruments such as the Advanced Very-high Resolution Radiometer (AVHRR) and the Moderate-Resolution Imaging Spectroradiometer (MODIS). These groundbreaking results have been accepted for publication in Geophysical Research Letters and also serve as the basis for another proposal submitted by Code 913 to continue and expand this work.

As part of the effort to extend SeaWiFS aerosol retrievals over ocean to retrievals over land, development has begun of a new algorithm for retrieving aerosol optical thickness over arid and semi-arid regions using SeaWiFS radiances. The ability to determine such aerosol characteristics over these climatically important these regions using satellite data has historically been difficult. Sensitivity studies for this work have been conducted, and validation of preliminary results using retrieved aerosol optical thickness over the Sahara and Sahel region from the Aerosol Robotic Network (AERONET) database look promising.

Studies of the diurnal variation of the direct radiative forcing of tropospheric aerosols continue, using satellite data on a regional scale. Aerosol optical thickness has been retrieved from geostationary satellites such as Meteosat, which was then normalized to those derived from SeaWiFS to account for the calibration problem associated with the Meteosat radiance measurements.

Objectives for the Coming Year

Studies of radiative forcing of tropospheric aerosols using satellite, aircraft, and ground measurements will continue. The aerosol information collected from ACE-Asia will help strengthen understanding of the aerosol property assumption used in calculating the radiative forcing of Asian dust.

A new CERES-Terra and SeaWiFS collocated data set will be created to compare the empirically derived values of direct forcing of smoke aerosols generated from biomass burning activities in Southeast Asia with theoretically simulated values to gain further understanding of the processes involved. These results will also be compared with those derived from smoke aerosols generated in other regions of the world such as South America and Africa.

Efforts will continue to refine the SeaWiFS algorithm to determine aerosol characteristics over surface areas that have previously been difficult to measure. More Meteosat data will be collected to continue investigation of the diurnal variation in radiative forcing caused by smoke and dust. The direct radiative forcings of aerosols derived using diurnal cycle data obtained by the geostationary satellites will be compared with those are based solely upon data from polar orbiting satellites,

which sample the Earth's atmosphere only once a day.

Task 916-21-144: **Tropospheric Ozone from Satellite Measurements**

GEST Investigator: Jerry Ziemke

Collaborators: P. K. Bhartia (PI, GSFC), Sushil Chandra (GSFC)

Abstract

Part of the work done during FY 02-03 was to develop and maintain the current NASA tropical data set of tropospheric column ozone (TCO) and stratospheric column ozone (SCO) data for 1979-present. These data are obtained from Total Ozone Mapping Spectrometer (TOMS) ozone measurements using the Convective Cloud Differential (CCD) method. With the CCD method, stratospheric column ozone is measured above high-reflectivity clouds and then subtracted from nearby clear-sky total column ozone in the atmosphere to derive TCO. The CCD TCO and SCO data are updated monthly and made available to the world science community by either `ftp` or Internet access. Two important new algorithms being developed under this task are the cloud-slicing and cross-calibration methods. Cloud slicing derives tropospheric ozone profile information, and the cross-calibration method (which uses CCD SCO) provides daily global measurements of column ozone in the troposphere.

Description of Research

The general purpose of this task is to derive tropospheric ozone data products from satellite-based ozone measurements. Research on tropospheric ozone for this task is conducted in Code 916 at GSFC by developing scientific algorithms and computer programs, validating the derived data products with ground-based measurements and conducting scientific assessment of derived ozone data. Validation includes comparisons with ground-based sonde-based ozone profile data. Half of this task is devoted to using existing TOMS ozone data for deriving tropospheric ozone. The other half is devoted to developing algorithms to derive tropospheric ozone from the Ozone Monitoring Instrument (OMI), scheduled for launch in 2004 on the Earth Observing System (EOS) Aura satellite.

Accomplishments During the Reporting Period

During FY 02-03 a new “cloud-slicing” algorithm was investigated, which is a refinement of the more generalized CCD method. This algorithm uses column ozone measured over clouds with large optical depth to derive ozone profile information in the troposphere. Cloud slicing will become an important method in the future to derive global tropospheric ozone profile information from satellites, as future satellite instruments will have small fields-of-view compared to current TOMS instruments, enabling a large database of derived ozone. The cloud-slicing data from TOMS are currently being validated and have not yet been released to the science community.

Another new TCO satellite data product was developed during FY 02-03 from the TOMS and Microwave Limb Sounder (MLS) stratospheric ozone data. The constructed TOMS/MLS data set represent daily TCO maps with nearly global coverage. This is the first such high-resolution TCO data set derived from multi-satellite/ instrument platforms. The derivation of TCO used a newly applied instrument cross-calibration method, which will be used for future satellite platforms for deriving TCO, including ozone instruments on the upcoming EOS Aura satellite. Previous attempts at deriving TCO from satellite data were not possible because of cross-instrument calibration differences. As with cloud slicing, the TOMS/MLS data are currently being validated and have not yet been released to the science community.

Other work done in FY 02-03 involved cross-analyzing National Oceanic and Atmospheric Administration (NOAA) outgoing longwave radiation (OLR; measured in Wm^{-2}) and TOMS reflectivity converted to OLR units for 1979-present to study long-term climate effects from clouds.

During FY 02-03 analysis was done of ozone levels and distributions for the 2002 World Meteorological Office (WMO)-United Nations Environmental Program (UNEP) assessment of ozone depletion (Section on Dynamical Influence On Global Ozone Trends). Participation in meetings included international EOS Aura ozone monitoring instrument (OMI) meeting in Greenbelt Maryland, and the EOS Aura OMI meeting in Finland, where a short presentation was given on TCO derived from TOMS/MLS and the upcoming EOS Aura platform.

Objectives for the Coming Year

The primary objective for FY 03-04 will be to develop algorithms to derive tropospheric ozone from the EOS Aura instruments, primarily the OMI and High-resolution Dynamics Limb Sounder (HIRDLS). The scheme will be to use current existing TOMS and MLS ozone data to establish these algorithms prior to the launch of EOS Aura in 2004.

Task 923-02-067: **AERONET Ground-based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Oleg Dubovik

Collaborators: Brent N. Holben (PI, GSFC)

Abstract

In the past year, the main efforts focused on performance verification of the currently operational version—and development of an improved version—of the Aerosol Robotic Network (AERONET) inversion code. The new method employs light scattering of polydisperse, randomly oriented spheroids instead of conventionally used spheres. It was proposed for desert dust retrievals and implemented in operational AERONET processing. Analysis of AERONET retrieval results was conducted to improve knowledge of aerosol optical properties and to clarify the contributions of “anomalous” nonaerosol absorption. The research resulted in developing a climatology of the variability of aerosol properties (including particle size distribution, refractive index, absorption etc.), based on analysis of AERONET retrievals obtained at different geographic locations and under different meteorological conditions. The analysis of the AERONET retrievals at low aerosol loading suggested no indications of any “anomalous” nonaerosol absorption in the atmosphere. Collaboration with other researchers involved analysis of AERONET aerosol retrievals at different locations and times.

Description of Research

The lack of detailed knowledge of the optical properties of aerosols is 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 deriving detailed aerosol optical properties at key locations. Therefore, ground-based aerosol measurements are widely used both to validate satellite retrievals of aerosol properties and to derive high-accuracy information addressing local aerosol properties. The research in this task focused on developing and improving the retrieval algorithm to derive detailed aerosol optical and microphysical properties from measurements made by the automatic sun-sky scanning radiometers that are globally distributed as a part of the Aerosol Robotic Network (AERONET). AERONET was initiated by NASA as a major ground-based remote sensing facility to validate aerosol retrievals by sensors on Earth Observing System (EOS) platforms.

Accomplishments during the Reporting Period

Eight years' worth of worldwide data from the AERONET ground-based radiometers were used to characterize the aerosol absorption and other optical properties in several key locations to establish the climatology of absorption and optical properties of key aerosol types observed in worldwide locations [Dubovik *et al.*, 2002]. The results characterize the significant variability of absorption for the same aerosol type due to different meteorological and source characteristics and different emission characteristics. There are important differences with previous assessments, and the work clarifies some features inherent in each type of aerosol (*e.g.*, spectral dependence of single scattering albedo, partition of fine and coarse mode in particle size distributions, etc.). For example, it was found that in contrast to aerosol models found in the literature, and in qualitative agreement with recent analysis of satellite data, desert dust absorption of solar radiation is very weak for wavelengths greater than 550 nm.

A new retrieval method was developed, accounting for particle nonsphericity [Dubovik, 2002b], proposing a method for the retrieval of the optical properties of non-spherical aerosols based on a shape mixture model of randomly oriented polydisperse spheroids. The motivation for this study was that all aerosol remote-sensing retrievals still rely on Mie theory, because retrievals accounting for particle non-sphericity are not as well defined methodologically and are computationally demanding. This is despite the need to account for particle nonsphericity in modeling the optical properties of dustlike aerosols. The new retrieval method provides significant improvements in dust-particle phase functions, size distributions, and refractive indices retrieved by AERONET for desert dust.

Nonaerosol absorption is defined as atmospheric absorption not associated with a known gas, *e.g.*, ozone or water vapor, and not correlated with the presence of aerosols. If organic gases emitted in the process of biomass burning or gases emitted from pollution sources together with the aerosol have an unknown absorption, it would not be reflected in the nonaerosol absorption described here, but rather in the reduced aerosol single-scattering albedo reported by AERONET. The non-aerosol absorption is determined as the extrapolation of the measured absorption optical thickness as a function of the aerosol scattering optical thickness, τ_{scat}, to $\tau_{scat} = 0$ [Kaufman *et al.*, 2002]. It was found that non-aerosol absorption in the atmospheric windows 0.44, 0.66, 0.86, and 1.02 µm has an optical thickness indistinguishable from zero with uncertainty of 0.002, leading to the conclusion that there is no unknown absorption of sunlight in the atmospheric windows covered by AERONET.

Objectives for the Coming Year

A primary objective for FY 03-04 is to further develop and improve the inversion code employed by AERONET to retrieve aerosol optical properties from measurements of atmospheric radiation. Specifically, polarization measurements will be inserted into the retrieval code to improve the flexibility of the scalar inversion code in its application to measurements with various geometries and wider spectral range. In addition, the inversion algorithm will be modified for simultaneously retrieving both aerosol and surface optical properties from simultaneous radiance measurements in both the downward and upward propagating directions. Specifically, inversion of AERONET measurements will be implemented with simultaneous airborne Cloud Absorption Radiometer (CAR) measurements and/or Multiangle Imaging Spectroradiometer (MISR)/Moderate-Resolution Imaging Spectroradiometer (MODIS) observations.

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

GEST Investigator: Thomas F. Eck

Collaborator: Brent N. Holben (PI, GSFC)

Abstract

The work performed in the past year included investigating the interannual variability of the aerosol optical depth (AOD) in the southern Amazon basin and the relationship between satellite-detected fire counts and the smoke AOD. Additional work included analysis of the optical properties of smoke aerosols for cases of very high aerosol concentrations. These events represent the extreme of smoke particle accumulation mode growth due to increased growth rates by coagulation at high concentrations. Fine mode smoke particles from these regions showed a wide range of sizes also due to combination of factors, including aerosol age (distance from source), combustion type (flaming/smoldering ratio), and smoke composition (fuel type). AERONET data from the Aerosol Characterization Experiment (ACE)-Asia campaign (Spring 2001) in eastern Asia were analyzed. Large dynamics in both size distributions and spectral single scattering albedo were quantified in both the fine and coarse mode aerosol components.

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. The research in this activity centers on analysis of measurements made by automatic sun-sky scanning radiometers that are globally distributed as a part of the NASA-managed Aerosol Robotic Network (AERONET). The measurements of spectral direct sun intensity and sky radiance distributions are used to infer a complete description of the 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 interactions with clouds.

Accomplishments during the Reporting Period

In this fiscal year, a primary focus of scientific data analysis for this task was the analysis of the interannual variability of the AOD in the southern Amazon basin and the relationship between the satellite-detected fire counts and the smoke AOD. The PI traveled to Brazil from July 5-19, 2002 to attend the Large-Scale Biosphere Atmosphere Experiment in the Amazon (LBA) International Scientific Conference in Manaus, and to assist in establishing AERONET monitoring sites in two new sites and in upgrading one established site in Rondônia, in Brazil's southern Amazon basin. These three sun-sky radiometer-monitoring sites collected data in support of the LBA Smoke Aerosols, Clouds, Rainfall and Climate (SMOCC) field campaign, which was conducted from September through November 2002. Principal objectives of this campaign are to investigate the physical and chemical interaction of biomass burning aerosols and cloud droplets in the transition period from dry to wet seasons in southern Amazônia. Additionally, data from these three sites will provide valuable validation of AOD retrievals from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on the Earth Observing System (EOS) Terra and Aqua satellites.

AERONET data from the ACE-Asia campaign (Spring 2001) in eastern Asia, from sites in China (Beijing, Dunhuang, and Yulin), South Korea (Anmyon and Cheju), and other sites in Mongolia, Taiwan, and Japan were analyzed. The almucantar retrievals processed with the new Dubovik spheroid model algorithm were used, since nonspherical desert dust particles are frequently present in this region in springtime. The 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. The analysis of the optical properties of smoke aerosols continued for cases of extremely high aerosol concentrations. These

events represent the extreme of smoke particle accumulation mode growth due to increased growth rates by coagulation at high concentrations. Comparisons of long range smoke transport cases (at GSFC from Quebec taiga fires on July 8, 2002; and at Moldova on September 11, 2002, from boreal peat fires in Russia) with source region cases (savanna burning in Zambia; tropical forest/pasture burning in Brazil) show a very wide spread in absorption, ranging from nearly nonabsorbing (peat fires) to strongly absorbing (savanna fires). Fine-mode smoke particles from these regions showed a wide range of sizes also due to a combination of factors, including aerosol age (due to the distance from the source), combustion type (due to the flaming/smoldering ratio), and smoke composition (due to fuel type).

Objectives for the Coming Year

A primary objective for the coming year is to participate in establishing AERONET monitoring sites in Thailand and Vietnam. These placements will be made to study the dynamics of biomass burning and urban aerosol optical properties and the interactions of these aerosols with clouds, as there are no data on aerosol optical properties in the literature from this region. Plans include establishing four to six AERONET sun-sky radiometer sites and approximately 20 hand-held sunphotometer sites. Another major research focus will be to analyze the retrievals of aerosol size distributions, refractive indices, and single-scattering albedo from sites that typically have mixtures of fine- and coarse-mode aerosols, such as are found in northern Asia (in springtime), India (year-round), and West Africa in the biomass burning season. These sites often have non-spherical desert dust aerosol present; analysis will therefore utilize the new spheroid retrieval algorithm developed by Dubovik, described elsewhere in this volume. Further, multi-year AERONET data sets from the southern Amazon basin in Brazil will be further analyzed to examine the relationship between smoke aerosol optical depth, fire counts, and meteorological phenomena, such as rainfall.

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 fiscal year focused on the analyses of the diurnal behavior of various types of atmospheric aerosols and its parameters. Multi-site, multi-year aerosol optical depth data from the Aerosol Robotic Network (AERONET) provided a unique opportunity for a comprehensive analysis of diurnal aerosol variations according to aerosol types and landscapes. A model of the maritime aerosol component derived using AERONET data from island locations in the Atlantic, Pacific, and Indian Oceans was also developed. The aerosol optical model includes information about optical parameters (aerosol optical depth and its spectral dependence, phase function, and single scattering albedo) and microphysical characteristics (size distribution and its parameters, refractive index). Nine peer-reviewed papers that were authored or co-authored by the GEST investigator were submitted, accepted, or published during this 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, and 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 nonintrusive nature.

Accomplishments during the Reporting Period

Diurnal variability of aerosol optical depth is important for various applications, including satellite aerosol data validation, radiative forcing computations, studies of aerosol interaction with humidity and clouds, and public health. Aerosols frequently exhibit widely varying optical properties over time due to diffusion and aging processes such as coagulation, humidification, scavenging by precipitation, and gas-to-particle phase conversion. Combined with varying source strengths and advection by local to synoptic meteorological processes, these properties create a dynamic atmospheric constituent with effects on climate, environment, and public health. In particular, diurnal effects are largely unknown and little studied due to a paucity of data. Long-term exposure to aerosols is being shown to be critically important to public health, particularly for lung cancer and cardiopulmonary mortality and respiratory diseases. However, little data exist that potentially could assess the impact of diurnal exposure. Multi-site, multi-year aerosol optical depth data from AERONET provide a unique opportunity for a comprehensive analysis of diurnal aerosol variations according to aerosol types and landscapes.

Analysis of the diurnal cycle over major urban/industrial areas within the network showed a prevailing pattern of the optical depth increase by 10-40% during the day at most sites. Diurnal variability range is <10% over various sites where dust aerosol is a major contributor to optical depth. Sites in southern Africa influenced by distant sources of biomass-burning aerosol show no diurnal cycle, while the presence of local sources causes a diurnal trend with a maximum aerosol loading observed in the afternoon hours. Over oceans, because of the very low optical depth, even 20% departure from the daily average is practically within the measurement uncertainty.

The quality of bio-optical products of satellite ocean color sensors is strongly dependent on the accuracy of atmospheric correction algorithms. Aerosol optical properties over the oceans vary considerably, depending on contributions of major aerosol components, *i.e.*, urban/industrial pollution, desert dust, biomass burning, and maritime. The optical characterization of these aerosols is fundamental to the parameterization of radiative forcing models and to the atmospheric correction of ocean color imagery. We present a model of the maritime aerosol component derived using AERONET data from three island locations: Bermuda (Atlantic Ocean), Lanai, Hawaii (Pacific Ocean), and Kaashidhoo, Maldives (Indian Ocean). The aerosol optical model includes information about optical parameters (*e.g.*, aerosol optical depth and its spectral dependence, phase function and single scattering albedo) and microphysical characteristics (*e.g.*, size distribution and its parameters, refractive index). The aerosol model can be employed as a maritime look-up table (LUT) kernel in coupled atmospheric retrieval and correction algorithms. It can also be advantageously employed as a LUT inversion kernel in pure aerosol retrieval schemes or in algorithms for classifying aerosol mixtures. The maritime aerosol model can be used as the defining single component of pure maritime air masses or in combination with various aerosol types (*e.g.*, dust, biomass burning, etc.). Finally, the model can serve as a source of input to aerosol transport models and radiative forcing simulations. The model encompasses a variety of maritime conditions in the simplest manner possible. It requires further validation based on the accumulated evidence of microphysical and optical measurements tied to radiative transfer closure experiments.

Objectives for the Coming Year

Task goals for the coming year will focus on developing the maritime aerosol optical model, participating in aerosol retrieval analyses for an aerosol optical properties climatology paper, and establishing additional AERONET sites.

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

GEST Investigator: Alexei Lyapustin

Collaborator: Robert E. Murphy (PI, GSFC)

Abstract

Recent theoretical studies have shown that three-dimensional radiation effects caused by surface inhomogeneities play an important role in the remote sensing of atmospheric aerosols and land-surface reflectance. These effects may contribute significantly to the retrieval error budget over a broad range of sensor resolutions, from Landsat to Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) and Multiangle Imaging Spectroradiometer (MISR) scales. The current work is dedicated to developing accurate atmospheric correction algorithms for the EOS instruments MODIS and MISR, and the Landsat Enhanced Thematic Mapper + (ETM+) imager. In the past year, an atmospheric correction algorithm for ETM+ has been developed that uses ancillary aerosol information generated by Aerosol Robotic Network (AERONET) stations. The retrieved surface reflectance is used for validation purposes and for generating surface climatology required to improve satellite aerosol retrievals. A new 3-D method of aerosol retrievals from ETM+ data over land has also been developed. Initial validation showed that this method effectively removes biases in the aerosol optical thickness caused by the use of 1-D theory in current algorithms.

Description of Research

The main objective of this research is to develop generic aerosol retrieval/atmospheric correction algorithms for the EOS MODIS and MISR instruments and the Landsat ETM+ imager. The new algorithm is based on a recently developed theory that rigorously describes 3-D radiation effects, gaseous absorption in the atmosphere, and surface bidirectional reflectance properties.

Accomplishments during the Reporting Period

Efforts by researchers under this and related tasks over the past four years have led to significant developments in the theory and numerical codes for 3-D atmospheric radiative transfer over inhomogeneous and anisotropic surfaces [Lyapustin and Knyazikhin 2001, 2002; Lyapustin 2002]. The new theory applies invariably to all remote sensing scales and potentially allows uniform data processing and comparison of products from different instruments at different resolutions and view geometries. This is invaluable for cross-scale and cross-instrument thematic studies, and for data product validation. Instead of traditional approximate or empirical techniques, the new theory rigorously treats 3-D adjacency effects, surface BRDF, and gaseous absorption.

In the past year, 3-D theory was applied to develop a Landsat ETM+ atmospheric correction algorithm based on external aerosol information. A number of ETM+ scenes around AERONET sites in the Baltimore–Washington region were corrected for atmospheric effects. The analysis of relationships between surface reflectance in the red and blue bands and reflectance in the 2.1 μm region (a foundation for the dark dense vegetation (DDV) method of satellite aerosol retrieval [Kaufman *et al.* 1997]) shows the need for creating regional/seasonal surface climatology to improve the accuracy of aerosol retrievals. In parallel, initial validation of a new 3-D method of aerosol retrieval over land that removes the biases of 1-D theory [Lyapustin and Kaufman 2001] has been conducted.

Objectives for the Coming Year

In the coming fiscal year, task activities will finalize the generic aerosol retrieval/atmospheric correction algorithm for Landsat data. The full algorithm for atmospheric correction for EOS MODIS and MISR data with external aerosol information will be developed and validated; it will be then applied to small areas around AERONET sites. The results will be used for instrument cross-validation of the land-surface bidirectional reflectance distribution function (BRDF) and albedo. Using atmospherically

corrected data, regional surface climatology will be developed, required to improve the accuracy of aerosol retrievals by the DDV method. An additional theoretical research will be done to incorporate atmospheric gaseous absorption into the SHARM-3D code.

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

GEST Investigator: Yujie Wang

Collaborator: Jeffrey L. Privette (PI, GSFC)

Abstract

Recent developments in atmospheric radiative transfer theory have shown that three-dimensional radiation effects caused by surface inhomogeneities play an important role in the optical remote sensing of atmospheric aerosols and land-surface reflectance. These effects may contribute significantly to the error budget of retrievals over a broad range of sensor resolutions, from Landsat to Earth Observing System (EOS) Moderate-Resolution Imaging Spectroradiometer (MODIS) and Multiangle Imaging Spectroradiometer (MISR) scales. The current work is dedicated to implementing this new 3-D theory in a new, accurate atmospheric correction algorithm for the EOS instruments, MODIS and MISR, and the Landsat Enhanced Thematic Mapper+ (ETM+) imager.

Description of Research

The main objective of our research is to develop a generic sensor/resolution-independent aerosol retrieval/atmospheric correction algorithm for the EOS instruments, MODIS and MISR, and the Landsat ETM+ imager. The new algorithm is based on a recently developed theory that rigorously describes 3-D radiation effects, gaseous absorption in the atmosphere, and surface bidirectional reflectance properties.

Accomplishments during the Reporting Period

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 development of a sensor/resolution-independent algorithm that applies invariably to all scales of remote sensing, different instruments, and different sun-view geometries.

In the past year, work under this task was focused mainly on developing a rigorous 3-D radiative transfer atmospheric correction algorithm based on EOS MISR data. The new algorithm requires a sample of bidirectional reflectance distribution function (BRDF) shape of the surface as the starting point of the calculation. The possibilities afforded by land cover classification based on MISR BRDF shape parameters; the potential for this method as it applies to instantaneous land cover classification, and disturbance detection and identification were also studied. In parallel, design and coding of the new MISR atmosphere correction algorithm are underway.

Objectives for the Coming Year

In the coming fiscal year, the full algorithm for atmospheric correction for EOS MISR data will be completed. Validation and intercomparison of the algorithm with MODIS and Landsat data will be conducted. This atmospheric correction will be applied to subregions centered on Aerosol Robotic Network (AERONET) sites to perform cross-instrument validation of the land surface BRDF and albedo.

Task 900-39-175: **NPOESS Preparatory Project (NPP) System Calibration/Product Validation Studies**

GEST Investigator: Bruce Guenther (PI)

Collaborators: Robert Murphy (GSFC), Xiaoxiong Xiong (GSFC), Vincent Salomonson (GSFC)

Abstract

The research addressed under this task continues the development of the government team for the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) program in the area of sensor calibration and environmental data product validation (cal/val), development and oversight of the NPOESS Preparatory Project (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) sensor calibration, and continuing support and development for the EOS Moderate Resolution Imaging Spectroradiometer (MODIS) calibration data product. The work involves identifying and applying EOS lessons learned in cal/val to the NPOESS cal/val program. The VIIRS sensor builder has embraced the NASA calibration equation and is providing measurement requirements and testing consistent with accuracy according to the calibration equation. Refinements to the MODIS calibration and validation approaches have been identified and are under study. Advances were accomplished during this year for the NPP Engineering Development Unit (EDU) Data Exchange Project (NEXT) for processing NPP sensor EDU calibration and characterization data.

Description of Research

For the NPP, the research involves education and training of the NPOESS prime contractor and the Integrated Program Office (IPO) team on the optimum application of EOS lessons learned for sensor calibration and data product validation through discussions, internal memos, presentations, and conference and referred publications in the open literature. For the MODIS effort, the work involves continuing collaborative research with GSFC MODIS leadership and with the MODIS Characterization Support Team (MCST) to remain cognizant of their key accomplishments and issues, to challenge their approaches, and to identify potential areas of improved calibration performance through analysis, presentations, and publication in the peer-reviewed literature.

Accomplishments During the Reporting Period

The principal research accomplishment for NPP VIIRS is the acceptance within the IPO and Aerospace, Inc. community of the NASA VIIRS Thermal Emissive Bands (TEB) calibration equation. The NASA VIIRS TEB calibration equation provides proper accounting for the effects of sensor optics temperatures. This was accomplished through distribution of tutorial materials from the MODIS calibration activity and application of those principals for VIIRS to Aerospace, Inc. and the principal systems integrator staff, NGST.

The NEXT activity is moving forward with incorporation of EDU data from three of the four NPP sensors now incorporated into the NPP program. The day-to-day science leadership for NEXT is provided within the NPP cal/val effort. Initial negotiations to work closely with the Aerospace, Inc. team on the Advanced Technology Microwave Sounding (ATMS) cal/val effort have been fruitful as well.

The MODIS effort centers around techniques to use on-orbit calibrated data to enhance, validate, and improve sensor calibration. In particular, comparative analysis of data from an additional EOS Terra sensor, the Multiangle Imaging Spectroradiometer (MISR) with MODIS data has progressed to the point that an improved calibration approach is being tested. MODIS is a whiskbroom scanning sensor; MISR is a push-broom sensor with a narrow field of view centered at nadir. MODIS data indicate that the MODIS scan mirror is degrading on orbit, and a better method is needed to track these changes over time. As a push broom sensor, MISR does not have a two-sided scan mirror, so all MISR data use a

common mirror side. The MODIS-MISR comparisons are valuable for spatial fields where both MODIS and MISR observe simultaneously. These scenes are for MODIS observations near nadir, and in the reflected solar bands (RSF). Data analysis is underway to examine the average response for mirror side-1 data compared to mirror side-2 data. The expectation is that observations are completely random, and any systematic difference in the two data sets corresponds to a relative calibration error in the mirror-side calibration. The use of all data in the Earth-view (for scan angle of – 55? to + 55?) is being investigated; this comprehensive use of the Earth-view data will be validated by comparing the results from the MISR-MODIS analysis at nadir. If this approach can be verified, then sensor mirror-side differences at any time in orbit can be tracked for all scan angles.

The first data from an EOS mission publicly released is the MODIS calibration data product (L1B). Guenther *et al.* [2002] identifies the data qualifier attributes associated with those data, as well as tracks the MODIS performance throughout the first year of Terra-MODIS science data acquisition. The paper appears as the first science paper in a Special Issue of *Remote Sensing of the Environment*.

The GEST investigator received a Group Achievement Award from the Earth Observing System (EOS) Terra Project, and a Public Service Group Achievement Award from the Earth Observing System (EOS) AM Program Team during this reporting period.

Objectives for the Coming Year

The main objectives for the NPP activity are to integrate the Interim NPP Project Science Team into the NPP cal/val effort, analyzing NPP sensor EDU test data within the NEXT system to initially verify sensor radiometric calibration concepts, and to provide detailed comments and analysis on sensor test and analysis concepts. For MODIS, the main objectives are to complete strategies for tracking sensor mirror-side differences using Earth-view science data, to start the study to extend this approach from the RSB to the TEB data, and to assess the calibration accuracy of the reflected solar band low signal.

Task 924-21-142: **Water Vapor and Cloud Detection Validation for Aqua Using Raman Lidars and AERI**

GEST Investigator: Zhien Wang

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

Abstract

To estimate the possible effects of thin cirrus clouds on the retrievals of water vapor using IR sensors such as the Advanced Infrared Sounder (AIRS) and the Geostationary Operational Environmental Satellite (GOES), subtropical cirrus properties measured during the third Convection and Moisture Experiment (CAMEX-3) with the GSFC Scanning Raman Lidar (SRL) were analyzed. After the launch of Aqua satellite in 2002, a series of validation experiments were undertaken during August-November at GSFC with the SRL and radiosondes. Comparison of water profiles obtained from AIRS retrievals and SRL measurements provided important validation for AIRS measurements. The Vision 2 cloud scenario classification was delivered to the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University, for the CloudSat project. The project has been funded to start developing the combined satellite-based lidar and radar algorithm.

Description of Research

This activity is comprised of two main components: validating the upcoming AIRS sensor

on the Aqua spacecraft during its critical first year check-out phase by providing high-quality Raman lidar water vapor profiles during overpass periods; and studying the influence of thin cirrus clouds on the retrievals of water vapor using IR sensors such as AIRS and GOES. Existing and future Raman lidar and ancillary data will be analyzed to address both of these objectives. The analysis of data from the International Water Vapor Experiment, which occurred during May-June 2002 in the U.S. Midwest, focused on improving the understanding of convective storm initiation processes and quantitative precipitation forecasting. Task work also included cooperating with Dr. Kenneth Sassen at the University of Alaska, working on cloud classification algorithm development for the CloudSat project.

Accomplishments during the Reporting Period

Cirrus clouds affect the Earth's radiation budget strongly through both albedo and greenhouse effects. Their frequent occurrence, especially in the tropical region, results in some challenges to retrieving water vapor profiles using IR sensors. To evaluate the possible effects of thin cirrus clouds, radiative properties of subtropical cirrus derived from ~150 hrs of SRL measurements during CAMEX-3 were analyzed and compared with midlatitude counterparts. This dataset is one of the largest databases of cirrus measurements in tropical and subtropical regions obtained from high-quality Raman lidar measurements.

To validate AIRS water vapor retrievals, especially for upper tropospheric water vapor, a series of SRL and radiosonde measurements were taken during the launch +3 to launch +5 months window. During these three months, about 25 profiles were obtained during Aqua's early-morning overpasses of GSFC. These profiles cover many different conditions, and provide a valuable dataset to evaluate AIRS retrievals. Initial comparison with AIRS retrievals has been completed, but more detailed analysis is still under way in close cooperation with the AIRS retrieval team at GSFC.

Cloud scenario identification is an important step to apply to remote sensing algorithms for cloud property retrievals because of the different microphysical and radiative properties of water, ice, and mixed-phase clouds. The Vision 2 radar-only cloud scenario classification algorithm was delivered to the CIRA at Colorado State University for the CloudSat project during the summer of 2002. Funding has been obtained to begin integrating this algorithm with satellite-based lidar and radar algorithms, which will combine CloudSat radar and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) lidar measurements.

Objectives for the Coming Year

Combining the Raman lidar and satellite measurements to study the effect of optically thin cirrus clouds on the retrieval of precipitable water from satellite measurements will continue. GSFC AIRS validation data analysis and comparison with ARIS retrieved water vapor profiles will be pursued. Improving and refining the radar-only cloud classification algorithm for the CloudSat project, and developing satellite-based combined lidar and radar cloud classification algorithm will continue, as will developing new algorithms to study mixed-phase clouds, based on Atmospheric Radiation Measurement (ARM) field campaign ground-based observations.

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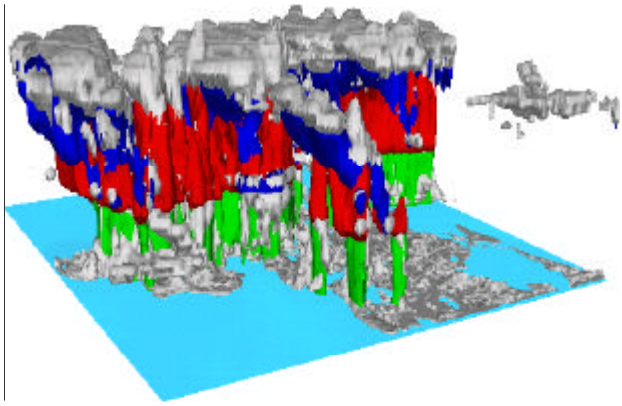
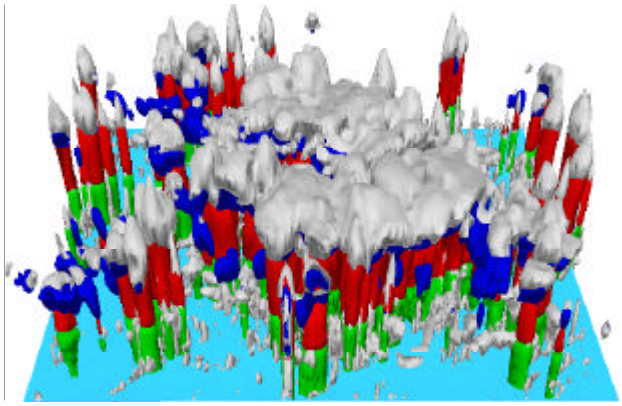
Clouds Research Group

SCSMEX **KWAJEX**



(a)



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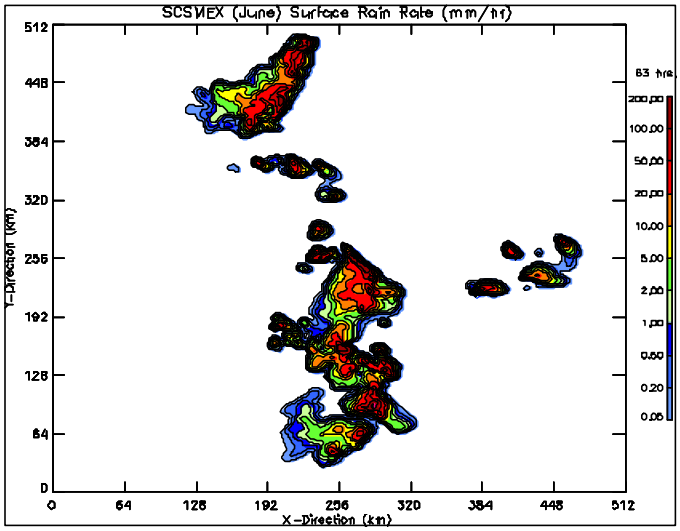

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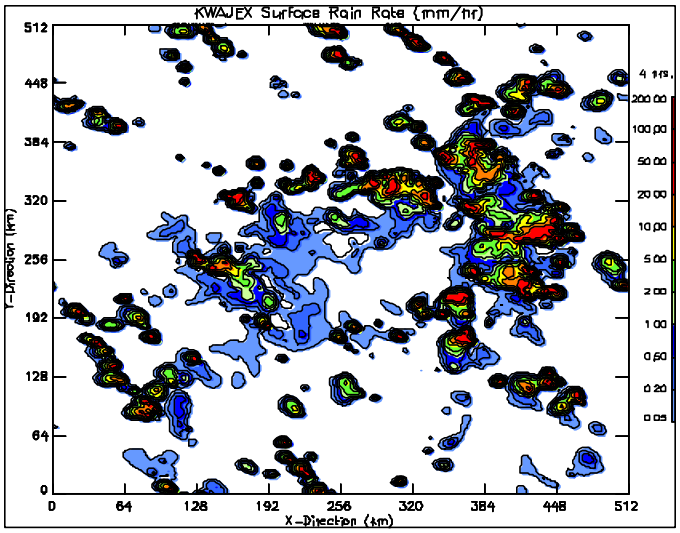


(d)

3-D GCE model-simulated cloud hydrometeor mixing ratios for (a) a SCSMEX and (b) a KWAJEX case. The white isosurfaces show the cloud water and cloud ice, blue the snow, green the rain water, and red the graupel. Also shown are the GCE-simulated surface rainfall rates (mm/hr) for (c) SCSMEX and (d) KWAJEX, corresponding to the same the cloud fields in (a) and (b). Most (but not all) of the surface rainfall is being produced by the melting of graupel [red surface in (a) and (b)] near 0 °C. This indicates the importance of ice processes even in tropical environments. The rainfall patterns resemble radar observations (Johnson et al. *2002; S. Yuter and R. Houze 2002, personal communication).*

Clouds Research Group

GEST Center Clouds Research Group scientists conduct multi-disciplinary research in many areas related to clouds and their impact on climate change and weather forecasting. The scientists also collaborate with NASA personnel and researchers at other institutions in developing retrieval algorithms for data interpretation, modeling techniques to represent physical processes, and assimilation methods used to combine observations, models, and instrument products.

The 2001 GEST Aerosols and Clouds Research Group was reorganized in 2002 into two research groups: the Aerosols and Lidars Research Group and the Clouds Research Group. The research performed by scientists in the Clouds Research Group addresses cloud formation, cloud modeling, cloud macro- and micro-physical properties, radiative effects of clouds at microwave and millimeter-wave frequencies, cloud and hydrometeor signatures from active and passive instruments, and air-sea interactions. The breadth of these topics can be narrowed down to a few encompassing topics: modeling, retrievals, and basic atmospheric science.

There are several distinct groups of GEST scientists involved in modeling studies. One group is working to improve the NASA Data Assimilation Office (DAO) finite volume Data Assimilation System (fvDAS) through assimilating satellite observations and retrievals (P. Norris) and through incorporating the Colorado State University next generation cloud scheme into the fvDAS (X. Lin). Another group of GEST scientists is improving cloud resolving models such as the Goddard Cumulus Ensemble model by updating microphysical processes (D. Johnson), validating models with respect to radiative transfer properties (D. Johnson and X. Li), and harvesting advances in computer CPU power (X. Zeng). The Goddard Cumulus Ensemble model was used to investigate the hydrological cycle, horizontal wind fields, and large-scale temperature and moisture forcing (C.-L. Shie). In addition, a four-dimensional variational data assimilation model was developed to work with the Pennsylvania State University/National Center for Atmospheric Research mesoscale community model (MM5) cloud-resolving model (Z. Pu).

GEST Cloud Group scientists performing retrievals use both active and passive instruments and estimate a variety of cloud properties. Studies using active instruments include developing the 94 GHz Cloud Radar instrument and testing it in a field experiment (L. Li); and radar brightband modeling, dual-wavelength investigations, and mirror-image algorithms to define attenuation (L. Liao). Studies involving active lidar systems were performed to characterize polar clouds and to determine the impacts of cloud hydrometeors on the radiation balance between the surface and the atmosphere at high latitudes (A. Mahesh). Retrievals of path integrated radar attenuation and its relationship to passive brightness temperatures was also investigated (L. Tian). Retrievals using both active and passive observations include using Tropical Rainfall Measuring Mission (TRMM) satellite data to determine path integrated attenuation taking care to ensure the optimal use of low-resolution radiometer information in high-resolution radar precipitation estimations (M. Grecu). Other combined passive and active retrievals include determining frozen precipitation characteristics (mass content and size distribution profiles) for both anvil and snowing clouds (G Skofronick-Jackson). Finally, the Visible Infrared Scanner (VIRS) on TRMM and Moderate Resolution Imaging Spectroradiometer (MODIS) observations are employed in the retrieval of cloud properties for partially covered imager fields of view (J. Coakley).

Understanding physical relationships between clouds and other measurables is a significant focus of all scientists in the GEST Cloud Group. There are a few scientists who are directly investigating physical relationships in basic atmospheric research. Such research topics include: studies of the physics of cirrus clouds and their role in global climate (R.-F. Lin); organization, structure and evolution of tropical convection in South China Sea monsoon and their mesoscale environment (J.-J. Wang); tropical cyclone intensity change and the impacts of the global climate on change on hurricane tracks (L. Wu); and studies of tropical synoptic-scale waves and their association with precipitation over the West African Continent (G. Gu). There are two scientists investigating the effects of extratropical air-sea interaction on the

predictability of warm season precipitation anomalies for the NASA Seasonal-to-Interannual Prediction Project (NSIPP) (H. Wang and F. Yang). Finally, an advanced three-dimensional radiative transfer algorithm is being developed in order to support the Global Precipitation Mission validation effort (K.-S. Kuo).

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

Gail Skofronick Jackson

Task 900-19-136: **Cloud Thermodynamic Phase Inference from Moderate Resolution Imaging Spectroradiometer Retrievals**

GEST Investigator: Jérôme C. Riédi

Collaborators: Michael D. King (PI, GSFC), Steven Platnick (GSFC)

Abstract

Major efforts during the reporting period involved working on various aspects of the Moderate Resolution Imaging Spectroradiometer (MODIS) cloud retrievals algorithm, data analysis, and product validation. Particular attention was paid to developing an improved cloud phase remote sensing algorithm and understanding ice and liquid cloud effective radius MODIS retrievals. The GEST investigator served as principal investigator for the French Polarization and Directionality of the Earth's Reflectances (POLDER) instrument during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL-FACE) campaign (1 July- 31 July 2002), leading POLDER instrumental development, and securing tight collaboration between French and American teams involved in the project. This participation was mainly to support validation of the Terra/Aqua MODIS cloud property retrievals.

Description of Research

It is now clearly recognized that improvement of weather and climate forecast requires a better understanding of cloud properties in order to implement a realistic representation of clouds within models. Among the various properties that drive cloud impact on climate, the cloud thermodynamic phase (ice *vs.* liquid water) plays an essential role because it controls both cloud/radiation interaction and energy transport in the atmosphere through latent heat exchange. Furthermore, cloud thermodynamic phase is a key parameter needed to retrieve other cloud microphysical and radiative properties from remote sensing. This research was performed to provide an improved cloud phase determination scheme for use in the MODIS cloud properties retrieval algorithm, and to help analyze and validate products.

Accomplishments during the Reporting Period

A new scheme for cloud thermodynamic phase determination was developed and implemented in the MODIS cloud properties retrieval algorithm. This involved in-depth analysis of the operational algorithm and product to track erroneous phase determination, producing visualization tools to analyze intermediate results of the algorithm, and developing a new scheme that takes advantage of the full range of MODIS multispectral measurements. These developments resulted in an operational implementation of a new and greatly improved phase determination algorithm that proved very useful in improving other cloud property retrievals.

