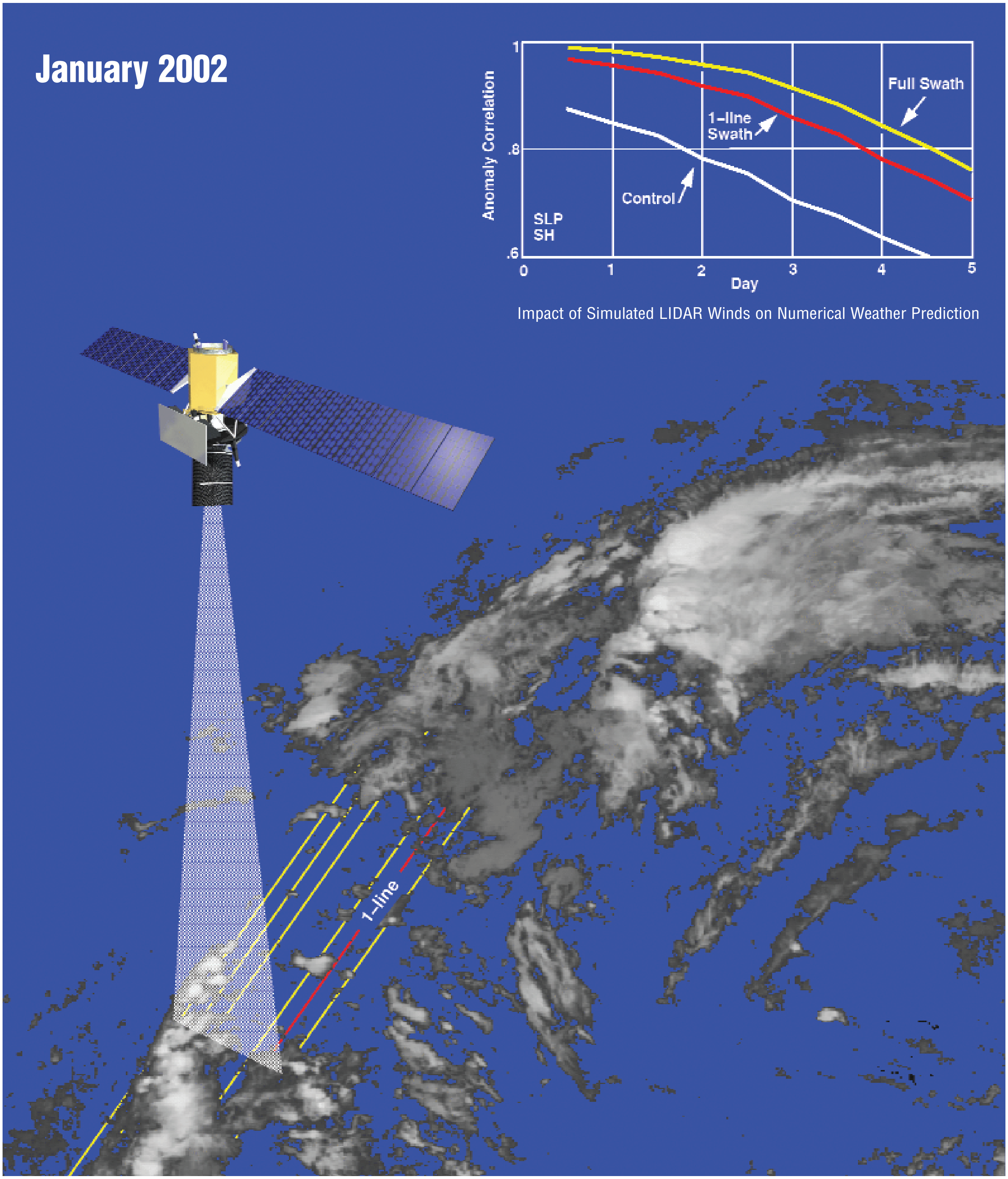
Laboratory for Atmospheres

PHILOSOPHY, ORGANIZATION, MAJOR ACTIVITIES, AND 2001 HIGHLIGHTS

January 2002



Impact of Simulated LIDAR Winds on Numerical Weather Prediction

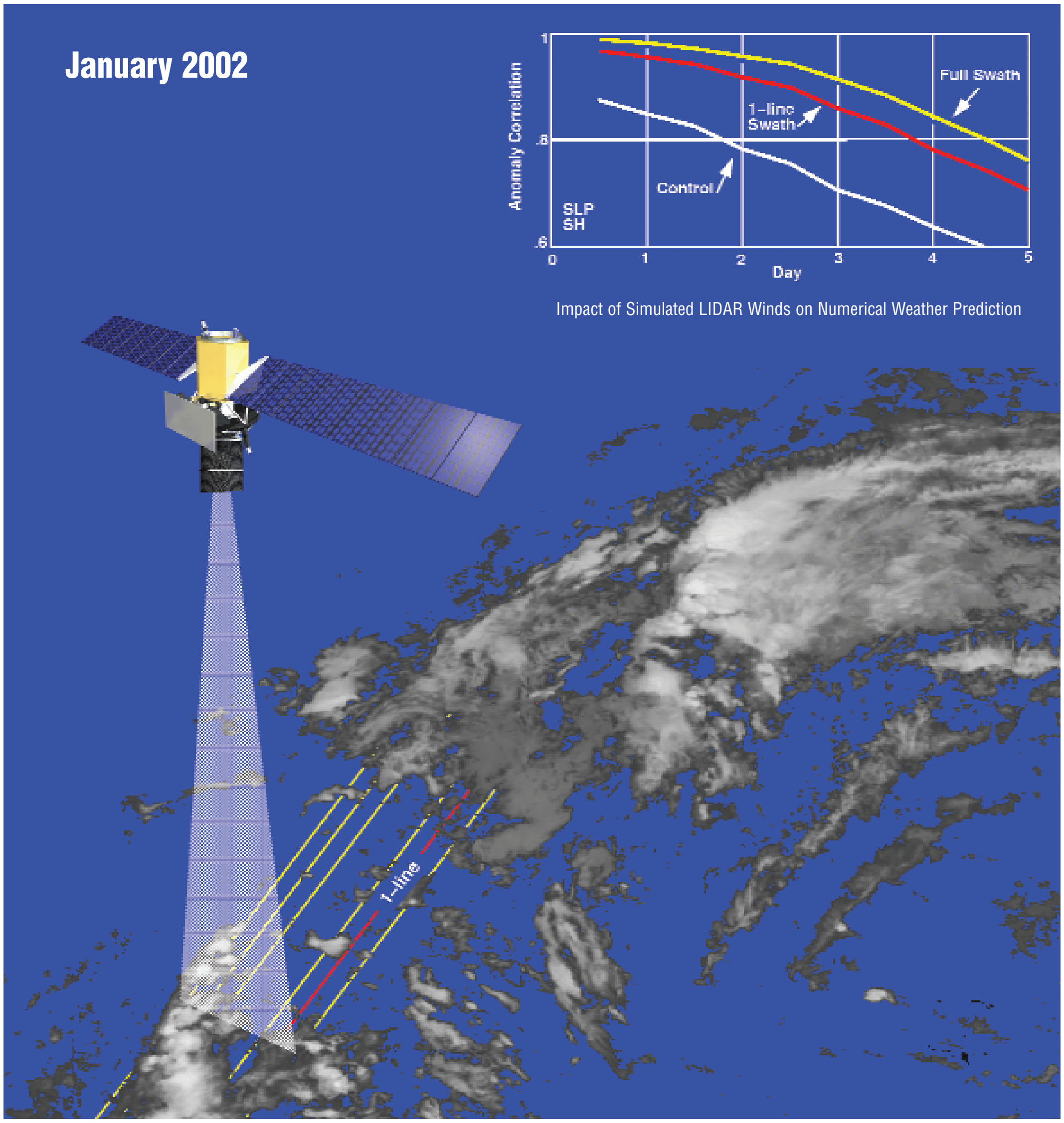
National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

NASA GODDARD SPACE FLIGHT CENTER

Laboratory for Atmospheres

PHILOSOPHY, ORGANIZATION, MAJOR ACTIVITIES, AND 2001 HIGHLIGHTS



The Laboratory for Atmospheres' Data Assimilation Office (DAO) uses a modeling technique called OSSE (Observing System Simulation Experiment) to study atmospheric monitoring capabilities. In this unique approach, the OSSE synthesizes the observations of a proposed satellite instrument and uses them in a data assimilation to predict the instrument's usefulness in forecasting. The cover shows simulations to evaluate various concepts for obtaining Doppler Wind Lidar (DWL) profiles from space. The drawing shows the cross-track coverage of a DWL in a 400 km orbit and the improved anomaly correlation for sea-level pressure in the southern hemisphere. The anomaly correlation shown on the ordinate in the chart indicates forecast accuracy. A perfect forecast has an anomaly correlation of 1.0, while the limit of useful forecast skill is about 0.6.

Photo courtesy of R. Atlas, J. Ardizzone, J. Terry, and D. Bungato of the Data Assimilation Office; G.D. Emmitt of Simpson Weather Associates; and T. Carnahan and C. Congedo of the Mechanical Systems Analysis and Simulation Branch, NASA Goddard Space Flight Center.

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
20771

Laboratory Chief's Summary

Dear Reader:

Welcome to the Laboratory for Atmospheres' annual report for 2001. I thank you for your interest. We publish this report each year to describe the Laboratory and its work and to summarize our accomplishments.

We intend for this document to address a broad audience. Our readers include managers and colleagues within NASA, scientists outside the Agency, graduate students in the atmospheric sciences, and members of the general public. Inside, you'll find descriptions of our philosophy, our people and facilities, our place in NASA's mission, and our accomplishments for 2001.

The Laboratory's more than 400 scientists, technologists, and administrative personnel are part of the Earth Sciences Directorate of NASA's Goddard Space Flight Center. Together, we pursue our mission of advancing the knowledge and understanding of Earth's atmosphere and the atmospheres of other planets. In doing so, we contribute directly to two of NASA's primary Enterprises, Earth Sciences and Space Sciences.

We accomplished much in 2001. Laboratory scientists hosted 111 seminars, participated in 67 workshops, 98 science team meetings, 3 science policy meetings, published 179 refereed papers, hosted 164 short-term visitors, and participated in an array of educational activities.

The NASA/NOAA Joint Center for Satellite Data Assimilation (JCSDA) achieved significant accomplishments in 2001. JCSDA is designed to optimize the use of satellite data in NOAA's operational activities. In 2001, JCSDA installed computing infrastructure at Goddard that will deliver combined AIRS/MODIS products within 180 minutes of ingest. In addition, JCSDA distributed to its members the first version of a community-based fast radiative transfer model. On January 15, 2002, JCSDA achieved another milestone with the assimilation of QuikSCAT data at NCEP. This achievement arose from a substantial collaborative effort during 2001 among the Laboratory's DAO, NCEP's EMC, and NESDIS.

The Laboratory continued its active role in developing and calibrating new and improved instruments for spaceflight and field campaigns. Among these instruments are the Triana/EPIC instrument (Earth Polychromatic Imaging Camera), which was calibrated at Goddard; SOLSE/LORE, a demonstration flight instrument to test the type of ozone profile measurements to be used on NPOESS; and MEIDEX, an Israeli instrument to study aerosols over the Mediterranean Sea using TOMS and MODIS channels. Both SOLSE/LORE and MEIDEX were calibrated in our Laboratory's RCDF (Radiometric Calibration and Development Facility). Triana is now in storage at Goddard awaiting a flight of opportunity. MEIDEX and SOLSE/LORE are now scheduled for a July 2002 shuttle flight.