The GEST investigator has been significantly involved in MODIS validation through the CRYSTAL-FACE field campaign, held in southern Florida in July 2002. He was funded by the Centre Nationale d'Études Spatiales (CNES) to fly the airborne POLDER on the Proteus aircraft during the field campaign. As principal investigator for the AirPOLDER instrument during CRYSTAL-FACE, the investigator participated in several science team and technical meetings related to the experiment. Other work has included supervising the development of the new POLDER acquisition system and coordinating instrument integration efforts between the French Laboratoire d'Optique Atmosphérique and Scaled Composite, which operates the Proteus aircraft.

During CRYSTAL-FACE, POLDER provided directional and polarimetric observations useful for inferring cloud phase, particle habit, and bidirectional reflectance patterns. Further, simultaneous observations from POLDER and the MODIS Airborne Simulator (MAS) during CRYSTAL-FACE provide valuable dataset to help in designing new synergistic algorithms with

MODIS/Aqua and Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL) during the A-Train time frame.

Objectives for the Coming Year

The main objectives for the coming year are to pursue analysis of data acquired during CRYSTAL-FACE field campaign and particularly those cases for which we have simultaneous observation from MAS and AirPOLDER. This work seeks to develop new synergistic algorithms for cloud phase and microphysical properties remote sensing from combined multispectral, multiangle, and polarimetric observations as provided by missions such as the Terra MODIS, POLDER2 on the Advanced Earth Observing Satellite (ADEOS)-2, or the A-Train (Aqua MODIS/PARASOL).

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

GEST Investigator: Peter M. Norris

Collaborator: Arlindo da Silva (PI, GSFC)

Abstract

A cloud parameter estimation system has been developed to assimilate satellite cloud data into the NASA Data Assimilation Office (DAO) finite volume Data Assimilation System (fvDAS). Cloud fraction and optical depth data from the International Satellite Cloud Climatology Project (ISCCP) and cloud liquid water path retrievals from the Special Sensor Microwave/Imager (SSM/I) instrument are currently assimilated. This procedure greatly improves the representation of cloud fraction in the model, as compared with ISCCP data. It also significantly improves mid-latitude longwave cloud radiative forcing, as independently validated against Clouds and the Earth's Radiant Energy System (CERES) data, and mid-latitude column-averaged liquid water path (LWP) over ocean, as validated against Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) data.

Description of Research

It is widely recognized that clouds play an essential role in moderating the climate. This recognition has prompted the recent development of a number 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 Data Assimilation Office's (DAO) Goddard Earth Observing System (GEOS) system — there are currently few mature efforts to directly assimilate cloud information into models. This provides the background for this task within the DAO: 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 during the Reporting Period

Cloud fraction and optical depth data from the ISCCP and cloud liquid water path retrievals from the SSM/I instrument are assimilated into the DAO's fvDAS using a parameter estimation method. The rationale behind this method is the existence of several empirical parameters in the model cloud/radiation parameterizations (*e.g.*, "critical relative humidity") that are not in fact universal, but that have remaining spatial and temporal dependencies. These parameters can be slowly adjusted in space and time to improve the model's representation of cloud properties.

As reported for the preceding year, an initial correlation of the observed cloud fraction and modeled fvDAS relative humidity indicated that model's simple cloud fraction parameterization was insufficient to represent the observations. Specifically, the Community Climate Model (CCM3). Slingo-type relative humidity (RH)

dependence, with a quadratic rise of cloud fraction from zero above a critical value, RH_0, was replaced by a generalized S-shaped rise consistent with the observations. In addition to RH_0 and an upper threshold value, RH_1, usually equal to grid-averaged saturation (100%), at which cloud fraction is one, the new form includes an asymmetry parameter, α, that governs the asymmetry of the rise of the cloud fraction in the [RH_0, RH_1] transition. The two parameters RH_0 and α are adjusted in both low and mid-high cloud bands in order to minimize the difference between modeled and observed cloud fractions in these bands subject to slow temporal variation in these parameters.

Previously, U.S. Air Force Real-Time Nephanalysis (RTNEPH) cloud fraction was assimilated. During this reporting period, the use of ISCCP DX-derived cloud fraction — a long-term, well-studied dataset suitable for re-analysis was transitioned to the system; use of MODIS cloud data is planned. The earlier off-line tuning system has undergone major advancement to an on-line system fully incorporated within the fvDAS, significantly streamlining testing and analysis of the developing system. Implementing cloud fraction assimilation has greatly improved the representation of cloud fraction in the model as compared with ISCCP data. It also significantly improves mid-latitude longwave cloud radiative forcing (LWCF), as independently validated against CERES data, and mid-latitude column-averaged LWP over ocean, as validated against TMI data. Mid-latitude cloud fraction and LWCF were previously significantly underestimated by the fvDAS.

The cloud fraction assimilation, by itself, degrades the shortwave cloud radiative forcing at the top-of-atmosphere, but this is recovered (as validated against CERES) by assimilating SSM/I, LWP, and ISCCP optical depth data via adjustment of the CCM3 diagnostic cloud water parameterization and the dependence of the CCM3 column optical depth on layer cloud fractions. This is an example of how data assimilation can provide significant positive feedback to the general circulation model (GCM) parameterization community. Specifically, the inability of the GCM cloud/radiation parameterizations to simultaneously accept the observed cloud fractions and cloud optical depth/microwave liquid water path data has revealed some shortcomings in these parameterizations. Two such shortcomings in the CCM3 are the oversimplified combination of clear and cloudy shortwave radiative transfer within a grid column, and the neglect of cloud layers thinner than a single model grid layer. These shortcomings are being investigated and corrected.

Other activities for the past year included participating in the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL-FACE) field experiment representing the DAO analyses/Global Assimilation and Modeling of Ice Clouds in a Sub-synoptic Environment (GAMICSE) project and for familiarization with potential case study data for GCM cirrus parameterization validation and improvement. Finally, CERES ARM Radiation Experiment (CAVE) surface radiation measurements were used to begin validation of the surface fluxes from the new cloud assimilating fvDAS.

Objectives for the Coming Year

Continuing work focuses on improvements to the oversimplified GCM cloud condensate parameterization and cloudy shortwave radiative transfer parameterization that currently limit the full acceptance of assimilated cloud data. This work will be particularly interesting to developers of GCM cloud/radiation parameterizations. Opportunities will also be taken to look at new cloud data sets, including EOS Terra and Aqua MODIS cloud data, data from GOES satellites, lidar cloud boundaries from the Geoscience Laser Altimeter System (GLAS), and CloudSat radar data.

Task 910-14-124: **Implementing the Next-Generation Cloud Scheme in the NASA DAO Model**

GEST Investigator: Xin Lin

Collaborators: Arthur Hou (PI, GSFC), David A. Randall (Colorado State University)

Abstract

A next generation cloud scheme for use in global climate models has been developed recently by researchers at Colorado State University (CSU). This advanced scheme adopts a prognostic liquid-water approach and can predict five microphysical parameters in clouds, including water vapor, cloud water, cloud ice, rain, and snow. It also includes sophisticated parameterizations of prognostic cloud fraction and mesoscale organization. This research is to successfully transfer the CSU cloud scheme into the GSFC Data Assimilation Office (DAO) finite volume General Circulation Model (fvGCM), so that remote sensing cloud data can be well assimilated into the DAO model. Such work can have a significant impact on NASA's efforts in weather forecasting and climate simulations.

Description of Research

The CSU cloud scheme is one of the most advanced cloud schemes used in climate models. It is based on the bulk cloud microphysics equations originally developed for mesoscale models and includes prognostic equations of cloud water and ice contents. Cloud optical peoperties are parameterized in terms of liquid water and ice path. This scheme is more physically based and has many advantages over the diagnostic cloud scheme being used in the current DAO model. NASA is planning a few major satellite missions (such as CloudSat and the Global Precipitation Mission) within the next 10 years to better understand the interactions between clouds and the hydrologic cycle. This research is paving the way for the DAO model to assimilate these cutting-edge data and helps to address important issues on climate change and weather forecasting.

Accomplishments during the Reporting Period

The current version of the DAO fvGCM is based on the finite-volume dynamic core developed at GSFC [Lin and Rood 1996; Lin and Rood 1997], with National Center for Atmospheric Research (NCAR) Community Climate Model (CCM)-3 physical parameterization [Kiehl *et al.* 1996]. Tremendous efforts have been devoted to replace the model's cloud parameterization with the advanced CSU prognostic cloud scheme. Cloud optical depths have been modified, so that the cloud scheme can directly interact with the radiation scheme. Preliminary five-year runs and data analyses have been performed, and initial results look very promising. The coupling between the new cloud scheme with the old parameterization of the planetary boundary layer is still being examined.

Objectives for the Coming Year

The objectives for the coming year are to use available satellite observations to evaluate the model's performance, and to perform sensitivity tests to finely adjust cloud parameters. Long-term climate simulations and short-term forecasting will be conducted and evaluated.

Task 912-02-027: **TRMM Validation Using ER-2 Combined with Other Field Campaign Observations; Analysis of Dual-wavelength Radar Measurements from CRYSTAL-FACE**

GEST Investigator: Lin Tian

Collaborator: Gerry Heymsfield (PI, GSFC)

Abstract

Research performed during the past fiscal year focused on analysis of airborne radar and radiometer measurement with emphasis on microwave path-integrated attenuation (PIA). The relationship between the brightness temperature and PIA was analyzed, taking into account the variation of the surface emissivity, atmosphere temperature and raindrop size distribution. This analysis also included the radar reflectivity profiles. In addition, the radiometer-derived PIA is compared with the radar-derived PIA using a surface reference method. Another focus of the research is to combine observations from the Cloud Radar System (CRS) at 3 mm (94 GHz) with the ER-2 Doppler Rader (EDOP) at 3.2 cm (10 GHz) to estimate the raindrop size distribution in light rain and to provided support for the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL-FACE).

Description of Research

Attenuation at microwave frequencies is important in various applications, including improving rainfall measurement and understanding precipitation process. The attenuation may be derived from the reflected power of the surface measured by radar, or from the brightness temperature measured by radiometer. PIA, derived using radar-measured surface returns, does not involve any assumptions about precipitation, but does assume that surface return is the same inside and outside of the precipitation region. On the other hand, radiometer-derived PIA requires information on surface emissivity, atmosphere temperature, and drop size distribution. Therefore, combining the measurements from both radar and radiometer not only serve as a consistency check between the two instruments, but also provides some insight into precipitation processes themselves. Field campaigns to support the Tropical Rainfall Measurement Mission (TRMM) have provided a number of excellent multi-instrument, multi-platform data sets that facilitate a more complete picture of the structure of precipitation regions. The data used in this research were obtained from the airborne EDOP and radiometers on NASA's ER-2 aircraft and NCAR's ground-based S-band radar.

Accomplishments during the Reporting Period

Measurements during TRMM campaigns of reflectivities, Doppler velocity, and differential reflectivity, Z_{dr}, were analyzed. The analysis of the surface return power showed PIA exceeding 20 dB in many deep and intense convective storms over land in Florida and Brazil. Two case studies showed that this large attenuation could not be explained in terms of raindrop size alone, unless a very small drop, inconsistent with Z_{dr} observation, is assumed. Further analysis concluded that melting ice particles might contribute to the large attenuation. This work showed the potential power of airborne EDOP radar combined with multi-parameter, ground-based radar (Tian *et al.* 2002a).

One important aspect of TRMM validation activities is to compare measurements from radar (an active instrument) and radiometers (passive instruments). The difference between the two may aid in understanding precipitation processes and to improve algorithms for deriving rainfall estimates. The brightness temperature from an X-band radiometer is used to derive the PIA in precipitation over the ocean using a simple, one-layer radiation transfer model. The derived PIA shows a general agreement with radar-derived PIA using the surface reference technique (SRT). The discrepancy, found at high values of PIAs, may have been caused by saturation of the X-band brightness temperature, or by uncertainties in wind roughening of the sea surface, which affects the SRT. Such study can provide valuable information

for TRMM, in which both radar and radiometers are used for rain measurements (Tian *et al.* 2002b).

The CRS, operated at 94 GHz, flew for the first time on the ER-2 along with the EDOP during the CRYSTAL-FACE experiment in July 2002. Data analysis shows that reflectivity is still above the noise level in relatively weak precipitation regimes, despite the strong attenuation at 94 GHz. Such observations provide an opportunity to estimate the rainfall rate and attenuation from the reflectivity and Doppler velocity measured at two frequencies. So far, dual-wavelength reflectivity has calibrated and corrected the Doppler velocity due to unfolding and aircraft motion. A study is underway to derive the raindrop size distribution of stratiform rain.

Objectives for the Coming Year

The goals for the coming year will focus on studying the bright band, characterizing the vertical profiles of the reflectivity and Doppler velocity in stratiform cloud from all TRMM field campaign and CRYSTAL-FACE, and retrieving the ice and liquid water content from dual-wavelength measurements.

Task 912-02-029: **Application of Data Assimilation and Numerical Modeling to Understand and Predict Mesoscale Precipitation Systems**

GEST Investigator: Zhaoxia Pu

Collaborator: Wei-Kuo Tao (PI, GSFC)

Abstract

Work performed under this task involves applying data assimilation and numerical simulations in mesoscale studies. During the past year, progress has been continued on assimilating Tropical Rainfall Measuring Mission (TRMM) rainfall data into a mesoscale model with four-dimensional variational data assimilation (4DVAR) techniques. High-resolution numerical simulations were also conducted to understand the mesoscale precipitation systems associated with ocean narrow cold fronts. In addition, an effort to link the mesoscale numerical model with the Goddard Earth Observing System (GEOS) global analysis system has been accomplished.

Description of Research

Precipitation systems are the key components of mesoscale studies and numerical weather forecasts. Rapidly increasing amounts of satellite and remotely sensed data offer great opportunities to improve understanding and forecasts of the mesoscale precipitation systems. Assimilating satellite and remotely sensed (rainfall) data usually improves the model initial conditions and subsequent forecasts. The results of mesoscale numerical simulations and forecasts can be validated by the remotely sensed observations, and can be used as complementary information to better understand the structure and dynamics of mesoscale systems.

Accomplishments during the Reporting Period

Based on the Pennsylvania State University/National Center for Atmospheric Research (NCAR) mesoscale community model (MM5) and its adjoint system, a 4DVAR system was created that is capable of assimilating multitime observations into the MM5 model. In the past year, research has continued on further developing the system to assimilate TRMM rainfall data into the 4DVAR system. The adjoint code of a Blackadar planetary boundary layer (PBL) scheme (developed by W. Huang, NCAR) was implemented and tested within the MM5 adjoint system. This implementation made it possible to integrate the adjoint model for six hours out; thus, the 4DVAR system can assimilate the data in a relatively longer time window.

Research also addressed high-resolution numerical simulations (~1-km grids) of a NOAA P-3 instrumented aircraft observing intense, fast-moving ocean narrow cold frontal rainbands (NCFRs), as they approached the U.S. Pacific Northwest coast on 19 February 2001 during the

Pacific Coastal Jets Experiment. The NCFRs produced hail along the California coast when it made landfall and were particularly hard to detect by coastal radars due to their shallow nature. The airborne Doppler radar showed that the echo from the top of very-high-radar reflectivity of convective cores, which characterized this NCFR at low levels, extend only to ~4-5 km. The outstanding feature of an NCFR is the gaps (breaks) exhibited in NCFR's narrow ribbon of high reflectivity, probably as a result of hydrodynamic instability along its advancing cold pool leading edge.

In collaboration with Dr. David Jorgensen at NCAR and Dr. W.-K. Tao at GSFC, a study was conducted that used the high-resolution (~1-km grids) numerical simulation results in conjunction with the radar, dropsonde, and *in situ* data to document the detailed precipitation and kinematical structure of the NCFR. Specific attention was given to the structure near the gap regions. The study confirmed many aspects of NCFR structure that have been seen in previous studies, along with the presence of some new NCFR features. In contrast to some earlier studies of cold front rainbands, this study indicated that density current theory described the motion of the overall front. Based on radar data analyses and numerical simulations, the character of updraft structure associated with the heavy rainfall at its leading edge was demonstrated to vary across the gap regions. The vertical shear of the cross-frontal low-level ambient flow exerted a strong influence on the updraft character. These new findings are consistent with theoretical arguments developed for squall lines describing the balance of vorticity at the leading edge, and also suggest that the mechanism for gap maintenance is not self-sustaining.

Considering the advantages of the GEOS global analysis systems and the linkage between the mesoscale modeling efforts and DAO global studies, an effort was made to link the mesoscale numerical model with the GEOS global analysis system. A software package was implemented to plug the GEOS-3 and GEOS-4 global analysis products into MM5 pre-processes. As the large-scale analysis provides the boundary conditions for mesoscale simulations and also the first-guess field for mesoscale analysis/data assimilation, this linkage offers a new option for future MM5 applications.

The new community weather and forecasting model (WRF) and its data assimilation system are on the way to be implemented by NCAR, the National Centers for Environmental Prediction (NCEP), and the university community. Regular participation in WRF planning meetings was part of this part year's activities.

Objectives for the Coming Year

Work in the coming year will continue to address rainfall data assimilation. Specifically, studies will be performed to assimilate multi-satellite data into the mesoscale model for improving quantitative precipitation forecasts (QPFs).

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

GEST Investigator: Ruei-Fong Lin

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

Abstract

Cirrus clouds are important modulators of the Earth's radiation budget: the exchange of solar and infrared energy between the planet and space and the redistribution of energy internally by radiative processes. As such, cirrus must be properly presented in global models. This year, the research foci were to understand the effects of nucleation modes on the synoptically forced cirrus using a one-dimensional numerical model and cirrus anvil case studies selected from the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE).

Description of Research

Recent studies have indicated that heterogeneous nucleation may be the dominant nucleation mode for synoptically forced cirrus (vertical wind speed less than 0.1 ms^{-1}) unless the air is devoid of ice nuclei (IN) and, thus, homogeneous freezing of concentrated aqueous solution droplets prevails. In comparison with homogeneous nucleation, heterogeneous nucleation, which is of meteorological interest, starts at a lower supersaturation and a smaller ice particle formation rate. Therefore, there may be significant differences in the cloud microphysical and optical properties of clouds generated by different nucleation modes. Furthermore, the starting supersaturation and ice particle formation rate vary among IN species, their number concentration, and heterogeneous nucleation modes.

Accomplishments during the Reporting Period

A series of numerical studies were conducted to examine the sensitivity of cloud properties to a range of activation supersaturation and ice particle formation rates. In this series of tests, a frequently used deposition nucleation formula and homogeneous nucleation are the two extremes: small activation supersaturation and ice particle formation rate for the former, and the opposite conditions for the latter. The average cloud properties were found to be unresponsive to monotonic change of these two parameters. For the range studied, an increase in the ice particle formation rate may enhance local ice production. The average cloud properties are more sensitive to the activation supersaturation. The lower the activation supersaturation is, the smaller the excess water vapor in the upper portion of the cloud, and the greater the cloud-top and mid-cloud nucleation.

In the area of tropical anvil cloud research, the July 23, 2002 case was selected for detailed study. Intensive and persistent convective cells were formed between 1700-2100Z east of Lake Okeechobee, Florida. Six research airplanes flew many flight legs parallel to the anvil outflow. Reruns of the Mesoscale Model Version 5 (MM5) after the mission used Eta 40 km analysis for initial and boundary conditions; these analyses were able to capture most of the significant features of the convective activities for that day. The setup for MM5 was two-way nesting with coarse domain grid size of 6 km and a fine mesh grid size of 2 km. For such fine resolution, cumulus parameterization was switched off, and MM5 was run in the cloud-resolving mode. The model-generated products were compared with observational data, *e.g.*, wind field statistics are compared with the WB57 airborne platform measurement, and the cloud mask was compared with the composite cloud mask from the ER2 Cloud Physics Lidar (CPL) and the Cloud Radar System (CRS).

Objectives for the Coming Year

The MM5-generated vertical wind and anvil thermodynamics profile will be used to drive a high-resolution cirrus model to examine whether the outflow is turbulent and the possibility of generation of ice crystals in the cirrus anvil, for the July 23, 2002 case. A scheme will be developed to combine lidar and cloud radar data, and a one-dimensional cloud model in a single-column mode. The combination is not only beneficial for lidar and cloud radar data interpretation, but also helps to reduce uncertainties in cloud modeling.

Task 912-06-088: **(a) Space-borne Lidar Studies of Polar Clouds and Climate; (b) Cloud Properties Derived from Combined Lidar and Spectral Observations; (c) The Climate of Antarctica**

GEST Investigator: Ashwin Mahesh

Collaborators: (a) James Spinhirne (PI, GSFC); (b) James Spinhirne (GSFC); (c) Von Walden (University of Idaho, Moscow)

Abstract

The Geoscience Laser Altimeter System (GLAS) was launched on board the Ice, Cloud, and Land Elevation Satellite (ICESat) in January 2003. GLAS is the first spaceborne laser; this will permit active profiling of atmospheric layers – a significant improvement over the passive remote-sensing techniques used to date. Data from the polar regions will permit unambiguous detection of cloud layers, and permit the development of a climatology of clouds over both the Arctic and the Antarctic. Along with ground-based synoptic, laser, radiosonde, and ozonesonde observations from South Pole Station, and high-spectral data—both from the ground and from orbiting spectrometers— the microphysical and radiative properties of Antarctic clouds can also be deduced. In the course of pursuing the larger interest outlined above, local phenomena specific to Antarctica—blowing snow at the surface, polar stratospheric clouds—are also being studied. Further, a technique to improve cloud particle size detection using spectral data is also being developed using the spectral observations.

Description of Research

Photons from the laser beam traveling through the atmosphere interact with cloud and aerosol particles; this nature of these interactions can be deduced from observations of the photons that are returned to the receiver on the satellite. This is a key improvement over the passive imaging technologies used to date: because clouds and snow look very similar from space (both in the infrared and at visible wavelengths), passive images often cannot distinguish the two, and GLAS's unambiguous detection is a significant improvement in space-based detection and analysis. Observations from GLAS will be available beginning in March or April 2003 and can be used to begin a number of specific questions. The layering of Antarctic clouds, their frequency of occurrence, and their typical thickness will be studied to develop a complete climatology of clouds over the entire high plateau.

Multi-decadal ground-based observations of the Antarctic atmosphere are also available for study along with such satellite observations. Using these and the GLAS observations, a 'standard' atmosphere of the Antarctic can be compiled. Since the late 1970s, climate modelers have used standard atmospheres to represent various climate regions in their models; an Antarctic profile, however, does not exist. Defining standard profiles to represent the Antarctic atmosphere is vital to estimating and understanding the changes in regional and global weather expected over the next few decades.

The satellite and ground-based measurements provide ways to characterize the Antarctic atmosphere broadly; in addition to these it is necessary to understand the microphysical and radiative properties of atmospheric layers. A climatology of blowing snow over the high plateau is being developed from surface-based spectral and laser observations. Polar stratospheric clouds are also being studied using the same instruments. The spectral data are also being used to test a new algorithm to improve the determination of cirrus cloud particle sizes.

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.

Accomplishments during the Reporting Period

Algorithms to quantify multiple scattering effects on GLAS observations were developed as part of the preparatory science for the ICESat mission. Using typical representations of occurrence and thickness for Antarctic clouds and the observed variability in these properties, an estimate of the scattering effect on space-based altimetry was developed. Similar assessments were also made using blowing snow, which is found frequently in the lower atmosphere of the Antarctic plateau. It was found that space-based altimetry, the primary objective of GLAS, is possible once the scattering effects of the atmospheric layers are properly considered [Mahesh *et al.* 2002].

Observations of blowing snow made by surface observers at the South Pole Station were analyzed using data from the 1990s. A climatology developed from these observations showed blowing snow to be present roughly a third of the time. Typical wind velocities and directions during blowing snow events were also noted. Laser observations of near-surface atmospheres were also carefully screened to find blowing snow cases, and typical heights of such layers was determined. The radiative effect of blowing snow was quantified using spectral data; the energy balance at the surface of Antarctica is affected by blowing snow comparably to the effect from thin clouds.

Objectives for the Coming Year

As observations from GLAS become available, a climatology of polar clouds will be developed from them. This will be compared to earlier studies of Antarctic clouds based on ground-based observations [Mahesh *et al.* 2001a,b]. A standard atmosphere of the Antarctic plateau will be established; separate profiles may be created to represent different phases of the climate of the high plateau (spring, summer, and winter). These will be made available to global climate modelers. Simultaneous spectral and lidar observations of polar stratospheric clouds will be analyzed to determine their frequency of occurrence and radiative effect. Similar observations will also be used to study the accuracy of techniques to determine cloud boundaries from spectral data. Using spectral data from space-borne and ground-based interferometers, an improved algorithm for particle-size detection will be developed.

Task 912-10-109: **Various Numerical Applications on Tropical and Mid-Latitudinal 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 year consisted of three major studies on radiative-convective systems and their respective interactions with atmospheric large-scale environment, using numerical simulations obtained from the Goddard Cumulus Ensemble (GCE) model. Each of these studies served a different goal. In the first study, which used more of an idealized approach, the respective impacts of the large-scale horizontal wind shear and surface fluxes on the modeled tropical quasi-equilibrium states of temperature and water vapor were examined. For the second study, a handful of real tropical episodes, based on Tropical Rainfall Measuring Mission (TRMM) field experiments (*i.e.*, the South China Sea Monsoon Experiment (SCSMEX), 1998; TRMM Kwajalein Experiment (KWAJEX), 1999) were simulated such that several major features including the rainfall amount, the Q1/heat, and Q2/moisture budgets were investigated. In this study, the observed large-scale heat and moisture advections were continuously applied to the model. The third study aimed at understanding the major physical and microphysical processes involved in snowstorms that developed during a mid-latitudinal cold-air outbreak (*i.e.*, the Winter Mesoscale Convective Systems (MCS) Observations (WMO), 2001) over the Japan Sea.

Description of Research

In recent years, increasing attention has been given to cloud-resolving models (CRMs) for their ability to simulate the radiative-convective system, which plays a significant role in determining regional heat and moisture budgets in the Tropics. The growing popularity of CRM usage can be credited to its inclusion of realistic mechanisms such as explicit cloud-scale dynamics, sophisticated microphysical processes, and explicit radiative-convective interactions. The primary objective of this research, which involves a series of systematic numerical simulations using the GCE model (a CRM), aims to better understand the role radiative-convective systems (clouds) have played on the hydrological (water and energy) cycle in climate systems by examining interactions between clouds and large-scale environmental components such as horizontal wind fields, sea-surface fluxes, and large-scale temperature and moisture forcing. In addition to studies of cloud phenomena that mainly focus on the tropical region, CRM applications have been extended to a convective system that occurs during cold-air outbreaks at mid-latitudes.

Accomplishments during the Reporting Period

A series of systematic numerical experiments were simulated for a long-term period using a 2-D GCE model by varying imposed environmental components—sounding data from the 1956 Marshall Island Experiment in Central Pacific—to produce various quasi-equilibrium thermodynamic states. Numerical results showed that the genesis of a warm/wet quasi-equilibrium state was mainly due either to large surface fluxes or strong vertical wind shear, while a cold/dry quasi-equilibrium state was attributed to a remarkably weakened mixed-wind shear along with weak surface winds. Latent heat flux and net large-scale temperature forcing dominated the beginning stages of the simulated convective systems, which then considerably weakened in the final stages, leading to quasi-equilibrium states. A warmer/wetter thermodynamic state was found to produce more rainfall, as convective clouds were the leading source of rainfall over stratiform clouds even though they occupied much less area. The convective systems that consisted of distinct cloud types due to the variation in horizontal winds were also found to propagate differently. Convective systems with mixed-wind shear generally propagated in the direction of shear, while systems with strong, multidirectional wind shear propagated in a more complicated way. Vertical structures of the heat (Q1) and moisture (Q2) budgets, and several specific atmospheric features (such as cloud structure, rainfall distribution, atmospheric stability, and mass fluxes) were also examined and found to be significantly different between diverse quasi-equilibrium states.

Soundings and large-scale forcing data from both SCSMEX (1998) and KWAJEX (1999) were applied in the GCE model to simulate the tropical convective systems. One major objective of the SCSMEX study was to better understand the key physical processes for the onset (May 18-26, 1998) and post-onset (June 2-11, 1998) of the South China Sea monsoon. The numerical results agreed well with observations in rainfall amount and variation, and the domain-averaged heat and moisture budgets. Surface evaporation from the ocean prior to the monsoon onset dominated that post-monsoon onset when rainfall increased. In the KWAJEX study, there were three 1999 convective episodes simulated, *i.e.*, August 7-12, August 18-21, and August 29-September 13. Preliminary model results captured several of the observed features such as the temporal evolution of the vertical distributions of Q1 and Q2 and the domain-averaged temperature and water vapor budgets.

In contrast to the tropical work described above, other task work included a pioneering study to identify the major physical and microphysical processes for snowstorms (WMO, 2001) that developed during a mid-latitudinal cold-air outbreak over the Japan Sea. Two episodes of Intensive Observation Periods (IOP1, January 12-17; IOP2, January 26-31) were simulated, where the former involved in the cold-air outbreak and the latter was during passages of several synoptic scale cyclones. Model results showed excellent agreement with observations in both the Q1 and Q2 fields. However, more snowfall was simulated in IOP1 than in IOP2, while the latter involved a more-organized cloud structure than did the former.

Objectives for the Coming Year

Next year's research tasks will continue most of the ongoing projects. The impacts of several specific large-scale mechanisms on the quasi-equilibrium states of radiative-convective systems will be further examined, and 3-D simulations will be further considered and performed.

Task 912-10-116: **Multi-Day Cloud-resolving Modeling Studies of Tropical and Mid-Latitude Convective Systems**

GEST Investigator: Daniel Johnson

Collaborator: Wei-Kuo Tao (PI, GSFC)

Abstract

Several multi-day simulations of convective activity over tropical and mid-latitude environments have been conducted using the cloud-resolving Goddard Cumulus Ensemble (GCE) model. These simulations have been utilized in studies of atmospheric heating and moisture budgets, precipitation, cloud microphysics, dynamics, surface fluxes, and radiation processes. Three-dimensional simulation data has been provided for inclusion into the Tropical Rainfall Measuring Mission (TRMM) retrieval algorithm database. An updated ice microphysical bulk scheme, a detailed "bin" microphysical model, and an updated radiation package have been implemented into the GCE, resulting in significant improvements. A highly efficient OpenMP version of the GCE code has been developed and is operational on large CPU shared-memory systems. Results from GCE multi-day simulations of convective systems have and are being published. Results have also been submitted to cloud modeling studies, which have the goal of improving cloud parameterizations in climate models, and surface and radiation processes in Cloud-Resolving Models (CRMs).

Description of Research

The physical complexity and nonlinearity of interactions between deep convective cloud systems and the large-scale environment is one of the key uncertainties in understanding climate change. Cloud systems largely influence atmospheric radiative and latent heating, as well as air-surface interactions due to latent and sensible heat release. These processes must be better understood before global models can be substantially improved. A CRM, such as the GCE model, can be used to explicitly resolve and quantify the collective effects of cloud systems, and to examine the role, in which large-scale processes relate to the development, maintenance, and structure of deep convective clouds. The goals of this research are to further develop and utilize the GCE model in studies to better understand tropical and mid-latitude convective cloud systems, and to improve cumulus parameterizations in global models. Principal efforts include studies of microphysical processes, effects of aerosols on rainfall production, and the roles of surface, radiation, ice-habits, and dynamical processes in the evolution of deep convective systems.

Accomplishments during the Reporting Period

Several 2-D and 3-D multi-day CRM simulations of convective systems in both tropical and mid-latitude environments were performed using the GCE model. The simulated systems utilized large-scale thermodynamic forcings diagnosed from the Tropical Ocean Global Atmospheres Coupled Ocean Atmosphere Response Experiment (TOGA-COARE; Pacific Ocean), the Global Atmospheric Research Program Atlantic Tropical Experiment (GATE; Atlantic Ocean), the Atmospheric Radiation Measurement (ARM; Oklahoma) program, the South China Sea Monsoon Experiment (SCSMEX), and the Preliminary Regional Experiment for Stormscale Operational and Research Meteorology (PRESTORM; Kansas). GCE model data from these simulations were used to study the atmospheric heating and moisture budgets, microphysical processes, rainfall production, convective and stratiform

separation, radiation and cloud feedbacks, and ocean/land surface processes in these different environments. In addition, thermodynamic, dynamic, and microphysical fields from these simulations were provided for incorporation into the TRMM retrieval algorithm database. Results from several TOGA-COARE GCE simulations were published [Johnson *et al.* 2002], which examined the heating, moisture, and microphysical budgets, as well as the impact of model dimensionality, domain size, and model numerics on the simulated results. GCE simulated data, model code, 3-D figures, and animations were created and provided to individuals within GSFC and outside sources, including NOAA, NASDA, Hebrew University, and Columbia University.

A modified ice bulk scheme was implemented, and contributions were made to an updated radiation package into the 3-D GCE code, which improved results from prior multi-day simulations. Simulations using an explicit "bin" microphysics model were conducted over several hours for tropical (TOGA-COARE) and mid-latitude (PRESTORM) systems, and the results produced more realistic hydrometeor fields with observations compared to the traditional bulk microphysics. Another major task was the completion of an OpenMP GCE version to run on large-CPU shared-memory systems, with the assistance of the Parallel Tools Team at NASA Ames Research Center. Major debugging of the 3-D model was undertaken to improve portability of the code. Programs were also developed to read in and visualize the model data, including 3-D images and animations.

Results from GCE simulations of convection during the ARM experiment were submitted to the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS) Working Group 4 (WG4) and have been published. Work is also underway to lead an offline study to better understand radiation and surface processes in the CRMs participating in the GCSS WG4. So far seven modeling groups have submitted results for this study; further information can be found at: http://rsd.gsfc.nasa.gov/users/djohnson/gcsswg4.

Objectives for the Coming Year

Goals for the coming year include completing several 2-D TOGA-COARE simulations examining the impact of microphysical process, surface fluxes, and radiational heating/cooling. Another objective is to complete the offline study for models involved in the GCSS WG4. New studies will involve comparing and investigating 3-D and 2-D GCE multi-day simulations of TOGA-COARE and GATE convection, bulk and bin microphysical studies of PRESTORM and TOGA COARE cases, and 3-D ARM multi-day studies of midlatitude storms. 3-D GCE simulations of different convective cases will also be provided for inclusion in the TRMM rain and latent heating retrieval algorithm databases.

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

GEST Investigator: Liguang Wu

Collaborator: Scott Braun (PI, GSFC)

Abstract

Research performed under this task is designed to advance our understanding of tropical cyclone activities. During the past year, two research tracks have been addressed: impacts of global climate change on tropical cyclone tracks, and dynamics of the intensity change of tropical cyclones. The research suggests that climate change can significantly affect tracks of tropical cyclone in the northern West Pacific because of the associated change in large-scale flows. Other work demonstrated the inhibiting effect of the hurricane asymmetries on the intensity change. The asymmetries primarily arise from the interaction of hurricanes with large-scale environmental influences such as vertical shear and beta effect.

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, numerical simulations were conducted with three different models: a triply nested movable mesh primitive equation model (TCM3), a coupled hurricane-ocean model, and Mesoscale Model 5 (MM5). Meanwhile, the possible impacts of the global climate change on tropical cyclone tracks were investigated by proposing a new diagnostic approach.

Accomplishments during the Reporting Period

Tropical cyclone activities were investigated during the past year by focusing on the intensity change and the impacts of the global climate change on tracks. The study on tropical cyclone intensity was conducted by numerical modeling with three numerical models. First, a hydrostatic primitive equation model (TCM3) was used to investigate the roles of environment-induced asymmetries on simulated hurricane intensity. In these idealized experiments, the hurricane asymmetries resulted from uniform flow, vertical shear, and the beta effect. Second, a coupled hurricane-ocean model was used to examine the influence of air-sea coupling on hurricane intensity. It is found that the symmetric component of the resulting SST anomaly with respect to the tropical cyclone center dominates the negative feedback. Finally, simulations of Hurricane Erin (2001) were made with MM5. The simulations have been validated with Convection and Moisture Experiment (CAMEX)-4 observations and Tropical Rainfall Measuring Mission (TRMM) data. Results showed 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.

A study on assessing impacts of global warming on tropical cyclone tracks was conducted by proposing a new approach, based on the premise that characteristics of future tropical tracks are primarily determined by changes in large-scale steering flows. It was demonstrated that these characteristics can be derived from the climatological mean velocity of tropical cyclone motion by using a trajectory model. The future motion velocity, composed of large-scale steering and beta drift, is determined with the output of the Geophysical Fluid Dynamics Laboratory (GFDL) R30 climate model. By assuming that the mean beta drift in the future climate state is unchanged, the change in the general circulation by 2059 will decrease tropical cyclone activities in the western North Pacific, but favor a northward shift of typical tracks. As a result, storm activities in the South China Sea will decrease by about 12%, while the Japan region will experience an increase by 12-15%. It is also suggested that tropical storms will more frequently affect Japan and the middle latitude region of China, given that the formation locations and numbers remain the same as in the current climate state.

Objectives for the Coming Year

In the next year, task work will continue to focus on understanding tropical cyclone activities. Most of the research work will focus on the formation of tropical cyclones and the possible influence of climate change on such formation.

Task 912-19-131: **Cloud Radar System Development, Calibration, Field Observation, and Data Analysis**

GEST Investigator: Lihua Li

Collaborator: Gerry Heymsfield (PI, GSFC)

Abstract

During the past year, work performed under this task has concentrated on developing and calibrating NASA's Cloud Radar System (CRS) and using it for cloud field observation during a field campaign, followed by data processing. In July 2002, CRS was installed on the NASA ER-2 and used during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment (CRYSTAL-FACE), based in southern Florida. CRS successfully collected its first airborne data from this experiment. After CRYSTAL-FACE, a series of system calibrations using a point target were carried out at GSFC. To verify the calibration results, CRS was set up at the University of Massachusetts, Amherst for intercomparison with another W-band cloud radar. Data analysis and algorithm development are under going for radar calibration and cloud microphysical property retrieval.

Description of Research

Improvement in understanding the radiative impact of clouds on the climate system requires a comprehensive view of clouds, ranging from their physical dimensions, to the dynamical processes producing them, to detailed microphysical properties. The lack of fine-scale cloud data is apparent in current climate model simulations. In acquiring such data, millimeter-wave radars offer significant advantages over lower-frequency radars. The high scattering efficiency and short wavelengths at millimeter-wave frequencies make it possible to construct compact, low-power radars for use in portable systems, especially for airborne and spaceborne applications.

The CRS is a 94 GHz (W-band) Doppler polarimetric radar developed for autonomous operation on the NASA ER-2 high-altitude aircraft and for ground-based operation. It provides high-resolution profiles of reflectivity and Doppler velocity in clouds. It is highly desirable, from a radiative standpoint, to take measurements from above the cloud layers. Cirrus cloud observations using ground-based W-band radars must address the strong water vapor and oxygen absorption in the boundary layer. Since the ER-2 flies at an altitude of 20 km, CRS is capable of measuring almost all meteorologically significant cloud systems from the surface to the upper troposphere. For high cirrus cloud detection, CRS collects data at a closer range than a ground-based system. This makes it possible to take advantage of the higher radar sensitivity in the near range without suffering the attenuation from water vapor and oxygen absorption present at lower altitudes.

Radar calibration is crucial to ensure the data quality. Different approaches have been tried to ensure the accuracy of CRS calibration, including external calibration using a trihedral corner reflector and using ocean surface measurements obtained from CRYSTAL-FACE. In addition, CRS was set up side-by-side with another independent ground-based W-band cloud radar at the University of Massachusetts, Amherst. By measuring the same cloud volume, CRS calibration was verified.

Accomplishments during the Reporting Period

During the past year, task work has made substantial progress in radar hardware development, system calibration, and data analysis. CRS system development was accomplished, and the system test was conducted in the laboratory and on a rooftop for cloud and precipitation measurements. There were two test flights at the NASA Dryden Flight Research Center. System failures, due to the malfunction of the hard drive, were debugged and fixed. The radar was prepared for its first field deployment, which involved participating in the CRYSTAL-FACE experiment, including near-real-time data processing. CRS external calibration was performed using a trihedral corner reflector, and

an intercomparison with the Cloud Profiling Radar System at the University of Massachusetts, Amherst was performed. Data processing code was developed to process CRS data and to save data in a format required for NASA data archives and other research groups. CRS ocean surface measurements from the CRYSTAL-FACE experiment were analyzed, as were cloud data collected by CRS, GSFC ER-2 Doppler Radar (EDOP), and the GSFC Cloud Physics Lidar from the CRYSTAL-FACE to retrieve cloud particle size and ice water content.

Objectives for the Coming Year

Radar measurements from the CRYSTAL-FACE experiment suggest that a larger size antenna is a cost-efficient approach to improve the system sensitivity for weak cirrus cloud detection. In the coming year, research will investigate the feasibility of using a larger CRS antenna on the ER-2. Other system upgrades, including radio frequency front-end transmit and receive switches and an internal calibration loop will be conducted. Radar calibration and intercomparison will continue in the coming year. Millimeter-wave cloud radar calibration is not trivial. Issues such as surface clutter effects, range weighting function, and atmospheric absorption could result significant uncertainties in radar calibration. Details will be investigated to ensure calibration accuracy. CRS ocean surface measurements will be compared to theoretical models. These models have been used for microwave radars but not for millimeter-wave frequencies, due to the lack of experiment data. Analysis from CRS measurements will be valuable to the study of ocean surface scatter characteristics at 94 GHz. The results will provide crucial reference for the ongoing NASA 94 GHz CloudSat radar system development. Data analysis will focus on the retrieval of cloud particle size and ice water content using CRS, EDOP, and GSFC Cloud Physics Lidar measurements from CRYSTAL-FACE. This unprecedented data combination will lead a new and more perceptive approach to study clouds microphysical properties and their effects on the global radiation budget.

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

GEST Investigator: Mircea Grecu

Collaborator: Robert F. Adler (PI, GSFC)

Abstract

This research is directed towards extending a technique to estimate precipitation from airborne radar and radiometer observations developed by the investigator and his collaborators. The technique selects from a set of precipitation estimates (that exactly satisfy the radar observations) those that lead to the best agreement between radiometer-observed brightness temperature observations and their simulations, derived from a radiative transfer model. Past investigations indicated the superiority of combined radar and radiometer estimates over radar-only estimates in the case of airborne retrievals. The technique's extension to data from satellite instruments is not straightforward, given the differences in the instruments' sampling volumes. In this research, an approach was developed to overcome the difficulties raised by the sampling volume differences. The extended technique is applied to Tropical Rainfall Measuring Mission (TRMM) data.

Description of Research

Developing a combined approach to estimate precipitation from satellite-based active and passive microwave observations requires developing a rigorous framework to mitigate the difficulties created by the different spatial and sampling resolutions of the satellite instruments. This research addresses the formulation and investigation of such an approach. A model that, given reflectivity profiles and a small set of parameters (including the cloud water content, the intercept drop size distribution, and a variable describing the frozen hydrometeor properties),

simulates high-resolution brightness temperatures is used. The high-resolution simulated brightness temperatures are convolved at the real sensor resolution. An optimal estimation procedure is used to minimize the differences between simulated and observed brightness temperatures. The approach is applied to TRMM data and the results are analyzed.

Accomplishments during the Reporting Period

Most challenges in estimating precipitation from satellite passive observations arise, because each observation characterizes the radiative interaction of precipitation particles with other sources of radiant energy in very large atmospheric volumes. The particle size distributions (PSD) vary considerably in these volumes, which makes it difficult to determine one-to-one relationships between radiometer observations and the precipitation amounts. Additional information, derived from theoretical models and independent practical observations, is then needed to develop algorithms that describe such relationships. An example of such additional information is that provided by the Precipitation Radar (PR) on the TRMM satellite. Although better defined, the PR estimates are still subject to uncertainties caused by variations of the hydrometeor size distributions in its sampling volumes. Various studies demonstrated that an independent estimate of the totally path-integrated-attenuation (PIA) for radars operating at attenuating wavelengths can be used to estimate the intercept of the particle drop size distributions and consequently improve the precipitation estimates. Independent PIA estimates may be derived from the Surface Return Technique (SRT) and radiometer observations. The PIA estimates from the SRT are subject to large uncertainty because of variations in the surface wind speed, which induce large variability in the surface's return values. Consequently, a better estimate of the PIA or additional related information is desirable. This is the reason why combined radar-radiometer retrievals, which may provide more accurate estimates of PIA and PSD intercept, have been intensively investigated in recent years.

The combined approach developed and investigated in course of this research incorporates information from passive observations in a radar rain-profiling algorithm by iteratively modifying the radar retrievals as a function of a small number of parameters (able to provide a large number of possible solutions given a profile of attenuated reflectivity) until the differences between calculated and observed brightness temperatures reach a minimum. This approach differs from others in the sense that the PIA is not directly estimated from passive observations and equated to the radar algorithm produced PIA in order to determine the PSD intercept. Instead, a set of parameters, including the intercept, a parameter describing the cloud content, and a parameter describing the liquid to solid precipitation phase transition are determined iteratively by minimizing the differences between observed and model simulated microwave brightness temperatures. The input to the radiative transfer model consists of the three aforementioned parameters and the corresponding radar-retrieved hydrometeor profiles. Other required input variables, such as the temperature profiles, are specified using statistical relationships. Additional statistical information is considered in the retrieval to make the solution better determined. Such approaches were avoided in the past due to computational considerations. However, although apparently computer intensive, this approach may be efficiently implemented using a variational analysis and an adjoint formulation.

A successful formulation and implementation of such formulation were accomplished, which allows for the optimal use of low-resolution radiometer information in high-resolution radar precipitation estimation. Results indicate good agreement between radiometer derived PIAs and PIA estimates from SRT, when the latter estimates are reliable. The formulation is robust and computationally efficient, which makes the technique readily applicable to large TRMM data sets. The analysis of the retrieved PSDs seems to indicate systematic differences from the PR-only estimates when the PIA is low. This suggests that the combined approach may be used to derive more appropriate reflectivity precipitation relationships when the independent PIA estimates are deemed unreliable.

Objectives for the Coming Year

During the coming year work will focus on validating the estimates from the combined approach. Polarimetric ground-based radar data will be used to more completely quantify the radar/radiometer model errors. Polarimetric observations may yield the most accurate retrieval of precipitation fields and will therefore be used to investigate the existence of systematic errors in the combined retrievals. If such errors are detected, the hypotheses underlying the combined approach formulation will be refined. Otherwise, the PSD databases retrieved using the combined approach will be used to reformulate the default relationships in PR-only retrievals.

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

GEST Investigator: Guojun Gu

Collaborator: Robert F. Adler (PI, GSFC)

Abstract

A Tropical Rainfall Measuring Mission (TRMM) daily product (3B42) has been applied to study tropical synoptic-scale waves and their association with precipitation over the West African continent. These waves can effectively modulate and organize surface rainfall during the boreal summer. However, convective coupling mechanisms for these waves seem to be different in the southern and northern parts of West Africa. Positive correlations between diabatic heating due to deep convection and wave dynamics appear primarily in the southern part, along the Intertropical Convergence Zone (ITCZ). Interannual variability in the wave activity is evident and exists in both the strength and propagating characteristics, which could enhance our understanding of the variability in African Monsoon and Atlantic hurricane activity.

Description of Research

Tropical synoptic-scale waves are very important modulators of surface rainfall over the West African continent during the boreal summer, which can readily be seen from daily satellite images and synoptic maps. Also, most Atlantic hurricanes originate from these waves. Evident interannual variabilities in West African rainfall and Atlantic hurricane activity were already demonstrated in earlier studies. Thus, the first primary objective of this study is to examine whether a similar interannual variability exists in synoptic-scale wave activity.

Deep convection and precipitation always accompany these synoptic-scale waves along the ITCZ, but they are seldom coupled with each other in the northern Sahelian regions. Hence, the second objective of this work is to examine how these waves interact with deep convection and whether a latitude-dependent convective coupling mechanism exists due to the sharp northward reduction of low-level moist air over West Africa.

Accomplishments during the Reporting Period

By applying a 2D wavelet analysis method, tropical synoptic-scale waves are quantified from a five-year TRMM daily rainfall dataset (3B42). These waves were shown to modulate surface rainfall patterns during the boreal summer, particularly along the ITCZ. Evident interannual variability exists not only in the waves' strength, but also in their spectral properties, *i.e.*, dominant frequency and wavenumber ranges. Furthermore, these variabilities can partly be ascribed to year-to-year variations in their embedded large-scale environment, especially the status of the African Easterly Jet (AEJ). Generally, a stronger (weaker) AEJ indicates more (less) instability energy and a stronger (weaker) disturbance activity season.

Horizontal distributions of surface rainfall relative to the waves' dynamic structures are inferred from a 1D wavelet cross-spectrum analysis between TRMM daily rainfall and 850 mb National Center for Atmospheric Research (NCAR)/National

Centers for Environmental Prediction (NCEP) meridional wind fluctuations. Different phase relations are discovered between the regions south and north of about 12.5°N. This implies that in the southern part of West Africa, *i.e.*, approximately along the mean latitudes of the ITCZ, most rainfall occurs near the wave trough zone, suggesting that convective heating tends to enhance wave development. In the northern part, however, rainfall is primarily observed directly behind the southerly wind maximum, close to the wave ridge, implying a minor—or even negative—impact on the waves. Thus, there is speculation that the coupling between the waves and deep convection (and surface rainfall) is strongly latitude-dependent, as are the horizontal structures. This latitude dependence might be very important in exploring the relationship between wave activity and Atlantic hurricanes, since more intense and moist waves (positively coupled with convective heating) may evolve more easily into tropical cyclones.

Objectives for the Coming Year

The African monsoon rain band does not continuously move to the north with the migration of surface confluence zone. A sudden break is always observed in July. This phenomenon is generally called the "Monsoon Jump." With the availability of high-quality satellite observations, such as TRMM rainfall, sea-surface temperature, and QuickSCAT surface winds, research will be conducted to quantify the evolution of this jump and explore its possible association with the formation and annual cycle of the eastern Atlantic cold tongue complex. In addition, a gridded near-real-time product (3B42rt) from the TRMM project provides much higher quality, and spatial and temporal resolution rainfall information than previous archived satellite datasets. To reasonably interpret this information, ground-based validations are essential. During this coming year, detailed ground validation will be conducted over Australian and North American regions using surface rain gauge data.

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

GEST Investigator: Kwo-Sen Kuo

Collaborator: Eric Smith (PI, 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 designed to further 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 to simulate illumination by a spaceborne radar.

Description of Research

The physical radiative transfer model will take as input a hydrometeor profile (measured by a Doppler profiler), a temperature/humidity profile (measured by radiosonde), and surface emissivity (measured by a downward-pointing multispectral 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 the 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 during the Reporting Period

A new mathematical-physical framework for the retrieval of raindrop size distributions using a

dual-frequency (Ku/Ka-band) precipitation radar was developed, in which effective radius and effective variance of the size distribution along with liquid water content are proposed to form the parameter set that best specifies drop size distribution and the related rain rate parameter. Both equivalent reflectivity factor and specific attenuation are accurately determined by this set of parameters in which the influence of size distribution to the two radar parameters becomes inconsequential. Therefore, they provide a more robust basis for radar rainfall retrieval than methods based on *ad hoc* Z-R and k-R relationships, or methods based on specific drop size distribution models. Furthermore, this triad of parameters nicely predicts the mean Doppler velocity in calm air. Using this parameter, along with the first moment of the measured Doppler spectrum, the updraft can be further estimated; in turn, the updraft can be incorporated into the estimation of in-cloud rain mass flux. This is an improvement over current methods that do not take this factor into account.

Theoretical derivations have been carried out to generalize the adjoint formulation [Box *et al.* 1988] to three-dimensional time-dependent vector radiative transfer problems. Since three-dimensional radiative transfer calculations require enormous computer memory and lengthy run-time, the perturbation technique enabled by the adjoint formulation provides a more efficient means for analyzing radiative effects.

Progress has also been made in collecting, installing, and testing the electromagnetic scattering software, such as the Mie solution for multilayered spheres [Johnson 1996], the discrete dipole approximation [Draine and Flatau 2002], and the extended boundary condition method (also known as T-matrix method), which are necessary for computing the single-scattering properties of more realistic, non-spherical hydrometeors. These single-scattering properties will be the input to the three-dimensional radiative transfer model under construction for this task.

Objectives for the Coming Year

In the coming year, task work will continue to finish the construction of a three-dimensional microwave radiative transfer model, incorporating realistic hydrometeor composition and morphology.

Task 912-29-152: **Simulating Precipitation Systems with the GCE Model**

GEST Investigator: Xiaowen Li

Collaborator: Wei-Kuo Tao (PI, GSFC)

Abstract

The Goddard Cumulus Ensemble (GCE) model has been used to simulate precipitation systems, both in the tropics and at mid-latitudes. Two cases of 3-D simulation of precipitation systems in tropical Brazil have been used as inputs to a microwave radiative transfer model. The simulated brightness temperatures are then compared with observed brightness temperature from instruments on satellites and aircraft in a Tropical Rainfall Measurement Mission (TRMM) field campaign. The results show a general agreement between the simulation and observation. However, a discrepancy still exists, especially when simulation of the Feb. 23, 1999 case was compared with observations. This discrepancy has been linked to the overprediction of graupel concentration in the simulated system.

Description of Research

The GCE model is capable of reproducing many features of different precipitation systems reasonably well. However, differences still exist between observations and simulations. Efforts have been made to improve the physical processes of the GCE model (*e.g.*, initialization, bulk type microphysics parameterization, radiation, etc.) using observations from the passive microwave imager on board TRMM satellite (TRMM Microwave Imager, TMI) and NASA's ER-2 aircraft (using the Advanced Microwave Precipitation Radiometer (AMPR)) during the

TRMM Brazilian Large Scale Biosphere-Atmosphere Experiment – Amazon (LBA). In addition, a 2-D version of GCE model has been combined with an explicit bin spectra microphysical model. The model is being tested using different horizontal and vertical resolutions, and the results have been compared with the GCE model using bulk-type microphysics.

Accomplishment during the Reporting Period

The TRMM LBA field campaign took place in Brazil early in 1999. Representative cases of two types of precipitation systems—in easterly and westerly flow—have been simulated using the GCE model. Sounding data from January 26, 1999 have been chosen to represent a typical easterly flow precipitation system. The February 23, 1999 case represents a system in westerly flow. The simulated 3-D structure of ice and water were used as input to a microwave radiative transfer model. Brightness temperature fields calculated with the radiative transfer model were compared with both TMI and AMPR microwave imager observations, with the result that GCE model simulations reflect major differences between convection in easterly and westerly flow. The January 26 case produces a much larger precipitation system with stronger intensity compared with the February 23 case, and the mean brightness temperature in the January 26 case is lower. These results agree well with both TMI and AMPR observations.

When the January 23 case (the only case with simultaneous TMI and AMPR coverage during the field campaign) was used for a detailed comparison with GCE model outputs, the model produces much colder minimum brightness temperature (T_b) at 37 and 85 GHz, compared with both observations. Further sensitivity tests reveal that cold T_b was mainly caused by overprediction of graupel concentration in the GCE model. In this case, the model generates much stronger convection when compared with observation. Further sensitivity tests are being carried out to improve initialization, microphysics, and other related physical processes to identify the causes and to minimize the discrepancy.

A bin spectra microphysics scheme has been combined with a 2-D version of the GCE model. Because of rapid increases in computational power, the bin spectra model has become the most advanced tool to study cloud and precipitation microphysics in the realistic dynamical frame provided by the GCE model. Task work over the past year has, therefore, involved testing and developing the GCE bin spectra model. Two sets of tests have been carried out: a change of both horizontal and vertical resolution, and comparison between the bin spectra model and a bulk-type model in both tropical and mid-latitude regions. Model simulations are consistent when the resolution of the bin spectra model is varied. Furthermore, increasing vertical resolution provides more details in melting processes around 0°C. Melting processes contribute significantly to both active and passive microwave radiation observations. The spectra bin model with high vertical resolution around 0°C is expected to simulate the details of this process, and therefore provide reliable information on retrieval of microwave radiation observations.

The 2-D bin spectra and bulk scheme model were compared using the same initialization profile in simulations of mesoscale convective systems in both the tropics and mid-latitudes. Bulk scheme simulations produce stronger and longer-lasting systems in both regions. One reason for this is that graupel melting extends into much lower levels in the bulk scheme than in the bin spectra scheme. Latent heat absorption due to melting in lower levels intensifies the cool pool at lower levels, which in turn produces stronger convection.

Objectives for the Coming Year

In the coming year, task work will continue with simulations using the GCE model. Stratocumulus cases in both the Barbados Oceanographic and Meteorological Experiment (BOMEX) and the Atlantic Stratocumulus Transition Experiment (ASTEX) will be simulated. Further developments of the bin spectra model are planned, including implementing the bin category into both shortwave and longwave radiative transfer schemes, specific simulation of melting layers, and addition of aerosol/cloud concentration nuclei transportation processes into the GCE model. Furthermore, TMI and radar data will be used to validate the performance of the GCE model, and to improve the physical parameterizations in mesoscale simulations.

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

GEST Investigator: Xiping Zeng

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

Abstract
In contrast to numerical weather prediction models, cloud-resolving models use fine spatial resolution so that they represent clouds explicitly, avoiding cumulus parameterization. With the aid of massive parallel computation, they may expand their domain size to thousands of kilometers in the following years. A cloud-resolving model with the domain size of 10^3 km can represent explicitly both clouds and synoptic large-scale circulation, 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 in 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 future exploration of clouds in weather and climate change.

Description of Research
Clouds play a central role in weather and climate change. They are related to atmospheric aerosols, radiation, and circulations, connecting these processes to each other. Due to the scale difference of aerosols, clouds, and large-scale circulation, numerical simulation plays an important role in studying the nonlinear relationships between clouds and other factors. Thus, an interesting topic is how to represent clouds correctly in numerical models. Numerical weather prediction models use a large spatial grid size and represent clouds implicitly with cumulus parameterization. However, cumulus parameterization is far from satisfactory, especially in the Tropics. In contrast, cloud-resolving models use fine spatial resolution. They represent clouds explicitly and introduce the microphysical physics of clouds with parameterization. Thus, cloud-resolving models provide an ideal framework to study the interactions between clouds and other factors (*e.g.*, aerosol, radiation, and large-scale circulations).

Accomplishments during the Reporting Period
Due to limitations of computational power, current cloud-resolving models usually use domain sizes on the order of 10^1-10^2 km and cannot accommodate large-scale circulation. With the aid of massive parallel computational capabilities, the models may expand their domain sizes to 10^3-10^4 km in the following years so that they can explicitly represent clouds and large-scale circulation. In response to this computational development, a cloud-resolving model is being developed as a suitable framework for the interaction between clouds and large-scale circulation. The three-dimensional Goddard Cumulus Ensemble (GCE) model is a cloud-resolving model. It has been improved over the past two decades, and been used to make many important contributions towards understanding precipitation processes and to NASA missions generally. This model is being developed in its second generation for better performance in science and engineering to address such topics as terrain, water species, and parallel computation techniques.

During the past year, task work included cooperation with scientists at NASA and NOAA, finishing the coding of the GCE model for parallel computation, and finishing the design for the second generation of the GCE model.

Objectives for the Coming Year
In the coming year, work will continue with NASA scientists to realize the second generation of the GCE model, and to finish testing. Special attention will be on the interactions between tropical convection and large-scale circulation.

Task 913-12-117: **Climate Dynamics and Climate Diagnostics: Effects of Extra-Tropical Air-Sea Interaction on Predictability of Warm Season Precipitation Anomalies over the United States**

GEST Investigator: Hailan Wang

Collaborator: William Lau (PI, GSFC)

Abstract
The goal of the project is to investigate the relative role of sea surface temperature (SST) variability in different oceanic basins, particularly air-sea interaction in extratropics, in contributing to predictability of warm season precipitation anomalies over the U.S.

Description of Research
This work investigates the mechanisms and the roles of extratropical air-sea interaction on the predictability of U.S. summertime precipitation anomalies, using observations; a simple, dry, dynamical model; and general circulation models (GCMs). The research focuses on identifying and understanding boreal summer teleconnection patterns, their associated variability in oceanic low boundary conditions, and the linkage to interannual variation of warm season precipitation over the U.S..

Accomplishments during the Reporting Period
In this late-year-initiated task, the potential roles of air-sea interactions in the North Pacific has been investigated by comparing existing NASA Seasonal-to-Interannual Prediction Project (NSIPP)-1 Atmospheric Model Intercomparison Project (AMIP) outputs to observational data. Preliminary analysis indicates that the interannual variability of observed precipitation over the U.S. during the warm season is largely related to SST variations in the North Pacific Ocean, whereas the NSIPP AMIP-simulated summer precipitation variation over U.S. mainly reflects impact of the El Niño/Southern Oscillation (ENSO) in the tropical Pacific. This implies the potential importance of air-sea interactions in the North Pacific in explaining the interannual variability of summer time precipitation over U.S.

Objectives for the Coming Year
In the coming year, the effects of extra-tropical air-sea interactions on warm season precipitation anomalies over the U.S. will be further investigated by analyzing existing NSIPP-1 AMIP and NSIPP coupled model simulations. The relative importance of local air-sea interchange processes and oceanic dynamics in the North Pacific and North Atlantic will be evaluated. To further address the relative roles of SST variability in different oceanic basins in explaining boreal summertime precipitation in the U.S., a series of modeling experiments will be performed, using the NSIPP AMIP-Ocean Mixed Layer (OML) model with constant mixed layer depth and the AMIP-OML model with variable mixed layer depth. Results gained from the mixed-layer modeling experiments will be compared to empirical benchmarks.

Task 913-12-117: **Climate Dynamics: Effects of Extratropical Air-Sea Interaction on Predictability of Warm Season Precipitation Anomalies over the U.S.**

GEST Investigator: Fanglin Yang

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

Abstract
Early work in this newly initiated task has focused on developing a multi-layer mixed-layer ocean model and testing the Goddard Earth Observing System (GEOS)-II general circulation model (GCM).

Description of Research

This work is an investigation into the mechanisms and the roles of extratropical air-sea interaction on the predictability of U.S. summertime precipitation anomalies using GCMs. The research will focus on identifying boreal summer teleconnection patterns and associated extratropical sea-surface temperature (SST) variability, and how they relate to tropical SSTs, *i.e.*, El Niño/Southern Oscillation (ENSO) phenomena. The research is based on the working hypothesis that there may be additional sources of potential predictability for warm season precipitation anomalies for the U.S., which can be harnessed from extratropical SST variability distinct from ENSO.

Accomplishments during the Reporting Period

A mixed-layer ocean model was developed, suitable for coupling with the GSFC Data Assimilation Office (DAO) GEOS GCMs and the NASA Seasonal-to-Interannual Prediction Project (NSIPP) GCMs. These coupled models will be used to study mid-latitude air-sea interactions. A 10-year simulation of the GEOS-II 4x5 GCM was performed with climatological sea-surface temperatures as boundary conditions. Selected output from this simulation was used to force the mixed-layer ocean model offline to compute flux correction terms.

Objectives for the Coming Year

Work to be performed in the coming year will include constructing a multi-level, mixed-layer ocean model, and coupling this model to the GSFC/DAO finite-volume GCM (fvGCM) and the NSIPP atmospheric GCM. Simulations for several decades will be performed, using each coupled model to diagnose climate drift and climate variability of the system. Experiments will be done to study mid-latitude air-sea interactions after a final version of the coupled system is established.

Task 970-31-156: **Studies of Performance and Science Implications of TRMM/VIRS and TMI**

GEST Investigator: Cheng-Hsuan Lyu

Collaborators: Bill Barnes (PI, GSFC), James C. Shuie (GSFC)

Abstract

Four years of on-orbit solar calibration data have been used to quantify the temporal degradation of the two reflected solar bands of the Visible and Infrared Scanner (VIRS) aboard the Tropical Rainfall Measuring Mission (TRMM) satellite. The quality of the VIRS radiometry was examined by comparing data from the five VIRS spectral bands with similar Terra-based Moderate Resolution Imaging Spectroradiometer (MODIS) bands while viewing near-coincident nadir scenes. An improved calibration method for the TRMM Microwave Imager (TMI) was developed using the TMI deep-space data from inertia (or pitch) maneuvers performed on 7 January, 8 January, and 2 September 1998. This study indicates that the moon can be used as an alternative calibration source for other microwave radiometers.

Description of Research

The on-orbit performance of both TRMM/VIRS and TMI must be monitored and calibrations performed for these sensors. Also, the science implications for the data retrieved by these sensors must be determined.

Accomplishments during the Reporting Period

Four years of on-orbit solar calibration show fluctuations of the VIRS 1.61 µm band responsivity of less than 0.5% and no indication of any long-term trend. The solar responsivity of the 0.62-µm band has degraded. The annual degradation rate is 1.15%. The newly derived solar responsivities will be used for the upcoming TRMM/VIRS data reprocessing.

Four years of integrated lunar reflectances have been measured for phase angles ranging from 1.6 to 106 degrees; analytic photometric functions have been constructed for the VIRS 0.62- and 1.61-µm data. The six-parameter lunar photometric model of Hapke provides a good description of the VIRS 0.62 µm data; however, the Hapke model does not fit the 1.61 µm data.

Radiometric comparisons of the five spectral bands of TRMM/VIRS have been made with similar bands from the Terra MODIS. These comparisons used data from scenes that were viewed near nadir by both sensors within a few minutes of one another.

An improved calibration method for the TRMM/TMI has been developed using the TMI deep-space data from inertia maneuvers performed on 7 January, 8 January, and 2 September 1998. The calibration algorithms differ from those adopted by earlier researchers [Wentz *et al*. 2001; Kummerow *et al*. 2000] in two respects. First, the along-scan error has been removed by using only the deep-space observations of the 2.735 K uniform, cosmological background from the TRMM inertia maneuvers uncontaminated by Earth emissions. These observations insure the uniformity of the along scan pixel-to-pixel scene. Second, in correcting for the warm bias of the TMI, an alternative algorithm was used, which better corrects the variations of the electronic gains of the radiometer. The corrected antenna temperatures of TMI are comparable to those of the Special Sensor Microwave/Imager (SSM/I) instruments on the operational Defense Meteorological Satellite Program (DMSP) spacecraft, F10, F11, and F13. For purposes of providing precise radiometric calibration, this algorithm accounts for more variables in the instrument's operation.

Additionally, from one of the deep space observations, the mean microwave brightness temperature of the moon was found to vary with frequency from 87-150 K. After corrections of the beam-filling effect, the derived microwave brightness temperature of the moon is comparable to that presented in a prior study by other researchers, which indicated that the lunar target can be used as an alternative calibration source for other microwave radiometers.

Objectives for the Coming Year

Upcoming work will include supporting the development of calibration and product validation plans for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP).

Task 975-32-159: **Retrievals of Microphysical Properties by Air and Spaceborne Radars**

GEST Investigator: Liang Liao

Collaborator: Robert Meneghini (PI, GSFC)

Abstract

The focus of studies under this task involves using microwave radar to retrieve hydrometeor properties. Significant progress has been made in analyzing Tropical Rainfall Measuring Mission (TRMM) Passive Radar (PR) data and airborne radar measurements and in developing radar algorithms to accurately and effectively retrieve clouds and precipitation. Research accomplished during the past year is grouped into four main areas: radar bright-band modeling; dual-wavelength radar techniques; mirror-image algorithms; and determining effective dielectric constants for mixed-phase hydrometeors.

Description of Research

Research topics addressed in this work include: simulating polarimetric radar returned from stratiform and convective rain to interpret dual-wavelength, polarimetric radar measurements; developing radar algorithms to retrieve hydrometeor properties; analyzing and comparing measurements from spaceborne radar and ground-based measurements for the purpose of validation; implementing mirror-image algorithms to process the TRMM PR data to validate the standard TRMM algorithms to estimate rain path attenuation; and extending research into the effective dielectric constant of mixed-phased hydrometeors.

Accomplishments during the Reporting Period

Radar has proven to be one of the most effective tools to investigate melting processes of frozen hydrometeors while falling through the 0°C isotherm in stratiform rain. Among the difficulties

encountered in calculating radar or radiometric scattering characteristics of partially melting snow or ice is the determination of the effective dielectric constant of the mixed-phased hydrometeor. The problem tends to be more difficult when realistic, nonuniform melting processes, where the fractional water content within the particle varies in location, is involved. In a numerical approach, the so-called conjugate gradient-fast Fourier transform (CG-FFT) was used to compute the internal electric fields of melting hydrometeors, from which effective dielectric constants can be derived. The method shows great flexibility in solving the effective dielectric constant of various non-uniformly mixing particles. To better represent the physical processes involved, the melting hydrometeors are modeled as spherical nonuniform mixtures with fractional water content given as a function of the radius. Combined with a melting layer model that prescribes the fractional melting water and fall velocities of the particles, the radar profiles associated with the melting region, better known as the radar bright band, can be produced as the scattering characteristics of hydrometeors are computed from their effective dielectric constants. The simulated results of the radar bright band are compared with the measurements made by the TRMM PR and dual-wavelength airborne radar. The simulated results show excellent agreement with measured ones. This implies that the melting processes of hydrometeors are well represented by the models considered in the study. Consequently, it may be possible to estimate the characteristics of particle size distributions from the measured profiles obtained by dual-wavelength radar. These findings are of great significance for the development of the algorithms for the Global Precipitation Measurement (GPM) mission, in which the dual-wavelength radar will be deployed.

Use of dual-wavelength radar will reduce ambiguities, to a large extent, for the retrieval of the rain when compared with the single-wavelength radar, like the TRMM PR. To explore the dual-wavelength technique it is important to know the forms or functions of the rain droplet size distributions (DSD), which are often obtained by analyzing a series of particle size spectra measured from disdrometers. An investigation of the relationship between the dual-wavelength radar reflectivities and particle size parameters is crucial to develop the algorithms to infer rain rate. From some typical models, such as gamma and lognormal distributions, used to describe the DSD; a number of computations have been carried out to relate radar measurements to DSD parameters. Based upon the computed results, several methods have been designed for retrieval of DSD profiles. Their validity has been tested from the dual-wavelength airborne radar measurements (the CRL X and Ka band during the Convection and Precipitation/Electrification (CaPE) experiment, and PR-2 Ku and Ka bands during the fourth Convection and Moisture Experiment (CAMEX-4)). While great progress has been made to check the convergence of each method, uncertainties still remain as to how the distribution parameters are chosen.

Mirror-image returns, the echoes through double reflections of the ocean surface from rain, offer useful information that is associated with path attenuation when used together with direct returns. The relation linking the differences of direct and mirror-image returns to path attenuation has been studied. Because of the complex scattering mechanism of the mirror image, its computations are generally performed numerically and the results are subsequently parameterized as a function of the distance from the surface and the surface roughness. Under some approximations, the solutions can be expressed analytically. The mirror image algorithms have been successfully applied to the TRMM PR measurements to estimate path attenuation for the case of stratiform rain, which in turn may be used to evaluate the accuracy and validity of the standard TRMM algorithms.

To examine the theory and verify techniques in obtaining the effective dielectric constant of mixing particles, an experiment was conducted in the laboratory by employing a waveguide to measure transmission and reflection parameters of model mixing samples. In comparisons with measurements, the computations of the electric fields by means of the CG-FFT have been made for the same samples in free space. Some of preliminary results have been obtained, but more work is needed.

Objectives for the Coming Year

While the focus of the research is still on the retrieval of microphysical properties of hydrometeors from air- and space-borne radar, measurements from other instruments, such as microwave radiometers, will be combined with current radar applications to reduce some ambiguities resulting from insufficient measurements.

UMBC Grant: **Deriving Microphysical Cloud Profiles and Snow Using Active and Passive Microwave Observations (25974)**

GEST Investigator: Gail Skofronick Jackson (PI)

Collaborators: James A. Weinman (GSFC), James R. Wang (GSFC)

Student: Min-Jeong Kim

Abstract

The underlying focus of this research is to use high frequency (= 90 GHz) passive microwave brightness temperatures to detail the characteristics of frozen hydrometeors. In the process of detailing frozen hydrometeors, an iterative retrieval algorithm was designed to estimate microphysical cloud hydrometeor profiles using microwave observations from the ER-2 aircraft obtained during Tropical Rainfall Measuring Mission (TRMM) validation field campaigns. Microphysical parameter profiles for anvil, convective, and stratiform clouds over the Atlantic Ocean and associated with Hurricane Bonnie were estimated and validated using data from the third Convection and Moisture Experiment (CAMEX-3) in 1998. Data from CAMEX-4 in 2001 is currently being investigated. In another focus area, but still using high frequency information, snowfall over land estimation algorithms are being developed. These snowfall retrievals use the Advanced Microwave Sounding Unit-B (AMSU-B) satellite data to determine snowfall characteristics. The current case study is the March 5-6, 2001 New England blizzard that deposited 60 cm of snow on Burlington, VT USA.

Description of Research

Knowing the microphysical state of hydrometeors (*i.e.*, cloud water, rain, cloud ice, snow, graupel, and hail) in clouds is important for many reasons, including determining hydrological cycles, improving global change models, and validating cloud-resolving models. However, ascertaining the microphysical profile is impeded by difficulties in obtaining adequate *in situ* observations, land surface emissivity variations, and the nonlinear and underconstrained relationships between remotely sensed microwave signatures and the underlying cloud microphysics. The objective of this research is two-fold: first, to estimate microphysical profiles using active and passive microwave signatures of hydrometeors as obtained from the ER-2 aircraft during TRMM field campaigns; and second, to detect or estimate snowfall over land using high frequency microwave data from the AMSU-B NOAA satellites. Thus, the overall goal of this research is to model and estimate realistic hydrometeor profiles for various storm types (*e.g.*, convective, anvil, and stratiform), precipitation types (*e.g.*, liquid and frozen), and surface types (*i.e.*, land and ocean).

Accomplishments during the Reporting Period

The major research over the past year was investigating the use of the 183±1, ±3, and ±7 GHz in detecting snowfall over land surfaces. Snowfall and rain rate retrievals over land surfaces are complicated by the widely varying surface emissivities. The 183 GHz channels are sensitive to water vapor and thus often opaque to the unknown and varying land surface characteristics. Another advantage of the millimeter-wave frequencies is their sensitivity to the frozen hydrometeors. This sensitivity manifests itself as a decrease in brightness temperature caused by scattering from ice. For these reasons, the AMSU-B brightness temperatures at 89, 150, and 183±1,

±3, and ±7 GHz make a perfect channel set to investigate snowfall over land.

First, a relationship was qualitatively observed between the 183 GHz observations from the AMSU-B instruments on NOAA satellites and a surface based radar composite of the March 5-6, 2001 New England blizzard. This blizzard became the case study for our work. Radiative transfer code was modified for use with these channels and AMSU-B specifications. A parameterized cloud model was developed using four parameters for the four or five degrees of freedom (independent frequency channels). The four parameters of the cloud model include parameters that adjust relative humidity, snow mass, snow size, and surface emissivity (for 89 GHz). The parameterized profile characteristics were initialized by the Mesoscale Model 5 (MM5) cloud profile simulations performed for the March 5-6, 2001 blizzard.

Each of the four parameters was finely interpolated between two appropriately defined endpoints. Radiative transfer calculations were performed for all the permutations of the four parameters and the snow profiles they generated. The computed brightness temperature vectors were compared to the AMSU-B brightness temperature vectors. The difference between computed and observed vectors was minimized, and the profile that produced the brightness temperature vector that best matched the observations was considered the retrieved profile. Brightness temperature retrieved and observed comparison maps over the latitude and longitude range of the 2001 blizzard showed good agreement. A comparison between estimated snowfall rate and NOAA's Next-generation Radar (NEXRAD) surface radar data indicating regions of light to heavy snowfall (in dBZ) showed reasonable agreement given the uncertainties in both the radar data and snowfall parameterization. These are some of the first estimates of snowfall over land surfaces using satellite data.

Another goal of this research is to promote the inclusion of high frequency channels on the planned Global Precipitation Measurement (GPM) core satellite. There is no doubt that millimeter-wave frequencies will be on some of the GPM constellation satellites. With a snowfall retrieval algorithm and the higher latitude observations of the GPM satellites, a retrieved snowfall product can be developed as part of the GPM output. Knowledge of snowfall rates (or even detecting snowfall) would be a significant achievement in the atmospheric remote sensing community.

Objectives for the Coming Year

In the coming year, goals for this task will have three foci: first, improving the snowfall estimation algorithm through an adaptive optimization algorithm that searches the snow cloud parameter space to minimize differences in various observed and calculated parameters; second, investigating the electromagnetic properties of frozen hydrometeors and developing dielectric mixing theories appropriate for high frequencies; and third, transferring the CAMEX-3 based retrieval algorithm for use with the more recent (2001) CAMEX-4 data, which has a slightly revised channel set.

NASA Grant: **Organization, Structure and Evolution of Tropical Convection in the South China Sea Monsoon and their Mesoscale Environment (NAG5-9699)**

GEST Investigator: Jian-Jian Wang

Abstract

The goals of this study are to develop a physically consistent understanding of the organization, structure, and evolution of mesoscale convective systems occurring during the onset and mature phase of the South China Sea (SCS) summer monsoon. This study utilized the Doppler radar, satellite, rawinsonde, and rain gauge data collected in the South China Sea Monsoon Experiment (SCSMEX), one of the Tropical Rainfall Measuring Mission (TRMM) field campaigns in May-June 1998. The SCSMEX is especially important for TRMM to provide comparable observations from surface-based instruments to

TRMM satellite over SCS, an open oceanic region with importance to the global atmospheric energy and hydrologic cycle. This study involves documenting rainfall characteristics and kinematic structure of monsoon convection; and determining the effects of environmental conditions on the initiation, organization and evolution of monsoon convection.

Description of Research

The work performed under this task addresses two central research efforts: to define the initiation, structure and dynamics of precipitation processes associated with the onset of the monsoon; and to obtain quantitative vertical motion over a tropical oceanic site. This study involves determining the effects of environmental conditions on the initiation, organization, evolution, and propagation of monsoon convection; documenting rainfall characteristics and kinematic structure of monsoon convection; and characterizing transition precipitation from convective to stratiform precipitation.

Accomplishments during the Reporting Period

Task research in the reporting year consists of two major parts. First, the organization and evolution of monsoon convection has been studied during the early stage of summer monsoon onset under the influences of frontal passages. Second, dual-Doppler radar analysis has been used to investigate the rainfall characteristics and kinematic structure of a squall line case occurring in the late stage of monsoon onset.

One study focused on the monsoon convection associated with two subtropical frontal passages during the transition period of South East Asian Monsoon (SEAM) onset. The evolution and structure of the mesoscale convection in the SCS region were documented for the first time using primarily the dual-Doppler radar dataset collected during the SCSMEX. The onset of SEAM in 1998 started on 15 May when the two branches of southwesterly tropical airflow arrived in the northern SCS. At the same time, a southeastward moving frontal system from mainland China moved to the monsoon onset area. Different from the frontal rainband prior to the SEAM onset that dissipated rapidly after passing the coastal region, this frontal system was able to produce heavy rainfall in the SCSMEX radar observational domain with significant local intensification. The interaction between the tropical monsoon flow and the frontal circulation played an important role to the organization and structure of the mesoscale convection. Ahead of the 850-hPa wind shear line, the southwesterly monsoon flow converged with the original southwesterly frontal flow to generate a northeast-to-southwest oriented rainband; and behind the 850-hPa wind shear line, the southwesterly monsoon flow converged with the northerly frontal flow to produce a convective band with an east-to-west orientation [Wang 2002a].

Dual-Doppler and polarimetric radar analyses were combined for the first time to study the structure and characteristics of an oceanic squall line system. The focus of this study is to document the similarities and differences of this squall line system occurring in the late SCS summer monsoon onset from the previous studies on the tropical and subtropical squall lines. On 24 May 1998, the onset of the SCS summer monsoon was near its completion with the establishment of southwesterly flow at low-level and northeasterly winds at upper-level over the SCS region. On that day, there were three squall lines observed by the SCSMEX radar network.

Compared with the tropical and subtropical oceanic squall lines documented in early literature, the squall lines observed on 24 May had significant departures from the archetypal concept model. Having intense convection with maximum radar reflectivity over 50 dBZ, the squall lines had little stratiform precipitation. It was believed to be related to the environmental conditions with very dry mid- to upper-level air and weak upper level winds. The hydrometers brought aloft by the updrafts would evaporate quickly in a super dry environment before forming a considerable area of stratiform rain. Meanwhile, the weak environmental winds at the upper level also limited the extension of the possible stratiform rain, as it would not blow the hydrometers away from the convective part. From a vertical cross-section, a limited formation of stratiform rain associated with an intense cell from the second squall line was observed. Different from the typical position of the stratiform rain that is

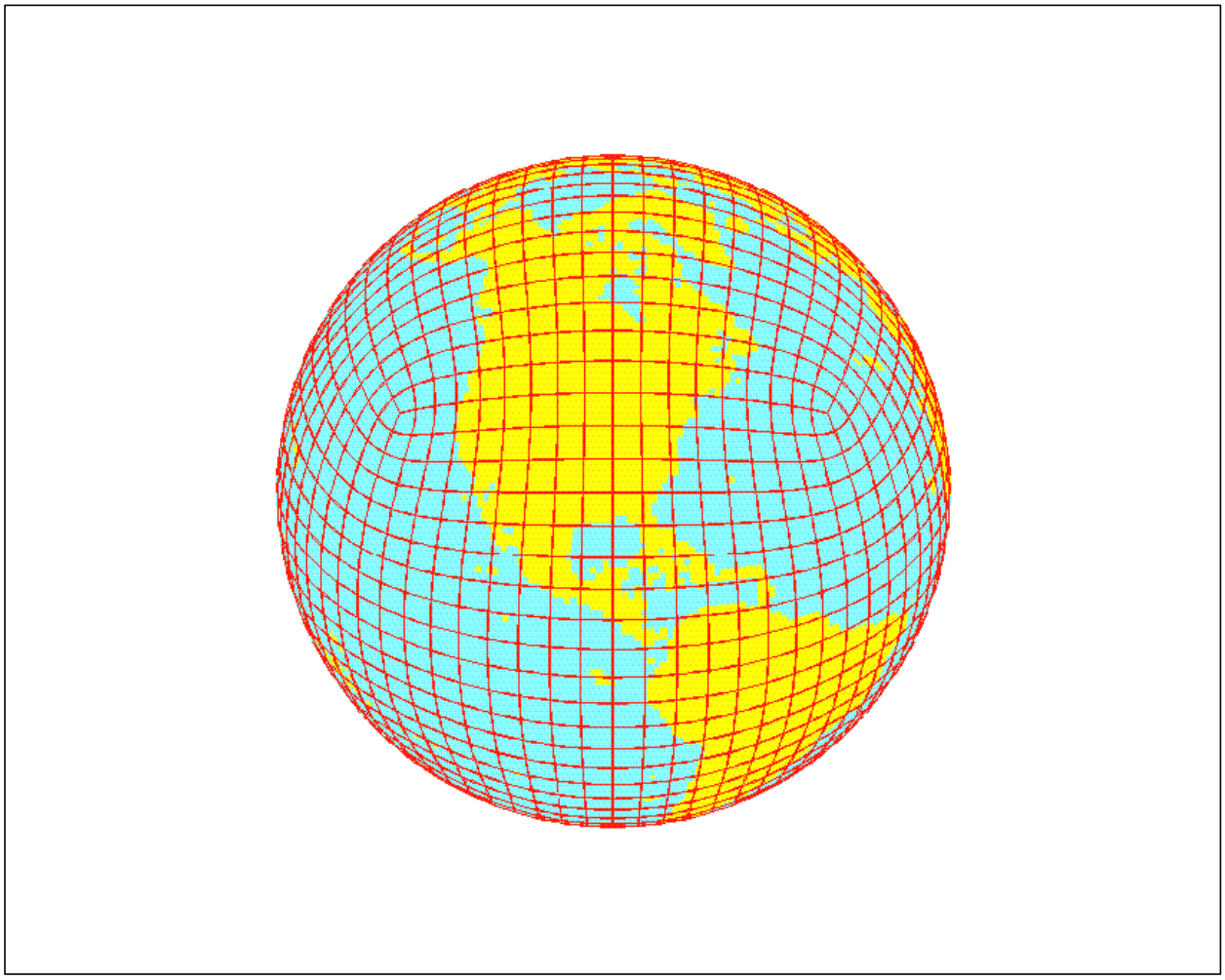
usually behind its counterpart, the stratiform rain observed here was ahead of the convective core. This type of leading-stratiform mode seldom occurs over the land, and even more rarely over the ocean [Wang 2002b].

In addition to the observational studies on SCSMEX, collaborative with Dr. W.-K. Tao's modeling group used cloud models to examine the different mechanisms responsible for the formation and evolution of severe convection [Shie *et al.* 2002]. The kinematic structure derived from the dual-Doppler radar analysis will also play a role in Dr. William Olson's study on latent heat profile estimation [Olson *et al.* 2002].

Objectives for the Coming Year

Effort to explore specific case studies will continue. In particular, polarimetric radar inferred microphysical (*e.g.*, hydrometeor type, amount, and size) and rainfall properties will be placed in the context of the mesoscale morphology and dual-Doppler derived kinematics for this vigorous squall line. The rain rate, mass of water, and mass of ice associated with the developing squall line will be calculated as well. In addition, the investigation of the regional variation of SEAM convection during the different stage of the summer monsoon period will begin. This study will utilize mainly the ground-based polarimetric radar data and the data derived from TRMM Precipitation Radar (PR) and Microwave Imager (TMI) observations. We will compare our results with studies focusing on field experiment in other monsoon regions, in particular, the TRMM Large-scale Biosphere-Atmosphere (LBA) Experiment in the Amazon.