Our Laboratory developed the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE), a new lidar and remote sensing technique for measuring atmospheric winds without using Doppler information. On December 10, 2001, the Atmospheric Experiment Branch delivered the Neutral Gas and Ion Mass Spectrometer (NGIMS) flight model to Johns Hopkins University APL for integration onto the CONTOUR spacecraft. The instrument was managed and built in the Laboratory with the help of Code 500. Special thanks go to Jack Richards, the NGIMS instrument manager.

The Laboratory had an exciting year participating in international field campaigns, where Laboratory members were PI's and active participants. We supported GTE/TRACE-P (Global Tropospheric Experiment/Transport and Chemical Evolution over the Pacific). Our real-time forecast products (based on SeaWiFS, TOMS, and DAO assimilation data) helped the GTE/TRACE-P team plan aircraft flights. Anne Thompson supplied satellite and meteorological analyses. We supported ACE–Asia (Aerosol Characterization Experiment) with field instruments and model forecasts of aerosols to guide flight planning. During TOMS3-F (Total Ozone Measurements by Satellites, Sondes, and Spectrometers at Fairbanks), Lab scientists from Code 916 studied the cause of differences between total column ozone as measured by TOMS and by ground-based instruments. In November, the Stratospheric Ozone Trailer arrived in Lauder, New Zealand, to participate in a Dobson intercomparison at the NDSC (Network for the Detection of Stratospheric Change). The trailer will also be used in a lidar validation campaign in April 2002. CAMEX-4 (Convection and Moisture Experiment) employed NASA and NOAA aircraft, satellites, and ground assets to study Atlantic basin hurricanes from August through September. Camex-4 also contributed to TRMM validation and calibration efforts. The MPL-Net (Micro Pulse Lidar Network) group installed an improved instrument to begin the third year of active monitoring of Antarctic cloud cover at the South Pole. The South Pole experiment site is part of preparations for next year's GLAS satellite mission. Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) took place at Wallops Flight Facility July 10–August 2, 2001, to validate MODIS, MISR, and CERES aerosol and radiation measurements from the Terra satellite, and to enhance our knowledge of the ocean spectral surface reflectance and aerosols.

On April 17 and 18, the Goddard Micro Pulse Lidar (MPL) Network site detected an unusual elevated layer of haze considered to be Asian dust that was transported across the Pacific and North America. This was the East Coast's first ground-based lidar observation of the vertical profile of the dust. Two MP lidars were operating in Western China and on the NOAA ship Ron Brown off the coast of Japan during ACE–Asia. Another MPL site was in Oklahoma. In a significant human drama, real-time cloud ceiling height information from the MPL was made available to pilots as they attempted a rare nighttime landing at the Amundsen-Scott South Pole Research Station to evacuate the station's ailing doctor.

A significant part of the Laboratory's science has been extended by the increase of TRMM's orbit from 350 km to 400 km. This increase added about 2 years to the satellite's life. Bob Adler did an outstanding job advocating and justifying this change on behalf of the scientific community.

The 10th anniversary meeting for UARS was interrupted by the tragic events of September 11. The meeting adjourned after hearing the news, but reconvened offsite on September 12–13. After the instruments were shutdown September 24–30, science observations were resumed on October 1. UARS is now operating in a lower-cost "Traceability Mission Option" with the primary focus of providing validation/calibration measurements for upcoming missions: TIMED, SAGE III, ENVISAT-1, ADEOS II, EOS Aqua, and SORCE.

In 2001, many Laboratory members earned awards for their outstanding work. David Atlas was installed as an Honorary Member of the American Meteorological Society (AMS) at the 81st Annual Meeting in Albuquerque. Joanne Simpson is the only other Goddard scientist who is an Honorary Member. Wei-Kuo Tao was elected a Fellow of the AMS and received the certificate at the AMS annual meeting in January 2001. Marshall Shepherd and Dennis Chesters received the GSFC Group Award for "Outstanding Teamwork" on the Horizon (EO-3) Proposal Development Team. Stan Scott received the astronauts' Silver Snoopy Award, which is given for special achievements on space shuttle and other manned flight missions. Stan was recognized for his outstanding contribution to the success of the ISIR experiment on STS-85. Hans Mayr received an invitation to present the CEDAR Prize Lecture at the joint CEDAR Quadrennial STP Symposium in June. Hans was nominated for his work on the “Theory of wave driven non-linear flow oscillations in the atmospheres of planets and the Sun.” The Earth Observatory team was presented with NASA HQ’s “Group Achievement Award.” LaRC presented a group achievement award to our Laboratory members of the Aerosol and Polar Stratospheric Cloud Lidar Team who worked on the SOLVE mission. Siegfried Schubert of the Data Assimilation Office was recently approved by the American Meteorological Society council to become an editor of the Journal of Climate.

The year 2001 was also a time to bid farewell to valuable members of the Laboratory. Mark Schoeberl became the Chief Scientist of the Earth Sciences Directorate, and Jack Richards became the Assistant Director of Operations for the Earth Sciences Directorate.

I am pleased to greet the new members of the Laboratory. Arlyn Andrews from Harvard and Scott Janz from UMBC joined the Atmospheric Chemistry and Dynamics Branch. Caroline Maswanganye joined 910 as a student aid.

These developments occurred in a time of transition for the Laboratory. This should be my last year as Acting Chief of the Laboratory for Atmospheres, as we hope to find my replacement in 2002. I wish to thank the senior staff and the secretaries for keeping the Laboratory running while my attention is drawn even more to the Directorate as a whole. I’m grateful to Walt Hoegy for orchestrating the assembly and publication of this report, and for helping Chuck Cote with the Laboratory operations. I especially wish to thank Chuck Cote for his tireless efforts in ensuring the Laboratory stays on an even keel. His expertise, gained from 40 years of work at Goddard, and his dedicated efforts as the Associate Chief of the Laboratory are an invaluable contribution to this Laboratory’s success.

Sincerely,

Franco Einaudi, Acting Chief, Laboratory for Atmospheres, Code 910
Director, Earth Sciences Directorate, Code 900
Phone: 301-614-6786
Fax: 301-614-6301
E-mail: franco.einaudi@gsfc.nasa.gov

TABLE OF CONTENTS

Mission: ***The Laboratory for Atmospheres is dedicated to advancing knowledge and understanding of the atmospheres of the Earth and other planets.***

1. INTRODUCTION

How can we improve our ability to predict the weather—tomorrow, next week, and into the future?

How is the Earth's climate changing? What causes such change? And what are its costs?

What can the atmospheres of distant planets teach us about our own planet and its evolution?

The Laboratory for Atmospheres is helping to answer these and other scientific questions about our planet and its neighbors. The Laboratory conducts a broad theoretical and experimental research program studying all aspects of the atmospheres of the Earth and other planets, including their structural, dynamical, radiative, and chemical properties.

Vigorous research is central to NASA's exploration of the frontiers of knowledge. NASA scientists play a key role in conceiving new space missions, providing mission requirements, and carrying out research to explore the behavior of planetary systems, including, notably, the Earth's. Our Laboratory's scientists also supply outside scientists with technical assistance and scientific data to further investigations not immediately addressed by NASA itself.

The Laboratory for Atmospheres is a vital participant in NASA's research program. The Laboratory is part of the Earth Sciences Directorate (Code 900) based at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The Directorate itself is comprised of the Global Change Data Center (902); the Earth and Space Data Computing Division (930); three laboratories—the Laboratory for Atmospheres (910), the Laboratory for Terrestrial Physics (920), and the Laboratory for Hydrospheric Processes (970); and the Goddard Institute for Space Studies (GISS) in New York, New York.

In this report, you'll find a statement of our philosophy and a description of our role in NASA's mission. You'll also find a broad description of our research and a summary of our scientists' major accomplishments in 2001. The report also presents useful information on human resources, scientific interactions, and outreach activities with the outside community.

For your convenience, we have published a version of this report on the Internet. Our Web site includes links to additional information about the Laboratory's Offices and Branches. You can find us on the World Wide Web at http://atmospheres.gsfc.nasa.gov/

2. PHILOSOPHY

As we carry out our work at the Laboratory for Atmospheres, we strive to honor the following values:

Individual Well-being

Personal Freedom

Individuals are free and encouraged to express their views and offer diverging opinions. Laboratory scientists submit research proposals with different technical or technological approaches and, in some cases, may even compete with one another. This freedom promotes creativity, competition, and openness.

Programmatic and Research Balance

Our Laboratory often has relatively large programs, sizable satellite missions, or observational campaigns that require the cooperative and collaborative efforts of many scientists. We aim to ensure an appropriate balance between our scientists' responsibility for these large collaborative projects and their need for an active individual research agenda. This balance allows members of the Laboratory to continuously improve their scientific credentials.

Research Quality

The Laboratory places high importance on promoting and measuring quality in its scientific research. We strive to assure high quality through peer-review funding processes that support approximately 90% of the work in the Laboratory. The overall quality of our scientific efforts is evaluated periodically by committees of advisors from the external scientific community, as detailed in Appendix 2 of this document.

Scientific Partnerships

Synergy Between Science and Technology

The Laboratory aims to increase its interaction with the Applied Engineering and Technology Directorate (AETD) through the formation of joint teams to develop new technologies and engineering solutions for scientific questions.

Goddard offers enormous opportunities for synergy between engineering and scientific expertise. Experimental activities are spread across the Laboratory to foster communication and to maximize the direct application of technology to scientific goals. In addition, a major effort is underway to increase our interactions with engineering groups outside the Laboratory. Healthy collaboration between our scientists and the Center's engineers is vital to our success in the competitive research environment in which we operate.

Interactions with Other Scientific Groups

The Laboratory depends on collaboration with the academic community, with other NASA Centers and Federal laboratories, and with foreign agencies. Section 5 discusses some of these relationships more fully. The Laboratory has MOUs (Memorandum of Understanding) with a number of universities for cooperative atmospheric science programs, and we have close ties with universities in the area through three centers: GEST (Goddard Earth Science and Technology) Center with UMBC (University of Maryland Baltimore County) and Howard

University; JCET (Joint Center for Earth Systems Technology) with UMBC; and ESSIC (Earth System Science Interdisciplinary Center) with UMCP (University of Maryland College Park).

Support for Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers, the project manager and the project scientist, who are the principal leaders of project management and science respectively.

The project scientist must provide continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Taking on the responsibilities of a project scientist provides a unique opportunity for Laboratory staff to obtain significant scientific management experience. Typically, the Laboratory invites candidates from the senior ranks to fill these roles.

Outreach and Education

Members of the Laboratory interact with the general public to support a wide range of interests in the atmospheric sciences.

Among other activities, the Laboratory raises the public's awareness of atmospheric science by presenting public lectures and demonstrations, by making scientific data available to wide audiences, by teaching, and by mentoring students and teachers.

Section 7 presents details of the Laboratory's outreach activities during 2001.

Human Resources

The Laboratory is committed to addressing the demographic imbalances that exist today in the atmospheric and space sciences. We must address these imbalances for our field to enjoy the full benefit of all the Nation's talent. To this end, the Laboratory always seeks qualified women and underrepresented ethnic groups when hiring new scientists and technologists. The Laboratory will continue to make substantial efforts to attract new scientists to the fields of atmospheric and space sciences.

Opportunities for the Commercial Sector

The Laboratory fully supports government/industry partnerships, Small Business Innovative Research (SBIR), and technology transfer activities. The Laboratory intends to devote at least 10% to 20% of its resources to joint activities with industry.

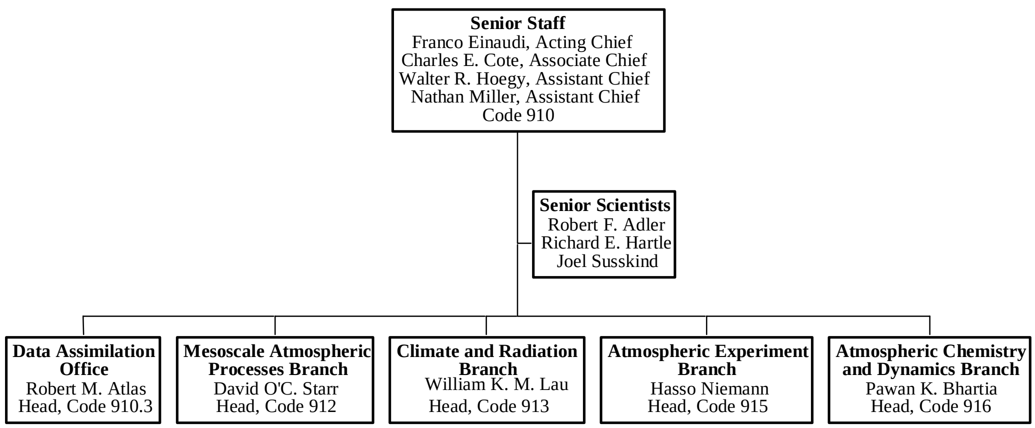
3. STAFF, ORGANIZATION, AND FACILITIES

Staff

As of this writing, the Laboratory staff consists of 101 civil servants. Of these, 77 are scientists, and 7 are engineers; 70 hold doctoral degrees. In addition, over the past year we hosted 97 visiting scientists from NRC, ESSIC, JCET, and GEST and 222 non-civil-service specialists supporting the various projects and research programs throughout the Laboratory.

Organization

Figure 1 shows the Laboratory organization.



Branch Descriptions

A brief description is given here for each of the Laboratory's five Branches. At the beginning of Section 6, the Head of each Branch summarizes that Branch's science highlights for 2001.

Data Assimilation Office (DAO), Code 910.3

The DAO combines all available meteorologically relevant observations with a prognostic model to produce accurate time-series estimates of the complete global atmosphere. The DAO performs the following functions:

- Advancing the state of the art of data assimilation and the use of data in a wide variety of Earth-system problems.
- Developing global data sets that are physically and dynamically consistent.
- Providing operational support for NASA field missions and Space Shuttle science.
- Providing model-assimilated data sets for the Earth Science Enterprise.

For additional information on DAO activities, consult the World Wide Web (http://dao.gsfc.nasa.gov/)

Mesoscale Atmospheric Processes Branch, Code 912

The Mesoscale Atmospheric Processes Branch studies the physics and dynamics of atmospheric processes, using satellite, aircraft, and surface-based remote-sensing observations as well as computer-based simulations. This Branch develops advanced remote-sensing instrumentation (with an emphasis on lidar) and techniques to measure meteorological conditions in the troposphere. Key areas of investigation are cloud and precipitation systems and their environments—from individual cloud systems, fronts, and cyclones, to regional and global climate. You can find out more about Branch activities on the World Wide Web (http://rsd.gsfc.nasa.gov/912/code912/).

Climate and Radiation Branch, Code 913

The Climate and Radiation Branch conducts basic and applied research with the goal of improving our understanding of regional and global climate. This group focuses on the radiative and dynamical processes that lead to the formation of clouds and precipitation and on the effects of these processes on the water and energy cycles of the Earth. Currently, the major research thrusts of the Branch are climate diagnostics, remote-sensing applications, hydrologic processes and radiation, aerosol/climate interactions, seasonal-to-interannual variability of climate, and biospheric processes related to the carbon cycle. You can learn more about Branch activities on the World Wide Web (http://climate.gsfc.nasa.gov/).

Atmospheric Experiment Branch, Code 915

The Atmospheric Experiment Branch carries out experimental investigations to further our understanding of the formation and evolution of various solar system objects such as planets, their satellites, and comets. Investigations address the composition and structure of planetary atmospheres, and the physical phenomena occurring in the Earth's upper atmosphere. We have developed and are constantly refining neutral gas, ion, and gas chromatograph mass spectrometers to measure atmospheric gas composition using entry probes and orbiting satellites. You can find further information on Branch activities on the World Wide Web (http://webserver.gsfc.nasa.gov/).

Atmospheric Chemistry and Dynamics Branch, Code 916

The Atmospheric Chemistry and Dynamics Branch engages in four major activities:

- Developing remote-sensing techniques to measure ozone and other atmospheric trace constituents important for atmospheric chemistry, climate studies, and air quality.
- Developing models for use in the analysis of observations.
- Incorporating results of analysis to improve the predictive capabilities of models.
- Providing predictions of the impact of trace gas emissions on our planet's ozone layer.

For further information on Branch activities, consult the World Wide Web (http://hyperion.gsfc.nasa.gov/).

Facilities

Computing Capabilities

Computing capabilities used by the Laboratory range from high-performance supercomputers to scientific workstations to desktop personal computers.

The supercomputers are operated for general use by the NASA Center for Computational Sciences (NCCS). Their flagship machine is a Cray T3E, with 512 DEC 21064 Alpha microprocessor processing elements, each with 64 Gbytes (Gb) of random access memory. Supercomputer resources are also available through special arrangement from NASA's Ames Research Center's Numerical Aerospace Simulation (NAS) facility.

Each Branch maintains a distributed system of workstations and desktop personal computers. The workstations are typically arranged in large clusters involving 30 or more machines. These clustered systems provide enormous computing and data storage capability, economical to maintain and easy to use. These machine clusters have been acquired to support specific programs, but may be made available for other research on a limited basis.

The Laboratory operates an autonomous ground station for continuously receiving, processing, and serving the Imager and Sounder radiometric data from the GOES satellites. The site also offers recent international geosynchronous satellite data from Japan (GMS-5), China (FY-2), and Europe (METEOSAT-5 and -7). In addition, we are developing a database of full-resolution radiances from India's geosynchronous satellite (INSAT).

Mass Spectrometry

The Laboratory for Atmospheres' Mass Spectrometry Laboratory is equipped with unique facilities for designing, fabricating, assembling, calibrating, and testing flight-qualified mass spectrometers used for atmospheric sampling.

The equipment includes precision tools and machining, material processing equipment, and calibration systems capable of simulating planetary atmospheres. The facility has been used to develop instruments for exploring the atmospheres of Venus, Saturn, and Mars (on orbiting spacecraft), and of Jupiter and Titan (on probes). The Mass Spectrometry Laboratory will also be used in support of comet missions. In addition, the Laboratory has clean rooms for flight instrument assembly and equipment for handling poisonous and explosive gases.

Lidar

The Laboratory has well-equipped facilities to develop lidar systems for airborne and ground-based measurements of aerosols, methane, ozone, water vapor, pressure, temperature, and winds.

Lasers capable of generating radiation from 266 nanometer (nm) to beyond 1,000 nm are available, as is a range of sensitive photon detectors for use throughout this wavelength region. The lidar systems employ telescopes with primaries up to 30 inches in diameter and high-speed counting systems for obtaining high vertical resolution. The Cloud, Aerosol, Lidar, Radiometer Laboratory has specialized facilities for optical instrument development, including optical tables, large auto-collimator, air handlers, and flow bench.

Lidars developed in the Laboratory include the Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL) to measure ozone, temperature, and aerosols; the Stratosphere Ozone Lidar Trailer Experiment (STROZ LITE), to measure atmospheric ozone, temperature, and aerosols; the Large Aperture Scanning Airborne Lidar (LASAL), to measure clouds and aerosols; the Cloud Physics Lidar (CPL), to measure clouds and aerosols; the Scanning Raman Lidar, to measure water vapor, aerosols, and cloud water; and the Edge Technique Wind Lidar System, to measure winds.

Radiometric Calibration and Development Facility

The Radiometric Calibration and Development Facility (RCDF) supports the calibration and development of instruments for space-based measurements, for Space Shuttle demonstration flights, and for new ozone-measurement techniques.

As part of the Earth Observing System (EOS) calibration program, the RCDF will provide calibrations for future Solar Backscatter Ultraviolet/version 2 (SBUV/2) and Total Ozone Mapping Spectrometer

(TOMS) instruments. Calibrations were conducted on the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), flying on European Space Agency's (ESA) Environmental Satellite (ENVISAT) mission (2001); ODIN Spectrometer and IR Imager System (OSIRIS), on the Canada/Sweden ODIN mission (2001); and the Mediterranean Israeli Dust Experiment (MEIDEX) shuttle instrument (2001). The facility also is the home of Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA) and Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE).

The RCDF contains state-of-the-art calibration equipment and standards traceable to the National Institutes of Standards and Technology (NIST). Calibration capabilities include wavelength, linearity, signal to noise (s/n), instantaneous field of view (IFOV), field of regard (FOR), and goniometry. The facility is also capable of characterizing such instrument subsystems as spectral dispersers and detectors. A tunable dye laser operating in the UV VIS is also used to measure optical filter characteristics with high accuracy and to characterize instrument throughput such as slit functions and wavelength registration.

The Facility includes a class-10,000 clean room with a continuous source of N_2 for added contamination control.

Skyrad measurements of the zenith sky radiance will be conducted from the Radiometric Calibration and Development Facility. Measurements will be made in the near UV and VIS using several spectrometers and radiometers including the SSBUV, which was previously flown on the Space Shuttle for inter-calibration of BUV ozone instruments. The purpose of these measurements is to revise the UV VIS radiative transfer code used in TOMS and SBUV retrievals, to refine their algorithms, and to provide cross calibration of present BUV instruments (TOMS, SBUV/2, and GOME) and future instruments such as SCIAMACHY, OMI, GOME-2, and OMPS.

A sky cloud camera is an Intel-based continuously operating electronic camera to record full-sky cloud conditions in support of all the ground-based instruments operating from the Earth System Science Building (Bldg. 33).

4. OUR WORK AND ITS PLACE IN NASA'S MISSION

NASA's Enterprises

NASA's overall program, as outlined in the Agency's strategic plan, is composed of five enterprises:

- Earth Science
- Space Science
- Aerospace Technology
- Biological and Physical Research
- Human Exploration and Development of Space

The Laboratory for Atmospheres concentrates on two of these, the Earth Science and Space Science Enterprises.

Earth Science

The mission of NASA's Earth Science Enterprise (ESE) is to develop our understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. Within this enterprise, the Laboratory for Atmospheres addresses both short-term weather forecasting and long-term climate studies. The wide array of our work reflects the Laboratory's history of atmospheric research, from the early days of weather satellites and emphasis on weather forecasting to our present focus on global climate change. Our goal is to increase the accuracy and lead-time with which we can predict weather and climate change.

In support of the U.S. Global Change Research Program and the U.S. Weather Research Program, the Earth Science divisions of the Earth Science Enterprise have established certain priorities:

- Atmospheric Chemistry
- Biology and Biogeochemistry of Ecosystems, and the Global Carbon Cycle
- Climate Variability and Prediction
- Global Water and Energy Cycles
- Solid Earth Science

The Laboratory for Atmospheres conducts basic and applied research in most of these priority areas.

Specifically, Laboratory scientists focus their efforts on the following areas:

- Aerosols and radiation
- Atmospheric hydrological processes
- Atmospheric ozone and trace gases
- Climate variability
- Mesoscale processes

Our work involves four primary activities or products: measurements, data sets, data analysis, and modeling. Table I depicts these activities and the topics they address.

Table I: Laboratory for Atmospheres Earth Science Activities

Measurements	Data Sets	Data Analysis	Modeling
Space Aircraft Balloon Ground Field campaigns	DAO assimilated products Global precipitation TOMS aerosols TOMS surface UV TOMS total ozone TOVS Pathfinder TRMM validation products	Aerosols Climate variability and climate change Clouds and precipitation Global temperature trends Ozone and trace gases Radiation UV-B measurements Validation studies	Atmospheric chemical Clouds and mesoscale Coupled climate/ocean General circulation Radiation transfer Retrievals and data assimilation

The divisions among measurements, data sets, data analysis, and modeling are somewhat artificial, in that activities in one area often affect those in another. These activities are strongly interlinked and cut across science priorities and the organizational structure of the Laboratory. The grouping corresponds to the natural processes of carrying out scientific research: ask the scientific question, identify the variable needed to answer it, conceive the best instrument to measure the variable, analyze the data, and ask the next question.