Information Science and Technology Research Group



Application of quasi-uniform spherical grids, with a homogenous distribution of grid elements over the globe, is expected to solve some of the most critical numerical and computational problems in modeling the climatic syste.

Information Science and Technology Research Group

The Information Science and Technology (IS&T) research group conducts research and development to enhance science and mathematics education using advanced information technologies.

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. GEST is also committed to NASA's mission to inspire the next generation of explorers. Computational optics is one of the focus areas in the IS&T Research Group. The research team maintains an active optical bench to explore principles and requirements, advanced mirror designs, and development for Earth and space science missions.

IS&T researchers are developing a framework to integrate regional and global models of the Earth's atmosphere. An additional direction from which IS&T researchers are attacking the challenge of extraction of knowledge from massive and complex Earth science data sets is through the development of sophisticated data assimilation processes. The goal of this research is to integrate all that is known about atmospheric chemistry, both observationally and theoretically, to yield a "best" analysis of the atmosphere's chemical composition. This product can then be used for detailed scientific analysis of such issues as ozone depletion and its causes, and how this changes over time and/or location. Data assimilation facilitates this integration and is a valuable tool in maximizing the science return from observations of atmospheric chemistry.

Advanced detectors produce large data volumes, and managing the resulting data sets is quite challenging. IS&T researchers are developing data compression algorithms to facilitate the movement of science data without compromising the accuracy of information retrieval processes.

Co-registration of multiple images can also be a complicated process. Several IS&T activities target the challenging problem of registration of Earth and space imagery. Changes in field-of-view among images, due to the motion of the satellite or due to the fact that images often originate from different sensors and/or different platforms, introduce uncertainties in the absolute position calibration of the datasets. These uncertainties are difficult to correct, given variations in viewing geometry and pixel resolution. IS&T scientists are studying various algorithms to compensate for these effects, including wavelet decomposition of the images and an edge-detection approaches.

Many image processing and analysis routines are computationally intensive and lend themselves to parallel processing. GEST scientists are developing system-level software and applications for implementation on Beowulf-class parallel computers, (*i.e.*, clusters of commodity PCs running the Linux operating system, connected through dedicated local area networks). These clusters facilitate running NASA's Earth and space science applications on low-cost, high-performance computers, integrated seamlessly into the working environment of multiple personal workstations. Software development to assist scientists in porting their applications to parallel machines is also underway.

Activities on gathering and processing data would be wasted energy if—once the data were analyzed—they could not be accessed by the broader scientific community. Investigation into technologies to support the development of a semantic web for science and education is an active area of research at GEST.

Ultimately, the information and knowledge from NASA's Earth and space science missions is to be communicated to scientists, educators, learners, and the general public. IS&T activities include studies of use of state-of-the-art information technologies to enhance science, mathematics, and technology education through Internet-based products derived from content on NASA's missions. Additionally, IS&T researchers, in collaboration with U.S. and Irish partners, are building the infrastructure for a virtual

observatory to enable students in classrooms (and learners of all ages) to remotely operate telescopes, study astronomy, and enhance science literacy.

Through all these activities, IS&T group members are not only supporting many of NASA's activities, but they are providing cutting-edge concepts and tools to enhance NASA's missions generally.

Susan Hoban

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

GEST Investigator: Thomas J. Albert, Jr.

Collaborator: Robert Gabrys (PI, GSFC)

Abstract

Advances in information technology provide classrooms with potential access to a wealth of previously untapped learning opportunities for educators and students. Educators face the challenge of accessing data and information needed in the brief time allotted during the school day. Teachers must find this material in order to plan for the activity or lesson; students face many of the same needs and constraints. As GSFC's Education Office continues supporting the educators and school systems in its service area with science and technology content, there is a significant need to provide ways to efficiently glean the needed information from the vast pool of Internet sources. Because each Website is unique in layout, often more time is then needed to learn to navigate the site than to find the desired item, such as a graphic, video clip, document, etc. The challenge addressed under this task was to create an Internet-based interface that would allow teachers and students to obtain the desired content in a minimum amount of time—and within three mouse clicks. The successful result is a user interface called the *ED Mall*.

Description of Work

Since educators and students alike search the Internet for specific content, it was important to define the "piece" of content and use that as the starting point for *ED Mall* development. Additionally, it was important to address the need for a unique, dynamic search tool to find the desired content, since the standard "keyword" search in a search engine environment can result in a list of thousands of individual Web pages, many having nothing to do with the desired target. Therefore, the best strategy was to create a unique interface that produced a database of desired science content within three mouse clicks. Another goal was to instruct GSFC customers in its use.

Accomplishments during the Reporting Period

The beta version of the *ED Mall* has been designed, based on input from representative educators, who were polled to identify "pieces of content" they would be interested in obtaining for their pedagogical purposes. From this poll, 44 pieces of content were defined and each was labeled as an educational "element." Elements include specific images, lesson plans, coloring books, virtual scientific tools, etc. To obtain an Element within the three-click goal, a hierarchy and sorting process had to be designed.

The *ED Mall* first asks the customer to use their first mouse click to select a category from the five NASA Enterprises: Earth Science, Space Science, Aerospace Technology, Biological and Physical Research, and Human Exploration and Development of Space. A new window then opens, displaying an interface unique to that Enterprise. Each Enterprise has subtitles or components that make up that Enterprise. For example, Earth science is sectioned into several "Spheres": Atmosphere, Biosphere, Cryosphere, Lithosphere, and Hydrosphere. At present, Earth Science is the only Enterprise to have decomposed in this manner, and is, therefore, the only current operational component within the *ED Mall*. The Space Science Enterprise is presently being addressed in a similar fashion.

Within each Sphere is a list of "Concepts" that pertain to that Sphere. The Concept is the customer's second drop-down menu selection in the *ED Mall*. Once this second selection is made, the customer moves to the last drop down menu and selects the desired Element and clicks "GO." The results appear in the bottom half of the window with details, descriptions, and hot-linked URLs to the exact locations of where the various Elements resides on the Internet, the choice constitutes the third mouse click, consistent with the design specification. An additional feature of the *ED Mall* allows for "hard-wired" access to

scientist presentations from training, workshops, and courses of study developed for schools/systems in collaboration with the GSFC Education Office.

Objectives for the Coming Year

As Mr. Albert will be leaving the GEST Center in March 2003, no further work on this aspect of this task is envisioned at this time.

Task 130-05-085: **Learning Technologies: The LEARNERS Initiative**

GEST Investigator: Susan Hoban

Collaborators: Robert Gabrys (PI, GSFC), Daniel Laughlin (UMBC/GEST)

Abstract

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, math, engineering, and technology —a trend that contributes to our national shortage of well-trained scientists, engineers, and computer scientists. This problem is of paramount interest to NASA. NASA's Learning Technology Project sponsors the Leading Educators to Applications, Research and NASA-related Educational Resources in Science (LEARNERS) initiative, based at GSFC, which seeks to support science, mathematics, and technology education through the infusion of NASA-related information into classroom activities through the development of information-technology-based educational products. LEARNERS provides educators with information technology tools for unique teaching experiences for the purpose of educating and inspiring the next generation of explorers, as only NASA can. LEARNERS themes cut across NASA Enterprise disciplines. The products under development provide hands-on and minds-on experiences for learners using a variety of new educational technologies or a combination of traditional and information-technology-based techniques. Further detail on specific LEARNERS activities can be found on the Web at http://learners.gsfc.nasa.gov.

Description of Research

The LEARNERS team conducts research and development activities generally relating to educational technologies at GSFC, other NASA centers, and in the education community. Activities focus on the infusion of NASA content into the K-12 educational and lifelong learning environments through the use of advanced information technologies. GEST researchers work with the LEARNERS investigators from universities and private industry, K-12 educators, and NASA scientists and managers to facilitate access to NASA data, information, and technology for research and development of technologies for science, mathematics, and technology education.

Accomplishments during the Reporting Period

Task work included assisting the NASA HQ Educational Technology Program Officer in planning and participating in the NASA-wide Educational Technology Training Conference held in May 2002 at NASA Kennedy Space Center. Ongoing research continued to assist the Education Office develop strategic directions for future Learning Technologies development. Refinements to a whitepaper, *NASA Technology for Learners in the New Millennium*, are in progress. The work of four summer students who participated in the project (M. Blum, J. Holmes, A. Scott, R. Yesha) focused on an analysis of state-of-the-art Earth and space science educational technology applications.

In addition to presentations at conferences and meetings, the investigator was invited to present NASA's Solar System exploration to the students at R. K. Mellon Elementary School in Ligonier, PA. The enthusiastic response of the students and teachers led to an invitation to be the keynote speaker at the Mellon's "launch" into their participation in NASA's Imagine Mars project.

The investigator served as a session chair at the LEARNERS Dissemination Workshop, organized by GEST researcher Dr. Daniel Laughlin, and served as a reviewer of Small Business Innovation

Research (SBIR) proposals for NASA's Earth Science Enterprise (ESE).

Other task work includes developing a technology-based science and mathematics activity, affectionately called the Principles of Remote Exploration Project (PREP). Prototype implementations included an activity with high school students in the Cooperative Satellite Learning Project at GSFC, and a training session with middle school teachers as part of the teacher training session at the NASA Solar-Terrestrial Probe/Living With a Star Middle School Space and Earth Science Workshop, at DuVal High School, Greenbelt, MD.

For additional information on these and related projects, see the article by Dr. Daniel Laughlin, elsewhere in this volume.

Objectives for the Coming Year

Task work will continue with the conduct of research for strategic planning for new directions for NASA Learning Technologies, in particular in light of the reorganization at NASA Headquarters, which resulted in the new Enterprise for Education, Code N. The investigator will participate in the upcoming review panel for the Learning Technologies LEARNERS II Cooperative Agreement Notice. Other work will include coordinating a conference for the new LEARNERS II investigators. The development of the PREP will continue, with implementations expected for developmentally challenged students, middle schools students (targeted at NASA's Explorer Schools), and elementary school students (in the form of a coordinated competition) in addition to offering *PREP for Mars* at NASA's "Inspire the Next Generation of Explorers Day." At the suggestion of Vice Provost Weidemann, the investigator and Dr. Yelena Yesha (UMBC/CSEE) initiated discussions with Dr. John Lee of UMBC to discuss collaboration with UMBC's Urban Teacher Education initiative. The investigator will be Session Chair for the Remote Exploration track of the Educating with Virtual Experiences (EVE 2003) International Workshop, planned to be held in Ireland late in 2003.

Task 550-06-087: **Phase-controlled Multiple Aperture Telescope Systems**

GEST Investigator: Gregory Solyar

Collaborator: Richard Lyon (PI, GSFC)

Abstract

A new optical system was built consisting of two 14" Celestron Schmidt-Cassegrain C-14 telescopes, positioned on motorized computer controlled rotational and translational stages from New Port Corp.; a motorized, computer controlled, sparse aperture mask with three independent aperture blocks; and an objective with a liquid wave-guide illumination device and detector unit. Special algorithms were also written to control the movement of the apertures to follow any given physical trajectory. Design has been completed for a ground-based optical Fizeau interferometer testbed, and construction has begun.

Description of Research

Successful use of segmented—rather than monolithic—mirror structures in new telescopes such as the Keck system is vital to attain many of the compelling science goals outlined in NASA's *Space Science Strategic Plan*. Such telescopes will help research the formation and development of structure in the universe over cosmic history, the history of energy release and element formation, the habitability of planets, and other related topics.

The primary goals for testbeds developed under this task are to explore principles and requirements for Earth and space science missions under study such as Stellar Imager (SI), formation flying, and Interferometers/Sparse Aperture Telescope missions. Closed-loop control of the sparse aperture optical system must be demonstrated to keep beams in phase and to optimize imaging. The testbed allows assessment of various image reconstruction algorithms, such as phase diversity and maximum entropy methods, for their utility and accuracy by application to real data.

Accomplishments during the Reporting Period

The testbed includes two 14" Celestron Schmidt-Cassegrain C-14 telescopes, a light source, charge-coupled device (CCD) detectors and a rotating aperture mask built to test phase diverse algorithms in a closed-loop control. The telescopes are positioned on motorized computer-controlled rotational and translational stages from New Port Corp.

The motorized, computer-controlled mask allows positioning three variable-size apertures on one plane-following variable trajectory by means of two motorized, computer-controlled rotational stages from New Port Corp. with the aid of designed mathematical and computer algorithms. This mask consists of three exchangeable circular aperture blocks. The mask is a very simple, unique, and elegant method of testing sparse aperture systems and algorithms with different baseline distances and aperture sizes in dynamics.

The graphical user interface(GUI), written in Lab Windows CVI, allows the user to read the positions of six motorized actuators and information from a CCD camera. This interface also enables the use of any image processing software.

The image degradation and reduction of dynamic range due to vibration noise and leakage of light from a light source was eliminated by positioning the incandescent source outside of an optical table and using the liquid wave-guide to illuminate the object (film). However, poor design and fabrication of the telescopes caused some comatic aberration that impedes the interference between three apertures. A solution to this problem is being investigated.

A ground-based UV-optical Fizeau interferometer testbed has been designed and is now being built. The testbed consists of the white light source collimating secondary mirror, collimating primary mirror, imaging array, imaging secondary mirror, and a fast CCD detector. All the elements have been built or are being delivered from manufacturers. The system consisting of imaging array of seven spherical mirrors on piezo actuators and controllers driven by computer has been built. The interface for rough alignment control has been designed and tested, and dispersed fringe sensor for coarse phasing of segmented secondary mirror is being designed.

Objectives for the Coming Year

A key objective for the Phase Diverse testbed is to find the source of the aberrations, compensate for them, if theoretically possible, and test the phase diversity algorithms in a closed-loop control. For the ground-based UV-optical Fizeau interferometer testbed, the objective is to design the metrology and alignment system. The whole system will be built, and integrate (including control algorithms) and prescriptions for closed-loop control phase diverse algorithms will be written.

Task 693-42-179: **Data Compression Algorithms Design for LEISA**

GEST Investigator: Gregory Solyar

Collaborator: Dennis Reuter (PI, GSFC)

Abstract

A key to success in data compression is determined by how much information that is required to be stored will be later retrieved for future data processing. Whether or not a compression technique is effective is measured by the degree of loss in future information retrieval rather than information recovery. This project investigates data compression from an information extraction and retrieval viewpoint.

Description of Research

The purpose of the task is to develop intelligent and adaptive algorithms for the Linear Etalon Imaging Spectral Array (LEISA) Atmospheric Corrector (AC) on the Earth Observing-1 (EO-1) mission based on data compression to retrieve the

maximum useful information from hyperspectral data.

Research addresses a three-stage data compression concept consisting of information extraction-based band selection in the first stage, followed by information retrieval-based Linear Spectral Mixture Analysis (LSMA) compression in the second stage, and priority coding-based Multistage Pulse Code Modulation (MPCM) compression in the third stage, where the data compression is performed in a hierarchical fashion. While the compression in the first two stages is designed primarily to remove spectral redundancy, the third-stage MPCM-based compression is included to remove spatial redundancy. Unlike most compression techniques that treat remotely sensed imagery as three-dimensional (3D) image cubes and attempt to compress the data cubes as a whole, the proposed compression hierarchically does spectral and spatial coding. It is a very flexible conceptual approach in the sense that a compression stage may be skipped when it is not necessary.

Accomplishments during the Reporting Period

Recently, hyperspectral data calibration for the LEISA atmospheric corrector was performed, and development of data compression techniques began. One component of this work is to extract information from hyperspectral data. Remote sensing instrumentation is capable of producing high spectral resolution and special data at a continuous set of spectral wavelengths. The purpose of this aspect of the task will be to develop intelligent and adaptive algorithms for obtaining the maximum useful information from this class of instrumentation based on the properties of the instrument and the image characteristics. This includes data compression methodologies. Synthetic data and data from the LEISA Atmospheric Corrector (LAC) on the EO-1 mission are examples of data to be processed. For the LAC data, procedures must be compatible with existing libraries and in a form meeting the needs of LEISA data users.

Another component of this work is to perform spectral and radiometric calibration of the hyperspectral remote instrumentation. This facet of the task involves developing robust methodologies to provide calibration for space-based spectral imagers on long-duration missions. This work is directed toward defining and measuring the characteristics of the LEISA infrared imager that will fly on the New Horizon mission to Pluto.

A third component of this work is intelligent instrument design. This involves modeling general instrumental characteristics for classes of instrument types so that specific design choices can be made to optimize the utility of the returned data for various types of applications. The coupling of the details of the specific instrument with the type of data expected should lead to more optimal research design..

Objectives for the Coming Year

Data compression algorithms, which are implemented in the data analysis pipeline after image calibration and correction, will be designed for the LAC.

Task 902-00-005: **Executive Scientific/Technology Secretariat Support to NASA HQ/Earth Science Enterprise on the U.S. Global Change Research Program's Interagency Working Groups on the Global Water Cycle and Global Observations and Monitoring; U.S. Global Climate Observing System; World Meteorological Organization Global Observing System; United Nations Committee on the Peaceful Uses of Outer Space/Sustainable Tourism Stewardship Council**

GEST Investigator: Sushel Unninayar

Collaborator: Lola Olsen (PI, GSFC)

Abstract

The function of the Secretariat is to provide high-level, scientific planning and technological support to NASA ' s Earth Science Enterprise (ESE) on interagency (U.S.) and international programs and projects dealing with all aspects of the U.S. Global Change Research Program (USGCRP); the President's initiative on Climate Change Research Initiative (CCRI); the World Climate Research Program (WCRP); the International Geosphere-Biosphere Program (IGBP); the Integrated Global Observing Strategy (IGOS); the Global Climate Observing System (GCOS); the international WCRP Global Energy and Water Cycle Experiment (GEWEX); the new Global Observing Systems' initiative of the World Meteorological Organization (WMO-GOS); NASA/ESE's and GCRP/CCRI's cross-cutting climate modeling, observing systems, and data assimilation initiatives; the recently tabled (following the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space; UNISPACE-III) environmental themes of the UN Committee on the Peaceful Uses of Outer Space (UN-COPUOS/STSC); interfaces with the UN Framework Convention on Climate Change (UNFCCC); interfaces with the science assessments of the Inter-Governmental Panel on Climate Change (IPCC); and interactions with the Boards, Committees, and Panels of the National Academies of Sciences (NAS) National Research Council (NRC).

Description of Research

NASA Headquarters assigned this task to GEST through the Global Change Data Center (GCDC) through GSFC Code 900. It provides the scientific, technological, and research leadership required by White House Office of Science and Technology Policy (OSTP)'s Committee on Environment and Natural Resource (CENR) ' s subcommittee on . The task also provides input to NASA HQ in a variety of other Earth Science Enterprise (ESE) interagency and international programs such as the Global Water and Energy Cycles Program; 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; Committee on Earth Observation Systems (CEOS); and others such as the interconnections with the USGCRP-Global Carbon Cycle (GCC) program, International Council for Science (ICSU)/IGBP, etc.

Accomplishments during the Reporting Period

The 2002-2003 period involved continued and extensive interactions with the USGCRP office, the new Climate Change Science Program Office (CCSPO) (incorporating the USGCRP and the presidential initiative on CCRI) regarding the development of the long-term strategic scientific plans for the USGCRP/CCRI's various new initiatives as directed by the OSTP and the Office of Management and Budget (OMB). A culminating CCSP workshop was held in December 2002, in Washington DC. Work progresses in revising the Strategic Climate Change Science Program (CCSP) science plan following comments provided at the workshop and "public" comments, obtained via the Internet/Web. The CCRI represents, de facto, the U.S. response to the international/intergovernmental COP dealing with the UN Convention on Climate Change, which has not yet been ratified by the U.S. A draft interagency Global Water Cycle

(GWC) scientific implementation plan, initially prepared in November 2001, was revised and recirculated for interagency discussion. A science advisory panel was established by the Investigators Working Group (IWG)-GWC to guide the scientific priorities for the implementation USGCRP-GWC.

A coordinated interagency report on the GWC, as a part of the USGCRP's *Our Changing Planet FY 2002* report, was released. As primary rapporteur for the December 2002 high-level CCSP Workshop session chaired by Ghassem Asrar (NASA-HQ), a comprehensive report was prepared and submitted to the Climate Change Science Program Office (CCSPO) for public distribution on cross-cutting issues (observations, modeling, and data assimilation). Initial coordination was established and the science/implementation plans of WCRP/GEWEX and GEWEX/Coordinated Enhanced Observing Period (CEOP) were reviewed. The *Second International Report on the Global Climate Observing System* was reviewed in depth, and comments on deficiencies in the descriptions on requirements and climate monitoring principles were submitted to the Geneva Secretariat. Other activities included authorship of several sections and acting as an invited reviewer of all other inputs to the USGCRP (*i.e.,* the CCSP, incorporating the USGCRP and the CCRI) *Scientific Strategic Plan*. Work continues on revisions to the *CCSP Strategic Plan on the Global Water Cycle* for the observations and monitoring, and Earth system modeling themes. Other activities included the continued activity regarding the space-based observing systems component of the U.S. *Detailed National Report on Systematic Observations for Climate* under the auspices of the U.S. GCOS program and the UNFCCC (Conference of Parties). Work continues in support of the WMO's High-Level Panel on Future GOS (NASA being represented by Ghassem Asrar), including reviews of scientific requirements for WMO-GOS. Documentation previously prepared and submitted to the WMO on requirements and scope for a future GOS were accepted by the WMO Executive Council. Various sessions at various meetings/conferences were chaired.

Research also continued on forced, bounded, nonlinear, chaotic-dynamic systems, and climate system modeling and climate prediction modeling/applications.

Objectives for the Coming Year

Work for the coming year will include ongoing Executive Science/Technology Secretariat Support to NASA HQ/ESE. There will be follow-on research support to the CCSP (USGCRP + CCRI Integrated Planning), and national and international coordination on various programs and projects. There will be further development of international GEWEX Science Plans, and GEWEX/CEOP. Research will continue on nonlinear, forced, bounded systems, and climate system modeling/applications.

Task 902-00-006: **Data and Information Working Group coordinator**

GEST Investigator: Leslie H. Meredith

Collaborator: L. Olson (PI, GSFC)

Abstract

This year, the interagency Global Change Research Program (GCRP), Data and Information Working Group (DIWG) was successful in providing interagency coordination of data management programs, between participating agencies and with other interagency efforts, increasing the ability of users to find the data and information they need, and supporting the needs of the U.S. GCRP (USGCRP) and its other working groups.

Description of Research

The purpose of this task is to provide the Executive Secretariat research leadership, coordination, and implementation functions

required by the USGCRP's DIWG. This work includes helping to ensure the support of the USGCRP and National Academy of Sciences (NAS), for DIWG activities.

Accomplishments during the Reporting Period

There was continued Executive Scientific/Secretarial Support to NASA HQ and the Earth Science Enterprise (ESE), including a review of a decade of U.S. Global Change Research Program's achievements in observing systems and science. The strategic implementation plan for the GCRP-GWC Program was finalized. There was a survey of agency and interagency activities contributing to the research objectives of the GCRP-GWC and NASA's Global Water and Energy Cycle (GEWEC), and review of activities contributing to improved observations and modeling of global water and energy cycles. Development of interagency scientific priorities for systematic global observing of the Earth/Climate system continued, as was coordination with the programs and projects of the World Meteorological Organization (WMO), the World Climate Research Program, and others.

Objectives for the Coming Year

No further work under this task is planned, as Dr. Meredith retired in December 2002.

Task 910-03-047: **Chemical Data Assimilation**

GEST Investigator: David Lary

Collaborator: Ricky Rood (PI, GSFC)

Abstract

For many reasons, an objectively optimized Earth observation strategy is a desirable goal based on developing software elements for a dynamic data retrieval control system. The control system will dynamically adapt the what, where, and when for the observations made online to maximize information content, minimize uncertainty in characterizing the system's state vector, and minimize both the required storage and data processing time for a given observation capability. This approach potentially allows for the possibility of directing unmanned suborbital platforms and drones to make additional observations. Such a system is particularly desirable in facilitating dynamic tracking of evolving sharp gradients—for example, those in chemical tracer fields often located at the polar vortex edge, the tropopause, and the day/night division.

Description of Research

The goal of this research is to combine existing observational and theoretical knowledge of atmospheric chemistry with an estimate of the reliability of the information to give us a "best" analysis of the atmosphere's chemical composition. This consensus dataset can then be used for detailed scientific analysis of such issues as ozone depletion and its causes, and how chemical abundances change with time and location.

Measurements of atmospheric constituents made over the last decade or more have cost many millions of dollars. Intelligent use of Earth science data addressing a wide variety of species is a nontrivial task, as the observations are not colocated in time or space. Satellites make measurements of atmospheric constituents with a range of methods and at a range of times and locations. Since analyzing satellite measurements is so complex, often the measurements have not been used to their full potential. Naturally, such information can only be exploited if it includes a theoretical understanding of the chemical system. Data assimilation facilitates such understanding, and is a valuable assistant in making better use of atmospheric chemistry observations.

The basic idea behind an objectively optimized Earth observation strategy is the desire for symbiotic communication to dynamically guide the Earth observation system. Such a system will also use automatic code generation and automatic parallelization to facilitate the implementation of the system and its possible use on a variety of

hardware. Automatic documentation of both software and data products facilitates code maintenance and the production and quality monitoring of self-consistent analyses. These analyses can be used by scientists to understand and answer major scientific questions, and by policy makers to establish sound policy decisions, thus increasing the accessibility and utility of Earth science data. Automatic compression minimizes both the required cost of storage and dissemination, and the required time for electronic product transfer/download.

Accomplishments during the Reporting Period

In comparison to the analysis of meteorological variables, chemical trace species have received little attention. Current methods tend to be either simple comparison of observations with a model (which are not necessarily constrained to be directly comparable) and/or treat species independently, ignoring the complex balances which exist between species. Moreover, the large diurnal variations in the concentrations of many species are either accounted for in very simple ways, or avoided by analyzing concentrations at fixed local time. There is a significant downside to these approaches, as the shape of a species' diurnal cycle, and the relative partitioning between species, contain valuable information that is lost. Naturally, such information can only be exploited if it includes a theoretical understanding of the chemical system. Data assimilation is a valuable assistant in making better use of observations of atmospheric chemistry.

In support of these goals, chemical data assimilation system has been automated. The user specifies the chemical species of interest, and a preprocessor program (called *pick)* then takes this list, searches a database of thousands of known reactions, and selects those involving the chemical species specified. A second preprocessor program (called *roc*, short for "rate of change") then uses this list to automatically construct a set of ordinary differential equations that describe the time evolution of the chemical species specified. The set of ordinary differential equations is then symbolically differentiated twice to give the Jacobian and Hessian. When this is complete, the Fortran code necessary to simulate the chemistry of the species specified in a numerical model is generated together with the code necessary to perform Kalman filtering, Kalman smoothing, and 4D variational data assimilation. This data assimilation, then, allows combining the theoretical model with all available observations. In addition, suitable documentation is also generated, describing the automatically generated numerical model in a set of LaTeX documents, consisting of a descriptive paragraph detailing the number of chemical species and reactions, reaction tables, the ordinary differential equations, the Jacobian, and the Hessian.

Other programs have been written to automatically access the accuracy of the analysis once the data assimilation for a given time window has been performed, to generate graphics scripts to illustrate the results, and to generate Web sites to publish results for general access and for data mining.

Objectives for the Coming Year

A detailed data assimilation analysis of satellite observations from the Upper Atmosphere Research Satellite (UARS) and other platforms will be performed to examine the scientific implications that may arise. This use will be the first time that Kalman filter data assimilation has been used in this fashion. Software for an objectively optimized Earth observation strategy will also be further developed and optimized.

Task 930-01-023: **Globalization of Regional Models of the Atmosphere**

GEST Investigator: Miodrag Rančić

Collaborator: James Fischer (PI, GSFC)

Abstract

The objective of this project is to investigate and develop a prototype of the numerical framework intended for globalization of regional models of the atmosphere. This globalization framework (GF) will be based on application of quasi-uniform (QU) gridding of the sphere and different strategies for including variable resolution (VR) of the underlying mesh. The GF is expected to significantly increase versatility and inter-operability between regional and global atmospheric models. At some later stage GF will be incorporated in the Earth System Modeling Framework (ESMF). A portion (~50%) of this project, including graduate scholarship for a research assistant, is supported by the National Science Foundation (NSF).

Description of Research

The idea behind the GF is to abolish an artificial boundary that exists between regional and global models of the atmosphere. This will be accomplished by applying novel modeling tools (QU and VR grids) and modern information technology, including high-performance computing and communication (HPCC) and some elements of object-oriented programming design. Within the context of this project, "globalization" is defined as a highly modular method for covering the entire globe by judiciously combining regional model elements. A regional ETA model from the U.S. Weather Service, with its unique step-wise treatment of the terrain, strict global conservation of relevant integral properties, and comprehensively tested physics is used for globalization.

Accomplishments during the Reporting Period

Quasi-uniform (QU) grids are generally constructed by different spherical expansions of polyhedral and dihedral geometrical bodies. Within this project, we consider only three major groups of quadrilateral grids (cubic, double-octagonal, and double-square), which include further subclasses consisting of quasi-conformal, equiangular, equidistant, smoothed, and scaled elements.

Similarly, there are three major prevailing methods to approach the problem of the variable mesh resolution that are applicable in this context: these are grid stretching, grid overlapping, and asymmetric gridding (also known as a Schmidt transformation).

The dynamics of the regional ETA model are revised and adjusted for globalization on QU grids. Because these grids usually assume curvilinear coordinates, finite-difference schemes of the model are generalized using general forms of metric coefficients rather than specific formulations appropriate for particular grids. Generally applicable vector invariant formalism is used in this process, although an alternative, strong conservative formalism may also be very attractive for some QU grids (for example, the double-square grid). The problem of the successful treatment of the nonlinear cascade of energy within the vector invariant formalism is addressed (Rančić and Zhang 2002b), but the suggested solution is yet to be tested in the full 3D model. The original E-grid indexing of the ETA model is replaced with the more convenient B-grid indexing, but the more efficient formulation of the E-grid numerical schemes is preserved. This way, the original and the most computationally optimal setup is achieved. The algorithm for marching in time in the original ETA model is also slightly advanced by replacing the order of executions of the adjustment terms. A free-source form of the FORTRAN95/90 programming style is consistently applied through the modified code. The message-passing interface (MPI) version of communication libraries was developed and tested using the Compaq machine at GSFC as the main parallel platform. The code that creates the B-grid

version of the step terrain on a QU grid has been developed, but has been tested only on the cubic grid.

A software engineering approach was adopted, where all user decisions about underlying mesh, local enhancement of resolution, etc. are handled at the level of *make* files and controlling shell scripts, rather then within the source code. Eventually, all these scripts will be connected through a graphical user interface (GUI).
At the beginning of 2002 a graduate student from UMBC, Hai Zhang, joined the project. As a part of his introduction to the project and familiarization with the ETA model, Mr. Zhang has installed a high-resolution version of the regional ETA model to operate over the state of Maryland. This setup is now routinely producing daily weather forecasts for UMBC, Baltimore, and the Washington, D.C. areas (http://130.85.154.27/).

Important collaborations were established, negotiated, or continued over the past year. The most noticeable included collaboration with Dr. Jim Purser, from the National Oceanic and Atmospheric Administration's (NOAA) National Center for Environmental Prediction (NCEP), on the development of a FORTRAN90 version of QU grid generators and the development of double square grid; with Dr. Fedor Mesinger, NCEP/University Corporation for Atmospheric Research (UCAR), on introducing the slope within the global step terrain; with Dr. Jules Kouatchou, Morgan State University/GSFC, on developing an efficient parallel multi-grid solver for QU grids in the presence of step terrain); and with Dr. Jin Ping Gwo, UMBC, on the perspective for coupling a global ETA model framework with a watershed model.

Objectives for the Coming Year

The goals for the coming period include finishing benchmark testing of the GF with the cubic grid; including octagonal and double-square grids in the GF; comparing different methods for local enhancement of resolution; introducing GUIs into the system; introducing appropriate physics into the simulation; and running GF both in a weather prediction and seasonal-to-interannual and climate mode.

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

GEST Investigator: Susan Hoban

Collaborator: Paul Hunter (PI, GSFC)

Abstract

The investigator participated in NASA's Applied Information Systems Research Program (AISRP) and worked with the Office of the Chief Information Officer at GSFC on issues relating to information science and technology, including the Backup and Recovery Study Team (BURST).

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 science.

Accomplishments during the Reporting Period

The investigator organized a workshop for the AISRP, held at NASA Ames Research Center in October 2002. Various issues relating to information science and technology at GSFC have been addressed, and task work includes participation in the Goddard Friends of Information Science committee, which is comprises of heads of information science and technology organizations at GSFC. Other work includes activities on the BUSRT that was constituted after the terrorist attacks of September 11. Along with the rest of the team, the GEST investigator was named in a GSFC Group Achievement Award, which comes with a cash award for civil servants, but simply a certificate for non-government employees. The investigator is working with developers in Code 588 to design

and implement a Website to disseminate AISRP products and information.

Objectives for the Coming Year

A whitepaper on strategic directions for the AISRP will be developed in the Spring 2003. A workshop for AISRP investigators will be organized, and participation in the annual panel review will take place. Research into advances in information technology for science applications will continue.

Task 930-12-115: **PARAMESH Development and Application**

GEST Investigator: Kevin Olson

Collaborator: Daniel Spicer (PI, GSFC)

Abstract

The research conducted in the past year focused on developing and improving software for high-performance, parallel computer architectures. Specifically, this work has focused on maintaining and improving PARAMESH, a software package designed to give a user an easy route to parallelizing an existing structured mesh application. Also, work has focused on applying PARAMESH to several specific applications, including collaboration with researchers at the Naval Research Laboratory to help develop a Flux-Corrected Transport magnetohydrodynamic code with dynamic adaptive mesh capability. This code will be used to simulate solar and magnetospheric phenomena. PARAMESH has also been successfully and widely employed by a group at the University of Chicago for astrophysical applications. Several new collaborations have also been forged. The first of these is to collaborate in using and modifying PARAMESH for use by one of the round-3, Earth and Space Sciences, Computational Technologies (ESS/CT) project's funded external research groups. Task work also involved service as a contact scientist for the ESS/CT project and participation in several negotiations with research groups in various disciplines as part of the project's Cooperative Agreement Notice (CAN)

Description of Research

Use of large parallel computer architectures for scientific simulation purposes is not a straightforward exercise and requires a great deal of expertise to write efficient software. The work over the past year has focused on developing PARAMESH—a software package designed for an application developer who already has a serial code that 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 or is planned for use by various applications in the Earth and space sciences. These include—but are not limited to—simulations of the Earth's magnetosphere, solar coronal events, astrophysical X-ray bursts, Type-I supernovae, gamma-ray bursts, galaxy cluster collisions, and gravitational waves

Accomplishments during the Reporting Period

PARAMESH has been extended and improved in two main areas. The first involves the addition of the capability to deploy PARAMESH as a precompiled library, to which a user can link their application. Previously, PARAMESH required that a user set parameters in a configuration file and then compile PARAMESH along with their application. This is no longer necessary, as the user can now specify these parameters at runtime. This capability was required by one of the grand-challenge teams funded by the ESS/CT project to meet their milestones.

The second main area in which PARAMESH has been improved is in its ability to support more general interpolation algorithms at jumps in mesh refinement. Accordingly, routines have been written and added to PARAMESH that allow a user to specify the order of interpolation to match the requirements of their application.

The GEST investigator also served on the in-house team of scientists for the ESS/CT project. The duties in this role included negotiations with several of the NASA-funded research groups selected under the CAN for this project. These negotiations led to collaboration being forged with one of these groups to aid in extending and using PARAMESH.

Objectives for the Coming Year

The main objective for the upcoming year is to improve the overall performance of PARAMESH. Work is being conducted in this area to eliminate unnecessary data movement, both on a single processor and between the multiple processors of a parallel processing architecture. Attempts will also be made to improve the functionality of PARAMESH, so that more applications can be supported. Work has been done in this area to support finite element applications. Progress on the PARAMESH project has been severely limited because off-site developers of PARAMESH cannot be monitored and managed in an efficient manner. Therefore, PARAMESH will be made an open-source project, and its development will be managed from within GSFC by its original developers (K. Olson and P. MacNeice of Drexel University), using the SourceForge Website and tools. Work will also be conducted to find and assist new users of PARAMESH as part of the ESS/CT project.

Task 935-01-022: **Parallel and Distributed Computing**

GEST Investigator: Udaya A. Ranawake

Collaborator: John Dorband (PI, GSFC)

Abstract

A scalable version of the parallel debugger was implemented. The debugger can run efficiently on thousands of processors. New features were added to the graphical user interface (GUI) to make the debugger more user friendly. The debugger also includes support for debugging NAG F95 compiler-based parallel programs. Also, several users were assisted in porting their parallel programs to the Medusa PC cluster, and benchmarks were performed to analyze the performance of a newly built 512-processor machine, the Thunderhead PC cluster, at GSFC.

Description of Research

The work performed under this task addresses research and development into various software tools to facilitate the use of parallel and distributed systems. It also assists users in porting and optimizing large-scale scientific programs to run efficiently on these platforms.

Accomplishments during the Reporting Period

A scalable version of the message-passing interface (MPI)-based parallel debugger was implemented. The debugger can be used with parallel programs consisting of thousands of processors. Also, the debugger now includes support for debugging NAG F95 compiler-based parallel programs. The accuracy of the debugger was tested using several large FORTRAN programs containing tens of thousands of lines of code and incorporating many complex features of the FORTRAN95 programming language. These tests were performed on Medusa PC clusters consisting of up to 128 parallel processors. Work is underway to test the debugger on the newly built 512-processor machine, the Thunderhead PC cluster.

The debugger is based on a client-server type model. The server process is responsible for the GUI that handles the user input and displays information to the user. It also spawns the client processes and communicates with them to receive data and status information and to send user commands. The client processes are spawned—one per MPI process and on the same node—by the server using a binary tree algorithm. Each client process spawns a native, node-level debugger as a subprocess that is attached to the corresponding MPI process. The client processes merely send commands from the server to the node-level debugger and then forwards the output

of the node-level debugger and its status back to the server. This use of a client-server-type model that communicates using binary tree algorithms has resulted in a parallel debugger that scales to large numbers of processors.

The debugger has a X-window-based user interface. The user interface for the debugger consists of four windows. One is the command window, which consists of a dialog box to accept user commands. It also contains some command buttons for commonly used debugger commands. The second window is the GNU Project Debugger (*gdb)* output window, which is used to display the output of the *gdb* processes. The third window is the source window, which is used to display the source line at which a process has stopped. Users can set or clear breakpoints by clicking on a given line. Finally, the status window is used to display the status of the *gdb* processes. Also, this window is used to switch between the buffers displayed in the output window and the source window.

Several users were assisted in porting their scientific applications to PC clusters. This work exposed several errors in the MPI communication software library, and these errors were corrected.

Benchmarks were performed to study the performance of the recently built Thunderhead PC cluster at GSFC. This cluster consists of 536 Pentium-4 Xeon processors running at 2.2 GHz, interconnected by a 2.0 GHz Myrinet.

The Linpack Benchmark was run to evaluate the performance of the PC cluster. This benchmark solves a dense system of linear equations, and is used to rank computers worldwide. The top 500 list (available at http://www.top500.org) lists the 500 most powerful computers of the world based on their performance on this benchmark. Preliminary results on the Thunderhead PC cluster indicate that it would be ranked in the upper 10% of the top 500 list, delivering a sustained performance of greater than more than one teraflops.

Objectives for the Coming Year

The primary focus in the coming year will be to address the scalability issues and user needs, as PC clusters consisting of thousands of processors are built and move into the main stream of scientific computing at GSFC. This may include modifying parallel programs to give good performance on architectures with large numbers of processors, performing benchmarks to evaluate the performance of PC clusters, and implementing (or modifying) software tools such as the parallel debugger, the MPI communication library, and a batch job scheduling system.

Task 935-11-113: **Automatic Registration of Multisensor and Multitemporal Remotely Sensed Imagery**

GEST Investigator: Tarek El-Ghazawi

Collaborator: Jacqueline Le Moigne (PI, GSFC)

Abstract

Principal Component Analysis (PCA) is effective at compressing information in multivariate data sets. Unfortunately, the information content in hyperspectral images does not always coincide with such projections. In addition, since PCA is a global transformation, it does not preserve local spectral signatures, and therefore may not preserve all information useful in obtaining a good classification. This rotational transform is also time-consuming because of its global nature. In single-processor machines, the global nature of the transformation results in inefficient use of the memory hierarchy. In parallel machines, the global operations imply large interprocessor communication overhead. For these reasons, work was undertaken to explore a new dimension-reduction method based on wavelet decomposition and a hybrid technique that combines the strengths of wavelets and PCA.

Description of Research

The principle of method addressed here is to apply a discrete wavelet transform to hyperspectral data in the spectral domain and at each pixel location. This not only reduces the data volume, but it can also preserve the spectral signature characteristics. Each reduced spectral pixel preserves the peaks and valleys of the original spectrum, but in a smaller representation. On the other hand, PCA seeks to form linear combinations of the bands based on the global covariance matrix, whereas wavelet approaches seek a smaller subset of the original bands, based on a moving average of pixel vector values. Thus, the wavelet approach yields decomposed spectra that are smoother than the original spectra. Because of the lack of relationship among neighborhood pixels in the spatial domain, and because of wavelet coefficient redundancy, a hybrid technique is being investigated that combines wavelet analysis and PCA: the wavelet method filters and subsamples each original spectrum into a reduced set of wavelet coefficients; PCA then decorrelates the band-to-band spectral information contained in the wavelet coefficients, and therefore yields a new, smaller data set in an uncorrelated coordinate system.

Accomplishments during the Reporting Period

Automatic wavelet spectral reduction and the hybrid reduction techniques were developed, and proof of concept studies were completed through experimental studies using data sets obtained from NASA. The automatic wavelet spectral reduction algorithm was developed using this correlation measure and a user-specified threshold (Th). For each pixel in the hyperspectral scene and for each level of decomposition, the correlation between original and reconstructed signals is computed. All correlations higher than the user specified threshold contribute to the histogram for that level of decomposition. When all pixels are processed, the lowest level of wavelet decomposition needed to produce such correlation is used for the remainder of the algorithm. With a high number of bands produced from hyperspectral sensors, the Wavelet Reduction method yields accuracy that is similar to—or better than—classification accuracy obtained from PCA. This may be because wavelet-reduced data represent a spectral distribution similar to the original distribution, but in a compressed form. Furthermore, at a decomposition level similar in reduction rate to the number of principle components (PCs), automatic wavelet reduction is more efficient from a computational point of view. This is because the wavelet has a better time complexity, the wavelet has better data locality characteristics, and the wavelet is better suited to parallel processing.

In general, the best results for accuracy assessments were obtained from utilizing two levels of wavelet decomposition of high dimensionality data sets and, as mentioned earlier, although the first level of decomposition better represents the original spectral distribution, larger data dimensions cause a loss in classifier performance.