Space Science

The mission of NASA's Space Science Enterprise is to solve mysteries of the universe; explore the solar system; discover planets around other stars; search for life beyond Earth; chart the evolution of the universe; and understand its galaxies, stars, planets, and life. Within this enterprise, the Laboratory studies the evolution, composition, and dynamics of the atmospheres of other planets. We have flown instruments on the Atmosphere Explorers, Dynamics Explorer, Pioneer Venus Orbiter, and Galileo missions. These instruments have measured ion and neutral gas composition, neutral gas temperature and wind, and electron temperature and density.

Laboratory for Atmospheres scientists have completed work on two instruments flying on the Cassini mission. The Gas Chromatograph Mass Spectrometer (GCMS) will measure the chemical composition of gases and aerosols in the atmosphere of Titan. The Ion and Neutral Mass Spectrometer (INMS) will measure the chemical composition of positive and negative ions and neutral species in the inner magnetosphere of Saturn and in the vicinity of Saturn's icy satellites.

Laboratory scientists have also completed work on a Neutral Mass Spectrometer (NMS) to measure the neutral atmosphere of Mars. That instrument is being flown on a joint mission with Japan called *Nozomi*. *Nozomi* is scheduled to arrive at Mars in December 2003.

The Neutral Gas and Ion Mass Spectrometer (NGIMS) on the Comet Nucleus Tour (CONTOUR) mission was designed, built, and calibrated in our Laboratory. NGIMS was delivered to JHU/APL for integration on the CONTOUR spacecraft in December 2001. CONTOUR is scheduled for launch in July 2002. It will measure the abundance and isotope ratios for many neutral and ion species in the coma of each comet during the flyby. These measurements, together with data from a dust experiment on this mission, will contribute to our understanding of the chemical composition of the nucleus itself and will allow us to study differences between the comets. The first comet encounter, with Encke, is planned for November 2003.

5. MAJOR ACTIVITIES

In the previous section, we provided a snapshot of the activities we pursue in the Laboratory for Atmospheres. Let's have a closer look. This section presents a more complete picture of our work in measurements, data sets, data analysis, and modeling. In addition, we'll discuss the Laboratory's support for the National Oceanic Atmospheric Administration's (NOAA) remote sensing requirements. Section 5 concludes with a listing of our project scientists, a description of our interactions with other scientific groups, and an overview of our efforts toward commercialization and technology transfer.

Measurements

Studies of the atmospheres of our solar system's planets–including our own–require a comprehensive set of observations, relying on instruments on spacecraft, aircraft, balloons, and on the ground. All instrument systems perform one or both of these functions:

- Provide information leading to a basic understanding of the relationship between atmospheric systems and processes.
- Serve as calibration references for satellite instrument validation, or perform both functions.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations. Balloon and airborne platforms let us view such atmospheric processes as precipitation and cloud systems from a high-altitude vantage point but still within the atmosphere. Such platforms serve as a step in the development of spaceborne instruments.

Table II shows the principal instruments that have been built in the Laboratory or for which a Laboratory scientist has had responsibility as Instrument Scientist. The instruments are grouped according to the scientific discipline each supports. Table II also indicates each instrument's deployment—in space, on aircraft or balloons, or on the ground. Further information on each instrument appears on the pages following Table II.

Table II: Principal Instruments Supporting Scientific Disciplines in the Laboratory for Atmospheres

	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation	Planetary Atmospheres/Solar Influences
Space		Total Ozone Mapping Spectrometer (TOMS) - Earth Probe (EP) Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE) – Shuttle Earth Polychromatic Imaging Camera (EPIC) - Triana	COmpact Vis IR (COVIR) - Shuttle	Gas Chromatograph Mass Spectrometer (GCMS) – Cassini Huygens Probe Ion and Neutral Mass Spectrometer (INMS) – Cassini Orbiter Neutral Mass Spectrometer (NMS) – *Nozomi* Neutral Gas and Ion Mass Spectrometer (NGIMS) – Comet Nucleus Tour (CONTOUR)
Aircraft	ER-2 Doppler Radar (EDOP) Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)	Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL) Raman Airborne Spectroscopic Lidar (RASL)	Cloud Physics Lidar (CPL) Leonardo Airborne Simulator (LAS) Cloud Radar System (CRS)	
Ground/ Laboratory	Scanning Raman Lidar (SRL) Goddard Lidar Observatory for Winds (GLOW) Lightweight Rainfall Radiometer (LRR)	Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE) Tropospheric Ozone Lidar Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA) Aerosol and Temperature Lidar (AT Lidar) Brewer UV Spectrometer Goetz Radiometer SSBUV – Sky Radiance Aerosol Lidar (AL)	Micro Pulse Lidar (MPL) cloud THickness from Offbeam Returns (THOR) Lidar Scanning Microwave Radiometer (SMiR) Surface Measurements for Atmospheric Radiative Transfer (SMART) Sun-Sky-Surface photometer (3S)	

Spacecraft-Based Instruments

The ***Total Ozone Mapping Spectrometer (TOMS***) on Earth Probe (EP) continues to provide daily mapping and long-term trend determination of total ozone, surface ultraviolet (UV) radiation, volcanic SO_2, and UV-absorbing aerosols since 1996. For further information, contact Richard McPeters (Richard.D.McPeters.1@gsfc.nasa.gov).

The ***Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE)*** measures ozone profiles from the stratosphere down to the tropopause with high vertical resolution. SOLSE is a grating spectrometer that operates in the UV and visible wavelengths while LORE is a filter radiometer with channels in the UV and visible wavelengths. The instruments have been reconfigured in the Laboratory for Atmospheres' Radiometric Calibration and Development Facility to more accurately simulate the performance expected from the Ozone Mapper and Profiler System (OMPS) where both will measure high vertical resolution profiles in the stratosphere down to the tropopause. The OMPS is the ozone sounder instrument planned for the National Polar Orbiting Environmental Satellite System (NPOESS). A SOLSE/LORE reflight is manifested on STS 107 now scheduled for launch in 2002. The mission is partially funded by the Integrated Program Office as a risk mitigation activity for future ozone measurements. For information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov), or Richard McPeters (Richard.D.McPeters.1@gsfc.nasa.gov).

Earth Polychromatic Imaging Camera (EPIC) on Triana is a 10-channel spectroradiometer spanning the UV to the near-infrared (IR) wavelength range (317.5 to 905 nm). The main quantities measured are (1) column ozone, (2) aerosols (dust, smoke, volcanic ash, and sulfate pollution), (3) sulfur dioxide, (4) precipitable water, (5) cloud height, (6) cloud reflectivity, (7) cloud phase (ice or water), and (8) UV radiation at the Earth's surface. We will also measure other quantities related to vegetation, bi-directional reflectivity (hotspot analysis) and ocean color. EPIC has two unique characteristics: (1) EPIC takes the first spaceborne measurements from sunrise to sunset of the entire sunlit Earth and (2) EPIC performs the first simultaneous measurements in both the UV and visible wavelengths. These capabilities will allow us to determine diurnal variations and permit extended measurements of aerosol characteristics (2002). The Triana spacecraft and instruments are complete and tested for flight; however, they are temporarily in storage awaiting a flight opportunity. For further information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

COmpact Vis IR (COVIR) is an engineering model of an imaging radiometer for small satellite missions. The instrument is being developed under the Instrument Incubator Program (IIP) and will measure visible and IR wavelengths in the following ranges: 10.3-11.3 µm, 11.5-12.5 µm, 9.5-10.5 µm, and 0.67-0.68 µm. The system employs uncooled microbolometer focal plane detectors. The goal of COVIR is to enable future multisensor Earth-science missions to utilize smaller and lower-cost infrared and visible imaging radiometers. This will lead to improved cloud sensing through increased spatial resolution and coverage with spectral IR data. The design of COVIR is complete. Analysis was completed and a paper submitted on the results of infrared stereo cloud height retrieval by data acquired during the Infrared Spectral Imaging Radiometer shuttle hitchhiker experiment. For further information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The ***Gas Chromatograph Mass Spectrometer (GCMS)*** for the Cassini Huygens Probe will measure the chemical composition of gases and aerosols in the atmosphere of Titan (1997), starting in 2004. For further information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The ***Ion and Neutral Mass Spectrometer (INMS)*** on Cassini Orbiter will determine the chemical composition of positive and negative ions and neutral species in the inner magnetosphere of Saturn and in the vicinity of its icy satellites (1997), starting in 2004. For further information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The ***Neutral Mass Spectrometer (NMS)*** on the Japanese spacecraft *Nozomi* (Planet-B) will measure the composition of the neutral atmosphere of Mars to improve our knowledge and understanding of the energetics, dynamics, and evolution of the Martian atmosphere. The Nozomi spacecraft and mission were developed by the Japanese Institute of Space and Astronautical Science (1998). For further information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The ***Neutral Gas and Ion Mass Spectrometer (NGIMS)*** on the Comet Nucleus Tour (CONTOUR) mission has been calibrated and delivered to JHU/APL for launch in the summer of 2002. This instrument will provide detailed compositional data on both gas and dust in the near-nucleus environment at precisions comparable to those of Giotto or better (2002). For further information, contact Paul Mahaffy (Paul.R.Mahaffy.1@gsfc.nasa.gov).

Aircraft-Based Instruments

The ***ER-2 Doppler Radar (EDOP)*** is an X-band (9.6 GHz) system which measures vertical profiles of rain and winds within precipitation systems. It has been used for validation of spaceborne rain measurement algorithms used in TRMM and for providing improved understanding of the structure of mesoscale convective systems, hurricanes, and convective storms. It has been involved in 7 major field campaigns with the ER-2, including 3 TRMM validation efforts and 4 CAMEX convection and hurricane campaigns. For further information, contact Gerald Heymsfield (Gerald.M.Heymsfield.1@gsfc.nasa.gov).

The ***Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)*** measures cloud and aerosol structure and dynamics via laser backscatter in three dimensions. Utilizing a unique conical scanning holographic telescope and a diode pumped solid-state infrared laser, this compact high-performance lidar fits into low- to medium-altitude aircraft as well as in a portable ground-based environmental housing for relatively low-cost field experiment deployments. HARLIE was deployed to Wallops Island for the HARGLO wind intercomparison campaign. The next funded application is in an Army experiment in 2002 as a ground-based sensor to map dust plumes from troop activities at Fort Bliss in El Paso, Texas, to detect aerosol pollution. This will be followed by participation in IHOP during May–June in Oklahoma. Technical descriptions of the instrument and examples of data products are described on the HARLIE Web page: http://harlie.gsfc.nasa.gov/ For further information contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

The GSFC ***Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTEL)*** is a two wavelength lidar system (308 nm and 355 nm) that detects two elastically scattered wavelengths and N_2-Raman scattered radiation at 332 nm and 387 nm. The system uses 20 data channels spread over the four detected wavelengths. The instrument was on board the DC-8 during the SOLVE campaign in the winter of 1999/2000. Colleagues at NASA Langley Research Center contributed data channels for depolarization measurements at 532 nm and channels for aerosol backscatter at 1064 nm. Data products are aerosol backscatter and vertical profiles of ozone and temperature. We plan to install the AROTEL instrument on the DC-8 in another science and validation mission similar to SOLVE, which is scheduled to take place in the winter of 2002/2003, and will involve validation of SAGE III and other satellites. For further information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Raman Airborne Spectroscopic Lidar (RASL)*** was developed under NASA's Instrument Incubator Program (IIP) in collaboration with the Laboratory for Terrestrial Physics. The instrument will address a large number of high-priority atmospheric science measurement requirements, including water vapor, aerosol scattering, extinction, optical depth, depolarization, temperature, cloud liquid water amount and drop size, and cloud top and bottom heights. Through the use of a broadband spectrometer, full spectral tuning across the entire Raman band will also be possible, allowing us to attempt other experimental measurements such as cloud droplet temperature. For information contact David N. Whiteman (David.N.Whiteman.1@gsfc.nasa.gov).