Hybrid transformation is a preprocessing technique, which removes high-frequency components and reduces band-to-band correlation, especially in the case of noisy data. This hybrid transform combines both wavelet and PCA techniques. The transformation first performs an initial reduction using wavelet decomposition, where the original hyperspectral data is compressed into a reduced-compact form. Then PCA is applied, thus significantly reducing the computational load compared to the conventional PCA technique. Usually, the wavelet method filters and subsamples each original spectrum into a reduced set of wavelet coefficients. In the algorithm, PCA decorrelates the band-to-band spectral information contained in the wavelet coefficients, and therefore yields a new smaller data set in an uncorrelated coordinate system. The degree of reduction is determined by the requirements of an allowable error. The two advantages of the hybrid technique: it takes into account local spatial information among neighborhood-class pixels, a property that the wavelet method is missing for visualization and classification purposes; and it removes spectral correlation among wavelet coefficients bands. The original hyperspectral imagery can be reconstructed from the reduced representation using an inverse principal component transform and an inverse discrete wavelet transform, although with some loss of information. By applying PCA after the wavelet decomposition, the most informative three features (the first three

PCs) obtained from the hybrid transform can be used.

A doctoral dissertation, *High-performance dimension reduction of hyperspectral data*, resulting from this work was successfully defended by Sinthop Kaewpijit, at George Mason University in August 2002. Furthermore, Dr. LeMoigne has filed an invention at GSFC for the wavelet reduction methods on behalf of the three collaborators in this work, El-Ghazawi, Stone, and Zavorin.

Objectives for the Coming Year

During this year, the techniques of PCA for image compression will be applied to more data sets, such as sounder data. In addition, applications of PCAs in data fusion will be explored.

Task 935-16-127: **Automatic Registration of Multisensor and Multitemporal Remotely Sensed Imagery**

GEST Investigator: Harold Stone

Collaborator: Jacqueline Le Moigne (PI, GSFC)

Abstract

Among the results obtained during the reporting period are the fine tuning of high precision registration algorithms, identifying the specific characteristics of imagery to which each algorithm is best suited, discovering and calibrating an offset in a downsampling filter, and developing a triangulation method that helps estimate the precision of registrations when ground truth is not available.

Description of Research

The thrust of the project is to register satellite imagery in various ways – multitemporal, multispectral, and multiplatform – to extract information that is not readily discernible in individual images. For example, high precision registration of imagery taken at different times is used for change detection. Cross-platform and cross-spectral registration can be used to classify regions by ground cover and land use.

Accomplishments during the Reporting Period

The main thrust of the project in 2002 was to develop subpixel registration techniques, including a comparison of various alternatives on a collection of typical satellite imagery. The image set came from the following platforms: Ikonos (approx. 4-m resolution), the Landsat Enhanced Thematic Mapper (ETM; 32-m resolution), the Moderate Resolution Imaging Spectroradiometer (500-m resolution), and the Sea-viewing Wide Field-of-View Sensor (SeaWiFS; 1-km resolution). The images covered four different sites, each displaying characteristics distinct from the others, including mountain terrain, prairie, and coastal regions.

For cross platform registration, the central issue is the resampling of the higher resolution imagery to a resolution compatible with the lower resolution of an image from a different platform. The project approach is to find downsampling filters to downsample by factors of two, for which downsampling has the highest precision, and then to use other techniques to determine any residual scale adjustment that is required. The filters studied were Simoncelli low-pass, Simoncelli band-pass, and Centered Splines. The Simoncelli filters introduce subprecision offsets in their downsampled images. The investigator was able to calibrate the offsets so that both Simoncelli filters can be effectively used, and the offsets can be removed after registration. This is important because Zavorin's study (reported elsewhere in this volume) showed that there are sets of conditions that favor each of the Simoncelli filters. If the offsets could not be removed, the Simoncelli filters would not be useful for a high precision registration.

High-speed correlation techniques for registration were pursued and subsequently compared with other registration techniques implemented by other team members. These techniques work well for cross-platform and multitemporal registration, but

they tend to yield poor results or fail completely for cross-spectral registration. The reason for the poor behavior is that the correlation is very low for cross-spectral imagery. Perhaps the best way to register such images is with methods based on maximizing mutual information, and this was corroborated with data developed by others. However, mutual information techniques are inherently more costly in computation than are the fast correlation techniques, so that fast correlation is preferred in situations when correlation and mutual-information methods can register with comparable precision.

Fast correlation can be used to register images that differ by small-scale differences (on the order of 10%) and by small rotations (on the order of a degree), even though the Fourier-based correlation algorithm looks only at translation differences. The scale and rotational differences were identified by registering a few hundred small chips only with respect to translation. Because the scale and rotation is small, most of the chips can be successfully registered. The collection of translational offsets from the chip registrations is used to drive a nonlinear search algorithm that finds the rotational angle, scale change, and translation offset that best explains the collection of translational offsets. The algorithm was successfully tested by registering Ikonos images to ETM images. The Ikonos images (4-m data) were downsampled by a factor of eight to create images whose resolution is nominally 32 m. These images were registered to ETM images whose resolution is also nominally 32 m, but not identical to the resolution of the downsampled Ikonos images. This method recovered the residual scale and rotational parameters without having to resample the images at a different scale and rotation. This is important because it avoids the precision loss due to resampling.

Another finding of note is the utility of triangulation to obtain precision estimates when ground truth does not exist. The idea is to extract this information from multiple pair-wise registrations. By using triangulation, the failed registration would show up by causing a sum of offsets to be different from zero by an unexpectedly large amount. With just three pair-wise registrations, one would know when one of the registrations has failed, but one could not tell which one of the three is at fault. With four or more pair-wise registrations, it is possible to identify a single culprit (if there is only one), and to eliminate it, thereby enhancing the precision of the final registration because it uses the best data and discards the poor data.

Objectives for the Coming Year

An objective of the coming year is to determine if the Thevenaz, Ruttimann, and Unser (TRU) iterative algorithm with a mutual-information measure gives results comparable to the other mutual information algorithms, and if so, if it is computationally more efficient. The project will investigate how cloud masks may be adapted to the other algorithms that handle cases not appropriate for cross-correlation registration algorithms. The project is moving toward a higher degree of automation with respect to image registration. The objective is to choose from a menu of possible registration algorithms to find the one algorithm, or combination of algorithms, to use for a particular registration pair. The choice of algorithm will depend on image characteristics that can be identified from metadata or through initial analysis of the images.

Task 935-19-124: **Automatic Registration of Multi-Sensor and Multi-Temporal Remotely Sensed Imagery**

GEST Investigator: Ilya Zavorin

Collaborator: Jacqueline Le Moigne (PI, GSFC)

Abstract

Work under this task investigates how various feature extractors, search techniques, and similarity metrics can be combined to produce reliable results when applied to multisensor data that have previously been systematically corrected.

The class of geometric transformations was expanded by including isometric scaling, which allowed images of different resolutions to be more precisely registered. A fast iterative gradient-based search strategy was adapted to the problem of satellite image registration. Also, a new method was devised to evaluate registration algorithm performance using various types of test data.

Description of Research

Image registration can be viewed as a sequence of two steps. First, image features are extracted from the original data. Then, using the given search strategy and similarity measure, the search space is traversed to find the best match. The previous focus was on determining the most robust type of image feature in terms of subpixel registration using exhaustive search as the simplest possible approach. Misalignment between images was assumed to consist only of rotation and translation; and exhaustive search through a discretized mesh of these parameters was used to find the best match.

Accomplishments during the Reporting Period

The results of earlier work, while promising, revealed that shift and rotation are insufficient for handling realistic data, and that exhaustive search is too time-consuming and can only achieve limited accuracy. Also, "real-life" satellite imagery usually comes with, at most, approximate ground truth (GT) information, which makes it difficult to systematically assess performance of a given registration method, especially when sub-pixel accuracy needs to be attained. On the other hand, synthetic imagery used was too simple, because there was radiometric differences between references and inputs. All of these issues have been addressed during the reporting period.

The first step was to transition from a method based on an exhaustive search of rotations and shifts to one that is faster, more accurate and that could also optimize isometric scaling. Such an algorithm was recently developed for medical imagery. It was implemented in a multi-resolution fashion using a spline-based low-pass wavelet pyramid. This is an iterative method that implies that it starts with an initial guess of the GT transform and then progressively refines it. The algorithm was augmented with two more multi-resolution pyramids, and several control parameters were added.

The new algorithms were tested on several sets of synthetic and "real-life" satellite data with the goal of comparing the robustness and accuracy of the algorithms and to find out to what extent different wavelet-based feature-extraction approaches can eliminate differences due to radiometric discrepancies between images produced by different sensors. While real test data did not provide accurate GT information, which prevented applying precise accuracy measures when assessing performance of the three algorithms, the synthetic data created by geometrically warping a reference image to produce an input image generated scenes that were too simple to register.

Therefore, the second stage of this work was to improve, upon performance assessment, methods for image registration algorithms. Both problems mentioned above were addressed by generating more sophisticated synthetic data and developing an approach to evaluate consistency and, possibly, accuracy of a given algorithm applied to images without accurate GT info. For images without accurate ground truth, a "triangulation" technique of consistency evaluation was proposed , which amounts to successive registration of a sequence of three or more images to obtain multiple estimates of registration parameters. When results are consistent, they also tend to provide a good estimate of the actual GT transformation between a reference and an input.

The new methodologies were applied to the new algorithms using several sets of multi-sensor and multi-temporal data, as well as synthetic data. The new synthetic image generation (SIG) consisted of geometric warping of a given "source" image followed by convolving the warped result with a point-spread function to mimic processing of a scene by an optical instrument. The triangulation approach was also demonstrated to be quite valuable, in that it appeared to provide estimates of GT that were more accurate than anything previously available. In addition, the testing method treated the algorithms as "black boxes", thus making it quite generic and useful to the image registration research community. To compare the various registration methods, a large

heterogeneous collection of realistic test data was processed that contained data obtained from the IKONOS and Landsat-7 satellites over four Moderate Resolution Imaging Spectroradiometer (MODIS) Validation Core Sites representing mountainous, agricultural, urban, and coastal terrains.

Mutual Information (MI) is a similarity metric for image registration. When MI is combined with a stochastic gradient search and Simoncelli multi-resolution pyramids, MI is found to be more robust than normalized correlation when applied to multi-sensor data, and that stochastic search approach is relatively accurate, provided the search is started close enough to the ground truth values.

Objectives for the Coming Year

The recently developed MI gradient-based registration method will be adapted to satellite image registration to handle radiometric differences significantly better than by using an L2-based approach. The test image database will be expanded by adding images from other platforms, and various algorithms developed by the Registration Group will be evaluated using the new data. The testing methodology [Zavorin *et al.* 2002c] will be evaluated by using more sophisticated point spread function (PSF)-based methods for synthetic image generation, and by establishing a way to assess the accuracy of the triangularization method applied to real data.

UMBC Grant: **Virtual Telescopes in Education (23333)**

GEST Investigator: Susan Hoban, PI

Collaborator: Robert Gabrys (GSFC)

Abstract

The NASA-sponsored Telescopes In Education project (TIE) (http://tie.jpl.nasa.gov) has been wildly successful in engaging the K-12 education community in real-time, hands-on, interactive astronomy activities. Hundreds of schools in the U.S., Australia, Canada, England, and Japan have participated in the TIE program, remotely controlling the 24-inch telescope at the Mount Wilson Observatory from their classrooms. In recent years, approximately 20 other telescopes have been—or are in the process of being—outfitted for remote use as TIE affiliates. The NSF-funded Virtual Telescopes in Education (VTIE) project is integrating these telescopes seamlessly into one Global TIE Observatory and providing the services required to operate this facility. Services include a scheduling service, an active data archive, tools for data manipulation, an online proposal preparation and review environment, an online *VTIE Journal* publishing results, and access to related educational materials provided by the TIE community. VTIE will leverage collaborators' ongoing projects to increase access to astronomy education at the K-12 and undergraduate levels, especially among traditionally under-served communities. This project is a collaborative effort among NASA GSFC; the University of Maryland Baltimore County; Tennessee State University; the TIE Foundation; Raytheon ITSS; the National University of Ireland, Maynooth; and TIE project affiliates at Little Thompson Observatory and Howard University Atmospheric Observatory.

Description of Research

The VTIE project is developing a framework to integrate and manage remotely controlled telescopes as one virtual observatory for science educationThe Web-based system will provide access to resources for teachers, students, and public users to conduct experiments in astronomy following the same procedures used by professional astronomers.VTIE will provide several resources and tools for learners, including access to research materials (and content-based tutorials) and tools to prepare and submit an observing proposal, analyze images, and prepare a paper describing the results of their experiment with online submittal to the *VTIE Journal*. Public users will have access to all of these functions except submittal; public users will have an option

to print their proposals and reports. For teachers, VTIE will provide access to on-line lessons and the means to review and comment on the students' proposals and papersThe system will be prototyped using three TIE affiliates: the original TIE 24-inch telescope at the Mt. Wilson Observatory, the Little Thompson Observatory, and the Howard University Atmospheric Observatory, in collaboration with the GSFC Education Office.

Accomplishments during the Reporting Period

Several papers describing various aspects of the system, such as system design, schedule optimization, and the proposal generation tool have been accepted for publication. The second international project meeting, VTIE2, was held in Pasadena, CA in April 2002. The investigator taught a series of astronomy classes, using the VTIE prototype, at the National University of Ireland Maynooth's Science Camp, in July 2002. The third international project meeting, VTIE3, was held in Nashville, TN in October 2002. The investigator and Karol Hennessy (a GEST-supported Visiting Exchange student from the National University of Ireland, Maynooth) demonstrated the prototype VTIE system at the NSF National Science, Mathematics, Engineering, and Technology Education Digital Library (NSDL) principal investigators' meeting in Washington, D.C. in December 2002.

Objectives for the Coming Year

The VTIE public site will be demonstrated for the first time at IBM Toronto in Spring 2003. The public site is expected to go online in summer 2003. The investigator plans to use VTIE to teach astronomy classes as part of the National University of Ireland, Maynooth Science Camp in summer 2003. Teacher training is planned for late summer and the registered user interface will come online at the same time. Student testing is planned for September 2003. The fourth international project meeting, VTIE4 will wrap-up the current effort in September.

Task 130-05-085: **Learning Technologies: The LEARNERS Initiative**

GEST Investigator: Daniel Laughlin

Collaborators: Robert Gabrys (PI, GSFC), Susan Hoban (UMBC/GEST)

Abstract

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, math, engineering, and technology — a trend that contributes to our national shortage of well-trained scientists, engineers, and computer scientists. This problem is of paramount interest to NASA. NASA's Learning Technology Project sponsors the Leading Educators to Applications, Research and NASA-related Educational Resources in Science (LEARNERS) initiative, based at GSFC, which seeks to support science, mathematics, and technology education through the infusion of NASA-related information into classroom activities through the development of information-technology-based educational products. LEARNERS provides educators with information technology tools for unique teaching experiences for the purpose of educating and inspiring the next generation of explorers, as only NASA can. LEARNERS themes cut across NASA Enterprise disciplines. The products under development provide hands-on and minds-on experiences for learners using a variety of new educational technologies or a combination of traditional and information-technology-based techniques. Further detail on specific LEARNERS activities can be found on the Web at http://learners.gsfc.nasa.gov.

Description of Research

The LEARNERS team conducts research and development activities generally relating to educational technologies at GSFC, other NASA centers, and in the education community. Activities focus on the infusion of NASA content into the K-12 educational and lifelong learning environments through the use of advanced

information technologies. GEST researchers work with the LEARNERS investigators from universities and private industry, K-12 educators, and NASA scientists and managers to facilitate access to NASA data, information, and technology for research and development of technologies for science, mathematics, and technology education.

Accomplishments during the Reporting Period

The investigator organized and oversaw an international workshop on disseminating educational technology projects in conjunction with Dr. Gabrys and Dr. Hoban. Education, science, and technology experts, representing NASA, academia, and commercial entities from across the U.S. and Canada gathered at UMBC's South Campus on August 1, 2002. The daylong workshop resulted in a whitepaper entitled, *Disseminating Educational Technology* that was delivered to Dr. Gabrys, the Learning Technologies Project management team, and the NASA Headquarters Educational Technology Program Officer.

The investigator participated in the "What Works Clearinghouse (WWC)" national forum on November 19, 2002 at the National Academy of Sciences in Washington, D.C. on the development of an evaluation instrument to assess the scientific quality of research on education. The WWC was established by the U.S. Department of Education's Institute of Education Sciences in 2002. The WWC seeks to develop standards for reviewing and synthesizing educational research and will provide its findings in searchable online databases. The investigator continues to be involved in the online review of this and other research evaluation instruments.

The investigator developed a Web-enabled CD-ROM to promote and introduce the existing LEARNERS projects to NASA's Educational Resource Center (ERC) and Aerospace Education Specialist Program (AESP) personnel. The ERC and AESP are primary contacts for teachers looking for NASA education resources. The investigator is currently overseeing a GSFC team enhancing the CD-ROM and adapting the structure and content to be used at the new LEARNERS Website.

The investigator participated extensively in proposal reviews for NASA's Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) Programs. The SBIR Program funds research by small businesses to meet many of NASA's research and development requirements.

In collaboration with Dr. Hoban, the investigator is developing the Principles of Remote Exploration Project (PREP). This inquiry-based program engages students in a simulated remote exploration of Mars to establish and experiential base to foster learning opportunities and enthusiasm for science and mathematics. Initial trials of the activity included teams of high school students on October 24, 2002 and with middle school teachers on January 25, 2003.

For additional information on these and related projects, see the article by Dr. Susan Hoban, elsewhere in this volume.

Objectives for the Coming Year

The investigator will continue to conduct research for strategic planning for new directions for NASA's Learning Technologies and participate in the upcoming review panel for the LEARNERS II Cooperative Agreement Notice. The investigator and Dr. Hoban will continue to develop and test PREP and will follow up on developing linkages with NASA educational initiatives. The investigator will also act as Session Chair for the Virtual Experience track of the Educating with Virtual Experiences (EVE 2003) International Workshop, planned to be held in Ireland in late 2003.

UMBC Grant: **Virtual Telescopes in Education (23333)**

GEST Investigator: Joel Sachs

Collaborator: Robert Gabrys (PI, GSFC)

Abstract

Responsibilities on the Virtual Telescopes in Education (VTIE) project include ensuring interoperability amongst the diverse components of the VTIE system and providing an environment that is conducive to the proposal of scientifically justified observation requests. An interoperability approach has been proposed based on standards of the World Wide Web Consortium's (W3C) Semantic Web activity, and an approach has been devised to automatically generate tutorials suitable for a learner's background.

Description of Research

A main component of VTIE is the active data archive, a repository for VTIE resources. VTIE takes a broad view of what constitutes a resource, and the archive seeks to make available all products of the end-to-end VTIE process. This includes observation proposals, captured images, and VTIE journal papers. All resources are being marked up with a combination of the extensible mark-up language (XML) and the resource description framework (RDF) to enable a broad range of content-based queries. One of the purposes of this research is to experiment with extending the types of queries that a data archive can support.

Accomplishments during the Reporting Period

A working prototype of an automatic link-induction tool was built to turn any exposition on a subject into a mini-tutorial on that subject, by automatically creating links to terms in a glossary. Learners are presented with a list of expositions to "glossarize," or they can input a uniform resource locator (URL) of their choice to be glossarized. For the glossary, an on-line encyclopedia of astronomy written at the college level was used. A student has been compiling a "multiglossary" with several definitions for each term, each targeted to a different education level. Ultimately, learners will be able to choose their own glossary level. Thus, the same underlying exposition will be suitable as the basis of a tutorial for several different levels.

XML schemas for proposals, observations, and journal papers were constructed. Records corresponding to these schemas are stored in the open-source Xindice XML database on the VTIE servers.

Members of the VTIE project participated in a NASA-wide pilot of the WebEx virtual meeting software to simulcast an observing session on the 14" Mount Wilson telescope. It was determined that the software can be an effective training tool for VTIE, as long as the participants are willing to make a long-distance phone call. Because of this limitation, the solution is not tenable for international partners.

Because of a desire that VTIE resources not be hidden from search engines, the investigator supervised master's degree student, Chanelle Bain, in successfully completing her thesis, "Indexing the Hidden Web: An Implementation Using Semantic Markup", leading to receipt of her degree in fall 2002. A prototype was built, showing how RDF can be added to the new W3C XForms specification, which enables a crawler/indexer to intelligently query a form and to index the results. This approach may be applicable to many Open-Archive Initiative (OAI)-compliant National Science Digital Library (NSDL) Web sites.

Objectives for the Coming Year

Objectives for the coming year include integrating the "multiglossary" into the tutorial-generation tool, and overseeing the end-to-end generation, processing, storage, and querying of XML data.

GEST Visiting Fellows Program

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Goddard Visiting Fellows Program

The Goddard Visiting Fellows program in the Earth Sciences continued into its third year. This program provides the opportunity for selected Ph.D.-level scientists to pursue independent research in collaboration with scientists in the laboratories within GSFC's Earth Sciences Directorate, either at GSFC or at the Goddard Institute for Space Studies (GISS). Research by visiting fellows addresses global change scientific issues leading towards an improved understanding of the state and variability of the coupled Earth-atmosphere-ocean-land system with theoretical and experimental studies using NASA technology, space observations, and information science. Research activities include instrument, algorithm, and model development, and remote sensing and *in situ* measurements. The principal areas of research addressed by Goddard Visiting Fellows include:

- *Atmospheric Research* – This work relates to the dynamic, radiative, and chemical properties of the Earth's troposphere, stratosphere, mesosphere, and thermosphere; and the atmospheres of the other planets. Research includes studies of dynamics, ozone, clouds, aerosols, precipitation, and severe weather phenomena
- *Terrestrial Physics* – Work in this area is related to the geological and geophysical processes of the solid Earth, and the planets; land surface biological and vegetative properties; and terrestrial and planetary magnetic fields. Research includes studies of the Earth's rotation, plate tectonics, volcanic activity, land surface topography, ecosystems, and physical-chemical-biological interactions within the overall climate system.
- *Hydrospheric Research* – These topics relate to oceanic, hydrologic, and cryospheric processes, and interactions between global water and energy cycle processes. Research includes studies of the global carbon cycle, soil moisture, land and sea ice cover, and interactions between the global hydrological and biogeochemical cycles.
- *Information Science and Technology* – This work relates to computer science, computer technology, and computational science. Research includes algorithm development associated with high-performance parallel computing, data assimilation, and data visualization techniques.

Visiting Fellow appointments are for one year or less. In the past year eight Fellows have been accepted into this prestigious program at levels ranging from post-doctoral to senior scientists. The Fellows selected include one member of the National Academy of Sciences, a Fellow of the Royal Society, and an editor of the Journal of Geophysical Research). The program has generated significant interest in the Earth sciences research community due to the substantial in-residence times provided. Through this program the broader national and international scientific community becomes increasingly aware of GSFC-based activities in the Earth sciences, and shares more fully in the results of those activities.

Bob Schiffer
Chief Scientist

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Task 900-37-172: **Research into Aerosols and Air Quality**

GEST Investigator: William L. Chameides (PI, on sabbatical leave from Georgia Institute of Technology)

Abstract

Three major areas of work were addressed during the sabbatical tenure at GEST. The first dealt with completing a National Academy of Sciences (NAS)/National Research Council (NRC) report on the effectiveness of major provisions of the Clean Air act and their implementation by governments at several levels. A second activity studied the climatic and biospheric effects of anthropogenic aerosols over East Asia. Finally, work was initiated to study iron solubilization in mineral aerosols as they are transported from the Gobi Desert to the North Pacific Ocean.

Description of Research

The work addressed under this sabbatical task continued the investigator's interests in studies of tropospheric gas-phase and aqueous-phase chemistry, air pollution, global climate cycles, and chemical change to better understand the role of chemical processes in the Earth's climate.

Accomplishments during the Reporting Period

A major accomplishment during the sabbatical period was to complete a report called for by the NAS/NRC's Committee of Air Quality Management in the United States. The committee was commissioned by the United States Congress to conduct a two-year scientific and technical evaluation of the effectiveness of the major air quality provisions of the Clean Air Act and their implementation by federal, state, and local government agencies, and to develop scientific and technical recommendations for strengthening the nation's air quality management system. The report of the committee, which is scheduled for peer-review in March 2003, is intended to be used by Congress to craft the next round of Clean Air Act Amendments. As Chair of the committee, the investigator has primary responsibility for preparing the final draft of the report. This task was largely completed during the six-months' stay at GEST.

Also during the sabbatical period at GEST, a long-standing research project continued, focusing on regional air pollution over East Asia, with emphasis on the effects of particulate matter on climate and terrestrial ecosystems. The work was carried out in collaboration with colleagues and graduate students at Georgia Tech, and has focused on the effects of black carbon (or soot) on climate and the attendant scientific uncertainties.

A new research project was initiated during the GEST sabbatical, related to understanding how iron (Fe) in Gobi Desert aerosols is solubilized during transport to the North Pacific Ocean. Iron is one of the nutrient elements needed for photosynthesis. In some remote areas of the ocean, iron is the nutrient that limits photosynthetic rates of phytoplankton; oceanic iron therefore may impact ocean ecosystem productivity and even exert a global-scale influence on climate by affecting the rate at which atmospheric CO_2 is fixed by oceanic biota. Most iron is delivered to the remote ocean via transport of iron-containing mineral aerosols from the continent. However, while iron must be in dissolved form to be used by phytoplankton, continental iron is found primarily in insoluble minerals (*e.g.*, iron-oxides and iron-aluminosilicates). The processes responsible for transforming insoluble iron minerals into soluble form as the iron is transported to the ocean remain poorly understood. During this GEST sabbatical visit, a study was undertaken to assess the viability of acidic Fe-III oxidation in mineral aerosols as a mechanism for producing dissolved iron in mineral aerosols that are advected from the Gobi Desert to the western North Pacific Ocean. The results of this investigation indicate that sulfur oxide pollution from East Asia may play a major role in solubilizing Fe in these aerosols.

Biographical Information

Dr. William Chameides received his Ph.D. in 1974 from Yale University. Subsequently he spent two years as a Research Scientist at the University of Michigan and four years on the faculty at the

University of Florida. In 1980 he joined the faculty at the Georgia Institute of Technology. He served as director of the School of Earth and Atmospheric Sciences from 1989 to 1994, and is currently the Smithgall Chair and Regents Professor of Atmospheric Sciences. Dr. Chameides was awarded the MacElwaine Award and elected a Fellow of the American Geophysical Union in 1983, and was elected to the U.S. National Academy of Sciences in 1998. Dr. Chameides is an atmospheric chemist whose research focuses on global biogeochemical cycles, biospheric/atmospheric interactions, air pollution, global change, and urbanization. Dr. Chameides has authored or co-authored over 100 scientific publications and four books, including the textbook, *Global Biogeochemical Cycles*. Dr. Chameides has been an active contributor to the scientific community throughout his career, and was elected a National Associate of the National Academies in 2002 "…in recognition of extraordinary service." He currently chairs the National Research Council's Committee on Air Quality Management in the United States, which was commissioned by the United States Congress to conduct a two-year scientific and technical evaluation of the effectiveness of the major air quality provisions of the Clean Air Act and their implementation, and to develop scientific and technical recommendations for strengthening the nation's air quality management system. Dr. Chameides has served as editor of the *Journal Of Geophysical Research*; chief scientist for the Southern Oxidants Study, a research program focused on understanding the causes and remedies for ground-level ozone pollution in the Southern United States; and the USA study director of CHINA-MAP, an international research program studying the effects of environmental change on agriculture in China.

Task 910-03-047: **Research in Atmospheric Chemistry and Dynamics**

GEST Investigator: Wookap Choi (PI, on sabbatical leave from the School of Earth and Environmental Sciences, Seoul National University, Seoul, Korea)

Abstract

Research work was done on various phenomena in the middle atmosphere, using models and data from satellite observations. The emphasis is on the use of limb sounding satellite determinations of trace constituents in the stratosphere.

Description of Research

Topics of particular interest to researchers in the field of atmospheric chemistry and transport occur in the middle atmosphere, most notably for this work in the region between the troposphere and the tropical tropopause. Trends in distributions and transport of methane and water vapor as a function of time were examined. Also of interest are long-term trends in several minor upper stratospheric species.

Accomplishments during the Reporting Period

Two research activities were conducted during a one-year sabbatical stay at GSFC, which was partially supported under the Goddard Visiting Fellows Program in Earth Sciences. The first one was to investigate the phenomena associated with transport between the troposphere and the stratosphere near the tropical tropopause. The distributions of methane and water vapor were obtained from observations over ten years from the Halogen Occultation Experiment (HALOE) on the Upper Atmosphere Research Satellite (UARS). Monthly distributions at the 100-hPa level in the tropical region show mainly seasonal variation. In addition to the annual variation, there are signs of variation associated with the El Niño/Southern Oscillation (ENSO) and the Asian monsoon.

Another area addressed during this period were the long-term trends in minor species in the upper stratosphere. The HALOE data provided mixing ratios for methane, water vapor, HF, and HCl. The mixing ratio of methane decreased from the early 1990s to 1996; the mixing ratio of HF has been increasing. The methane trend has not been explained quantitatively. In addition to the trends of each of these species, there is an asymmetry in chemical trends between the Northern and Southern Hemispheres, probably due to the change of the Brewer-Dobson circulation pattern. The

mixing ratios of the above species were simulated by a two-dimensional model of the stratosphere.

Biographical Information

Dr. Wookap Choi graduated from Seoul National University (SNU) in Seoul, Korea in 1983 and earned his B.S. degree in meteorology. In the same year he entered the University of Washington. He worked on the analysis of methane and nitrous oxide mixing ratio from Nimbus 7 SAMS associated with the equatorial SAO. He also simulated the tracer fields influenced by the SAO using a two-dimensional model. He received his Ph.D. degree in 1990 in atmospheric sciences. For the next three years he worked at Lawrence Livermore National Laboratory in the group that concentrated on the effects of physical-chemical-dynamical interactions in the stratosphere, and focused on improving the dynamical modules in the 2D model. Dr. Choi joined the Department of Atmospheric Sciences, SNU, in 1993 as an assistant professor, and now he is an associate professor at the School of Earth and Environmental Sciences, SNU. During his sabbatical year he is working at GSFC as a Goddard Visiting Fellow of Earth Sciences from March 2002 to February 2003.

Task 900-37-172: Retrieval of Cloud Properties for Partially Covered Imager Fields of View

GEST Investigator: James A. Coakley, Jr. (PI, on sabbatical leave from Oregon State University)

Abstract

A scheme is being developed to retrieve cloud properties for imager pixels that are only partially covered by clouds. Application of a working version of the scheme to Visible Infrared Scanner (VIRS)/Tropical Rainfall Measuring Mission (TRMM) observations reveals that for low-level marine stratus and stratocumulus systems approximately 40% of the 2-km fields of view are partially cloud covered. For these pixels, commonly used threshold retrieval schemes overestimate cloud fraction and droplet effective radius and underestimate cloud liquid water and cloud altitude. Systematic relationships are found between pixel-scale and 50-km regional-scale cloud properties. Such relationships should prove useful as guides to the development of cloud models. Further development includes tests designed to determine the potential accuracy of the retrieved cloud properties and the sensitivity of the retrieved properties to the spatial resolution of the imager data. The retrieval scheme will also be applied to 1-km Moderate Resolution Imaging Spectroradiometer (MODIS) observations.

Description of Research

Current schemes for retrieving cloud properties from satellite imagery data typically treat cloud-contaminated fields of view as being overcast. On the other hand, when looking at the sky, one commonly sees breaks in clouds and broken clouds that would seem to fail the overcast-pixel assumption. Assuming that pixels are overcast, when they are only partially covered, leads to biases in estimates of fractional cloud cover, cloud liquid water, and droplet sizes. To provide a first-order estimate of the potential biases, a new scheme is being developed to retrieve the properties of clouds for imager pixels that are only partially cloudy. For single-layered cloud systems, reflectances and emission at visible, near infrared, and thermal infrared wavelengths are used to determine the fractional cloud cover, cloud liquid water, and droplet effective radius for clouds in imager pixels that are only partially cloud covered. The altitude of the clouds is taken to be that for the layer of which they are a part. The layer altitude, in turn, is taken to be the same as that deduced for nearby pixels that are found to be overcast. Potential biases are being derived by comparing the cloud properties deduced for the partly cloudy pixels using the new retrieval scheme and the properties obtained, assuming that the partly cloudy pixels are overcast.

Accomplishments during the Reporting Period

A working version of the partly cloudy pixel retrieval scheme was developed and applied to 2-

km VIRS/TRMM data for February and March 1998. Based on comparisons with cloud properties derived using threshold methods, the threshold methods overestimate cloud fraction and droplet size and underestimate optical depth, cloud altitude, and cloud liquid water amount. For the VIRS 2-km fields of view, when single-layered, low-level clouds over ocean scenes were present, approximately 30% of the pixels were cloud-free, 30% were overcast, and the remaining 40% were partially cloud covered. Within 50-km scale regions, the fractional cloud cover in the partly covered 2-km pixels was governed by the regional scale cloud cover. If the regional-scale cloud cover was high, the cloud cover in the partly cloudy pixels was also relatively high. If the regional-scale cloud cover was low, the fractional cloud cover in the partly cloudy pixels was also relatively low. Optical depths, droplet radii, and cloud liquid water for the clouds in the partly cloudy pixels were systematically below those found in nearby overcast pixels. Such findings should prove helpful in developing models for the behavior of low-level marine clouds.

Objectives for the Coming Year

The cloud properties derived using the retrieval scheme for partly cloudy pixels are sensitive to the cloud altitude and radiative properties of the underlying surface, which, although derived from nearby pixels that are cloud-free and overcast, are somewhat uncertain. Sensitivity studies will be performed to determine the potential accuracy of the retrieved properties given realistic uncertainties for the cloud altitude and radiative properties of the underlying surface. In addition, the advantage of the partly cloudy pixel retrieval scheme over the more conventional threshold schemes is that the retrieved cloud properties should be relatively insensitive to the resolution of the imager. Tests will be performed, in which the spatial resolution of the radiance field will be degraded prior to performing retrievals to determine the sensitivity of the retrieved cloud properties to the spatial resolution of the radiance data. Finally, in cooperation with Steve Platnick, GSFC, the partly cloudy pixel retrieval scheme will be applied to 1-km MODIS observations and compared with the MODIS cloud products. Once successful retrievals are obtained with the MODIS data, cloud fraction and visible optical depth derived using the 1-km resolution data will be compared with those derived by applying threshold schemes to the 250-m resolution MODIS visible imagery.

Biographical Information

Dr. James Coakley received his degrees in physics: a B.S. (1968) from UCLA, and an M.A. (1970) and Ph.D. (1972) from Berkeley. He entered the atmospheric sciences in 1972 as a postdoctoral fellow in the Advanced Study Program at the National Center for Atmospheric Research (NCAR) and stayed at NCAR in various staff scientist positions until moving to Oregon State University in 1988. He is currently a professor of atmospheric sciences in the College of Oceanic and Atmospheric Sciences. His research focuses on the problems of climate change, and in particular on the remote sensing of aerosol and cloud properties from satellites and the effects of aerosols and clouds on the Earth's energy budget and climate. Dr. Coakley is a Fellow of the American Meteorological Society and has held various positions as associate editor and editor of the Journal Of Geophysical Research, the Journal of Climate, and Tellus. He has served as a member of the National Research Council's Committee on Meteorological Analysis, Prediction, and Research. He is currently serving on NOAA's Council for Long Term Climate Monitoring and on the American Meteorological Society's Committee on Atmospheric Radiation.

Task 910-03-047: **Radiative Properties of Atmospheric Aerosols**

GEST Investigator: Peter Colarco, PI

Abstract

In the past year, research has focused on the transport and radiative properties of various atmospheric aerosols. In particular, work has continued on modeling the transport and deposition of Saharan dust over the North Atlantic Ocean, collaborating with investigators from the Puerto Rico Dust Experiment (PRIDE) field program. A similar investigation simulates dust, smoke, and sea-salt aerosols over the Caribbean and Florida during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL/FACE). Investigating the transport and radiative properties of smoke from forest fires has begun, using remote sensing and *in situ* data along with the Global Ozone, Chemistry, Aerosol, and Radiative Transport (GOCART) model.

Description of Research

The main goal of this project is to study the atmospheric distribution of several radiatively important aerosol species. The approach used has been to simulate aerosol distributions using three-dimensional chemical transport models (CTMs) driven by assimilated meteorology. This approach allows quantitative comparison of modeled aerosol distributions with measurements from *in situ* and remote sensing platforms, which in turn aids in assessing the radiative properties of the aerosols. Simulations carried out in this fashion help to improve the models used and in the interpretation of field and remote sensing measurements, and provide assessments for aerosol radiative and pollution impacts on regional to global scales.

Accomplishments during the Reporting Period

Dust and sea salt transport was investigated using the National Center for Atmospheric Research (NCAR) Model for Atmospheric Transport and Chemistry (MATCH), an offline CTM driven by assimilated meteorology (National Centers for Environmental Prediction (NCEP)/NCAR reanalyses). MATCH is coupled to the University of Colorado Community Aerosol Radiation Model for Atmospheres (CARMA), an aerosol microphysics, radiation, and transport model. CARMA allows transport of an aerosol particle size distribution, which is important for simulating dust and sea-salt distributions, as the particle sizes are typically large and the particle size distribution undergoes significant modification by sedimentation, deposition, and wet removal.

The MATCH/CARMA model was used to study dust transport during the Puerto Rico Dust Experiment (PRIDE; conducted in June and July 2000). A dataset of remotely sensed and *in situ* measurements has been assembled to compare with the model, including satellite measurements from the Moderate Resolution Imaging Spectroradiometer (MODIS), the Total Ozone Mapping Spectrometer (TOMS), and the Advanced Very High Resolution Radiometer (AVHRR); ground-based measurements from the Aerosol Robotic Network (AERONET); the Micro-Pulse Lidar Network (MPLNet); and aircraft measurements made aboard the Space and Naval Warfare (SPAWAR) Systems Piper Navajo. The choice of a dust source model plays an important role in determining total aerosol amounts transported and near source distributions, but that far from sources (*e.g.*, Puerto Rico), the distribution of dust is more strongly controlled by transport dynamics. The dust vertical distribution was also studied during PRIDE, which demonstrates the importance of large-scale subsidence during transport in determining the downwind distribution.

Assembly of datasets and running simulations with MATCH/CARMA has begun for a retrospective analysis of dust, smoke, and sea-salt aerosols during the CRYSTAL/FACE in July 2002. Particle measurements made on the University of North Dakota Citation, the Naval Research Laboratory's Twin Otter, and the NASA WB-57 aircraft platforms are being analyzed, as are sunphotometer measurements from AERONET and lidar data from MPLNet. The goal is to provide a simulation of large-scale aerosol

transport to help investigators interpret data collected during the field project.

Work on biomass burning aerosols is following a similar approach. Various biomass burning emission estimates are being evaluated in the GOCART model, an offline CTM driven by the meteorological output from the Goddard Earth Observing System (GEOS)-Data Assimilation System (DAS) model. Key uncertainties in assessments of the aerosol direct radiative effect relate to the importance of biomass burning aerosols. There are considerable uncertainties in these estimates, and constraining those uncertainties has become a recent focus of task work.

GOCART simulations have begun, to investigate two biomass burning sources, one derived from Along-Track Scanning Radiometer (ATSR) fire counts and the other from Tropical Rainfall Measuring Mission (TRMM) fire counts, coupled with MODIS data for estimates of burned area. Data have been assembled for a case study of smoke and pollutant transport from boreal fires in Quebec, which impacted the northeastern U.S. during July 2002. Smoke from these fires may have coincidentally impacted observations made in Florida during CRYSTAL/FACE, but work focuses mainly on the impact of the smoke and pollutants observed over Washington, D.C. Microphysical simulations are being used to study the importance of particle coagulation on modifying aerosol size distribution and optical properties. Data from aircraft measurements made by the University of Maryland are being used to study the vertical distribution of smoke over the region during this period.

Objectives for the Coming Year

Work with the CRYSTAL/FACE dataset will continue over the coming year. The main effort, however, is directed toward completing studies of biomass burning aerosols. The first focus is to complete analysis of the Quebec fires from summer 2002. Work will also be done to constrain the emission estimates best suited for the GOCART model. Aside from evaluating different emission budgets, the importance of the initial smoke injection height on the aerosol distributions simulated will be investigated. Spaceborne lidar data from the Geoscience Laser Altimeter System (GLAS) will be used to study the heights of smoke plumes emitted, as will data from the MODIS instruments to assess the intensity of observed fires. The goal is to provide a parameterization for GOCART to improve assumed smoke injection altitudes, particularly in the boreal regions.

Biographical Information

Dr. Peter R. Colarco earned a B.S. in physics and astronomy from the University of Iowa in 1993; an M.S. in physics from Creighton University in 1997; and and an M.S. and Ph.D. in astrophysical, planetary, and atmospheric science from the University of Colorado in 2000 and 2003, respectively. While at Creighton University his research focused on numerical modeling of the laser-induced $^{12}CO_2/^{13}CO_2$ optogalvanic effect in human breath samples, which had application to noninvasive biomedical testing for stomach ulcers. This research was initiated while he was an American Institute of Physics Industrial intern at Alimenterics, Inc., of Morris Plains, New Jersey. At the University of Colorado, his research focused on modeling the emissions, deposition, and optical properties of Saharan dust aerosols. Publications from this work include estimates of the UV absorbing refractive index of Saharan dust particles derived from comparisons of numerical models with field and satellite data, and budget estimates for Saharan dust deposition into the North Atlantic Ocean. While at the University of Colorado he also participated as a flight planner and meteorological support scientist for the NASA Sage 3 Ozone Loss and Validation Experiment, in Kiruna, Sweden, during the winter of 1999-2000), and the Cirrus Regional Study of Tropical Anvils and Cirrus Layers/Florida Area Cirrus Experiment (CRYSTAL/FACE), Key West, FL in July 2002. Dr. Colarco has also taught undergraduate physics laboratory and recitation sections while at the University of Iowa and Creighton University, and basic atmospheric science laboratory sessions while at the University of Colorado. Dr. Colarco has been at GSFC and GEST since September 2002, where his research has focused on studying pollutant transport from forest fires, improving biomass burning emission estimates in global chemical transport models, and studying aerosol in the CRYSTAL/FACE region.