The ***Cloud Physics Lidar (CPL)*** measures cloud and aerosol structure from the high-altitude ER-2 aircraft, in combination with multispectral visible, microwave, and infrared imaging radiometers. The instrument operates at 1064, 532, and 355 nm wavelengths with a repetition rate of 5 kHz. The data are used in radiation and remote-sensing studies. For further information, contact Matthew McGill (Matthew.J.McGill.1@gsfc.nasa.gov).

The ***Leonardo Airborne Simulator (LAS)*** is an imaging spectrometer (hyperspectral) with moderate spectral resolutions. LAS will measure reflected solar radiation to retrieve atmospheric properties such as column water vapor amount, aerosol loadings, cloud properties, and surface characteristics. This was successfully deployed in the SAFARI-2000 campaign in the vicinity of South Africa. The instrument will participate in the July 2002 CRYSTAL/FACE campaign in Florida. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

The ***Cloud Radar System (CRS)*** is a W-band (94 GHz) millimeter-wave Doppler radar system for measuring cirrus clouds and other precipitation regions with lower reflectivities (smaller particles) than detectable with conventional rain radars. The system is designed for high-altitude ER-2 operation and operates at the same frequency as the CLOUDSAT radar. The first planned flights are during the CRYSTAL/FACE field campaign during July 2002. For further information, contact Gerald Heymsfield (Gerald.M.Heymsfield.1@gsfc.nasa.gov).

Ground-Based and Laboratory Instruments

The ***Scanning Raman Lidar (SRL)*** measures light scattered by water vapor, nitrogen, oxygen, and aerosols to determine the water vapor mixing ratio, aerosol backscattering, and aerosol extinction, as well as their structure in the troposphere. Measurements from this mobile system are important for studying radiative transfer, convection, and the hydrological cycle. They are also useful for assessing the water and aerosol measurement capabilities of surface-, aircraft-, and satellite-based instruments.

Using the SRL, a new technique was devised for measuring cloud liquid water, mean droplet radius and droplet number density. A new extension to the theory was developed that allows multiple scattering to be quantified. The technique is based on simultaneously measuring Raman and Mie scattering from cloud liquid droplets using the Raman lidar. The intensity of Raman scattering is known to be proportional to the amount of liquid present in cloud droplets. This fact is used as a constraint on calculated Mie intensity to calculate droplet radius and number density. The general relationship of retrieved average radius and number density is consistent with traditional cloud physics models.

A new technique for measuring cloud base altitude using SRL data was also developed. The technique has advantages over conventional elastic backscatter lidar measurements of cloud base during precipitating periods. A combination of the Raman-lidar-derived profiles of water vapor-mixing ratio and aerosol-scattering ratio, together with the Raman-scattered signals from liquid drops, can minimize or even eliminate some of the problems associated with cloud-boundary detection using elastic lidars. For further information, contact David N. Whiteman (David.N.Whiteman.1@gsfc.nasa.gov)

The ***Goddard Lidar Observatory for Winds (GLOW)*** is a van-based mobile Doppler lidar system that measures vertical profiles of wind from the surface to the stratosphere using the direct-detection Doppler technique. The instrument operates at two wavelengths to measure winds using the laser energy backscattered from aerosols (wavelength=1064 nm) or molecules (wavelength=355 nm). The 1064 nm-channel data products are high spatial-resolution wind profiles in the planetary boundary layer (altitudes < 2km) and the 355 nm channel provides wind profiles in the free troposphere and stratosphere (altitudes as high as 35 km). For further information, contact Bruce Gentry (Bruce.M.Gentry.1@gsfc.nasa.gov).

The small ***Lightweight Rainfall Radiometer (LRR)*** is a laboratory development under the Instrument Incubator Proposal (IIP) Program. The radiometer will employ an advanced technology Synthetically Thinned Aperture Radiometer (STAR) antenna at 10.7 GHz for future measurements in space. The instrument will provide global high temporal-resolution precipitation measurements from a constellation of small satellites. For further information, contact Eric Smith (Eric.A.Smith.1@gsfc.nasa.gov).

The ***Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE)*** measures vertical profiles of ozone, aerosols, and temperature. The system collects elastically and Raman-scattered returns using DIfferential Absorption Lidar (DIAL). The instrument has participated in over a dozen international measurement campaigns, and is currently deployed to Lauder, New Zealand. For further information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Tropospheric Ozone Lidar*** will measure tropospheric ozone at wavelengths that have a large ozone-absorption cross-section. The system will provide validation data for research and development programs aimed at monitoring tropospheric ozone from space. The system is in development to be completed in early 2002. For further information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA)*** instrument is under development in the Atmospheric Chemistry and Dynamics Branch. The primary objective is high-resolution measurement of NO_2, SO_2, aerosol, and O_3. The core design is a wide field-of-view (FOV) front-end telescope that illuminates a filter/focal plane array (FFPA) package. For more information, contact Scott Janz (Scott.J.Janz.1@gsfc.nasa.gov).

The ***Aerosol and Temperature Lidar (AT Lidar)*** is a trailer-based instrument that makes measurements of vertical profiles of atmospheric aerosols and stratospheric temperature. Aerosol information is gathered at three wavelengths to provide particle size information. This instrument is being modified to include water vapor and in-cloud temperature capabilities. For further information, contact Thomas J. McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Brewer UV Spectrometer*** is an operational ground instrument for ozone and UV irradiance measurements. There are many deployed ground-based networks. The Goddard Brewer instrument will have improved calibration and operability for special field campaigns for use as a reference for other network brewer instruments. For further information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov),

Goetz Radiometer is a ruggedized filter UV radiometer with precision filters and electronics for unattended field use for total and profile ozone and UVB irradiance measurements. The long-term objective is to collect accurate ozone UV and data with low-cost, reliable and highly accurate hardware. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

SSBUV is an SBUV/2 instrument modified for shuttle flight and is now used for zenith sky radiance measurements as part of the Skyrad program. The instrument is a scanning UV spectrometer and has been used as a laboratory standard for prelaunch cross calibration for nearly all BUV-type instruments. For further information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

The ***Aerosol Lidar (AL)*** is a collaborative effort with JPL to build and deploy a small autonomous aerosol lidar for the Network for the Detection of Stratospheric Change. This lidar will transmit 1064 and 532 nm and will retrieve ozone profiles from both those wavelengths. It will also provide depolarization information to determine the physical state of aerosol particles. The first deployment of the lidar will be to a remote site on Christmas Island, near the equator, south of Hawaii. Data will be collected as continuously as possible for a year to gather information on the cloud climatology above the island. If this climatology proves to be satisfactory for atmospheric measurements, further development of the site by the NDSC may proceed. For further information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Micro Pulse Lidar (MPL)*** makes quantitative measurements of clouds and aerosols. MPL is a unique "eye-safe" lidar system that operates continuously (24 hours a day) in an autonomous fashion. Twenty instruments are currently deployed. In 2000, the MPL program was initiated for continuous lidar monitoring at globally distributed sites. For further information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The cloud ***THickness from Offbeam Returns (THOR)*** Lidar will determine the physical and optical thickness of dense cloud layers from the cloud Green's function, which is the halo of diffuse light up to 0.5 km from the entry point of a lidar beam incident on the cloud layer. Lidar returns at these wide angles are stronger for thicker clouds and are relatively insensitive to cloud microphysics. Cloud thickness is important because clouds provide the single largest internal forcing of the climate system, estimated to be 20 W/m^2 cooling on a global annual average, which is 5 times larger than forcing due to doubled CO_2. This cooling is due to the reflection of solar radiation by clouds, especially the extensive "marine stratocumulus" clouds common over the oceans west of the major landmasses. CLOUDSAT and CALIPSO, due in 2004, together may determine clouds' 3-D structure, for the Earth Observing System (EOS). THOR system provides an inexpensive alternate approach to measuring cloud vertical structure, that eventually can be carried out on unmanned aircraft (UAVs) and perhaps even in space. The reflected "halo" measured by THOR is now being employed in retrieval of cloud properties, using a "nonlocal" approach that improves on the usual "independent pixel approximation" used for standard EOS products. This instrument was funded in 2000 and 2001 under DDF (Directors Discretionary Funds) funding; it is now funded under an RTOP in the Radiation Sciences Program with an expected completion date of 2005. Robert Cahalan is the PI, Matthew McGill the CoI, and John Kolasinski of Code 565 is the Chief Engineer. Planned operations are a validation flight on the Wallops P3 at the Wallops ARM site in the spring of 2002; a co-fly with AMSR on the P3 in the summer of 2002 in the Antarctic night; an ER-2 certification in the fall of 2002; and an ER-2 mission in the spring of 2003. For further information, contact Robert Cahalan (Robert.F.Cahalan.1@gsfc.nasa.gov).

The ***Scanning Microwave Radiometer (SMiR)*** will measure the column amounts of water vapor and cloud liquid water using discrete microwave frequencies. This instrument was successfully deployed in the SAFARI campaign in 2000 and ACE–Asia in 2001. The instrument will be participating in the CRYSTAL/FACE campaign in July 2002. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

The ***Surface Measurements for Atmospheric Radiative Transfer (SMART)*** is a suite of surface remote-sensing instruments developed and mobilized to collocate with satellite overpass at targeted areas for retrieving physical/radiative properties of the Earth's atmosphere and for characterizing surface properties. The SMART includes many broadband radiometers, shadow-band radiometers, Sun photometers, solar spectrometers, a whole-sky camera, a micro pulse lidar, and a microwave radiometer, as well as meteorological probes for atmospheric pressure, temperature, humidity, and wind speed/direction. The system will participate in the

CRYSTAL/FACE campaign in July 2002. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

The ***Sun-Sky-Surface photometer (3S)*** is under development in collaboration with Biophysics Branch (Code 923) and Detector System Branch (Code 553). The 3S contains 14 discrete channels, ranging from the ultraviolet to shortwave-infrared spectral region, and scans the upper (atmosphere) and lower (surface) hemispheres during its operation. For further information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

Field Campaigns

Field campaigns typically use the resources of NASA, other agencies, and other countries to carry out scientific experiments or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2 and DC-8, serve as platforms from which remote-sensing and in situ observations are made. Ground systems are also used for soundings, remote sensing, and other radiometric measurements. In 2001, Laboratory personnel supported many such activities as scientific investigators, or as mission participants, in the planning and coordination phases. Field campaigns supported in this way include the following:

An ***Intercomparison of Wind Profile Systems*** involving the HARLIE and GLOW instruments was conducted by scientists from Code 912 at the Atmospheric Physics Measurement Laboratory at NASA Wallops Flight Facility. During the 4-day experiment, wind profile data products from these two lidars were obtained along with wind profile measurements from GPS rawinsondes, NWS rawinsondes, and the SPANDAR Doppler Radar for intercomparison. During the experiment (dubbed HARGLO-2), HARLIE operated nearly continuously while GLOW and SPANDAR provided extended scheduled operations under a variety of atmospheric conditions to produce a large database of wind measurements. For example, GLOW obtained over 27 hours of tropospheric wind profile data during the experiment. Multiple daily rawinsonde launches were also scheduled to supplement the regular twice-daily NWS launches. Both the lidars and SPANDAR operate on the ground looking up, scanning the sky in a conical mode with a 45-degree elevation angle. HARLIE is a 1-micron backscatter lidar utilizing a novel Holographic Optical Element (HOE) scanner, and GLOW is a UV Direct Detection Doppler lidar system. The two took complementary data, HARLIE obtaining its measurements under high aerosol loading and from clouds; and GLOW obtaining its best measurements in clear air using the Rayleigh backscatter from air molecules. SPANDAR obtains its signals from refractive index structure due to moisture and density gradients as well as clouds and aerosols. The rawinsondes derive their wind profiles from the self-tracking of their location during balloon ascent using GPS or Loran geo-location systems. This work was supported by the Integrated Program Office as part of an effort to establish a calibration/validation capability for future spaceborne wind lidar measurements. For further information, contact Mr. G. Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov) or Mr. Bruce Gentry (Bruce.M.Gentry.1@.gsfc.nasa.gov).

Scientists from Code 916 participated in an ***International Dobson Comparison*** organized by NIWA (the New Zealand National Institute of Water and Air Research). Two instruments were sent: a Brewer instrument which measures the total ozone column, and also performs Umkehr measurements to retrieve an ozone profile; and the Stratospheric Ozone Lidar which measures vertical profiles of ozone, aerosol and temperature in the stratosphere. The lidar instrument was able to provide these measurements throughout the night, in order to determine the temporal variability of these parameters. Other participants were NOAA from the U.S., NIWA from New Zealand and CSIRO from Australia. For further information, contact Dr. Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The TRMM Satellite Validation Office (TSVO) played a significant role in the ***Keys Area Microphysics Project (KAMP)***, which was part of the NASA's Convection and Moisture Experiment (CAMEX)-4, based in Jacksonville, Florida. KAMP was based in the middle and lower Florida Keys. The TSVO took the opportunity during this program to develop contacts and lay the framework for utilizing the Keys area as a primary Ground Validation (GV) site for TRMM by installing a network of rain gauges and disdrometers to complement radar observations by the permanent WSR-88D radar operated by the Key West Weather Forecast Office, as well as two NASA radars deployed specifically for the experiment. In all, 28 rain gauges were placed and located in several clusters on several different Keys (Big Pine, Big Torch, Cudjoe, Marathon, No Name, Ramrod, Sugarloaf, and Summerland). Four Joss-Waldvogel disdrometers were also deployed, all of which were collocated with rain gauge clusters of two or more gauges. One of the principal goals of the TSVO during KAMP was to show that the radar, gauge and disdrometer data could be quality controlled, processed and distributed in near real-time. This goal was achieved and is documented in the Web site http://trmm-fc.gsfc.nasa.gov/Field_Campaigns/KAMP. For further information, contact Mr. Rich Lawrence (Richard.J.Lawrence.1@gsfc.nasa.gov).

The TOMS group in the Atmospheric Chemistry and Dynamics Branch (Code 916) conducted *a total column ozone intercomparison campaign* in Fairbanks, Alaska, ***TOMS3-F***, to understand the cause of persistent differences between the total column ozone measured by TOMS and ground-based instruments. This location was chosen because these differences appear to be larger under conditions of high ozone, and in Alaska in March ozone is frequently 50% higher than normal— 450 Dobson Units (DU) or more compared to the global average of about 300 DU.

The University of Alaska at Fairbanks hosted the comparison, while Steve Lloyd, Johns Hopkins University, acted as coordinator. Participants included NOAA/CMDL, which brought the World Standard Dobson instrument I83, and the Canadian Atmospheric Environment Service, which brought Brewer Instrument #85, their traveling standard instrument. Information on the vertical profiles of ozone and temperature is critical, so balloon-borne ECC ozonesondes were launched daily by University of Alaska Fairbanks and NOAA/CMDL personnel. Comparisons were also made with ozone profiles from the NOAA 16 SBUV/2 instrument and the NRL POAM instrument.

Initial results show that Brewer total column ozone was on average about 1% higher than TOMS ozone, while Dobson ozone was consistently about 2% lower. Analysis is being done to show how much of the differences between Dobson and TOMS and Brewer can be explained. The Dobson algorithm uses a single climatological temperature, and if the actual temperature deviates significantly, the effective ozone cross section is wrong. High ozone at high latitude is usually associated with very low stratospheric temperatures, which can lead to an underestimate of ozone by Dobson. Both TOMS and Brewer use a latitude- and altitude-dependent temperature climatology. Data from this intercomparison should help resolve the cause of some of the observed differences. For further information, contact Dr. Richard McPeters (Richard.D.McPeters.1@gsfc.nasa.gov).

Scientists from Code 916 played a key role in the ***International Aerosol Characterization Experiments in the Asian Pacific Region (ACE–Asia)***. The campaign is designed to study the compelling variability in spatial and temporal scales of pollution and naturally occurring aerosols over eastern Asia and the western rim of the Pacific. Scientists were responsible for providing model aerosol forecasts to guide daily flight planning. The Georgia Tech/Goddard Global Ozone Chemistry Aerosol Radiation and Transport (GOCART) model was one of the 3 models used in the field (the other 2 were the NCAR MATCH model and the U. Iowa/U. Kyushi RAMS model).

It has been shown that the constituents forecasting is a very useful tool and played a key role for the field operation, and it will be an indispensable part for the future field missions. The measurements also provide an instantaneous evaluation of the model prediction. The close connection of models and daily field operation benefits both sides. During ACE–Asia, the transport of dust and pollution from the Asian continent was observed on every flight with high concentrations and highly inhomogeneous distributions. The general features were that at low altitudes (below 1 km), most aerosols were pollution aerosols (sulfate and carbonaceous, etc.) which were mixed with dust at higher altitudes, but dust was the major aerosol at altitudes 4 km or above. For further information, contact Mian Chin (Mian.Chin.1@gsfc.nasa.gov).

In April the ***Goddard MP Lidar Network Site*** operated by Code 912 detected an unusual elevated layer of haze considered to be Asian dust that has been transported across the Pacific and North America. It is thought to be the first such observation for the East Coast. Coincidentally the Aerosol Characterization Experiment–Asia (ACE–Asia) was in progress with MP lidars operating in Western China and on the NOAA ship Ron Brown off the coast of Japan. Another MPL site is in Oklahoma. These instruments were intended to track development of the dust layer from its source. Near real-time screen images from the Goddard MPL system can be seen at the following link: http://virl.gsfc.nasa.gov/cgi-bin/Mplnet/nssl.cgi/GSFC/. For further information, contact Dr. James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

Real-time cloud ceiling height information was available to pilots during a rare nighttime landing at the Amundsen-Scott South Pole Research Station to evacuate the station's ailing doctor. A Code 912-operated ***Micro Pulse Lidar (MPL)*** housed at the South Pole since December 1999 provided researchers with extended measurements of optical properties in the lower polar atmosphere. The lidar instruments are highly sensitive to the presence of cloud particles and are inherently effective in giving accurate measurements of cloud base heights. This information could be extremely important to pilots attempting to land at the Pole due to the lack of any sunlight and few distinguishing ground markers near the station. The site meteorologist and communications team in charge of communicating with the pilots will have real-time access to the lidar readings thus allowing them to relay the most up-to-the-moment cloud information to the pilots as they prepare and execute their descent and landing at the Pole. More information: http://virl.gsfc.nasa.gov/mpl-net/. For further information, contact Mr. James Campbell (James.Campbell.1@gsfc.nasa.gov).

The ***TRACE-P*** Science Team designed the flight tracks for the NASA P3B and DC-8 over the first weekend of operations in late February, from the chemical forecasts provided by the Harvard TRACE-P team, using the forecast products from the Goddard DAO. The flights were seeking an Asian CO plume located at 135W, 43N, according to the forecast. Near real-time forecast products were used to predict regions of high and low carbon monoxide and ozone. Flights were then directed to these targets, with the goal of understanding the production and outflow of polluted air off of the Asian continent. The flight team cited numerous times when the ability of the DAO system to represent frontal structures and related convective activity has led to successful missions. The DAO specifically developed numerical schemes to represent meteorological realism, and this served as verification of projected model capabilities. For further information, contact Dr. Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

The ***South Pole Experiment*** site is part of the MPL-Network and an important part of preparations for the GLAS satellite mission. The lidar continuously monitors the structure and properties of clouds. In order to characterize the effect of clouds for the upcoming GLAS mission, the experiment included angular scans through vertical to measure the lidar signal increase at zenith from gravitationally aligned ice crystals. The Micro Pulse Lidar data show the presence and height structure of Polar Stratospheric Clouds (PSCs) for most of the 2001 austral winter. PSCs were initially found at 16 to 20 km altitudes in June. In addition to PSCs, blowing snow clouds extending from the surface to 10 to 200 meters altitude were almost continuously present during the winter. The South Pole Experiment is in collaboration with the University of Washington and is believed to be the first full-time lidar monitoring in Antarctica. Ref. http://virl.gsfc.nasa.gov/mpl-net/. For further information, contact Dr. James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The SSBUV has seen the sky for the first time since 1996 on its last shuttle flight. Under a new Code 916 program, ***Skyrad***, the instrument observed zenith sky radiances in the UV from the RCDF clean room. The objective of this program is to collect data to improve radiative transfer models and algorithms. They are used by TOMS, SBUV, ground-based Dobson and Umkehr sensors and to perform validations for TOMS, SBUV/2, and Envisat SCIAMACHY (to be launched this October). The technique could be applicable to future operational ozone sounders (NPOESS-US, Eumetsat-Europe, and GCOM-Japan). For further information, contact Mr. Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

NASA sponsored the ***Convection and Moisture Experiment 4 (CAMEX-4)*** which focused on hurricane research in the eastern Atlantic region. The campaign was conducted jointly with NOAA and university scientists, and was under the U.S. Weather Research Program (USWRP) hurricane landfalling program. One of the high-priority goals of Goddard scientists in Code 912 and UMBC/JCET and GEST scientists was to measure high-altitude temperature and wind measurements simultaneously with radar measurements of the hurricane. The NASA ER-2 and DC-8 aircraft were instrumented with numerous remote sensing and in situ instruments to provide high resolution, detailed measurements of the structure of hurricanes. Two instruments played a key role in measuring the warm core of a mature hurricane. The Goddard ER-2 Doppler Radar (EDOP) is a downward-looking instrument that measures radar reflectivity and vertical velocity in precipitation regions. The ER-2 High-altitude Dropsonde system (EHAD) was a joint effort between JCET and NCAR. High-altitude dropsondes were released by EHAD into a hurricane while simultaneous radar measurements were taken by EDOP. These data sets are being analyzed to more fully understand the dynamics related to hurricane intensification. For further information, please contact Dr. Gerald Heymsfield (Gerald.M.Heymsfield.1@gsfc.nasa.gov) or Dr. Jeffrey Halverson (Jeffrey.B.Halverson.1@gsfc.nasa.gov).

Data Sets

In the previous discussion, we examined the array of instruments we use to gather weather and climate data. Once we have obtained the raw data from these instruments, we arrange the information into data sets useful for studying various atmospheric phenomena.

TIROS Operational Vertical Sounder Pathfinder

The Pathfinder Projects are joint NOAA/NASA efforts to produce multiyear climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is the TIROS Operational Vertical Sounder (TOVS). TOVS is comprised of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 to the present, using an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The TOVS Pathfinder Path A data set covers the period 1979–2001 and consists of global fields of surface skin and atmospheric temperatures, atmospheric water vapor, cloud amount and cloud height, OLR and clear sky OLR, and precipitation estimates. The data set includes data from TIROS N, and NOAA 6,7,8,9,10,11,12, and 14. Equivalent future data sets will be produced from

NOAA 15 and 16 ATOVS data and from AIRS data on EOS Aqua. We have demonstrated that TOVS data can be used to study interannual variability of surface and atmospheric temperatures and humidity, cloudiness, OLR, and precipitation. We have developed the 22-year TOVS Pathfinder Path A data set. The TOVS precipitation data is being incorporated in the monthly and daily GPCP precipitation data sets. We are developing improved methodologies to analyze ATOVS data to produce a future climate data set and also to use in conjunction with the DAO data assimilation system to improve analyses and numerical weather prediction skill. We have also developed the methodology to be used by the AIRS science team to generate products from AIRS for weather and climate studies. In joint work with the DAO, the AIRS sounding products will be assimilated into the DAO GEOS 3 system to demonstrate how well the AIRS data will improve weather prediction skill. For more information, contact Joel Susskind (Joel.Susskind.1@gsfc.nasa.gov).