Task 900-37-172: **Ecological Assessment of the Springtime Antarctic Ozone Depletion Using Multi-Sensor Satellite Data**

GEST Investigator: Dan Lubin (on leave from the Scripps Institution of Oceanography)

Abstract

The Total Ozone Mapping Spectrometer (TOMS) data set was combined with contemporaneous satellite passive microwave data sets to develop a climatology of solar spectral ultraviolet radiation (UVR) throughout Antarctica and the Southern Ocean. These UVR retrievals were collocated with a climatology of Southern Ocean chlorophyll derived from NASA Sea-viewing Wide Field-of-View Sensor (SeaWiFS) data, to determine what fraction of the Southern Ocean phytoplankton biomass lies under enhanced levels of biologically active UVR, brought about by the springtime decrease in Antarctic ozone. Shortly after the onset of the Antarctic ozone depletion (as early as 1982), 15-25% of the Southern Ocean biomass was exposed to enhanced UVR levels during October. During September 1992 approximately 20% of the Southern Ocean biomass lay under enhanced UVR. During more recent ozone "hole" events, such as that which occurred in October 1999, more than 40% of Southern Ocean biomass lay under enhanced UVR, and ecologically significant UVR enhancements persisted into December.

Description of Research

The objectives of this project are to develop a multidecadal climatology of UVR and photosynthetically active radiation (PAR) at the Earth's surface throughout Antarctica and the Southern Ocean, using various satellite data sets as input to a comprehensive radiative transfer model; and to evaluate the ecological significance of anthropogenic changes in the stratospheric ozone column throughout the Southern Ocean, with reference to the climatological distribution of chlorophyll derived from SeaWiFS data.

Accomplishments during the Reporting Period

The climatology of UVR and PAR throughout Antarctica and the Southern Ocean has been completed. Passive microwave data (from the Special Sensor Microwave Imager (SSM/I) and the Scanning Multichannel Microwave Radiometer (SMMR)) were used to specify sea ice concentration, from which surface albedo was parameterized using TOMS 360-nm reflectivity observations that were determined to be cloud-free using contemporaneous Advanced Very High Resolution Radiometer (AVHRR) data. Over the Antarctic continent ultraviolet snow surface albedo was parameterized in a similar fashion. TOMS 360-nm reflectivity measurements were used with these surface albedo retrievals to derive an effective cloud optical depth from a delta-Eddington radiative transfer model. With cloud optical depth and surface albedo thus defined, and the total ozone column derived from the TOMS Version 7 data product, a second delta-Eddington radiative transfer calculation was used to estimate the downwelling flux of UVR and PAR at the surface, with a spectral resolution of 5 nm. Because the TOMS data are collected at or close to local noon, once per day at every location, these fluxes are the instantaneous local noon value. To place these fluxes in a biological context, they are weighted by an action spectrum for inhibition of photosynthesis in Antarctic phytoplankton, derived from biological fieldwork, to produce an instantaneous local noon dose rate relevant to photoinhibition at the base of the Antarctic marine food web.

To assess the ecological significance of changes in UVR brought about by the springtime Antarctic ozone decrease, the resulting enhanced UVR must be referenced against climatological values. At any given Southern Ocean location, the mean climatological value of the photoinhibition dose rate was defined to be that under the 1979 column ozone amount and the climatological mean cloud effective optical depth. These mean climatological values were computed, and each year of the actual climatology was compared against the mean climatological values to determine where and when enhanced UVR dose rates occurred. This information was then combined with monthly maps of chlorophyll-a from SeaWiFS, provided by Prof. K. Arrigo (Department of Geophysics,

Stanford University), to determine what fraction of the surface biomass was subject to enhanced UVR throughout the Southern Ocean in each year between 1979-1999. The 1992 ozone "hole" event was analyzed in detail according to the following numerical simulation: UVR and PAR were propagated into a model water column containing phytoplankton, colored dissolved organic matter (CDOM), and a parameterization for mixing and mixed layer depth. Physiological models of phytoplankton growth rates in response to UVR and PAR levels were incorporated, and the phytoplankton growth rate and biomass were calculated. The UVR levels were determined, first by the actual 1992 ozone column, and then by the 1979 ozone column, with all other variables held constant as a control run. Results of these simulations have been published by Arrigo *et al*. [2003].

In a related investigation, the trends in TOMS 360-nm reflectivity were determined over the entire Southern Ocean for the period 1979-1994 [Lubin *et al.* 2003]. Throughout more than 280 degrees of longitude, there are statistically significant increasing trends in TOMS reflectivity, which are related to climate change at southern high latitudes. Analysis of these trends in conjunction with passive microwave observations of sea ice reveals that many trends occur where the sea ice concentration itself has been increasing, and many trends occur where the reflectivity of the underlying surface appears to be increasing, at fixed, moderate values of sea ice concentration (10-60%).

This research was supported by the NASA Atmospheric Chemistry Modeling and Analysis Program (ACMAP) under NAG5-8252

Objectives for the Coming Year

The numerical simulation capability involving satellite-derived UVR and PAR at the ocean surface, radiative transfer into the water column, and physiological response of phytoplankton will be improved in all aspects, including more rigorous atmospheric and in-water radiative transfer, and it will be applied to selected U.S. coastal locations for which comprehensive hydrographic and biological data sets exist. The objective of the latter will be to determine how satellite remote sensing can better monitor changes in global oceanic primary production.

Biographical Information

Dr. Dan Lubin is a GEST Visiting Senior Scientist, and is also a research physicist and senior lecturer at the Scripps Institution of Oceanography. Dr. Lubin received a B.A. degree in physics with departmental honors from Northwestern University in 1986, M.S. Degrees in geophysical sciences and astronomy and astrophysics from the University of Chicago (1987 and 1988), and a Ph.D. in geophysical sciences from the University of Chicago in 1989. For his Ph.D. research, Dr. Lubin made the first spectral radiometric measurements of enhanced solar ultraviolet radiation under the Antarctic ozone "hole", from Palmer Station on the Antarctic Peninsula. Since then, he continues to be involved with polar research in the areas of atmospheric physics and photobiology. In addition to UV spectroradiometry, Dr. Lubin has developed Fourier Transform Infrared (FTIR) instrumentation for research on the longwave radiative properties of clouds and trace gases. He is a veteran of three Antarctic field campaigns, and participated in the Surface Heat Budget of the Arctic (SHEBA) experiment and the 1994 Arctic Ocean Section, a joint U.S./Canada icebreaker crossing of the Arctic Ocean via the North Pole. Since 1994 Dr. Lubin has been the principal investigator for the Scripps Institution of Oceanography's Arctic and Antarctic Research Center (AARC), an NSF-supported satellite remote sensing facility that archives telemetry from the satellite tracking equipment at McMurdo and Palmer Stations in Antarctica and the U.S. Coast Guard icebreakers, and makes these data and related geophysical products available to the international research community. Dr. Lubin is presently a GEST Visiting Fellow from October 2002 through October 2003.

Task 900-37-172: **Estimation of the Aerosol Indirect Cloud Radiative Forcing by Using MODIS Retrievals and GOCART Simulations**

GEST Investigator: Harshvardhan (PI, on sabbatical from Purdue University)

Abstract

Preliminary work was done to identify Moderate Resolution Imaging Spectroradiometer (MODIS) granules that would be candidates for a study of the indirect aerosol effect on cloud forcing. The Global Ozone, Chemistry, Aerosol, and Radiative Transport model (GOCART) chemical transport and transformation model, developed at GSFC, was used to track aerosol plumes from continental regions over pristine ocean views. Regions that had low-level water clouds before and after the aerosol incursion were identified and have been selected for future study.

Description of Research

Aerosols in the atmosphere act as cloud condensation nuclei. The differences in aerosol loading over land and ocean lead to differences in the nature of water cloud microphysics. To a first approximation, continental clouds have higher droplet concentration and smaller drop sizes than marine clouds. However, aerosols of continental origin are transported over the oceans and can potentially change maritime cloud properties. Since the change in cloud properties also changes the radiative properties of the cloud layer, the aerosol is said to have indirectly changed the cloud radiative forcing.

The goal of this research is to quantify this indirect forcing on a global scale. The Intergovernmental Panel on Climate Change (IPCC) has reported that this particular radiative forcing is associated with the greatest level of uncertainty. Our plan is to use cloud property retrievals from MODIS on the EOS Terra and Aqua satellites to quantify the forcing. The aerosol influence will be identified by using simulated data from the GOCART chemistry transport and transformation model.

Accomplishments during the Reporting Period

During the five-month period of activity in the past year, GOCART aerosol simulated column concentration and profiles were processed over regions of the eastern North Pacific Ocean. This region is normally pristine, but is subject to incursions of aerosol from Asia, primarily China. During 2001, there was an intensive field experiment, Aerosol Characterization Experiment (ACE)-ASIA, that provided significant ground truth data, which have been used to validate GOCART results.

Days in March and April 2001 were selected when, over a period of one week, the aerosol loading in the region bounded by 40°N and 50°N, and 140°W and 150°W, changed dramatically as continental air moved in and out of the area. Terra MODIS granules from this period are being analyzed to detect an indirect effect of aerosol on cloud microphysical properties. MODIS retrievals provide optical depth and effective radius; the two can also be combined to calculate the cloud liquid water path. The signature of an aerosol effect is a reduction in effective radius. It is also possible to estimate the total droplet concentration, and this quantity would increase quite dramatically as marine clouds became more continental. Results from the study are not yet available.

Biographical Information

Dr. Harshvardhan received his Ph.D. in 1976 from SUNY, Stony Brook. He then spent the next eleven years atGSFC in the Laboratory for Atmospheres and its predecessor organizations. In 1988 he accepted a faculty position at Purdue University in the Department of Earth and Atmospheric Sciences, where he is currently professor and department head. His research focuses on the modeling of cloud and aerosol radiative processes. Dr. Harshvardhan is a Fellow of the American Meteorological Society and the recipient of the Henry G. Houghton Award of the AMS in 1993. He was an editor of the *Journal of Applied Meteorology* from 1996-2001. He has been a visiting scientist at the Max Planck Institute for Meteorology, Hamburg, Germany, and the National Centre for Medium Range Weather Forecasting, New Delhi, India. Most recently, he has been a visiting senior research scientist at GEST/UMBC.

Task 910-03-047: **Research in Atmospheric Physics and Chemistry**

GEST Investigator: Kenneth Minschwaner (PI, on sabbatical from the New Mexico Institute of Mining and Technology)

Abstract

Three research activities were conducted during the first half of a one-year sabbatical stay at GSFC, which was partially supported under the Goddard Visiting Fellows Program in Earth Sciences. The first investigation concerns the climate feedback by water vapor in the tropical upper troposphere. A numerical model was developed for diagnosing and predicting humidity changes between about 10 and 14 km in the Tropics as a function of sea-surface temperature and in response to changes in other major greenhouse gases, such as carbon dioxide. A second study focused on accurately quantifying the photochemical production and loss of ozone in the stratosphere. This work involves ultraviolet radiative transfer calculations that provide parameterized input to GSFC 2-D and 3-D models of the upper atmosphere. The third activity is a continuation of research, initiated in the summer of 2003, on satellite-based retrievals of the concentration of nitric oxide in the upper mesosphere and thermosphere, at altitudes between 85 and 200 km.

Description of Research

Although this research in atmospheric physics and chemistry spanned a wide range in altitudes (the upper troposphere, stratosphere, and thermosphere), it shares at least two common threads: the emphasis on infrared and ultraviolet radiative transfer and the processes of molecular absorption, emission, and fluorescent scattering; and modeling or measurement of key trace species in the Earth's atmosphere. For water vapor in the upper troposphere, the strong greenhouse forcing by this highly variable gas is expected to play a critical role in shaping the direction of future changes in climate. The magnitude and sign of the water vapor feedback in the tropical upper troposphere has been a subject of intense debate over the past decade. The goal of this work is to examine water vapor feedback mechanisms using a model specifically designed to predict the moisture content of the upper troposphere in the tropics. For stratospheric ozone, the goal is to improve model predictions of the response of ozone to man-made perturbations such as aircraft exhaust and changing emissions of halocarbon compounds. The current generation of models has difficulty reproducing observed seasonal variations in lower stratospheric ozone, particularly at high latitudes during summer. This problem is the primary focus of ozone research described here. For nitric oxide (NO) in the thermosphere, an understanding of its global distribution is important for many of the radiative, chemical, and dynamical processes involved with space weather, solar forcing, and anthropogenic effects on the upper atmosphere. For example, infrared emission by NO is one of the primary cooling mechanisms in the lower thermosphere.

Accomplishments during the Reporting Period

A radiative-convective model was specifically designed and developed to investigate the humidity budget of the tropical upper troposphere (10-14 km). This model utilizes fast and accurate calculations of infrared heating and cooling by water vapor, carbon dioxide, ozone, and minor greenhouse gases, and visible and ultraviolet absorption of solar radiation. Equilibrium states of this model unambiguously show that as the surface warms, changes in the vertical distribution and temperature of detraining air parcels from tropical convection lead to higher water vapor mixing ratios in the upper troposphere. However, the increase in mixing ratio is not as large as the increase in saturation mixing ratio due to warmer environmental temperatures, so that the relative humidity decreases. This analysis suggests that models that maintain a fixed relative humidity are likely overestimating the magnitude of the water vapor feedback in the tropical upper troposphere

A detailed investigation is being conducted into the photochemical production and catalytic loss of ozone in the high-latitude summer stratosphere. Production of ozone in this case is thought to be dominated by the ultraviolet photodissociation of

molecular oxygen. This process is being studied using a line-by-line treatment of the oxygen Schumann-Runge band system and Herzberg continuum. Results show a high sensitivity to oxygen cross-sections in a 190-210 nm window that controls O_2 photolysis. Preliminary calculations using the GSFC 2-D model show, however, that the failure of current models to accurately simulate ozone cannot be remedied through changes in assumed O_2 absorption cross sections alone, and that some combination of chemical loss and/or transport processes must be involved.

An analysis of ultraviolet dayglow was completed from the Ionospheric Spectroscopy and Atmospheric Chemistry (ISAAC) instrument, which was launched in February 1999 onboard the Air Force Advanced Research and Global Observing Satellite (ARGOS). This analysis included calibrating the overall instrument sensitivity, nonlinear effects, stray light, pointing, and Rayleigh-scattered background below 110 km. Residual spectra between 200 and 260 nm contain strong resonance-fluorescence signatures of the NO gamma bands, which were used for inversion of measured radiances to absolute NO concentrations. The measured NO provided tight constraints on the profile of O_2 in the mid-to-upper thermosphere; our results favor the lower O_2 densities in the updated Naval Research Laboratory Mass Spectrometer/Incoherent Scatter Radar (NRLMSISE)-00 empirical model as compared to MSIS90.

Objectives for the Coming Year

Objectives for the remainder of this research sabbatical will include further work on the controls of tropical humidity, including sensitivity to tropopause and lower stratospheric processes. Extension of the model and data analysis of water isotopes is planned, including investigation of radiances from the AIRS (Atmospheric Infrared Sounder) instrument onboard the EOS Aqua satellite.

Biographical Information

Dr. Ken Minschwaner received his B.S. and M.S. degrees in physics at Florida Atlantic University in 1984 and 1986, respectively, and his Ph.D. in earth and planetary sciences from Harvard in 1992. Dr. Minschwaner spent two years at the National Center for Atmospheric Research as a postdoctoral scientist in the Advanced Study Program; he joined the faculty of the Department of Physics at New Mexico Institute of Mining and Technology in 1994. He is currently an associate professor of physics at New Mexico Tech and will resume his duties as department chairman in fall 2003. Dr. Minschwaner's experience and research interests include experimental physics, analysis of atmospheric data, and numerical modeling. He has designed instruments and methods for measurements of atmospheric hydroxyl, surface ultraviolet radiation, and column ozone. He has analyzed data for scientific investigations from a number of instruments and platforms, including the Earth Radiation Budget Experiment (ERBE), the Total Ozone Mapping Spectrometer (TOMS), and the Upper Atmosphere Research Satellite (UARS), and has developed line-by-codes for both infrared and ultraviolet applications.

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Educational Programs

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Educational Programs

Summer 2002 was GEST's second year managing three long-running programs at GSFC. GEST also was instrumental in creating a new summer program held at Wallops Flight Facility.

Visiting Student Enrichment Program (VSEP)

VSEP is open to students in the physical sciences, mathematics, and computer science from high school through graduate school level, and is jointly sponsored by GSFC's Earth and Space Data Computing Division and other GSFC organizations. The objective of VSEP is to expose young people to opportunities in the Earth and space sciences, particularly those that apply computing technologies. Although many students are fascinated by computers, we need to encourage more of them to pursue a career in the application of computing to science. It also exposes students to NASA as an employer and serves as a tried recruitment tool.

Twenty-five students were selected in the summer of 2002 from over seventy applicants for this educational enrichment. Students were matched with mentors in ten divisions across four GSFC directorates for projects involving information technology, computer science, and Earth and space sciences. In addition to work on individual projects under the direction of their respective mentors, VSEP participants had the opportunity to listen to invited talks by scientists and NASA administrators, and to visit the National Air and Space Museum, NASA Headquarters, the University of Maryland, Baltimore County, and NASA's Wallops Flight Facility near Chincoteague, Virginia. At the end of the ten-week session everyone contributed to the poster session, and presented a talk on the results of their research, which are highlighted below:

Bradley Williams assisted in work to predict invasive species outbreaks using soil data. Emmanuel Cephas completed a benchmark evaluation and documentation of the Mesoscale Model 5 version 3 code. These test results, which will be available on the Web after verification, quantify the speed and efficiency of the NCCS parallel computing systems when they run the atmospheric model. Shean McMahon, David Wangerin, and Ernest Fessenden tested the capabilities of aCe, a programming extension developed to adapt the C language to parallel computing. Their work included a comparison between aCe and the Unified Parallel C extension, an adaptive mesh refinement code in aCe, and automatic calculation for the optimal number of threads in a parallel-computing program. Lori Petty worked on the development of a new model that calculates the lifetime of quark-antiquark virtual pairs. Ashley Thrall calculated the potential energy curves for molecules found in the tail of a comet. These calculations can be used to study photo-dissociation in comets. Tamara Battle attended a workshop on Remote Sensing and GIS Applications in Puerto Rico and participated in a research cruise led by Dr. Vernon Morris of Howard University to track African dust dispersal over the Caribbean, as part of her internship on environment and health.

The application pool for Summer 2003 is approximately four hundred; fifteen students are expected to be selected this year.

High-Performance Computational Earth and Space Sciences (HPC)

Sixteen advanced graduate students were selected n the summer of 2002 for this very competitive and extremely popular program, run by the Earth and Space Data Computing Division. HPC's objective is to provide the hands-on parallel systems training advanced students can obtain only at a major facility such as NASA's High Performance Computing and Communications labs. Participants have completed their Ph.D. qualifying examinations, and require large-scale numerical modeling on massively parallel architectures for their dissertation research. Their research can cover any topic in the Earth, space, or information sciences. Resident facilities include a 416-processor Compaq, a 1360-processor Cray T3E, a 512-processor SGI Origin 2000, numerous middle-sized supercomputing platforms, and several Beowulf-class systems. (Beowulf is a class of inexpensive massively parallel systems designed as a cluster of commodity PCs using Linux; Beowulf was first conceived at GSFC in the 1990s.) HPC consists of three weeks of intensive lectures on advanced topics in computational Earth and space sciences, with emphasis on computational fluid dynamics and particle methods. Lectures are presented on developing software for massively parallel architectures, along with hands-on parallel computer training and small-group interaction.

HPC is expected to continue in summer 2003 with 16 students.

Graduate Student Summer Program (GSSP)

The GSSP is intended for graduate students in the Earth, physical, or biological sciences, mathematics, or engineering to encourage careers in the Earth Sciences Directorate at GSFC. Students may either be early in their graduate career, seeking a research topic, or they may be more advanced and wish to work with specific research teams on their thesis or dissertation.

The theme for summer 2002 was "The Global Water Cycle and Climate Change." Ten students were selected; one worked at the Goddard Institute of Space Studies (GISS) in New York City, and nine worked at GSFC. The GSSP seminar series, which is open to the general public, was held from June 11 - 14, 2002 in the GSFC Visitors Center, and included dynamic presentations by over a score of scholars, including Soroosh Sorooshian, on the impacts of water system management and human demand on water resources; Wayne Higgins, on the relationships between weather extremes, climate variability and long-term trends; Thomas Schmugge, on evapotranspiration and its estimation with satellite data; and Bob Adler, on global precipitation observations, historical records and trends.

Participants in 2002 included Kate Yang, who studied regional transport modeling of East Asian dust storms; Jennifer Kay, who compared MODIS and SSM/I multispectral snow property recovery; Manuel Lonfat, who looked at TRMM datasets of precipitation distribution in cyclones; and Brian Thompson, who estimated Earth's gravity field using the Champ satellite. This research led to an invitation to all GSSP students to visit the Goddard Satellite Laser Ranging and Very Long Baseline Interferometry station in Greenbelt.

Up to ten students will be selected for the summer 2003 program, the theme of which is "Radiation Effects of Aerosols and Clouds on Climate." The seminar series will be held from June 10 - 13, 2003.

Goddard Coastal Research Graduate Fellowship Program (GCR)

This new program was conceived in spring 2002 to provide opportunities for graduate students in physical and biological oceanography to learn instrumentation technology and techniques, with the hope that this exposure will influence the choice of research topic selected by oceanography students, and, in future, increase the pool of future NASA talent. Six students were selected for the first year; they learned instrument techniques used in coastal research alongside the experts from the GSFC-managed Wallops Flight Facility located on the Eastern Shore of Virginia. The first week was spent at Wallops, and included a tour of the research facilities along with talks by researchers in all areas of Wallops expertise; the students then left for field research: Brenda Dolan and Nicholas Anderson worked with NPOL radar on the CRYSTAL-FACE project in south Florida; Kevin Riordan and Conan Noronha worked on experimental airborne advanced research lidar (EAARL) in Salisbury, Maryland; Mike Novak assisted in the preparation for the coupled-boundary layers air-sea transfer (CBLAST) experiment aboard a ship off the coast of Martha's Vineyard; and Andrea Vander Woude worked at Wallops on data from the World Ocean Circulation Experiment for her research on the California current's northward transport events. Students wrote papers and presented seminars on their research at the end of the program. Students and mentors gave GCR a resounding thumbs-up.

Due to the delay of the federal budget appropriations for 2003, funding for GCR has not been assured. Instead of the anticipated 10 students only two will be selected, and they will join the GSSP in order to have a sense of belonging. Once the program is fully funded, Northrop-Grumman will participate in the selection of participants, and will provide instrument platforms for interested selected students.

GEST Graduate Fellows

Two GEST graduate fellowships were created, one in the Physics Department at UMBC, and one in the UMBC's Department of Computer Science and Electrical Engineering. Ms. Michele McCourt was chosen from the Physics Department at UMBC. She has completed her Master of Science degree, and is currently enrolled in the Ph.D. degree program in Atmospheric Physics. She is also the current president of the UMBC Graduate Student Association.

A second fellow was selected from the UMBC's Department of Computer Science and Electrical Engineering. However, visa issues arising from new INS requirements precluded the student's acceptance of this award during the present school year. Two new candidates will be selected for these graduate fellowships that are to commence in the fall semester.

Short-Term Visitors

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Short-Term Visitors

GEST facilitates collaboration between scientists based at GSFC and those at other research institutions to support collaborative work at GSFC, field locations, and external conferences. For example, Marco Tedesco presented a seminar for GSFC Code 975 on microwave remote sensing of snow, and then—after being snowbound in Greenbelt during the blizzard of 2003—he continued on to Colorado to observe the techniques of the Cold Lands Processes Experiment so that they might be compared to similar research techniques used in the Italian Alps.

The AEROCENTER is a new GEST-assisted initiative in Code 913, intended first to develop new technical infrastructure for integrating current aerosol research and data resources at GSFC, and to increase the involvement of the larger national and international scientific community. The second main objective is to serve as an incubator for new ideas for analysis of both satellite- and ground-based measurements and models and new space missions. Many of the visitors to Code 913 list below are visiting GSFC and GISS as part of the AEROCENTER initiative.

Scientists who visited GSFC during this past year under the auspices of GEST included:

Visiting Scientist	Affiliation	GSFC Code Visited
Pinhas Alpert	Tel-Aviv University	913
Michael Box	University of New South Wales	913
Peter Bundi	University of the Witwatersrand, South Africa	916
Peter Coppin	Carnegie Melon University	930
Edmilson Dias de Freitas	University of São Paulo	913
Gabriëlle De Lannoy	Ghent University, Belgium	974
Martin Ehrendorfer	University of Innsbruck, Austria	910
Thierry Elias	University of Evora, Portugal	913
Jan Paul Fortuin	Royal Netherlands Meteorological Institute	916
Mona Tal Freiman	University of the Witwatersrand, South Africa	913
William Gustafson	University of California, Davis	971
Jenny Hand	National Center for Atmospheric Research	910
Chris Hennon	Ohio State University	912
Dirceu Herdies	National Institute for Space Research, Brazil	910
Gabriele Hegerl	Duke University	913
Gregory Jenkins	Pennsylvania State University	912
Amy Kaleita	University of Illinois at Urbana-Champaign	974
Arnon Karnieli	Ben Gurion University of the Negev, Israel	913
Min-Jeong Kim	University of Washington, Seattle	975
Eladio Knipping	University of California, Irvine	916
Dorothy Koch	Yale University	913
Ilan Koren	Tel-Aviv University	913
Tiruvalam Krishnamurti	Florida State University	912
Dinush Kurera	University of Melbourne	974

Visiting Scientist	Affiliation	GSFC Code Visited
Jean-François Léon	University of Lille, France	913
Kuo-Nan Liou	University of California, Los Angeles	913
Manuel Lonfat	University of Miami (former GSSP)	913
Lansing Madry	University of Colorado at Boulder	913
Maureen McMahon	California State University, Long Beach	930
Surabi Menon	Columbia University	913
Gary Morris	Rice University	916
Hyun-Jong Oh	Seoul National University	912
Ken-ichi Okamoto	Osaka Prefecture University	912
Roger Pielke	Colorado	912
Bernard Pinty	European Union Joint Research Center	913
Aline Procopio	University of São Paulo	910
Antonio Queface	Eduardo Mondlane University, Mozambique	913
Peter Ray	Florida State University	912
Dan Rosenfeld	The Hebrew University of Jerusalem	913
Alyssa Sarid	University of Arizona	921
Toshiaki Shinoda	NOAA Climate Diagnostics Center	971
Masato Shiotani	University of Kyoto	910
Thomas Smith	National Climate Data Center	971
Byung-Ju Sohn	Seoul National University	912
Harold Stone	Independent consultant	935
Tswen-Yung David Tang	National Taiwan University	971
Marco Tedesco	Carrara Institute of Applied Physics, CNR	975
Michel Verstraete	European Union Joint Research Center	913
Jonathan Verville	Michigan Technology University (former VSEP)	975
Grace Wahba	University of Wisconsin, Madison	913
Jeffrey Walker	University of Melbourne	974
Wei-Chyung Wang	State University of New York, Albany	912
Michael Winton	NOAA Geophysical Fluid Dynamics Laboratory	971
Martin Wooster	King’s College, London	913
Liming Xu	FM Global Research	912
Derimian Yvgeni	Ben Gurion University of the Negev, Israel	913
Hongbin Yu	Georgia Institute of Technology	913

APPENDICES

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Grant Proposals and Status
(sorted by funding agency)

Proposal Title	Funding Agency	PI (GEST Center)	Co-I(s) (GEST Center)	Status
Coastal Wetland Information System	CAN		Hoban	Pending
Utilization of remotely sensed satellite data to monitor and forecast Rift Valley fever and other vector-borne disease outbreaks proposal to Walter Reed Army Institute for Research (WRAIR) program	DoD		Anyamba	Funded
The use of observational data and a 3-D cloud-resolving model to improve the understanding and representation of cloud processes in General Circulation Models	DOE		Johnson	Funded
Using Radar, Lidar, and Radiometer Measurements to classify cloud type and study middle-level cloud properties	DOE	Wang		Funded
Characterization and detection of HAB species with Laser Excitation-Emission Matrix (LEEM) analysis	EPA	Chekalyuk		Pending
Using STIS to study physical conditions of molecular clouds	HST	Lyu		Pending
Simulation of shortwave VIIRS testbed for aerosol and land surface EDRs	IPO (Tri-Agency)	Lyapustin	Wang	Pending
An AGCM study of extreme winter weather events over the United States and their links to ENSO	NASA		Chang	Pending
A proposal for joint development of boundary layer cloud parameterization strategies for the GISS and NSIPP General Circulation Models	NASA	Bacmeister		Funded
Global and regional aerosol modeling study: Sources, distributions, and near-term to long-term climate effects	NASA		Colarco	Pending support
Satellite precipitation and latent heating estimates suitable for data assimilation and large-scale analysis	NASA	Olson	Yang	Pending
TRMM analysis for stochastic convective parameterization and mechanisms of precipitation variability	NASA		Bacmeister	Pending
Analysis of UV emission spectra from space-based observations	NASA	Minschwaner		Pending

Proposal Title	Funding Agency	PI (GEST Center)	Co-I(s) (GEST Center)	Status
Application of cloud and regional scale model in studies of convective system and their associated rainfall and latent heat structure for TRMM/GPM	NASA		Pu	Pending
Applications of MGS MOC and MOLA data to lava flows: Investigations of rheology topographic influences, and tectonic effects	NASA		Sakimoto	Funded
Assimilating real-time satellite snow observations into DAO's finite-volume Data Assimilation System	NASA	Sun		Pending
Assimilation of satellite observations of the land surface in support of NASA's Seasonal-to-Interannual Prediction Project	NASA		Reichle	Funded
Atmospheric transport of trace gases and aerosols: Evaluating models and observations	NASA		Olsen, Pawson, Rosenfield, Colarco	Pending
Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment (BASE-ASIA)	NASA	Hsu		Pending
Characterization of aerosol optical properties and column water vapor for LBA-ECO	NASA		Eck	Funded
Characterization of beamfilling effects with boresighted active and passive microwave sensors	NASA		Skofronick-Jackson	Pending
Climate and Health Impacts in North/East Asia: Tropospheric Experiment on Aerosols (CHINA-TEA)	NASA	Hsu		Pending
CloudSat level 2 combined radar and lidar cloud scenario classification standard product development	NASA	Wang		Funded
Determination of the penetration of UV radiation in the Earth's oceans from satellite data	NASA		Krotkov	Funded
Development of a multi-angle sky-viewing DOAS instrument for validating aura's OMI data products	NASA		Bucsela	Pending
Development of an airborne sun-sky auto-pointing photometer	NASA		Dubovik	Pending
Development of new instrumentation and methodology for measurements of column aerosol absorption in UV-VIS spectral region	NASA	Krotkov	Dubovik, Veselovskii	Pending

Proposal Title	Funding Agency	PI (GEST Center)	Co-I(s) (GEST Center)	Status
Dielectric mixing models for inhomogeneous atmospheric snow	NASA	Skofronick-Jackson		Rejected
Enhanced remote sensing of atmospheric aerosol by multi-sensor AERONET/MISR/MODIS retrieval	NASA	Dubovik		Pending
Enhanced sounding data, modeling support, and case study evaluation for CRYSTAL-FACE	NASA		Wang, Lin	Accepted
Error estimates for AMSR-E rainfall data	NASA		Kundu	Funded
Error estimates for TRMM and GPM average rain-rate maps	NASA		Kundu	Pending
Estimation of snowfall over land and determination of frozen hydrometeor characteristics	NASA	Skofronick-Jackson		Pending
From regional pollution to global atmospheric change: Modeling and data analysis in a global-regional atmospheric modeling system	NASA		Olsen	Pending
Frozen hydrometeor and snowfall inference from millimeter-wave radiometry	NASA	Skofronick-Jackson		Funded
Global nalysis and odeling of Ice Clouds in a Sub-synoptic Environment (GAMICSE)	NASA	Pawson		Funded
Ground-based aerosol measurement and characterization	NASA		Dubovik, Eck, Smirnov	Funded
Implementation of full Aerosol-Chemistry in fvDAS: Applications to aerosol effects on tropospheric dynamics and ozone chemistry	NASA	Ginoux	Weaver, Ziemke	Pending
Improvement of atmospheric boundary layer parameterizations in the finite-volume General Circulation Model at NASA Data Assimilation Office	NASA	Chern		Pending
Improvement of General Circulation Model simulations using global observations of precipitation/latent heating	NASA	Yang		Funded
Information extraction and retrieval-based data compression for remotely sensed imagery	NASA		Solyar	Pending

Proposal Title	Funding Agency	PI (GEST Center)	Co-I(s) (GEST Center)	Status
Investigate precipitation structures from combined use of TRMM precipitation radar with ground-based weather radars, and applications of such knowledge in improving Quantitative Precipitation Estimation by radar	NASA		Grecu	Pending
Investigation and mitigation of uncertainties in TRMM precipitation retrievals using a combined radar-radiometer approach	NASA	Grecu	Olson	Pending
Long term Chemical Analyses of Stratospheric Trace Species (CASTS) using Data Assimilation	NASA	Lary		Pending
Modeling Aeolian iron cycle and ocean primary productivity	NASA	Ginoux		Rejected
Observationally-based process evaluation of model transport: Improving atmospheric models and the GMI assessment capability	NASA	Strahan		Funded
Optimal land initialization for seasonal climate predictions	NASA		Ni-Meister	Funded
Optimal precipitation estimation for Global Land Surface Application	NASA		Gottschalck, Arsenault	Pending
Optimization of the sea ice model for ice deformation and visco-plastic rheology using satellite data assimilation	NASA		Ukita	Pending
Orbiting Carbon Observatory (OCO)	NASA		Pawson	Funded
Plains volcanism and small volcanic edifices on Mars	NASA	Sakimoto		Funded
Proposal for continued funding of the stratospheric general circulation with chemistry project	NASA		Olsen, Gupta	Pending
Reanalysis for stratospheric trace-gas studies (ReSTS)	NASA	Pawson		Funded
Regional climate extremes: Assessing the reliability of forecasts with global models	NASA		Chang	Funded
Retrievals of frozen and melting hydrometeors by AIR-/Space-borne radars and radiometers	NASA	Liao	Skofronick-Jackson	Pending
Spectral, angular, and vertical characterization of aerosols for radiative properties	NASA	Gatebe	Dubovik	Funded

Proposal Title	Funding Agency	PI (GEST Center)	Co-I(s) (GEST Center)	Status
Structure and variation of rainfall characteristics in South East Asia Summer Monsoon inferred from TRMM and ground-based polarimetric radar observations	NASA	Wang		Pending
Study of 3D effects in Landsat atmospheric correction	NASA	Lyapustin	Wang	Funded
Synthetic aperture radar analysis of multi-scale geologic and environmental processes in Idaho and the Intermountain West	NASA		Sakimoto	Funded
The application of NASA EOS MODIS data to agricultural assessment and forecasting by the USDA Foreign Agricultural Service	NASA		Anyamba	Pending
The effect of subgrid variability of snow cover in vegetated regions on Land-Atmosphere Interactions	NASA	Ni-Meister		Funded
The Global Aerosol System and its direct and indirect forcing of climate	NASA		Dubovik	Pending
The indirect effect of aerosols as deduced from ship tracks	NASA	Coakley		Pending
The interaction between the troposphere and stratosphere: The impact of climate change	NASA		Pawson	Funded
The long-term satellite record of volcanic sulfur dioxide emissions	NASA		Krotkov	Rejected
The NASA Water Cycle Data Center (WCDC)	NASA		Schlosser, Arsenault	Pending
The use of NASA land data assimilated products to improve flood and drought risk analysis and forecasting for water resources management in the Columbia River Basin	NASA	Arsenault		Funded
Thermal and mechanical analysis of small shallow magma reservoirs on Mars topographic influences, and tectonic effects	NASA		Sakimoto	Funded
Towards an objectively optimized earth observation strategy: A dynamic data retrieval direction system using the concepts of dynamic data and automatic code generation and code reusability	NASA	Lary		Pending
Understanding and prediction of tropical large-scale rainfall patterns in support of the modeling effort at DAO	NASA		Chen	Pending

Proposal Title	Funding Agency	PI (GEST Center)	Co-I(s) (GEST Center)	Status
Understanding bio-physical coupling in the Atlantic using combined satellite observations and ocean modeling	NASA	Wilson		Pending
Utilization of the Goddard Cloud Ensemble Model in studying large-scale tropical rainfall patterns	NASA		Chen	Pending
Validation and analysis of improved TOMS satellite estimated UV irradiances including cloud, aerosol, and snow-ice effects with applications to future satellite data	NASA		Krotkov	Funded
Variability of aerosols distribution and optical properties simulated by GOCART model using TOMS, aerosol data, and AERONET measurements	NASA	Ginoux	Dubovik	Funded
Volcanic evolution and erosional history of Tyrrhena & Hadriaca Paterae, Mars	NASA		Sakimoto	Funded
Atmospheric transport of trace gases and aerosols: Evaluating model and observations	NASA		Pawson, Rosenfeld, Colarco, Olsen	Pending
Improvement of convective/stratiform separation and latent heating profile estimation from TRMM	NASA	Olson	Yang	Funded
Multi-wavelength Raman Lidar Measurements for Studies of the Aerosol Indirect Effect and AERONET Algorithm Development	NASA		Veselovskii , Lin, Dubovik	Pending
Exploring planetary topography in the classroom using 3D models	NASA (DDF)		Sakimoto	Funded
Organization, structure and evolution of tropical convection in South China Sea Monsoon and their mesoscale environment	NASA TRMM	Wang		Funded
Comparison and validation of downward longwave radiation for NASA/NOAA land data assimilation system (LDAS)	NASA/NOAA (JCSDA)	Meng		Pending
Including Atmospheric Aerosols in the Optical Path Transmittance Model (OPTRAN)	NASA/NOAA (JCSDA)	Weaver		Pending
Advanced Laser Fluorescence (ALF) technology for estuarine and coastal environmental biomonitoring	NOAA	Chekalyuk		Pending

Proposal Title	Funding Agency	PI (GEST Center)	Co-I(s) (GEST Center)	Status
Assimilation of radiances in cloudy and precipitating regions by incorporating an advanced radiative transfer model into NCEP regional analysis system	NOAA	Pu		Pending
State-dependent data selection based on estimated background uncertainty	NOAA		Pu	Pending
Improved water demand forecasting for water resources managers	NOAA -GAPP, OGP		Arsenault	Funded
Characterizing land surface memory to advance climate prediction	NSF		Schlosser	Funded
Determination of the effects of non-modality on the data assimilation and numerical weather prediction problems	NSF	Errico		Pending
Educating with virtual experience	NSF	Hoban	Laughlin	Pending
Integrated technology based experiences in Astronomy	NSF		Hoban	Rejected
Quantifying water and energy fluxes at the land-atmosphere boundary: A detailed study of processes and feedback using coupled modeling and advanced data assimilation	NSF	Reichle		Rejected
Science on the semantic web: Prototypes in Bioinformatics	NSF		Hoban	Pending
Development and applications of adjoint models and ensemble techniques	ONR	Errico		Pending
A model for the evaluation of emerging zoonotic pathogens: Rickettsia africae and R.conorii in the Masai Mara	WRAIR		Anyamba	Pending

Biographies

Mr. Thomas J. Albert, Jr. is researcher in the Education Office at GSFC and a former classroom educator in the state of Maryland. Mr. Albert received his B.S. in science at the University of Maryland, and a Maryland Teaching Certificate in 1992. He was active in the classroom teaching Earth science in Howard County from 1992 to 1998, and was nominated for *First-Year Teacher of the Year* in 1992 and for the *Presidential Award for Excellence* in 1997. In the summer of 1995 Mr. Albert was selected and trained as a Teacher Ambassador to NASA. Subsequently, he was invited back for the summers of 1996 - 2001 to develop on-line, standards-based science activities and investigations using the most recent NASA data. Most recently, he was in charge of initiating the development of a state-of-the-art Internet–based access interface for classroom teachers called the *ED Mall*. In 1998 NASA selected Mr. Albert as a *Teacher on Loan* to the Education Office, where he was the lead for Earth science, coordinating and supporting educational initiatives for the GSFC service area. Mr. Albert left the position in the summer of 2000 to co-start the online educational company Quantum Education, focused on using the Internet to teach math and science to students nationwide, and creating Internet-based training modules for business-to-business customers. The business succumbed to the market crash in 2001 and Mr. Albert returned to the classroom in Frederick County, MD for one year. Mr. Albert joined GEST in the summer of 2002 to continue to develop and deliver the *ED Mall* system.

Dr. Assaf Anyamba is an assistant research scientist with GEST/UMBC at GSFC. He received his undergraduate degree from Kenyatta University, Nairobi, Kenya in geography and economics (1989) and a master's degree in geography from Ohio University, Athens (1992) He obtained his Ph.D. (1997) in geography with an emphasis 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, applications of remotely sensed data in drought and famine early warning, agricultural monitoring, and the links between climate and disease outbreaks. Dr. Anyamba currently supports research and development work for the United States Agency for International Development Famine Early Warning System Network project, the United States Department of Agriculture's Foreign Agricultural Service , and the Department of Defense's Global Emerging Infections Systems.

Ms. Kristi R. Arsenault received a B.S. in geography and climatology from Arizona State University in May 1997. While at Arizona State she interned at the NASA Mars Global Surveyor TES Laboratory for two years, working on the interplay between dust storms and the northern polar ice cap of Mars. After graduating, Ms. Arsenault attended The Ohio State University in Columbus, Ohio on a graduate fellowship, pursuing an M.S. in atmospheric sciences, and was offered a teaching assistantship for introductory level meteorology and geography courses, and a research assistantship at the Byrd Polar Research Center. Her graduate work involved investigating the role of air-sea interactions over the North Atlantic Ocean and their effects farther downstream over the Eurasian continent. Ms. Arsenault was awarded a GSFC internship for the summer of 2000 where she applied the catchment-based land surface model to a small catchment site. She began working at GSFC full-time in early January 2001. Her work at GSFC has led to her having received two major grant awards to pursue applications research, involving ongoing collaborative projects in the Hydrological Sciences Branch and partnerships with the U.S. Bureau of Reclamation and EPA.

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 postdoctoral fellow in the Atmospheric Chemistry and Dynamics Branch at GSFC. He joined the Middle Atmospheric Chemistry and Dynamics Branch at the Naval Research Laboratory in Washington, D.C. in 1992, where he led the development of a two-dimensional chemical

transport model, and established 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 25 refereed papers in the fields of gravity wave dynamics and parameterization, and atmospheric transport.

Deborah Belvedere is the program assistant to the Water Cycle Office at GSFC. Her work supports scientific collaboration and coordination for NASA's global water and energy cycle research. Currently she is involved in a NASA Energy and Water Cycle Study, GSFC's Water and Energy Cycle cross-cutting theme, and is about to start work with the GEWEX Americas Prediction Project. She has also participated in field work with the Cold Land Processes Experiment. Ms. Belvedere is a member of the American Geophysical Union and the American Meteorological Society, and has received several awards, including: the Division Peer Award for Support Service (2001); Hydrological Sciences Branch, On-the-Spot Award for Superior Performance (2000); Laboratory for Atmospheres, Outstanding Performance in Administrative Support (1998); and a Code 913 Performance Award (1996).