Tropospheric Ozone Data

Gridded data sets on tropospheric column ozone (TCO) and stratospheric column ozone (SCO) in the tropics for 1979–present are now available from NASA Goddard Space Flight Center via either direct ftp, World Wide Web, or electronic mail. Until recently, the primary method to derive TCO and SCO from satellite data was by combining TOMS and SAGE ozone measurements. At NASA Goddard, monthly averaged TCO and SCO data are derived in the tropics for January 1979–present using the convective cloud differential (CCD) method [Ziemke et al., J. Geophys. Res., 103, 22115-22127, 1998]. Further details regarding methodology and new adjustments made for aerosol contamination are discussed in Ziemke et al. [Bull. Amer. Meteorol. Soc., 81,580-583, 2000; J. Geophys. Res., 9853-9867, 2001]. These data have recently been used in several published studies within Code 916 to characterize tropospheric ozone variabilities from monthly to decadal time scales. The CCD, TCO, and SCO data may be obtained via World Wide Web (http://hyperion.gsfc.nasa.gov/Data_services/Data.html). For more information, contact Jerry Ziemke (Jerald.R.Ziemke.1@gsfc.nasa.gov) or Sushil Chandra (Sushil.Chandra.1@gsfc.nasa.gov).

Aerosol Products from the Total Ozone Mapping Spectrometer

Laboratory scientists are generating a unique new data set of atmospheric aerosols by reanalyzing the 17-year data record of Earth's ultraviolet albedo as measured by the TOMS. Since 1996, Laboratory staff members have developed techniques for extracting aerosol information from measured UV radiances. The UV technique differs from conventional visible methods in that the UV measurements can reliably separate UV absorbing aerosols (such as desert dust and smoke from biomass burning) from nonabsorbing aerosols (such as sulfates, sea-salt, and ground-level fog). In addition, the UV technique can measure aerosols over land and can detect all types of aerosols over snow/ice and clouds.

TOMS aerosol data are currently available in the form of a contrast index (and now as optical depth). The index provides excellent information about sources, transport, and seasonal variation of a variety of aerosol types. Work is currently in progress to release the data relating the index to aerosol optical thickness and single-scatter albedo.

Recently, new methods have been developed to quantitatively detect aerosols using SeaWiFS visible channels over many types of land surfaces as well as the oceans. Because of the high spatial resolution (1 km) we are now able to investigate the sources of dust and smoke by combining the data with calculations from high-resolution transport models. An example of this type of analysis has been made showing dust flowing through mountain passes in Afghanistan and Iran. The aerosol data is also being used to assess the degree of radiative forcing (excess heating) in the atmosphere caused by the presence of dust. The results are used to estimate heating rates related to climate change. For more information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

Multiyear Global Surface Wind Velocity Data Set

The Special Sensor Microwave Imagers (SSM/I) aboard three Defense Meteorological Satellite Program (DMSP) satellites have provided a large data set of surface wind speeds over the global oceans from July 1987 to the present. These data are characterized by high resolution, coverage, and accuracy, but their application has been limited by the lack of directional information. In an effort to extend the applicability of these data, the DAO developed methodology to assign directions to the SSM/I wind speeds and to produce analyses using these data. This methodology has been used to generate a 14-year data set (from July 1987 through June 2001) of global SSM/I wind vectors. These data are currently being used in a variety of atmospheric and oceanic applications and are available to interested investigators. For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Global Precipitation Data Set

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing intra-annual and interannual climatic fluctuations on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory have led the GPCP effort to merge microwave data from low-Earth-orbit satellites, infrared data from geostationary satellites, and data from ground-based rain gauges to produce the best estimates of global precipitation.

Version 2 of the GPCP merged data set provides global, monthly precipitation estimates for January 1979–present. Updates are being produced on a quarterly basis. The release includes input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at World Data Center A (located at the National Climatic Data Center in Asheville, North Carolina), at the Goddard Distributed Active Archive Center (DAAC), and at the Global Precipitation Climatology Centre (located at the Deutscher Wetterdienst in Offenbach, Germany). Evaluation is ongoing for this long-term data set in the context of climatology, ENSO-related variations and trends, and comparison with the new TRMM observations. Development of data sets with finer time resolution (daily and 3-hr) is proceeding. A daily, global analysis for 1997–present has also been completed for the GPCP and is available from the archives. A 3-hr resolution rainfall analysis combining TRMM and other satellite data is being developed and is currently being tested. For more information, contact Robert Adler (Robert.F.Adler.1@gsfc.nasa.gov).

SHADOZ (Southern Hemisphere ADditional OZonesondes) Data Set

The first-archived data set dedicated to tropical and subtropical ozonesonde profiles is coordinated in Code 916 within the Laboratory. Initiated in 1998 as a unique effort to fill in gaps in the tropical ozone profile record, SHADOZ (Southern Hemisphere ADditional OZonesondes) meets community needs for development of ozone retrieval satellite algorithms, validation of new ozone products, global chemical-transport model evaluation and for basic understanding of ozone in the tropics [Thompson et al., 2002]. With weekly ozonesonde launches at 10 tropical stations, and occasional tropical field campaigns, SHADOZ supplies high-quality ozone and temperature profiles to ~35 km and relative humidity to 12 km. In less than 4 years, over 1300 profiles have been added to the world's ozone data record. Thompson, A.M., et al., The 1998–2000 SHADOZ

(Southern Hemisphere ADditional OZonesondes) Ozone Climatology. 1. Comparison with TOMS and ground-based measurements, J. Geophys. Res., in press, 2002. For more information, contact Anne Thompson (Anne.M.Thompson.1@gsfc.nasa.gov).

Multiyear Data Set of Satellite-Based Global Ocean Surface Turbulent Fluxes

The fluxes of momentum (or wind stress), latent heat (due to evaporation), and sensible heat, called turbulent fluxes, at the global ocean surface are essential to weather, climate, and ocean problems. These fluxes are required for driving ocean models and validating coupled ocean-atmosphere global models, as well as performing climate studies. The Special Sensor Microwave/Imagers (SSM/I) aboard a series of Defense Meteorological Satellite Program (DMSP) satellites have provided near-global coverage with improved coverage, spatial resolution, and accuracy over prior passive microwave instruments. Laboratory scientists have developed methodology to produce a Version 2 data set of Goddard Satellite-Based Surface Turbulent Fluxes (GSSTF-2) from the SSM/I radiances and other data. It provides daily- and monthly-mean turbulent fluxes and some relevant parameters over global oceans for the period July 1987–December 2000 and the 1988–2000 annual- and monthly-mean climatologies of the same variables. These variables are wind stress, latent heat flux, sensible heat flux, 10-m wind speed, 10-m specific humidity, sea-air humidity difference, and lowest 500-m bottom-layer precipitable water. Its spatial resolution is 1° latitude x 1° longitude. The data set is archived at the Goddard Distributed Active Archive Center (DAAC) and participates in the Ocean Surface Turbulent Flux Project (SEAFLUX) for comparison with other flux data sets. For more information, contact Shu-Hsien Chou (Shu-Hsien.Chou.1@gsfc.nasa.gov).

Data Analysis

Atmospheric Ozone Research

The Clean Air Act Amendment of 1977 assigned NASA major responsibility for studying the ozone layer.

Data from many ground-based, aircraft, and satellite missions are combined with meteorological data to understand the factors that influence the production and loss of atmospheric ozone. Analysis is conducted over different temporal and spatial scales, ranging from studies of transient filamentary structures that play a key role in mixing the chemical constituents of the atmosphere to investigations of global-scale features that evolve over decades.

The principal goal of these studies is to understand the complex coupling between natural phenomena, such as volcanic eruptions and atmospheric motions, and human-made pollutants, such as those generated by agricultural and industrial activities. These nonlinear couplings have been shown to be responsible for the development of the well-known Antarctic ozone hole.

An emerging area of research is to understand the transport of chemically active trace gases across the tropopause boundary. It has been suggested that changes in atmospheric circulation caused by greenhouse warming may affect this transport and, thus, delay the anticipated recovery of the ozone layer in response to phase-out of CFCs. For more information, contact Paul A. Newman (Paul.A.Newman.1@gsfc.nasa.gov).

Total Column Ozone and Vertical Profile

Laboratory for Atmospheres scientists have been involved in measuring ozone since the late 1960s when a satellite instrument, the Backscatter Ultraviolet (BUV) Spectrometer, was launched on NASA's Nimbus-4 satellite to measure the column amount and vertical distribution of ozone. These measurements are continuing aboard several follow-on missions launched by NASA, NOAA, and, more recently, by the ESA.

An important activity in the Laboratory is developing a high-quality, long-term ozone record from these satellite sensors and comparing that record with ground-based and other satellite sensors. This effort, already more than a quarter century in duration, has produced ozone data sets that have played a key role in identifying the global loss of ozone due to certain human-made chemicals. This knowledge has contributed to international agreements to phase out these chemicals by the end of this century. For more information, contact Pawan K. Bhartia (Pawan.K.Bhartia.1@gsfc.nasa.gov).

Surface UV Flux

The primary reason for measuring atmospheric ozone is to understand how the UV flux at the surface might be changing and how this change might affect the biosphere. The sensitivity of the surface UV flux to ozone changes is calculated using atmospheric models and the measured values of ozone, aerosol, and cloud amounts. Yet, until recently, we had no rigorous test of these models, particularly in the presence of aerosols and clouds. By comparing a multiyear data set of surface UV flux generated from TOMS data and high-quality ground-based measurements, especially those from a cooperative effort with the U.S. Department of Agriculture, we are increasingly able to quantify the respective roles of ozone, aerosols, and clouds in controlling the surface UV flux over the globe. While the agreement between satellite and ground-based measurements of surface UB flux is becoming good, the satellite data covers regions not normally accessible by the ground-based instruments (e.g., oceans, deserts, etc.). We have recently extended the analysis of UV flux for penetration into the deep oceans and coastal regions. For more information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

Data Assimilation

The DAO in the Laboratory has taken on the challenge of providing to the research community a coherent, global, near real-time picture of the evolving Earth system. The DAO is developing a state-of-the-art Data Assimilation System (DAS) to extract the usable information available from a vast number of observations of the Earth system's many components, including the atmosphere, the oceans, the Earth's land surfaces, the biosphere, and the cryosphere (ice sheets over land or sea).

The DAS is made of several components including an atmospheric prediction model, a variational physical space analysis scheme, and models to diagnose unobservable quantities. Each of these components requires intense research, development, and testing. Much attention must be given to insuring that the components interact properly with one another to produce meaningful, research-quality data sets for the Earth system science research community. (See later section on Modeling). For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov) .

Observing System Simulation Experiments

Since the advent of meteorological satellites in the 1960s, considerable research effort has been directed toward designing space-borne meteorological sensors, developing optimum methods for using satellite soundings and winds, and assessing the influence of satellite data on weather prediction. Observing system simulation experiments (OSSE) have played an important role in this research. Such studies have helped in designing the global observing system, testing different methods of assimilating satellite data, and assessing the potential impact of satellite data on weather forecasting.