Mr. Timothy Berkoff received a B.S. in optics from the University of Rochester in 1988. He has more than 15 peer-reviewed publications and 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 grating sensing techniques. This experience also involved designing and implementing new fiber sensing techniques in the field, including the successful demonstration of an interferometric sensor 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 instruments for atmospheric measurements. He designed and modeled receiver optics for the Raman Airborne Spectroscopic Lidar instrument, and has experimentally investigated and successfully 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 the maintenance of existing MPL systems and the design and development of lidars for MPLNET.

Ms. L. Anathea Brooks is assistant director of GEST. She received her B.A. in environmental science/zoology from the University of California, Berkeley in 1978, and her M.S. in sustainable development and conservation biology from the University of Maryland, College Park in 1994. Following doctoral work in French and romance philology at Columbia University, she was appointed to the United Nations' International Fund for Agricultural Development in Rome. She has taught at the Universitá degli Studi di Milano, the University of Maryland, College Park, and at Columbia University, where she was assistant director of the Center for Environmental Research and Conservation for four years. She has published articles, edited books, and translated numerous works on conservation and environmental issues. In addition, she has lobbied Congress for science funding, consulted for the World Bank, and performed fieldwork in Europe, Brazil, and North and Central America. Her current research concerns the environmental causes of *Torreya taxifolia*'s population decline.

Dr. Eric Bucsela is an associate research scientist at GEST. Dr. Bucsela received a B.S. in physics from Emory University in 1983, an M.S. in electrical science from the Department of Electrical Engineering at the University of Michigan in 1986 and a Ph.D. in physics from the University of Michigan in 1994. At Michigan, he conducted research in aeronomy of the dayglow and developed instrumentation for *in situ*

measurements and remote sensing of the atmosphere. He completed a postdoctoral fellowship at the Naval Research Laboratory in 1997. At NRL, he developed models to investigate atomic and molecular excitation processes in the thermosphere. He also participated in the Defense Missile Satellite Program by playing a pivotal role in the calibration of the far-ultraviolet SSULI spectrometer. Additional research and publications have involved studies of thunderstorm electrification processes. Such processes create sprites and other visible emissions above thunderstorms. In addition to his work at NRL, Dr. Bucsela has been active in research at GSFC through affiliations with Raytheon, SSAI and most recently, UMBC. His work at GSFC 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 will be adopted for use with the OMI instrument on board the EOS Aura satellite, as part of an international venture between NASA and the Royal Dutch Meteorological Institute.

Dr. William L. Chameides received his B.A. in 1970 from SUNY (Binghamton), and M.Ph., Ph.D. degrees from Yale University in 1973 and 1974 respectively, with studies on the photochemical theory of tropospheric ozone. After a distinguished academic career, he is currently the Smithgall Chair and Regent's Professor in the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. He is a member of the National Academy of Sciences; in that capacity he has served as a member and as chairs of numerous committees, boards, and panels of the National Research Council. He has broad interdisciplinary interests in Earth System Science, especially the development of integrated physical/chemical/biological/sociological algorithms to study urban, regional, and global change. His specific field of research is atmospheric chemistry. Dr. Chameides is an internationally recognized expert in the study of tropospheric gas-phase and aqueous-phase chemistry, air pollution, global climate cycles and chemical change. His list of publications includes 4 books, over 80 refereed papers, and numerous other papers and reports. His interest is in developing multi-institutional studies and modeling and field experiments, to better understand the role of chemical processes in the Earth's climate.

Dr. Yehui Chang has been an associate research scientist at GEST since 2001. Dr. Chang received a B.S. in physics from East China Normal University in 1982, and a Ph.D. in geophysical fluid dynamics from the Florida State University in 1994. He held a lectureship in physics at the Nanjing College of Economics from 1982 to 1987. From 1994 to 2001 he served as a senior scientist at SAIC, studying climate and its variability and predictability, the variability and predictability of the Madden-Julian Oscillation, and 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. Dr. Chang's publications deal with EOF modeling, diagnostics of climate and the data assimilation system, dynamical seasonal prediction, and the impact of ENSO on extratropical low frequency noise in seasonal forecasts.

Dr. Alexander Chekalyuk received a B.S. in physics from Moscow State University (MSU) in 1977, and a Ph.D. in physics, also from MSU in 1982. Since 2001 he has conducted laboratory research on new technologies for phytoplankton taxonomic analysis at the GSFC Wallops Flight Facility (WFF). He has also perfected an airborne lidar technique for remote monitoring of aquatic photosynthesis (1998-present, WFF), and developed a submersible multispectral camera with laser illumination for small-scale structure studies (1997, Scripps Institution of Oceanography, CA). He developed a 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), a 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), and a 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, from 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 GSFC/WFF in 1998-2001.

Dr. Baode Chen received a B.S. degree in meteorology from Lanzhou University in 1983 and a Ph.D. degree in atmospheric sciences from UCLA in 1998. Prior to joining GEST, he worked for two-and-a-half years at USRA as a visiting scientist. Dr. Chen's research focuses on investigating various tropical motion systems and their interaction by using numerical models. He is currently involved in the NASA-funded large-scale tropical circulation study at the Climate and Radiation Branch at GSFC.

Dr. Jiun-Dar Chern received a B.S. from National Taiwan University in 1984 and a Ph.D. in atmospheric sciences in 1994 from Purdue University, where he developed the Purdue Mesoscale Model (PMM) and applied the model to study lee vortices and winter cyclogenesis over the western United Stated. From 1995 to 2000 he worked as a research associate at Purdue University, developing the Purdue Regional Climate Model and a snowpack and sea-ice model. The model has been applied to study the 1988 U.S. drought, the 1993 Midwestern U.S. flood, and the 1998 flood in Eastern Asia. In 2000 he joined GEST and has worked at the GSFC DAO to improve the physical parameterizations of the fvGCM and the interface between the fvGCM and fvDAS.

Dr. Wookap Choi is a Goddard Visiting Fellow in Earth Sciences for 2002-2003. After receiving his Ph.D. in atmospheric sciences from the University of Washington in 1990 he became a research associate at Scripps Institution of Oceanography and at Lawrence Livermore National Laboratory. He is currently an associate professor in the School of Earth and Environmental Sciences at the Seoul National University. He has been working on various phenomena in the middle atmosphere, using models and data from satellite observations. His particular expertise is in limb-sounding satellite determinations of trace constituents in the stratosphere.

Dr. Jim Coakley received his degrees in physics, with a B.S. from UCLA in 1968, and an M.A. and a Ph.D. from the University of California, Berkeley in 1970 and 1972, respectively. He began work in atmospheric sciences in 1972 as a postdoctoral fellow in the Advanced Study Program at the National Center for Atmospheric Research, and stayed there in various staff scientist positions until moving to Oregon State University in 1988. Dr. Coakley is currently a professor in the College of Oceanic and Atmospheric Sciences at OSU. At NCAR, Dr. Coakley was involved in various aspects of radiative transfer and climate modeling. He coauthored review papers on radiative-convective models and on simple energy balance climate models. He also performed one of the first general circulation model studies of the effects of aerosols on the climate. Among his accomplishments are the development of schemes for identifying cloud layers, and distinguishing between satellite imagery fields of view that are overcast from those that are only partially cloud covered. Dr. Coakley has been a member of various science teams devoted to studying clouds, aerosols, and the Earth's energy budget, including the Earth Radiation Budget Experiment Science Team, the First International Satellite Cloud Climatology Project Regional Experiment Science Team, and the Global Aerosol Climatology Project Science Team. Since 1988 he has been a member of the Clouds and the Earth's Radiant Energy System Science Team. Dr. Coakley has also been associate editor and editor for the *Journal of Geophysical Research*, the *Journal of Climate*, and *Tellus*, and has served as a member of the National Research Council's Committee on Meteorological Analysis, Prediction, and Research. Dr. Coakley currently serves on the American Meteorological Society's Committee on Atmospheric Radiation.

Dr. Peter R. Colarco earned a B.S. in physics and astronomy from the University of Iowa in 1993; an M.S. in physics from Creighton University in 1997; and and an M.S. and Ph.D. in astrophysical, planetary, and atmospheric science from the University of Colorado in 2000 and 2003, respectively. While at Creighton University his research focused on numerical modeling of the laser-induced $^{12}CO_2/^{13}CO_2$ optogalvanic effect in human breath samples, which had application to noninvasive biomedical testing for stomach ulcers. This research was initiated while he was an American Institute of Physics Industrial intern at Alimenterics, Inc., of Morris Plains, New Jersey. At the University of Colorado, his research focused on modeling the emissions, deposition, and optical properties of Saharan dust aerosols. Publications from this work include estimates of the UV absorbing refractive index of Saharan dust particles derived from comparisons of numerical models with field and satellite data, and budget estimates for Saharan dust deposition into the North Atlantic Ocean. While at the University of Colorado he also participated as a flight planner and meteorological support scientist for the NASA Sage 3 Ozone Loss and Validation Experiment, in Kiruna, Sweden, during the winter of 1999-2000), and the Cirrus Regional Study of Tropical Anvils and Cirrus Layers/Florida Area Cirrus Experiment(CRYSTAL/FACE), Key West, FL in July 2002. Dr. Colarco has also taught undergraduate physics laboratory and recitation sections while at the University of Iowa and Creighton University, and basic atmospheric science laboratory sessions while at the University of Colorado. Dr. Colarco has been at GSFC and GEST since September 2002, where his research has focused on studying pollutant transport from forest fires, improving biomass burning emission estimates in global chemical transport models, and studying aerosol in the CRYSTAL/FACE region.

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. Jiarui Dong received a B.S. in meteorology from Beijing Institute of Meteorology in 1989, an M.S. in computational mathmatics in 1992 from the Chinese Academy of Sciences (CAS), and a Ph.D. in atmospheric sciences in 1997 (also from CAS), where he developed a coupled model for simulating drought and regional flood disasters. He earned another doctorate 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, 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 GEST at the GSFC Hydrological Science Branch in 2002, working on land data assimilation for NASA's Seasonal-to-Interannual Prediction Project.

Dr. Oleg Dubovik received a B.S. and M.S. in 1985 in physics/optics from the Belarus State University (Minsk, Belarus). He received a Ph.D. in physics and mathematics from the Institute of Physics (Minsk, Belarus) in 1992. Dr. Dubovik began his research experience at the Institute of Physics (Minsk, Belarus) in 1985, employed first as a member of the assistant research staff and later (after receiving Ph.D.) as a research scientist. From 1995 to 1997 Dr. Dubovik worked at the National Institute for Environmental Studies (Tsukuba, Japan) as visiting scientist supporting the ILAS/ADEOS project. From April 1997 to the present, Dr. Dubovik has worked at GSFC as a contractor. 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 deriving aerosol optical properties from multispectral solar transmission measurements and multiangular sky radiance measurements. At present, Dr. Dubovik is in charge of developing inversion retrieval algorithms for the AERONET project. Dr.

Dubovik has authored or co-authored over 50 papers that have been published in refereed scientific journals.

Dr. Joseph L. Eastman received a B.A. in physics from the University of Minnesota. Dr. Walter A. Lyons then employed Dr. Eastman in 1987, where he aided in the design of a ground conductivity model for use in simulating a lightning detection network. He also performed a considerable amount of 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. Under the guidance of Dr. Roger A. Pielke, he earned his Masters degree in 1994, and his Ph.D. in the Graduate Degree Program in Ecology in 1999. His most recent work concentrates on the assessment of climate change with special examination of the relative contributions of CO_2 and human-induced land change. In his postdoctoral appointment, he was in charge of providing direction for the Long-Term Ecological Research national modeling efforts on massively parallel platforms. This included coupling meteorological models to synchronous and asynchronous ecosystem models. In his last research associate position under Dr. Roger Pielke, he continued regional climate research using coupled atmospheric and ecological models. Dr. Eastman is currently investigating the effects of land-surface interactions on hurricanes, and the impact of rivers on regional climate.

Mr. Thomas F. Eck received a B.S. in meteorology from Rutgers University in 1977, and an M.S. in meteorology from the University of Maryland, College Park in 1982, where his major interests were in micrometeorology and atmospheric radiation. In 1981 he began work at GSFC and has continued working there for more than 20 years. During his career, he has been involved in algorithm development and data analysis for the Nimbus-7 cloud climatology project, and was active in instrument calibration, field instrument deployment, and data analysis for the PARABOLA instrument project 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 project. He has authored and co-authored over 60 refereed papers; the most recent concentrate 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. Tarek El-Ghazawi is a professor in the Electrical and Computer Engineering Department at the George Washington University. He received his Ph.D. in electrical and computer engineering from New Mexico State University in 1988. His research interests are in high-performance computing, reconfigurable computing, performance evaluation, remote sensing and computer vision. He has over 100 research publications, based on research work that has been supported by NASA, DoD, NSF, NSA and industry. El-Ghazawi has also served on the faculty of the George Mason University and as a visiting scientist at CESDIS and GEST centers at GSFC and RIACS at the NASA Ames Research Center. He has also served in many editorial capacities and has had conference organization duties. He is a senior member of the IEEE and a member of the ACM and the Phi Kappa Phi honor society.

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. After completing his degree, Dr. Errico joined the Advanced Study Program at NCAR as a postdoctoral student, 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. During his tenure at NCAR, Dr. Errico took sabbaticals at the Naval Research Laboratory in Monterey from March 1989 to April 1990, and at the ECMWF for seven months in 1996. He left NCAR to join GEST and work at GSFC's Data Assimilation Office in July 2002. Since 1992, he has been chief organizer of eight international workshops, including four of the five International Workshops on the Application of Adjoint Models in Dynamic Meteorology and four 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. He developed NCAR's Mesoscale Data Assimilation System, which is currently the only weather prediction model with a complete and useful adjoint of all its physics.

Mr. Hui Feng joined GEST in November 2002 as a research associate through Hampton University. He received a B.S. in radio physics from East China Normal University in 1983, and an M.S. in oceanography from the University of New Hampshire (UNH) in 1996. Prior to joining GEST, he spent several years as a software development engineer for an industrial company. Mr. Feng has experience in applied mathematics, oceanography, remote sensing applications, and software development. His specific research interest is in the area of the inverse algorithms of remotely-sensed signals to recover ocean geophysical information. He is currently working towards a Ph.D. at UNH, where his research is focused on inversion algorithm for ocean color spectra to retrieve in-water parameters. His work in GEST is focused on improving the altimeter sea state bias correction algorithm.

Dr. Rosana Nieto Ferreira received a B.S. in meteorology from the University of São Paulo, Brazil in 1985, and a M.S. in meteorology from the University of São Paulo, Brazil, in 1988. Dr. Nieto Ferreira 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 Dr. Ferreira was a USRA Visiting Scientist at GSFC, working with the NSIPP group on the application of a variable resolution version of the NSIPP-1 GCM to the study of seasonal to interannual variability of the land-atmosphere system in the Amazon Basin. Since October 2000 Dr. Ferreira has been a member of the research faculty at GEST, working with the NSIPP group on studies of the variability and predictability of South American circulation and convection organization on synoptic-to-interannual timescales

Dr. Santiago Gassó—originally from Argentina—obtained a master's 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 United States where he completed Ph.D. dissertation 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 observations. Currently, he is working in a Navy-sponsored project to simulate global visibility conditions with an aerosol transport model. In addition, he is actively participating within the SMART group at GSFC in the design and development of a humidity-controlled nephelometry system.

Dr. Charles K. Gatebe received a B.Sc. (meteorology, mathematics, and physics) and M.Sc. (meteorology) degrees from the University of Nairobi, Kenya, in 1990 and 1994, respectively, and a 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 GSFC in 1999 as a resident research associate of USRA. He is currently an atmospheric scientist in GEST, 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-coordinated research project on air pollution using nuclear-related analytical techniques, and in 1994-1995 was a member of the United Nations Environmental Program/World Health Organization, Global Environmental Monitoring System/Air team of experts. Dr. Gatebe has been involved with modification of NASA's Cloud Absorption Radiometer to provide a modern data acquisition system and UV optical channels suitable for remote sensing of aerosol. He has participated in several fields campaigns, NASA's Cloud Absorption Radiometer. Currently, he is interested in remote sensing of aerosols and bi-directional reflectance distribution 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 during the Fifth International Geosphere Biosphere Programme-Scientific Advisory Committee meeting in Nairobi, Kenya, 1998, and is the winner of the 2000 World Meteorological Organization Young Scientist Award.

Dr. Paul Ginoux has been an assistant research scientist at GEST since January 2002. He completed his Ph.D. in 1997 at the Polytechnic School of the University of Brussels, based on work developing an original "telescopic" chemical transport model at NCAR. Following this, he started at GSFC by developing algorithms to include dust and sea-salt aerosols in the GOCART model. His development of a global dust source function was used for present and future scenarios by the IPCC 2001, and is now used worldwide by most dust transport models. Working in a satellite-data environment at GSFC, he developed fruitful collaborations with scientists working on satellite retrievals and is now a member of the TOMS science team. Dr. Ginoux particularly enjoys the constant scientific challenge of combining model results with observations.

Mr. Jonathan C. Gottschalck received both his B.S. and M.S. in meteorology from 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 doubling CO_2 levels 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. After leaving Pennsylvania State University, Mr. Gottschalck worked as a research associate at the University of Miami from 1997-2001, where he worked in a variety of research areas, including 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. He also investigated the relationship between the Madden Julian Oscillation (MJO) and El Niño. Also while at the University of Miami, he taught undergraduate weather forecasting classes and acted as the university meteorologist for all public and press inquires. Mr. Gottschalck is currently a research associate working at GSFC in the Hydrological Sciences Branch, where his research mainly focuses on satellite precipitation and vegetation datasets.

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. He joined GEST in 2002 after a postdoctoral position with the University of Connecticut. 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 TRMM project in progress at the Mesoscale Atmospheric Processes Branch of GSFC. His work is focused on the refinement and extension of algorithms for rain estimation from TRMM observations. Specifically, he investigates the combined use of active and passive microwave observations for rainfall estimation by employing radar and radiative transfer models in a variational estimation framework.

Dr. Guojun Gu received a B.S. in atmospheric physics from Nanjing University in 1986, and a Ph.D. in meteorology and physical oceanography from the University of Miami in 2001. In his doctoral research, he explored the relationship between tropical synoptic-scale waves and the Inter-Tropical Convergence Zone (ITCZ). From 2001 to 2002 he was a postdoctoral research scientist at Columbia University, where he conducted research in tropical precipitation and variability by means of the NASA Goddard Cloud Ensemble Model. In March 2002 Dr. Gu joined GEST as an assistant research scientist. His primary research interest is in the field of tropical meteorology, which includes tropical waves, the ITCZ, tropical precipitation and variability, and air-sea interaction. He is currently involved in the Tropical Rainfall Measuring Mission at the Mesoscale Atmospheric Processes Branch at GSFC.

Dr. Bruce Guenther erceived his Ph.D. from the University Pittsburgh in 1974. He was a member research staff at GSFC for over 26 years, with service as a Systems Engineering Fellow. He has also worked for Lockheed Martin Missiles Space Operations, served as the NASA Project Scientist on the EOS AM Project, and was the EOS Project Scientist for Calibration and Data Product Validation. He organized and developed the MODIS Characterization Support Team, and was responsible for the first publicly available EOS data sets. Dr. Guenther was also leader for the NPOESS Preparatory Project sensor calibration and data product validation effort. He has an extensive list of peer-reviewed publications and scientific meeting presentations, and was convener of the Workshop for Calibration and Validation of Global Change Measurements: May 10-12, 1995 for CEOS and GCOS. Dr. Guenther received the NASA Medal for Exceptional Service in 2001. His current research interests are in optical sensor characterization and calibration for the Earth sciences community, with particular experience in imaging spectroradiometer sensors, such as MODIS and VIIRS.

Dr. Mohan L. Gupta received a Ph.D. in Earth system science from the University of California, Irvine in 1996. 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 UCLA to work on testing and validating atmospheric chemistry components of the Earth System Model. 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 surface deposition issues. Besides atmospheric trace gas-related issues, atmospheric isotopes, and biogeochemistry, his current major research interests also involve problems in the global dimensions of regional and urban air quality, surface deposition, and atmospheric toxic gases.

Dr. Harshvardhan is professor and head of Earth and Atmospheric Sciences at Purdue University. He received his Ph.D. from SUNY, Stony Brook in 1976, and was an NRC post-doctoral fellow at GSFC from 1977-78. From 1978 to 1988 he was a university fellow at GSFC, affiliated with the University of Maryland, College Park. His research interests are in radiative modeling of clouds and aerosols, including the radiation parameterization of their properties in climate models. He has been an associate editor of the *Journal of the Atmospheric Sciences* and editor of the *Journal of Applied Meteorology*.

Dr. Hiroo Hayashi completed his education at Hokkaido University in Sapporo, Japan. His doctorate was awarded in 2001 for a dissertation on 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 descent in the polar vortices using trace-gas data from the ILAS satellite instrument. Dr. Hayashi joined GEST in April 2002 and has been working on the assimilation of tropospheric ozone using satellite ozone data at the GSFC Data Assimilation Office.

Dr. Susan Hoban received her Ph. D. in astronomy from the University of Maryland in 1989. She conducted research in cometary science at GSFC, first as a National Research Council Fellow, then as part of the 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 GSFC. 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 an associate research scientist in GEST, spokesperson for the Information Science and Technology Faculty group, and PI on the NSF-funded *Virstual Telescopes in Education* activity. Her interests include scientific information systems, digital library technologies and information technologies for science and mathematics education.

Dr. N. Christina Hsu received a B.S. from the National Taiwan University in 1984 and a Ph.D. in atmospheric sciences in 1991 from the Georgia Institute of Technology, where her research interest was in GCM modeling of ozone photochemistry and transport processes in the stratosphere. In 1994 Dr. Hsu moved to Maryland and began her studies in the area of remote sensing of tropospheric aerosols. She has published over 20 refereed papers, the most recent focusing on the retrieval of aerosol properties from satellite data and the determination of the radiative forcing due to tropospheric aerosols. Dr. Hsu also recently participated in the ACE-Asia campaign during April-May 2001 and provided near-real-time satellite retrieval of aerosols to help aircraft fight planning. She is currently an associate research scientist at UMBC, with work performed at GSFC.

Dr. Gail Skofronick Jackson received a B.S. degree from Florida State University in 1986, a M.S. degree in 1988, and Ph.D. in 1997 from Georgia Institute of Technology, all in electrical engineering. Her doctoral research was in developing methods to estimate rain rate using passive microwave remote sensing techniques. From 1988 to 1991 she worked at BellSouth Services. In 1997 she started working at GSFC as a contractor for the Universities Space Research Association, and in 2000 became a member of the GEST faculty. During her career, she has focused on rain rate and integrated ice content retrievals, cost-benefit tradeoff issues associated with instrument development/science objectives, and hydrometeor profile retrievals using both active radar and wideband brightness temperatures. Her current research efforts focus on the use of high frequencies to provide information on upper altitude ice structures and to detect and estimate snowfall. She won the GSFC Hydrospheric Processes Division Award for Outstanding Research Associate in 2002. She currently serves as the GEST Clouds Research Group leader and the Fourth Convection and Moisture Experiment Microphysical Properties Group co-leader.

Dr. S. Daniel Jacob received his Ph.D. in meteorology and physical oceanography from the University of Miami in 2000, having earlier obtained an M.S. in ocean engineering and a B.E. in civil engineering from India. His current research interests in the derivation of sea surface salinities stems from work that he had carried out on heat and mass transfers in the oceanic mixed layer in and around storm circulations. More recent interest focuses on the global hydrologic cycle, and climatic effects of salinity variations.

Ms. Urszula Jambor received her B.Sc. in atmospheric and oceanic sciences from McGill University, Canada in 1997, and her M.S. in meteorology from Pennsylvania State University in 2000. Her graduate work involved the evaluation of ice clouds produced by parameterizations in numerical prediction models with comparisons to corresponding remote-sensed measurements. This research developed her interest in applications of 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 project.

Dr. Daniel E. Johnson received a B.S. in mechanical engineering from the University of Minnesota, Minneapolis in 1988, an 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 the development and implementation of a detailed ice-microphysical package for cloud-resolving models in the study of winter storms. Dr. Johnson was awarded two fellowships with the NASA Graduate Student Researchers Program in 1994, and completed his Ph.D. research and dissertation while at GSFC, over the following two years. In 1996, he joined the Laboratory of Atmospheres at GSFC as a post-doctoral fellow, and began conducting research on deep tropical cloud systems using the Goddard Cumulus Ensemble (GCE) model. In 2001 Dr. Johnson joined GEST at UMBC, and is currently working on developing the GCE model, and conducting simulations of deep convective cloud systems in both tropical and mid-latitude 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. Richard Kelly received his B.Sc. (Hons.) from the University of Manchester, UK in 1988, and 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 has been a lecturer in physical geography at Birkbeck College, University of London, UK, where his major research activities have involved remote sensing of snow and ice using active and passive microwave 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 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, and the American Geophysical Union. He participated at the inception of the Snow and Ice Special Interest group within EARSeL.

Dr. Nickolay A. Krotkov received a B.S. from Moscow Institute of Physics and Technology in physics in 1983, an M.S. (with honors) in remote sensing in 1985, and a Ph.D. in oceanography (physics and mathematics) in 1990 from the P. P.Shirshov Institute of Oceanology at the Russian Academy of Sciences, where his major research was performed using polarization properties of light in oceanic remote sensing. Since 1993 he worked in close collaboration with TOMS scientists at NASA to study volcanic clouds, surface and underwater ultraviolet radiation, and aerosols. Dr. Krotkov has over 15 years of experience in UV radiative transfer modeling, satellite- and ground-based UV data analysis. He has published over 20 refereed papers, the most recent of which concentrates on the ultraviolet remote sensing of volcanic emissions and satellite estimation of the surface ultraviolet irradiance. He is currently employed as a senior research scientist by GEST.

Dr. Sujay V. Kumar received a B.Tech in civil engineering from the Indian Institue of Technology, Bombay in 1996, and an M.S. in civil engineering from North Carolina State University, Raleigh, in 1998. He continued at North Carolina State University for a Ph.D. in civil engineering, with emphasis on computer-aided, high-performance computing applications. He finished his Ph.D. degree in January 2002. He is currently a research associate at GEST.

Dr. Prasun K. Kundu received a B.S. (with honors) in physics from Calcutta University, India in 1974, and an M.S. in physics from the Indian Institute of Technology, Kharagpur, India in 1976. He joined the High Energy Physics Group at the University of Rochester in New York where, in 1981, he earned a Ph.D. in theoretical physics for his work on new class of exact and asymptotic solutions of the Einstein field equations for general relativity. From 1980-1982 he was a postdoctoral research associate at the Enrico Fermi Institute at the University of Chicago, and subsequently was an instructor at the University of Utah, Salt Lake City from during 1982-1985. His postdoctoral work involved mathematical problems of general relativity and quantum cosmology. In 1985 Dr. Kundo 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 at GSFC on various problems of rainfall statistics related to 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 B.S. in atmospheric science in 1983 from National Taiwan University, Taiwan, Republic of China, his M.S. in meteorology in 1987 from the South Dakota School of Mines and Technology (SDSM&T), 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 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 the University of Alabama in Huntsville to take a research scientist position. 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, and became an associate research scientist with Caelum Research Corporation in GEST in January 2002, working to create a more realistic physical radiative transfer model for the Global Precipitation Measurement mission.

Dr. Redgie S. Lancaster received a B.S. in physics from Bethel College in 1990 and a Ph.D. in Astronomy in 1997 from Boston University, where his major research interest was in atmospheric remote sensing. During 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 a research meteorologist onsite at GSFC, where he now conducts research in the field of cloud remote sensing.

Dr. David J. Lary was invited to come to GEST at GSFC by Drs. Ricky Rood and Franco Einaudi as the first Goddard Distinguished Visiting Fellow in Earth Sciences.
He is also a Royal Society University Research Fellow at Cambridge University (one of the highest honours a young scientist can be given in the U.K.), and has been an Alon Fellow (one of the highest honours a young scientist can be given in Israel) where he was also a senior lecturer. He graduated from Kings College London (England) in 1987 with a double first class honours B.Sc. degree in physics and chemistry; while there he was also awarded the Sambrooke Exhibition Prize in Natural Science. He next graduated from Churchill College Cambridge (England) in 1991 with a Ph.D. in atmospheric photochemistry. His doctoral research involved adding a detailed chemical scheme to a weather forecasting model, the first time this had been done. He remained at Cambridge for the next ten years, where he was personally invited by the chief scientific advisor to the prime minister to join the Unilever Center for Chemical Informatics in the Department of Chemistry in Cambridge University.

Dr. Daniel Laughlin received the first M.A. in ancient history from the University of Newcastle upon Tyne in 1986, and a Ph.D. in education from American University in 2001. His focus area was the implementation of information technology in education, doing 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. Dr. Laughlin is actively supporting the National Academy of Sciences' efforts to encourage the application scientific research methods to the study of education. His interests include information technology management, cognitive science, digital library technologies, and educational technologies.

Dr. Lihua Li received his Ph.D. in electrical and computer engineering from the University of Massachusetts at Amherst in 2000. Before joining GEST, he was a research engineer in the Microwave Remote Sensing Laboratory, University of Massachusetts. His research interests are microwave and millimeter-wave remote sensor development, data analysis, and cloud microphysical properties retrieval using cloud radar measurements. He joined GEST in October, 2001. His current project is the NASA Cloud Radar System, where he has made significant contributions to instrument development, calibration, data processing, and data analysis.

Dr. Shuhua Li received a B.S. from Nanjing Institute of Meteorology, China in 1984, and an M.S. from Macquarie 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 the GEST in April 2001, and has worked at the GSFC Data Assimilation Office to evaluate the finite-volume Data Assimilation System towards 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 in 1991. She worked as an associate researcher in the Chinese Academy of Meteorological Sciences for two years after receiving 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. Early in her career, Dr. Li pioneered research on direct radiative effects of anthropogenic aerosols in regional climate change. She was also a member of the China-Japan East Asia monsoon study project, and participated in surface turbulence observations on the Tibetan Plateau from 1994 to 1996. Her doctoral dissertation studied the evaporation in stratiform rain region using both 1-D and 2-D simulations. Dr. Li is currently involved in the mesoscale numerical simulation using the Goddard Cumulus Ensemble model, and improvement of both bulk and bin spectra microphysical schemes in the numerical model.

Dr. Liang Liao received a B.S. in radio physics and an M.S. 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 radio wave propagation, electric field scattering, and atmospheric radar and radiometer remote sensing of clouds and precipitation. Currently, he is a senior scientist at GEST with the 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 the National Taiwan University (NTU), Taiwan in 1990, and her M.S. and Ph.D. in meteorology from Pennsylvania State University in 1993 and 1997, respectively. Before joining GEST Center, she spent eight months at the NTU working as a postdoctoral research scientist, followed by two years at the Universities Space Research Association as a visiting scientist. Dr. Lin's expertise and research interests are numerical modeling of clouds, cloud physics, and radiative transfer. She participates in the Global Energy and Water Cycle Experiment Cloud Systems Studies (GCSS) Working Group on Cirrus Cloud Systems (WG2). She, together with Dr. David O'C Starr of 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 lead research efforts to implement the next-generation cloud scheme in the Data Assimilation Office model. 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. Dan Lubin is a GEST Visiting Senior Scientist, working at GEST from October 2002 through October 2003. He is also a research physicist and senior lecturer at the Scripps Institution of Oceanography. Dr. Lubin received a B.A. in physics with departmental honors from Northwestern University in 1986, an M.S. in geophysical sciences and astronomy, and astrophysics from the University of Chicago (1987 and 1988, respectively), and a Ph.D. in geophysical sciences from the University of Chicago in 1989. For his Ph.D. research, Dr. Lubin made the first spectral radiometric measurements of enhanced solar ultraviolet radiation under the Antarctic ozone "hole," from Palmer Station on the Antarctic Peninsula. He continues to be involved with polar research in the areas of atmospheric physics and photobiology. In addition to UV spectroradiometry, Dr. Lubin has developed Fourier Transform Infrared (FTIR) instrumentation for research on the longwave radiative properties of clouds and trace gases. He is a veteran of three Antarctic field campaigns and participated in the Surface Heat Budget of the Arctic (SHEBA) experiment and the 1994 Arctic Ocean Section, a joint U.S./Canada icebreaker crossing of the Arctic Ocean via the North Pole. Since 1994 Dr. Lubin has been the principal investigator for the Scripps Institution of Oceanography's Arctic and Antarctic Research Center (AARC), an NSF-supported satellite remote sensing facility that archives telemetry from the satellite tracking equipment at McMurdo and Palmer Stations in Antarctica and the U.S. Coast Guard icebreakers; he also makes these data and related geophysical products available to the international research community.

Dr. Alexei I. Lyapustin received B.S. and M.S degrees in physics from Moscow State University in 1987, and a Ph.D. in aerospace remote sensing from the Space Research Institute, Moscow, Russia in 1991. From 1993-1996 he was a principal investigator on contracts with Russian Space Agency, processing remote sensing data from the Mir space station. Before joining GEST in February 2002, Dr. Lyapustin was a research fellow for two years in the USRA, and an assistant research scientist in JCET at UMBC. Dr. Lyapustin actively works on 3D radiative transfer over anisotropic nonhomogeneous surfaces, developing the method of spherical harmonics. At present, he develops applications for a new theory for generic aerosol retrieval and atmospheric correction for the Landsat ETM+, EOS MODIS and MISR, and the future NPOESS VIIRS instrument. In the past two years, A. Lyapustin has been serving as the NASA algorithm adviser on the VIIRS Operational Algorithm Team.

Dr. Cheng-Hsuan Lyu received a Ph.D. in astrophysics from the Catholic University of America in 1993. He studied physical conditions in the interstellar medium of diffuse molecular clouds using the Space Telescope and Imaging Spectrograph and the Goddard High Resolution Spectrograph aboard the Hubble Space Telescope. He studied physical conditions of Venus' atmosphere using Magellan data. Dr. Lyu has been supporting instrument performance and calibration/validation studies for the TRMM/VIRS and TMI. Currently, he also supports the calibration and product validation plan for the National Polar-orbiting Operational Environmental Satellite System Preparatory Project. He holds a senior scientist/engineer staff position at Science Systems and Applications, Inc.

Dr. Sarith Mahanama received a B.Sc. in engineering 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 atmosheric general circulation models generated meteorological forcings. In 2000 he joined USRA to work at the Hydrological Sciences Branch at GSFC, and joined GEST later that year.

Dr. Ashwin Mahesh received a B.Sc. 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. In late 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 2002-2003, he developed the first climatology of blowing snow in the Antarctic plateau.

Dr. Jesse Meng received a B.S. in atmospheric sciences from National Taiwan University, Taipei, Taiwan, in 1991, and an 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 GEST in March 2001 as a research associate, spending half of his time at GSFC in the Hydrologic Sciences Branch (Code 974), and half at NOAA/NCEP/EMC, working on the NASA/NOAA joint Global Land Data Assimilation System (GLDAS). His primary duty in GLDAS is to generate near-real-time global land surface shortwave and longwave radiation fields, based on satellite observations to support land surface modeling, and to evaluate the consequent changes in land surface states in response to variations in radiation forcing.

Dr. Leslie H. Meredith received his Ph.D. from the State University of Iowa (1954) after performing cosmic ray rocket flights in the Arctic, and a year at Princeton working in nuclear fusion development. He then headed the NRL Rocket Sonde Branch Meteor and Aurora Section and continued his rocket research at White Sands and in the Arctic. He joined NASA at its inception becoming head of GSFC's Space Science Division in 1958. At GSFC he subsequently held a number of positions, including heading the Applications Directorate, Assistant Director, and Associate Director. Also, he was elected General Secretary of AGU, spent a year at ONR/London, conceived and "sold" to NASA the International Ultraviolet Explorer mission, represented GSFC on intercenter activities (*e.g.*, the Space Transportation System, the International Space Station, and the Hubble Space Telescope), was project scientist on several international space missions, and received NASA's Service, Leadership, and Scientific Achievement medals and a Presidential Citation. In 1987 he joined AGU as group director for their meetings and Congressional advocacy. In 1993 he became the executive secretary of the USGCRP's Data and Information Working Group.

Dr. Ken Minschwaner is a Goddard Visiting Fellow in Earth Sciences for 2002-2003. He received his B.S. and M.S. degrees in physics at Florida Atlantic University in 1984 and 1986, respectively, and his Ph.D. in earth and planetary sciences from Harvard in 1992. Dr. Minschwaner spent two years at the National Center for Atmospheric Research as a postdoctoral scientist in the Advanced Study Program, and joined the faculty of the Department of Physics at New Mexico Institute of Mining and Technology in 1994. He is currently an Associate Professor of Physics at New Mexico Tech and will resume his duties as department chairman in Fall 2003. Dr. Minschwaner's experience and research interests include experimental physics, analysis of atmospheric data, and numerical modeling. He has designed instruments and methods for measurements of atmospheric hydroxyl, surface ultraviolet radiation, and column ozone. He has analyzed data for scientific investigations from a number of instruments and platforms, including ERBE, TOMS, and UARS, and has developed line-by-codes for both infrared and ultraviolet applications.

Mr. Darius Mitchell received a B.A. in geology from Williams College in 2001. He is conducting research on ICESat altimetry data and data modeling for regions of Greenland and Alaska, and continuing MOLA data processing and analysis.

Dr. Ken-ichi Mizoguchi received an M.S. in oceanography from Kyushu University, Japan, in 1994; an 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 in 2002 and has been a GEST research associate since 2003.

Dr. Wenge Ni-Meister received her B.S. in meteorology from China, an M.S. in micrometeorology from the University of Connecticut, and a Ph.D. in remote sensing and surface hydrology from 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. She also works on another project to study the effects of sub-grid variability of snow cover in vegetated regions on land-atmosphere interactions.

Dr. Peter M. Norris received a B.S. and M.S. from the University of Auckland, New Zealand in 1986 and 1989, respectively, 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 he 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 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 GEST as an assistant research scientist, working at the Data Assimilation Office on cloud modeling and assimilation. During his career, Dr. Norris designed and conducted the first fully-Lagrangian large-eddy simulations of the cloud-topped marine boundary layer. He also participated in numerous atmospheric field experiments, including the FIRE Cirrus II, Kansas, 1991; FIRE ASTEX, Azores, 1992; TOGA-COARE, Solomon Islands, 1993; and CRYSTAL-FACE, Florida, 2002, taking roles in data collection, aircraft flight direction, and data analysis.

Dr. Mark A. Olsen received a B.S. in physics from the University of Northern Iowa in 1993, and a Ph.D. in physics from Iowa State University in 2000. His doctoral research examined near-tropopause dynamics and structure of baroclinic systems from total column ozone data and mesoscale model analyses. From 2000 to 2002 he held a National Research Council postdoctoral fellowship at GSFC, where his work concentrated on midlatitude stratosphere-troposphere exchange of ozone and mass. Dr. Olsen became a research associate at GEST in December 2002.

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 GSFC 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 his key achievements was to participate in the development of the PARAMESH software package. PARAMESH was developed to allow a user to more easily add dynamic adaptive mesh refinement to existing applications and to 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. 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 that use PARAMESH.

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. In 1988 she was a visiting scientist at the Institute for Solar Physics at Freiburg, Germany. She was appointed as a research associate at the University of Colorado at Boulder in 1989. She was a staff member of the 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, initially on a half-time position; she joined GEST full-time in December 2001. Dr. Pap conducts research on solar irradiance variations and their effect on the Earth's atmosphere and climate. She is using ground- and space-based images for modeling irradiance variations. She is a NASA-funded co-investigator on the ESA/NASA SOHO/VIRGO and MDI experiments, guest investigator of 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, C.N.R.S, (Paris, France), PMOD/WRC (Davos, Switzerland), and the Heliospheric Observatory (Debrecen, Hungary). Dr. Pap has organized several international meetings on solar irradiance variations, she was head of the Solar Electromagnetic Radiation Study for Solar Cycle 22 (SOLERS22) international research program operated under the auspices of STEP/SCOSTE. She is currently leading Working Group 1 “Solar Energy Flux Study: From The Interior To The Outer Layer” of the “International Solar Cycle Studies” international research project within SCOSTEP. She served as panel leader on Sun-Climate Connection during the World Public Affairs meeting in April 2000, in Boulder, CO. She is a full member of the International Astronomical Union, the Solar Physics Division of the American Astronomical Society, the American Geophysical Union, and a founding member of the European Astronomical Society.

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 dissertation examined aspects of the radiation balance and trace-gas transport in the middle atmosphere using data from the NIMBUS-7 LIMS instrument. Following a one-year position as a research fellow at the University of Oxford, Dr. Pawson moved to the Free University of Berlin in 1988. In both positions, he worked on developing middle atmosphere-climate models. In Berlin he became a junior faculty member in 1991, performing research into the middle atmosphere and climate, and also taught courses. He was awarded the Habilitation in 1997. Later that year he took a visiting scientist position with USRA, based in the Atmospheric Chemistry and Dynamics Branch at GSFC. In 1998 he joined the Data Assimilation Office (DAO). He was appointed as a senior research scientist at GEST in December 2000, and remains in the DAO where he leads the efforts for the stratosphere and for trace constituents. He has published over 40 refereed journal articles, leads an international model validation program, and has served on numerous national and international committees. He is presently editor of the *Journal of Geophysical Research – Atmospheres*.

Dr. Zhaoxia Pu received a Ph.D. in atmospheric sciences in 1997 from Lanzhou University, completing her research at the National Centers for Environmental Prediction (NCEP) /NOAA, Camp Springs, Maryland during 1993-1996. She continued her research at NCEP as a UCAR/NCEP postdoctoral fellow in 1997-1998. During her five years at NCEP, Dr. Pu joined several research efforts to improve the NCEP global data assimilation system. She also made significant contribution to developing the NCEP weather-targeting 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, emphasizing application of data assimilation in mesoscale studies of tropical cyclone and mesoscale convective systems. Dr. Pu has published over ten refereed papers in the leading professional journal. 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 Atmospheres, at 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. Prior to joining GEST he worked for four years at CESDIS on a subcontract with the Department of Computer Science and Electrical Engineering at 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. His research interests include developing algorithms for scientific computation, parallel and distributed computing, computer architectures, and computer networks. Dr. Ranawake is a member of the IEEE.

Dr. Miodrag Rancic received a Ph.D. in meteorology in 1988 from the University of Belgrade, Yugoslavia, where worked as a research and teaching assistant, and as an assistant professor beginning in 1988. In 1989 Dr. Rančić joined the Center for Analysis and Prediction of Storms at The University of Oklahoma, as a postdoctoral faculty. Dr. Rančić 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. His major research interest is in developing 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. Rančić initiated and contributed to the development of a nonhydrostatic version of the U.S. Weather Service's major regional model. He 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 in global atmospheric models. He has published or presented over 30 papers in refereed professional journals or 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 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 at the 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 explosively developing baroclinic cyclones, tropical cyclones, and extratropical sub-synoptic scale cyclones to different data types and different data assimilation procedures. In December 2002 Dr. Reale received the Oustanding Performance Award from the Data Assimilation Office in the Laboratory of Atmospheres at GSFC.

Dr. Rolf H. Reichle received a B.S. in mathematics (1992) from the University of Heidelberg, Germany, an M.A., and an M.S. in physics in 1996, and Ph.D. in environmental engineering in 2000 from the Massachusetts Institute of Technology (MIT). His doctoral dissertation was 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 GEST as a member of the research faculty. His main research interest is the seasonal prediction of climate variability in support of NASA's Seasonal-to-

Interannual Prediction Project, with his experience in land data assimilation. Dr. Reichle has published papers on land data assimilation and groundwater contaminant transport.

Dr. Jérôme C. Riédi received a B.S. in physics and a M.S. from the University of Lille, France, in 1997 and 1998, respectively. In 2001 he received a Ph.D. in atmospheric sciences, also from University of Lille, and came to GSFC, where he held a one-year research associate position at GEST. His research interests focus on the remote sensing of cloud properties using passive measurements from satellite and airborne instruments in the visible and infrared region of the spectrum. His doctoral research included the use of multi-angle and polarization measurements from POLDER/ADEOS for determination of cloud microphysical properties. He is currently involved in the POLDER project for his development of a cloud phase determination algorithm, in the MODIS and MODIS Airborne Simulator (MAS) cloud thermodynamic phase retrieval algorithms, and quality assessment of the cloud optical and microphysical retrieval products from both instruments.

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 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 Météorologiques in Toulouse. He took 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 GSFC as a USRA visiting fellow. He designed and led the development of a three-dimensional ozone assimilation system, while carrying out research in the area of state-dependent covariance modeling. In June 1999 he took a staff position at EUMETSAT in Darmstadt, with responsibility for developing user requirements for future space-based observing systems. In August 2000 he returned to the DAO to lead the development of its analysis system. 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; in 1969 she was awarded a Ph.D. in physical chemistry from the University of Minnesota. 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 GSFC 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 and dynamical processes in the stratospheric polar vortex, the radiative effects of aerosols, and the effects of increasing greenhouse gases on stratospheric trace species.

Mr. Joel Sachs received a master’s degree in mathematics from Syracuse University. He has worked on a number of data mining projects, both for scientific and e-commerce data, and accomplished the first successful application of data mining to e-commerce server logs at IBM/France in 1997. His projects at GSFC have involved data mining, content-based retrieval, and environmental information systems. His current research interest is science on the semantic web.

Dr. Susan E. H. Sakimoto received a B.A. in geology from Whitman College in 1989, an M.A. in earth and planetary sciences from the Johns Hopkins University (JHU) in 1991, and a Ph.D. in earth and planetary sciences (geophysics), also from JHU, in 1995. Her research career has 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 and includes extensive work with Mars Orbiter Laser Altimeter (MOLA) topography in colaboration 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), a USRA Visiting Scientist (1997-2000), and is currently an associate research scientist and group leader for the Land Surfaces and Hydrology Group with 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 Masters 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 co-chaired 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 theJet Propulsion Labs as a research engineer/scientist, involved in NASA's Planetary Exploration Program. He also currently holds the position of interim director of the International GEWEX Project Office located at GEST. His most recent accolade has been as the recipient of NASA Distinguished Service Medal, awarded after he retired from GSFC last year

Dr. C. Adam Schlosser is presently an associate research scientist at GEST, and is the scientific coordinator for the GEST/GSFC NASA Global Water and Energy Cycle support office. Dr. Schlosser received a B.S. in physics from the University of Massachusetts, Amherst in 1989. After spending a year in Ludlow, Vermont, working at a ski-resort, he attended graduate school at the University of Maryland, where he received a M.S. in meteorology in 1992, and a Ph.D. in meteorology in 1995. Dr. Schlosser's research and publications primarily deal with observations and modeling of land variations, particularly soil moisture and snow and their role in coupled hydroclimatological variability and prediction. Prior to joining GEST, he worked at the Center for Ocean Land Atmosphere Studies from 1997 to 2001, and conducted research examining the role of land variations, particularly, snow and soil moisture, in coupled climate predictions. He also participated in the Atmospheric Model Intercomparison Project. During his postdoctoral studies from 1995 to1997, Dr. Schlosser worked with Chris Milly (USGS) at the Geophysical Fluid Dynamics Laboratory (GFDL), where he conducted numerical experiments with the GFDL general circulation model to study soil-moisture predictability and its role in coupled atmospheric predictability. During that time, he also lead an international land-model comparison experiment, Phase 2d of the Project for the Intercomparison of Land-Surface Schemes.

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, which resulted in his earning an M.S. in meteorology from Pennsylvania State University in 1985. Missing sunshine, he moved to Florida State University, where he received his Ph.D. in meteorology in 1995. Then, returning to the cold Washington, D.C. metropolitan area, he became a research meteorologist at GSFC, affiliated first with SSAI (until March 2001), and then as an associate research scientist with GEST (since April 2001). During his early career, he worked on the development and improvement of an Empirical Orthogonal Functions model for surface humidity retrieval over the global oceans using the SSM/I precipitable water data. Since April 1997, he joined a new research project involving numerical simulations using 2- and 3-

dimensional Goddard Cumulus Ensemble models, and scientific analysis to study radiative-convective systems and their interactions with large-scale environment. In 2000, he won an Annual Outstanding Performance Award from the Mesoscale Atmospheric Processes Branch, GSFC. While working as a full-time researcher in science, he considers himself 50% a research meteorologist (cloud modeling, air-sea interaction, remote sensing, and atmospheric dynamics), 20% arts-lover, 20% philosophy-seeker, and 10% math-hobbyist. He has been moonlighting as an amateur Chinese Calligraphy teacher during his leisure time on weekends since 1995.

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 addressed atmospheric aerosol optical properties over the oceans. From 1980 to 1991 Dr. Smirnov served as a scientist and senior scientist at the 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 1996 Dr. Smirnov joined Science Systems and Applications, Inc., and started working on the AERONET Project. He has led 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 shipborne 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 50 peer-reviewed papers in the leading geophysical journals. He is presently one of three co-investigators on the AERONET Project.

Mr. Gregory Solyar received a B.S. in radio metrology from the Odessa Measuring College of Standards Committee of USSR in 1981, an M.S. in electrical engineering from Odessa State Polytechnic Institute in 1986, an M.S. in electrical and computer engineering from the Johns Hopkins University (JHU) 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 interests are in imaging methods and algorithms. In December 2000 he joined CESDIS and became an associate research scientist for 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 the Central Communications Design Bureau (1986-1990) he design metrology, algorithms, and microprocessor-embedded hardware and software for control and measurement equipment for communications lines. At JHU (1997-1999) he designed and experimented with optical parametric oscillators, passive Q-switched lasers, and laser diodes. At the National Health Institutes (1997-1998) he researched special surface effects in photomultiplier tubes, and designed, implemented, and tested systems with fast, small-size detectors for small fluorescent power emission. As a GEST scientist he is specializing in wave-front sensing methods, techniques, and algorithms, including phase-diversity and interferometry.

Dr. Harold S. Stone is known for his work on the perfect-shuffle interconnection network that stimulated architectural advances in parallel computing. His textbooks in computer architecture include *High-Performance Computer Architecture*, *Microprocessor Interfacing*, and *Computer Organization and Data Structures*. He has been a faculty member at Stanford and the University of Massachusetts, and has been a member of the visiting faculty at Berkeley, Cornell, NYU, Princeton, and other institutions, worldwide. At IBM he conducted research on cache memories. He retired from NEC in 2001 after making several contributions to image searching and registration. In retirement, he continues active research as a consultant.

Dr. Susan Strahan received a B.S. in chemistry from Stanford University in 1980 and a Ph.D. in chemistry from the University of California, Berkeley in 1986. She was an NRC postdoctoral fellow at NASA's 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 GSFC. Her research involves analysis of trace gas measurements from aircraft and satellite platforms. The observational analyses are used to develop diagnostics for 3D atmospheric models. She contributes to model evaluation and analysis efforts for the NASA Global Modeling Initiative and within the GSFC Data Assimilation Office.

Dr. Chaojiao Sun received a B.S. from the University of Science and Technology of China (USTC), and a Ph.D. in oceanography from Oregon State University, where her major research interest was 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 the El Niño/Southern Oscillation (ENSO) phenomenon, using the extended Kalman filter as a sequential estimator. She joined GEST in November 2000 and has been working on snow data assimilation with land surface models. Her major research interests are in data assimilation, land surface processes, ENSO, and ocean mixing.

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 USRA, working at GSFC. In October 2000 she joined GEST. Over the past three years, she conducted research in areas related to remote measurement of precipitation, understanding storm structures, and microphysical characteristics of precipitation using observations from the ER-2 airborne Doppler (EDOP) radar. She has analyzed EDOP data in support of TRMM to improve rainfall rate estimates. She also studied the microphysics of storms, such as raindrop size distribution and melting ice particles, using EDOP and ground-based polarimetric radar data. She has participated in three TRMM field campaigns and CRYSTAL-FACE experiments, and has 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 he conducted research in climate dynamics and geophysical fluid dynamics. Prior to joining GEST, he worked in the private sector, supporting the Internet industry 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 security. Currently, he is working on GSFC's Land Information System, a high-performance computing platform, for real-time land surface simulation and data assimilation.

Dr. Jinro Ukita received an M.S. in oceanography from University of British Columbia in 1986, an M.S. in atmospheric sciences in 1990, an M.S. in statistics from the University of Washington in 1993, and a Ph.D. in environmental sciences from Hokkaido University in 1997, where his research interest was theoretical mechanics and polar climate. In 1995 he joined the University of Tokyo as a tenured assistant professor. In 1996 he moved to the National Space Development Agency of Japan (NASDA). While at NASDA he joined the International Arctic Research Center of the University of Alaska, Fairbanks, as a subleader. In 2000 he moved to the United States to join NASA as a contractor/research scientist. He has published over 10 papers, and has been serving the community as a member of the WMO World Climate Research Program (WCRP)- ACSYS CLiC Observational Product Panel (OPP), the International Committee of IUGG-IAMAS, the steering committee of the Polar and High-latitude Region of the Meteorological Society of Japan, and the International Science Steering Group of Arctic-Subarctic Ocean Fluxes (ASOF). He has also served as a chair and organizer for conferences and workshops, including IUGG general meeting, Melbourne, 1997; the workshop on Arctic sea ice dynamics, Seattle, 2000; the

Sea Ice Data Assimilation Workshop, Annapolis, 2002; and the upcoming IUGG meeting to be held in Sapporo, Japan, in 2003.

Dr. Sushel Unninayar received a Ph.D in meteorology in the area of nonlinear interactions and global scale energetics of the atmospheric circulation, from the Hawaii Institute of Geophysics, University of Hawaii, in 1977, following degrees in electrical engineering, with an M. S. from the University of Hawaii (1971), a B. Technology (wit honors) from the IIT-Powai); and an EE from IEE-London in 1968. Between his M.S. and Ph.D, he designed and developed state-of-the-art electronic instrumentation for the in-cloud measurement of cloud electrification and precipitation processes, at the Cloud Physics Observatory, Hilo, Hawaii. In 1978 he was the deputy director of the International Monsoon Experiment (MONEX) Project Office at the National Center for Atmospheric Research (NCAR). MONEX was a part of the Global Atmospheric Research Program (GARP), with research aircraft field campaigns in Saudi Arabia, India, and Malaysia. Following MONEX, Dr. Unninayar was involved in developing the initial science plans for the Alpine Experiment (ALPEX) based in Geneva, Switzerland. In 1981, he joined the World Climate Programme (WCP), World Meteorological Organization, Geneva, Switzerland at its inception, as a division chief. There, he launched a number of international projects in climate research, data, and applications that continue to this day. In 1987 he was appointed senior scientific advisor to the United Nations Environment Programme's (UNEP) GRID center, Geneva, Switzerland, as a NASA contribution to develop joint research programs between UNEP and ICSU/IGBP and NASA's Telescience Testbed activities. In 1988 he returned to the U.S. as a program manager at the National Science Foundation to develop plans for NSF's data and research activities for the U.S. Global Change Research Program, and the International Geosphere-Biosphere Programme (IGBP). In 1991 he took a postion as a senior scientist at NASA Headquarters, developing plans for the Greenhouse Effect Detection Experiment (GEDEX) and its strategic implementation. Concurrently, he was involved in reviewing Earth systems modeling and developing a long-term strategy for research in modeling for the next decade. In 1993, he was seconded for a year by NASA as director for the International Projects at the United Nations Institute for Training and Education (UNITAR), Geneva, Switzerland. In 1994, he was director of research, University Corporations for Atmospheric Research's (UCAR) Globe Project. Since 1995, he has been a senior research scientist at UMBC, involved in executive scientific/secretariat support to NASA HQ on a variety of programs and projects. He has published over 100 scientific papers, monographs, and reports.

Dr. I. Veselovskii graduated from the faculty of Theoretical and Experimental Physics of Moscow Engineering Physical Institute in 1982. In 1987 he received a Ph.D. from the same Institute for the studies in photoacoustics, and joined the Physics Instrumentation Center of General Physics Institute in 1988. From 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 became the head of the lidar program. As a visiting researcher, he spent one year in South Korea and one year in Brazil. His current scientific interests include development of lidars for tropospheric ozone monitoring, the use of Raman lidars in studies of water vapor and liquid water, and multi-wavelength lidars for aerosol size distribution retrieval.

Dr. Augustin Vintzileos received a Diploma of Physics from the University of Patras (Greece) in 1989, a M.Sc. in computational fluid dynamics from the University of London, Imperial College in 1990, and a DEA on meteorology, oceanography, and the environment from the University of Paris VI in 1991. In 1996 he received a Ph.D. from the University of Paris VI for work on climate variability with a global atmosphere – tropical Pacific ocean coupled model. He continued as a postdoctoral fellow at the University of Paris VI until 1999, when he joined the NASA Seasonal-to-Interannual Prediction Project first through USRA and then through GEST. During his career, he developed several coupled models of the tropical Pacific area using a novel coupling interface—delocalized physics—that he developed and validated. He then used these models to understand coupled interactions between the ocean and the

atmosphere in the tropical Pacific. He is currently investigating forecasting of the ENSO phenomenon. He has published nine refereed papers, primarily on understanding the tropical Pacific climate.

Dr. Hailan Wang is a research associate at GEST. She received a B.S. in marine meteorology in 1994, from Ocean University of Qingdao in the People's Republic of China. She then pursued her graduate study at the University of Illinois at Urbana-Champaign, and obtained her M.S. and Ph.D. in atmospheric sciences in 1997 and 2000, respectively. In late 2000 she moved to Princeton, NJ, and worked in the Climate Diagnostic Group in Geophysical Fluid Dynamics Lab as a postdoctoral visiting scientist. In December 2002 she joined the Climate and Radiation Branch of GSFC. 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 has been investigating the potential importance of extratropical air-sea interactions in predictability of U.S. summertime precipitation variations.

Dr. Jian-Jian Wang received his Ph.D. in meteorology from the University of Hawaii in 1995. He also holds an M.S. in meteorology (1990), and a B.S. 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 stations, and aircraft and satellite data. His observational studies have focused on the syntheses of physical processes revealed by different data sources from mesoscale field experiments. 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 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 B.S. and an M.S. in physics from Tsinghua University, Beijing, China in 1994 and 1998, respectively, and a Ph.D. in geography from Boston University, Boston, MA in 2002. In July 2002 Dr. Wang joined GEST as a research associate. During his doctoral work, Dr. Wang’s research focused on prototyping and validating a 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 and the future NPOESS VIIRS instrument.

Dr. Zhien Wang is currently an assistant research scientist at GEST. Dr. Wang received a B.S. in physics in 1990, an M.S. in atmospheric optics in 1994, from a university in China, and a Ph.D., in meteorology, from the 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 GEST in 2002 he worked at the University of Utah as a postdoctoral research associate and an assistant research professor, and conducted research in cloud property retrieval by combining multiple remote sensors (active and passive). He, together with Dr. Whiteman at GSFC and Dr. Sassen of the University of Alaska, works on Aqua validation and CloudSat algorithm development. He is also funded by the DOE ARM program for ground-based, combined active and passive remote sensing algorithm development.

Dr. Clark Weaver's first scientific initiation was at Ohio State University at the Byrd Polar Research Institute. His masters thesis topic was the fractionation of isotopic oxygen in snow over Antarctica. He received his Ph.D. in atmospheric science from Colorado State University in 1987. His dissertation was on the mechanism for marine stratocumulus break-up. He then 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 has worked in the Atmospheric Chemistry and Dynamics Branch at GSFC since 1991. His current interests include stratospheric transport, data assimilation, and remote sensing.

Dr. Judd Welton received his B.S. degree in physics with a minor in mathematics from Jacksonville University in 1993, his M.S. in physics in 1996 from the University of Miami, and Ph.D. in physics in 1998, also from the University of Miami. He completed a one year postdoctoral appointment immediately thereafter. While in Miami his research focused on performing measurements of aerosol optical properties using sunphotometry and lidar on remote island locations and during research cruises at sea. The results were used to help improve aerosol models and in applications for the MODIS sensor onboard NASA's Terra spacecraft. During his time in Miami, Dr. Welton participated in several multi-national field experiments, such as AEROCE, ACE-2, MOCE-4, Aerosols99, INDOEX, and was also an AERONET site operator. Dr. Welton moved to Maryland in 1999 and began work at Science Systems and Applications, Inc. as a member of the Cloud and Aerosol Lidar Group at GSFC. Working with the group, he was instrumental in acquiring funding to start a worldwide network of micro-pulse lidar systems, and for lidar deployments to field experiments and cruises. This project has developed into the micro-pulse lidar network, or MPLNET. He also joined the team developing lidar applications using the GLAS sensor onboard NASA's ICESat spacecraft. In September 2000 Dr. Welton joined GEST. He served as the project scientist and manager for the MPLNET project and has been active in recent field experiments and cruises such as PRIDE, SAFARI, ACE-Asia, and CLAMS. He also continued work on GLAS algorithm development and calibration techniques, and planned post-launch calibration and validation efforts for GLAS using MPLNET sites and airborne lidar systems. In December 2002 Dr. Welton left GEST to accept a civil service position in GSFC's Laboratory for Atmospheres, where he continues his work on the MPLNET and GLAS projects.

Dr. Cara Wilson received a B.Sc. in oceanography from the University of Michigan in 1989. Before pursuing graduate studies, she worked at the Brookhaven National Laboratory on several different interdisciplinary oceanographic research projects. She received her Ph.D. in oceanography from Oregon State University in 1997, where her major research interest was the dynamics of hydrothermal plumes and their interactions with background hydrography and heat flux. After finishing her doctorate, she worked in Paris, France as the program coordinator for InterRidge, an initiative designed to foster interdisciplinary and international collaboration in the study of oceanic ridge-crest systems. In 1999 she switched her research focus to satellite oceanography when she started work at GSFC with USRA. Her current research interests involve using satellite ocean color, sea-surface height, and wind data to examine the relationship between mesoscale physical forcing and surface chlorophyll, on both seasonal and interannual cycles.

Dr. Liguang Wu is an assistant research scientist at GEST. He received a B.S. in meteorology from Nanjing University, China in 1984; an M.S. in meteorology from State Oceanic Administration (SOA), Beijing, China in 1990; and a Ph.D. in meteorology from the 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 the GSFC DAAC. His current research interest includes tropical cyclone structure, intensity, and motion; air-

sea interactions; numerical modeling; analysis and application of remote sensing data; and the relationship between climate changes and hurricane activities.

Dr. Yihua Wu received his B.S. in agrometeorology from the Nanjing Institute of Meteorology in China in 1982, an M.S. in horticultural sciences, and a Ph.D. in atmospheric sciences from North Carolina State University in the United States in 1993 and 1997, respectively. From 1982 to 1992 he worked as an engineer at the National Meteorological Administration (NMA), China. His major professional activities included research on modeling crop growth and development, and managing the national operational system of agrometeorological monitoring, information, and forecasts. Dr. Wu won an award from NMA for his contribution in promoting science and technology. He developed the real-time MM5 Mesoscale Environment Forecasting System over the Southeast U.S., and was awarded a Cray Fellowship when he did his postdoctoral work at the North Carolina State Climate Office in 1998. He developed a multiplayer biochemical dry deposition model when he worked as a visiting scientist at UCAR/EPA from 1999 to 2002. His recent research interests have included atmospheric dynamics, mesoscale modeling, dry deposition modeling, and atmosphere-biosphere interactions.

Dr. Fanglin Yang is an assistant research scientist at GEST. He received a B.S. in 1989 and an 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. 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. Dr. Yang's research focuses on climate modeling and diagnosis, utilizing 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, snow, and soil moisture. His current task at GSFC is to develop a mixed layer ocean model to be coupled to the GEOS and NSIPP GCMs to study extratropical air-sea interaction.

Dr. Song Yang received a B.S. in meteorology from Nanjing Institute of Meteorology in 1983, an M.S. in tropical meteorology from Zhongshan University in 1986, and a Ph.D. in satellite meteorology from Florida State University in 1996. He was a lecturer and researcher in Nanjing Institute of Meteorology from 1986 to 1992. His research involved tropical meteorology, atmospheric general circulation, and the study of precipitation systems. Dr. Yang participated in the Third Algorithm Intercomparison Project (AIP-3) and the Third Precipitation Intercomparison Project (PIP-3) in 1993-1996. He improved and validated the Florida State University rain profile retrieval algorithm from satellite microwave measurements. Dr. Yang, together with Dr. Eric A. Smith, developed software to evaluate TRMM operational rain-profile algorithms; they also supervised a validation project for the Day-1 operational TRMM rain-profile algorithms in 1997-1999 at Florida State University. Dr. Yang also investigates convective rain systems over tropical and mid-latitude land and ocean areas to determine the system evolution, diurnal variations, and climatologies based on TRMM datasets. His researches involved improving the radiative transfer modeling and the cloud model database that is used to improve the TRMM TMI rain algorithm, and evaluating retrieved precipitation and latent heating against estimates from ground-based measurements, when he was with the Joint Center of Earth and Science Technology (JCET) from September 1999 to February 2002. Dr. Yang has been a research faculty member with GEST since March 2002. His research activities have been associated with the Global Precipitation Measurement project. He still works on improving the TRMM TMI and TMI/PR combined rain algorithms, and investigates the impacts of TRMM rain products on general circulation model simulations.

Dr. Kao-San Yeh, also known as Kevin Yeh, has been an assistant research scientist at GEST since December 2001. 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 nonhydrostatic version of the Canadian Global Environmental Multiscale Model as a postdoctoral researcher 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 at the University of Maryland, College Park.

Dr. Dongliang Yuan graduated from Florida State University in 1995 with a Ph. D. in oceanography. He spent two years at the Department of Oceanography, Florida State University for postdoctoral training, and came to the GSFC through the USRA Visiting Scientist Program in early 1998. He joined GEST in 1999, and is currently a scientist at EER Systems, Inc., doing science support to MODIS data.

Dr. Boris Yurchak received a M.S. in electronics from the Kharkov Institute of Radioelectronics, USSR in 1969, and a Ph.D. in geophysics (physics and mathematics) in 1980 from the Institute of Experimental Meteorology, Goskomhidromet (USSR Weather Service), Obninsk. His major research interest was radar methodology applications in cloud and precipitation measurements and atmospheric diffusion. From 1969 to 1996 Dr.Yurchak served as a 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 to detect clouds of pollutants under emergency situations. He also successfully used remote sensing capabilities to study environmental contamination. In July 2002 Dr. Yurchak joined Caelum Research Corporation and started working on the NASA's Earth Science and Public Health Program. Dr. Yurchak has been with GEST since July 2002. 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. degree 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 multisensor 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. in atmospheric physics from Nanjing Institute of Meteorology. He then taught courses and conducted research of clouds in this institute from 1987 to 1995. In 1995 he began his Ph.D. studies in the Physics Department of New Mexico Tech Institute of Technology, focusing on the ensemble simulation of tropical convection and its interaction with large-scale vertical circulation. After receiving his doctorate, he continued his work as a postdoctoral research fellow, and then joined GEST as a research associate. Dr. Zeng now collaborates with scientists at GSFC, upgrading the Goddard Cloud Ensemble (GCE) cloud-resolving model. With the aid of massive parallel computation, the new-generation GCE will provide a useful framework for studying the interactions between clouds and other parameters (*e.g.*, aerosols, large-scale circulations).

Dr. Xiwu Zhan received his B.S. and M.S. degrees in meteorology from the Nanjing Institute of Meteorology. He then taught courses and conducted research in applied meteorology at the Institute. In 1990 he started his Ph.D. studies at Cornell University on sensitivities of land surface water vapor fluxes to atmospheric CO_2 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, and then 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 for the MODIS 250-m land cover change product as an associate member of the MODIS science team. Before he joined the GEST research faculty in 2002, he worked with the NPOESS-VIIRS product algorithm development team at Raytheon-ITSS Corporation. His current research interests include land surface energy and CO_2 flux modelin; generating remote sensing data product for land surface soil moisture, temperature, and vegetation type; and assimilating these data products into land surface models to provide better forecast accuracy for climate, hydrological, and/or ecological models.

Dr. Yunhe Zhao received a B.S. in computational mathematics from Xiamen University, Xiamen, China in 1984, and both an M.S. and Ph.D. in mathematics from North Dakota State University, Fargo, ND, in 1993 and 1997, respectively. He has been with Caelum Research Corporation, Rockville, MD, and he has worked on-site at the Oceans and Ice Branch, NASA GSFC as a contractor since May 1997. He currently is a senior analyst and works in GEST through Caelum Research Corporation. 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 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 the wavelet analysis method from SSM/I, NSCAT, and QuikScat data and using the derived data sets to study sea ice dynamics and the effects of atmospheric circulations (*e.g.* Arctic Oscillation) on sea ice motion and deformation.

Dr. Jerry R. Ziemke is an associate research scientist within the Aerosols and Clouds research group at GEST. His research interests include satellite retrieval of tropospheric ozone, surface UV, aerosol and cloud properties, atmospheric constituents, and the study of global trends. Dr. Ziemke earned a B.S. in physics and mathematics from Minnesota State University in 1981, an M.S. in physics/electrical engineering from the University of Minnesota in 1984, an M.A. in mathematics/statistics from Minnesota State University in 1986, and a Ph.D. in physics from Iowa State University in 1990. Following a postdoctoral appointment in the Physics Department at Iowa State University, he became a National Research Council fellowship recipient in 1994 in Code 916 at GSFC, to study ozone trends and trend models. He joined Code 916 in 1996 as a contractor, developing algorithm methods for deriving tropospheric ozone from satellite retrievals. Since 1998 he has provided tropospheric column ozone data for NASA. While at GSFC he has been actively involved as a science team member for the Upper Atmospheric Research Satellite and TOMS, and contributes to several national and international reports. He has been an active member of the EOS Aura OMI project science team since 2000 with the primary task of developing ozone validation products and global maps of tropospheric ozone, by combining OMI with other ozone measurements from EOS Aura instruments. Dr. Ziemke became an associate research scientist at GEST in March 2002.

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Mokal, Shahid	Computer Support

Acronyms and Abbreviations

4DDA	four-dimensional data assimilation
4DVAR	four-dimensional variational data assimilation
AAS	American Astronomical Society
AC	Atmospheric Corrector
ACE	Aerosol Characterization Experiment
ACRIM	Active Cavity Radiometer Irradiance Monitor
AEJ	African Easterly Jet
AERONET	Aerosol Robotic Network
AESP	Aerospace Education Specialist Program
AFWA	Air Force Weather Agency
AGCM	atmospheric general circulation model
AGRMET	Agricultural Meteorology Model
AGU	American Geophysical Union
AIRS	Atmospheric Infrared Sounder
AISRP	Applied Information Systems Research Program
ALF	Advanced Laser Fluorescence
AMF	air mass factor
AMIP	Atmospheric Model Intercomparison Project
AMPR	Advanced Microwave Precipitation Radiometer
AMS	American Meteorological Society
AMSR-E	Advanced Microwave Scanning Radiometer – EOS
AMSU-B	Advanced Microwave Sounding Unit-B
AOD	aerosol optical depth
ARGOS	Air Force Advanced Research and Global Observing Satellite
ARM	Atmospheric Radiation Measurement
ASD	Aerosol size distribution
ASLO	American Society of Limnology and Oceanography
ASOF	Arctic-Subarctic Ocean Fluxes
ASTEX	Atlantic Stratocumulus Transition Experiment
ATBD	algorithm theoretical basis document
ATMS	Advanced Technology Microwave Sounding
ATSR	Along-Track Scanning Radiometer
AVHRR	Advanced Very-high Resolution Radiometer
BASE-ASIA	Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment
BL	boundary layer
BOMEX	Barbados Oceanographic and Meteorological Experiment

BOREAS	Boreal Ecosystem-Atmosphere Study
BRDF	bidirectional reflectance distribution function
BURST	Backup and Recovery Study Team
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAM2	Community Atmosphere Model Version 2
CAMEX	Convection and Moisture Experiment
CAN	Cooperative Agreement Notice
CaPE	Convection and Precipitation/Electrification
CAR	Cloud Absorption Radiometer
CARMA	Community Aerosol Radiation Model for Atmospheres
CASTS	Chemical Analyses of Stratospheric Trace Species
CAVE	CERES ARM Validation Experiment
CCD	charge-coupled device
CCD	Convective Cloud Differential
CCM3	Community Climate Model
CCRI	Climate Change Research
CCSM	Community Climate System Model
CCSP	Climate Change Science Program
CCSPO	Climate Change Science Program Office
CENR	Committee on Environment Natural Resource's
CEOP	Coordinated Enhanced Observing Period
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth's Radiant Energy System
CG-FFT	conjugate gradient-fast Fourier transform
CHINA-TEA	Climate and Health Impacts in North/East Asia: Tropospheric Experiment on Aerosols
CIRA	Cooperative Institute for Research in the Atmosphere
CLAMS	Chesapeake Lighthouse and Aircraft Measurements for Satellites
CLM	Community Land Model
CLPE	Cold Lands Processes Experiment
CLPX	Cold Lands Processes Field Experiment
CMAP	CPC Merged Analysis of Precipitation
CNES	Centre Nationale d'Études Spatiales
COLA	Center For Ocean-Land-Atmosphere Studies
COP	Conference of Parties
COSPAR	Committee on Space Research
CPC	Climate Prediction Center
CPL	Cloud Physics Lidar
CRM	Cloud-Resolving Model

CRS	Cloud Radar System
CRYSTAL	Cirrus Regional Study of Tropical Anvils and Cirrus Layers
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment
CT	Computational Technologies
CTM	chemical transport model
DA	Data Assimilation
DAAC	Distributed Active Archive Center
DAK	Doubling-Adding KNMI
dAMF	differential air mass factor
DAO	Data Assimilation Office
DAS	Data Assimilation System
DDV	dark dense vegetation
DEM	digital elevation map
DIWG	Data and Information Working Group
DMSP	Defense Meteorological Satellite Program
DOAS	Differential Optical Absorption Spectrometer
DSD	droplet size distributions
DSP	Dynamical Seasonal Prediction
DSS	decision support systems
EARLINET	European Aerosol Research Lidar Network
ECMWF	European Center for Medium-range Weather Forecasts
EDOP	ER-2 Doppler Radar
EDU	Engineering Development Unit
EEP	eastern extreme precipitation
EGS	European Geophysical Society
EKF	Extended Kalman filter
EnKF	Ensemble Kalman filter
ENSO	El Niño/Southern Oscillation
EO-1	Earth Observing – 1
EOF	empirical orthogonal function
EOS	Earth Observing System
EP	Earth Probe
EPA	Environmental Protection Agency
ERC	Educational Resource Center
ESE	Earth Science Enterprise
ESMF	Earth System Modeling Framework
ESS/CT	Earth and Space Sciences, Computational Technologies
ESTC	Earth Science Technology Conference

ESTO	Earth Science Technology Office
ETM	Enhanced Thematic Mapper
EUG	European Union of Geoscience
EVE	Educating with Virtual Experiences
FACE	Florida Area Cirrus Experiment
FAROP	Forecast of Atmospheric Radiative and Optical Properties
FAS	Foreign Agricultural Service
FCI	foliage clumping index
FEWS	Famine Early Warning System
FIT	Fizeau Interferometer Testbed
FMI	Finnish Meteorological Institute
fvDAS	finite-volume Data Assimilation System
fvGCM	finite volume General Circulation Model
GAMICSE	Global Assimilation and Modeling of Ice Clouds in a Subsynoptic Environment
GAPP	GEWEX Americas Prediction Project
GARP	Global Atmospheric Research Program
GARP GATE	Global Atmospheric Research Program Atlantic Tropical Experiment
GATE	GARP Atlantic Tropical Experiment
GCC	Global Carbon Cycle
GCDC	Global Change Data Center
GCE	Goddard Cumulus Ensemble
GCM	general circulation model
GCOS	Global Climate Observing System
GCRP	Global Change Research Program
GCSS	GEWEX Cloud System Study
GCTM	Goddard Chemistry and Transport Model
GDAS	Global Data Assimilation System
gdb	GNU Project Debugger
GEIS	Global Emerging Infections Surveillance System
GEM	global environmental multiscale
GEMTM	General Energy and Mass Transfer Model
GEOS	Goddard Earth Observing System
GEWEX	Global Energy and Water Cycle Experiment
GF	globalization framework
GFDL	Geophysical Fluid Dynamics Laboratory
GIMMS	Global Inventory Mapping and Monitoring Studies
GLAS	Geoscience Laser Altimeter System
GLDAS	Global Land Data Assimilation Systems

GMI	Global Modeling Initiative
GMS	Geostationery Meteorological Satellite
GOCART	Global Ozone, Chemistry, Aerosol, and Radiative Transport model
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GORT	Geometric Optical Radiative Transfer
GOS	Global Observing Systems
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRIPS	GCM-Reality Intercomparison Project for SPARC (GRIPS)
GSA	Geological Society of America
GSSTF2	Goddard Satellite-Based Surface Turbulent Fluxes Version 2
GSWP	Global Soil Wetness Project
GT	ground truth
GTS	Global Telecommunications Systems
GUI	graphical user interface
GWC	Global Water Cycle
GWD	gravity wave drag
GWEC	Global Water and Energy Cycle
HALOE	Halogen Occultation Experiment
HICSS36	36th Hawaii International Conference on System Sciences 2003
HIRDLS	High-resolution Dynamics Limb Sounder
HIRS	High-resolution Infrared Radiation
HPCC	high-performance computing and communication
HYCOM	Hybrid Coordinate Ocean Model
ICAR-5	International Conference on Wind Erosion and Aeolian Processes
ICESat	Ice, Cloud, and Land Elevation Satellite
ICSU	International Council for Science
IEEE	Institute of Electrical and Electronics Engineers
IGARSS	International Geoscience and Remote Sensing Symposium
IGBP	International Geosphere-Biosphere Program
IGOS	Integrated Global Observing Strategy
IN	ice nuclei
IOP	Intensive Observation Periods
IPC	interpolation and profile correction
IPCC	Intergovernmental Panel on Climate Change
IPO	Integrated Program Office

IS&T	Information Science and Technology
ISAAC	Ionospheric Spectroscopy and Atmospheric Chemistry
ISCCP	International Satellite Cloud Climatology Project
ITCZ	inter-tropical convergence zone
IWG	Investigators Working Group
IWMMM-3	Third International Workshop on Multiangular Measurements and Models
JCET	Joint Center for Earth Systems Technology
JCSDA	Joint Center for Satellite Data Assimilation
JFM98	January March 1998
JPL	Jet Propulsion Laboratory
KNMI	Koninklijk Nederlands Meteorologisch Instituut
KWAJEX	Kwajalein Experiment
LAC	LEISA Atmospheric Corrector
LAI	leaf area index
LBA	Large-Scale Biosphere Atmosphere Experiment in the Amazon
LDAS	Land Data Assimilation Systems
LEARNERS	Leading Educators to Applications, Research and NASA-related Educational Resources in Science
LEEM	Laser Excitation-Emission Matrix
LEISA	Linear Etalon Imaging Spectral Array
LES	large eddy simulations
LIS	Land Information System
LPA	laser phytoplankton analyzer
LPSC	Lunar and Planetary Science Conference
LSM	land surface model
LSMA	Linear Spectral Mixture Analysis
LUT	look-up table
LWCF	longwave cloud radiative forcing
LWP	liquid water path
MAS	MODIS Airborne Simulator
MATCH	Model for Atmospheric Transport and Chemistry
MAXDOAS	Multi-access DOAS
MCS	Mesoscale Convective Systems
MCST	MODIS Characterization Support Team
MDI	Michaelson Doppler Imager
MGS	Mars Global Surveyor
MI	Microwave imager
MISR	Multiangle Imaging Spectroradiometer

MLBC	multi-layer biochemical
MLS	Microwave Limb Sounder
MM5	Mesoscale Model 5
MOC	Mars Orbiter Camera
MODIS	Moderate Resolution Imaging Spectroradiometer
MOLA	Mars Orbiter Laser Altimeter
MOM	Modular Ocean Model
MPCM	Multistage Pulse Code Modulation
MPI	Message Passing Interface
MPL	Micro-Pulse Radar
MPLNET	Micro-Pulse Lidar Network
NAAPS	Navy Aerosol Analysis and Prediction System
NACP	North American Carbon Program
NAP	North American pattern
NAS	National Academy of Sciences
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCFR	narrow cold frontal rainband
NCR	National Research Council
NEXRAD	Next-generation Radar
NEXT	NPP EDU Data Exchange Project
NLDAS	North American LDAS
NO	nitric oxide
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NRA	NASA Research Announcement
NRLMSISE	Naval Research Laboratory Mass Spectrometer/Incoherent Scatter Radar
NSDL	National Science Digital Library
NSF	National Science Foundation
NSIPP	NASA Seasonal-to-Interannual Prediction Project
OAI	Open-Archive Initiative
OCO	Orbiting Carbon Observatory
O-F	observation minus forecast
OGCM	ocean general circulation model
OLR	outgoing longwave radiation
OMB	Office of Management and Budget
OMI	Ozone Monitoring Instrument

OML	Ocean Mixed Layer
OMPS	Ozone Mapping and Profiler Suite
OPE3	Optimizing Production Inputs for Economic and Environmental Enhancement
OPTRAN	Optical Path Transmittance Model
OSTP	Office of Science and Technology Policy
P&P	pump-and-probe
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
PBL	planetary boundary layer
PBMR	Pushbroom Microwave Radiometer
PCA	Principal Component Analysis
PCTM	parameterized chemical transport model
PEB	phycoerythrobilin concentration
PIA	path-integrated attenuation
PIERS	Progress in Electromagnetics Research Symposium
PNA	Pacific-North American
POAM	Polar Ozone and Aerosol Measurement
POLDER	Polarization and Directionality of the Earth's Reflectances
PR	precipitation radar
PREP	Principles of Remote Exploration Project
PRESTORM	Preliminary Regional Experiment for Stormscale Operational and Research Meteorology
PRIDE	Puerto Rico Dust Experiment
PRT	physical radiative transfer
PSAS	Physical-space Statistical Analysis System
PSC	polar stratospheric cloud
PSD	particle size distributions
PSII	photosystem II
psu	practical salinity unit
PUB	phycourobilin concentration
QPF	quantitative precipitation forecast
QU	quasi-uniform
RAMS	Regional Atmospheric Modeling System
RDF	resource description framework
RegCM2	regional climate model
ReSTS	Reanalysis for Stratospheric Trace gas Studies
RH	relative humidity
RSF	reflected solar bands

RTM	River Transport Model
RTNEPH	Real-Time Nephanalysis
RVF	Rift valley fever
SACZ	South Atlantic Convergence Zone
SAFARI 2000	Southern African Regional Science Initiative, 2000
SAGE	Stratospheric Aerosol and Gas Experiment
SALLJ	South American Low-Level Jet
SBIR	Small Business Innovation Research
SBUV/2	Solar Backscatter UltraViolet/2
SCAR-A	Sulfates, Clouds, And Radiation – Atlantic
SCAR-B	Smoke, Clouds, and Radiation Experiment - Brazil
SCO	stratospheric column ozone
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SCS	South China Sea
SCSMEX	South China Sea Monsoon Experiment
SEAM	South East Asian Monsoon
SeaWiFS	Sea-viewing Wide Field-of-View Sensor
SGP	Southern Great Plains
SHADOZ	Southern Hemispheric Additional Ozonesondes
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Ocean Studies
SIPS	Science Investigator-led Processing Systems
SLAM	Small Lidar Advanced Measurement
SMEX	Soil Moisture Experiments
SMMR	Scanning Multichannel Microwave Radiometer
SMOCC	Smoke Aerosols, Clouds, Rainfall and Climate
SO	Southern Oscillation
SOHO	Solar and Heliospheric Observatory
SPARC	Stratospheric Processes and their Role in Climate
SPAWAR	Space and Naval Warfare Systems
SPIE	International Society for Optical Engineering
SRL	Scanning Raman Lidar
SRT	surface reference technique
SRT	Surface Return Technique
SSB	sea-state bias
SSH	sea-surface height
SSM/I	Special Sensor Microwave Imager
SSS	Sea Surface Salinity
SST	sea-surface temperature

STE	stratosphere-troposphere exchange
STIO	southern tropical Indian Ocean
STTR	Small Business Technology Transfer
SVATS	Soil-Vegetation-Atmosphere Transfer Schemes
SWE	snow water equivalent
SWH	significant wave height
T/P	TOPEX/Poseidon
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment
TCO	tropospheric column ozone
TEB	Thermal Emissive Bands
Th	threshold
TIE	Telescopes In Education project
TMI	TRMM Microwave Imager
TOA	top-of-atmosphere
TOGA-COARE	Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TOVS	TIROS Vertical Sounder
TP	Tibetan Plateau
TRMM	Tropical Rainfall Monitoring Mission
TRU	Thevenaz, Ruttimann, and Unser
TTT	transilient turbulence theory
UARS	Upper Atmosphere Research Satellite
UCAR	University Corporation for Atmospheric Research
UKMO	United Kingdom Meteorological Office
UN-COPUOS/STSC	UN Committee on the Peaceful Uses of Outer Space
UNEP	United Nations Environmental Program
UNFCCC	UN Framework Convention on Climate Change
UNISPACE-III	Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space
UPRM	University of Puerto Rico Mayaguez
URL	uniform resource locator
USAID	United States Agency for International Development
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity
VIIRS	Visible Infrared Imaging Radiometer Suite
VIRS	Visible Infrared Scanner

VR	variable resolution
VTIE	Virtual Telescopes in Education
W3C	World Wide Web Consortium
WatER	Water and Energy Research
WCDC	Water Cycle Data Center
WCRP	World Climate Research Program
WEP	western extreme precipitation
WG4	Working Group 4
WGCV	Working Group on Calibration and Validation
WMO	World Meteorological Office
WMO-GOS	World Meteorological Organization Global Observing Systems
WRAIR	Walter Reed Army Institute for Research
WRF	weather and forecasting model
WSPC	World Scientific Publishing Company
WWC	What Works Clearinghouse
WWMCA	World-Wide Merged Cloud Analysis
XML	Extensible Markup Language
Z_{dr}	Differential Reflectivity