At the present time, OSSEs are being conducted to (1) provide a quantitative assessment of the potential impact of currently proposed space-based observing systems on global change research, (2) evaluate new methodology for assimilating specific observing systems, and (3) evaluate tradeoffs in the design and configuration of these observing systems. Specific emphasis over the past year has been on space-based lidar winds and advanced passive sensors. For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Seasonal-to-Interannual Variability and Prediction

One of the main thrusts in climate research in the Laboratory is to identify natural variability on seasonal, interannual, and interdecadal time scales, and to isolate the natural variability from the human-made global-change signal. Climate diagnostic studies use a combination of remote-sensing data, historical climate data, model outputs, and assimilated data. Climate diagnostic studies will be combined with modeling studies to unravel physical processes underpinning climate variability and predictability. The key areas of research include the El Niño Southern Oscillation (ENSO), monsoon variability, interseasonal oscillation, and water vapor and cloud feedback processes. A full array of standard and advanced analytical techniques, including wavelets transform, multivariate empirical orthogonal functions, singular value decomposition, canonical correlation analysis, and nonlinear system analysis are used.

The Laboratory, in conjunction with the Laboratory for Hydrospheric Processes (Code 970), plays a lead role in NASA's Seasonal-to-Interannual Prediction Project (NSIPP). NSIPP promotes and facilitates collaboration between NASA and outside scientists in developing a coupled ocean-atmosphere-land modeling system to predict El Niño events, and their impacts on the extratropics by utilizing a combination of satellite and in situ data. NSIPP will also employ a high-resolution atmosphere-land data assimilation system that will capitalize on a host of new high-resolution satellite data including MODIS and Landsat. This capability will allow scientists to better characterize the local and remote physical processes that control regional climates and limit predictability.

Promoting the use of satellite data for better interpretation, modeling and eventually prediction of geophysical and hydroclimate system is a top priority of research in the Laboratory. Satellite-derived data sets for key hydroclimate variables such as rainfall, water vapor, clouds, surface wind, sea surface temperature, sea level heights, land surface characteristics from the EOS Terra and Aqua series, from TRMM, QuikSCAT and TOPEX/Poseidon and Jason-1, as well as from the Earth Radiation Budget Experiment (ERBE), the International Satellite Cloud Climatology Project (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), SSM/I, MSU, and TOVS Pathfinder data will be used extensively for diagnostic and modeling studies. For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Rain Measurements

Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the Advanced Microwave Scanning Radiometer (AMSR) on EOS Aqua.

The retrieval techniques include the following: (1) A physical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface. This multifrequency technique also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations. (2) An empirical relationship that relates cloud thickness and other parameters to rain rates, using TOVS sounding retrievals. (3) An analysis technique that uses low-orbit microwave, geosynchronous infrared, and rain gauge information to provide a merged, global precipitation analysis. The merged analysis technique is now being used to produce global daily and tropical 3-hourly analyses.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, the climatological contribution of tropical cyclone rainfall, and the validation of global models. For more information, contact Robert Adler (Robert.F.Adler.1@gsfc.nasa.gov).

Rain Measurement Validation for the TRMM

The objective of the TRMM Ground Validation Program (GVP) is to provide reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained at GV sites is available via the Goddard DAAC. With these products, the validity of TRMM measurements will be established with accuracies that meet mission requirements. For more information, contact Robert Adler (Robert.F.Adler.1@gsfc.nasa.gov).

Predicting Errors in Satellite Rainfall Measurements

To use TRMM maps of monthly rainfall, we need some measure of the accuracy of the satellite average. We have developed a statistical model of rain behavior that predicts that the random error in satellite rainfall averages–not including systematic biases that might be present–should depend in a straightforward way on the local average rain amounts and simple measures of rain variability. We have seen behavior consistent with the prediction in a number of studies based on simulations using rain gauges and radar data. The model prediction has recently been confirmed using rain observations from the Defense Meteorological Satellite Program satellites. Based on the model, we are developing a simple method of estimating the error levels in satellite rainfall so that satellite rain products can be accompanied by documented estimates of intrinsic error in the averages provided. For more information, contact Thomas L. Bell (Thomas.L.Bell.1@gsfc.nasa.gov).

Reference:

Bell, T.L., P.K. Kundu, and C.D. Kummerow, 2001: Sampling Errors of SSM/I and TRMM Rainfall Averages: Comparison with Error Estimates from Surface Data and a Simple Model. J. Appl. Meteor., 40, 938-954.

Aerosols/Cloud Climate Interactions

Theoretical and observational studies are being carried out to analyze the optical properties of aerosols and their effectiveness as cloud condensation nuclei. These nuclei produce different drop size distributions in clouds, which, in turn, will affect the radiative balance of the atmosphere.

We developed algorithms to routinely derive aerosol loading, aerosol optical properties, and total precipitable water vapor data products from the EOS-Terra Moderate Resolution Imaging Spectroradiometer (MODIS). These algorithms are being evaluated, modified, and verified using the global MODIS data and information from the Aerosol Robotic Network (AERONET) of sun/sky radiometers. MODIS and AERONET data are being used to evaluate the global distribution of aerosols, their properties, and their radiative forcing of climate. Evaluation of the MODIS aerosol data with AERONET shows that they are as accurate as predicted in papers from 1997 and that MODIS and Landsat data are also used to measure a key aerosol property important to understanding climate change—namely aerosol absorption of sunlight. Measurements of absorption of sunlight by Saharan dust particles show that they absorb only 1/3 as much as the value previously used in models of the last decade. This change in dust's absorption properties suggests it has a much stronger effect on the Earth's energy balance than previously suspected. For more information, contact Yoram Kaufman (Yoram.J.Kaufman.1@gsfc.nasa.gov).

Laboratory scientists are actively involved in analyzing data recently obtained from national and international campaigns. These campaigns include the Puerto Rico Dust Experiment (PRiDE) which observed transported Saharan dust in the Caribbean, the Southern Africa Fire-Atmosphere Research Initiative (SAFARI) 2000 which characterized aerosols from southern African biomass burning, and the Chesapeake Lighthouse Aircraft Measurements for Satellites (CLAMS) which was an excellent opportunity to characterize both aerosol and various ocean surface conditions off the East Coast of the United States. For more information, contact Lorraine Remer (Lorraine.A.Remer.1@gsfc.nasa.gov).

Hydrologic Processes and Radiation Studies

Scientists in the Climate and Radiation Branch of the Laboratory are developing methods to estimate atmospheric water and energy budgets. These methods include calculating the radiative effects of absorption, emission, and scattering by clouds, water vapor, aerosols, CO_2, and other trace gases. Algorithms for global measurements of aerosol thickness are developed from MODIS data. Calibration/validation and scientific experiments on aerosols and clouds are conducted in various climatic regions of the world, with ground-based and airborne instruments, e.g., the SAFARI experiment in South Africa, PRiDE in Puerto Rico, and ACE–Asia in central Asia. Also developed are arrays of highly mobile and versatile measurement platforms for direct measurements of surface radiation, water vapor and cloud properties for deployments in field campaigns, e.g., Surface Measurements for Atmospheric Radiation Transfer (SMART) and the off-beam lidar (THOR) for cloud thickness measurements.

Using long-term satellite and satellite-blended data and four-dimensional assimilated data, Laboratory scientists study the response of radiation budgets to changes in water vapor and clouds during El Niño events in the Pacific basin and during westerly wind-burst episodes in the western tropical Pacific warm pool. Also investigated are the relative importance of large-scale dynamics and local thermodynamics on clouds and radiation budgets and modulating sea surface temperature. In addition, research effort is devoted to understanding and predicting the impacts of basin-scale sea surface temperature fluctuations such as the El Niño on regional climate variability over the Indo-Pacific region, North America, and South America. For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Modeling

Coupled Atmosphere-Ocean-Land Models

To study climate variability and sensitivity, we must couple the atmospheric GCM with ocean- and land-surface models. Much of the work in this area is conducted in collaboration with Goddard's Laboratory for Hydrospheric Processes, Code 970. The ocean models predict the global ocean circulation–including the sea surface temperature (SST)–when forced with atmospheric heat fluxes and wind stresses at the sea surface. Land-surface models are detailed representations of the primary hydrological processes, including evaporation; transpiration through plants; infiltration; runoff; accumulation, sublimation, and melt of snow and ice; and groundwater budgets.

One of the main objectives of coupled models is forecasting seasonal-to-interannual anomalies such as the El Niño phenomenon. Laboratory scientists are involved in the NASA Seasonal-to-Interannual Prediction Project (NSIPP), which was established in collaboration with Goddard's Laboratory for Hydrospheric Processes. NSIPP's main goal is to develop a system capable of assimilating hydrologic data and using that data with complex, coupled ocean-atmosphere models to predict tropical SST with lead times of 6–14 months. A second goal is to use the predicted SST in conjunction with coupled atmosphere-land models to predict changes in global weather patterns.

NSIPP is currently producing routine seasonal forecasts. Each month surface and subsurface hydrographic data are assimilated to produce initial conditions for the ocean component of a coupled ocean-atmosphere-land forecast system. A 10-member ensemble forecast is then integrated for 1 year. In addition to this coupled forecast of SST, NSIPP also performs monthly "Tier 2" forecasts, using predicted SSTs to force more detailed atmospheric models. NSIPP's forecasts are available on the Internet at http://nsipp.gsfc.nasa.gov and are used by prediction centers for guidance in their assessments.

In addition to its forecasting work, NSIPP is engaged in research activities in land surface modeling, coupled processes, low-frequency atmospheric phenomena, and various aspects of data assimilation. More on this work can be found at the above Web site, together with a large archive of model-simulated data. For information, contact Max Suarez (Max.J.Suarez.1@gsfc.nasa.gov).

Global Modeling and Data Assimilation

Development of the Data Assimilation System

The DAO currently uses the GEOS-3 DAS to support the EOS Terra Mission. The GEOS-3 DAS is a major upgrade of the GEOS-1 DAS used for the first NASA reanalysis. The GEOS-3 DAS provides data products at a higher horizontal resolution (1° longitude by 1° latitude) and employs a new Physical-space Statistical Analysis System (PSAS). Other improvements include an interactive Mosaic-based land surface model, a state-of-the-art moist turbulence scheme, an on-line estimation and correction procedure for systematic forecast errors, and assimilation of space-borne observations of marine surface winds, total precipitable water, and Level 1B radiances from TOVS using a 1D variational scheme.

For the EOS-Aqua and beyond, the DAO is developing a next-generation numerical model for climate prediction and data assimilation in collaboration with NCAR. In addition, DAO is developing advanced data assimilation techniques using a combination of Kalman filtering and four-dimensional variational approaches. These techniques will allow us to make better use of synoptic observations. DAO is also developing flow-dependent covariance models to maximize the benefit of high spatial resolution of the observations and of the model.

In FY01, the Data Assimilation Office has released the first version of its next generation data assimilation system. This system involves a state-of-the-art general circulation model based on the finite-volume dynamical core developed at DAO, coupled to physical parameterizations from NCAR. The system employs an adaptive statistical quality control, which examines the quality of the input data stream taking in consideration the "flow of the day." The system ingests data from a variety of conventional and remotely sensed data including rawinsondes, TOVS Level 1B radiances and scatterometers. In the core of the assimilation algorithm is DAO's Physical-space Statistical Analysis System (PSAS), a global 3-D VAR class solver that combines model short-term forecast with observations to provide an optimal estimate of the atmospheric state. Compared to the previous GEOS-3.2 operational system, the next generation system has superior forecasts skills, has a much improved stratospheric circulation, realistically captures the evolution of synoptic systems, and has a competitive climate. The Finite-volume Data Assimilation System (fvDAS) is scheduled to become operational in the first half of 2002. For more information contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Cloud and Mesoscale Modeling

The mesoscale (MM5) and cloud-resolving (Goddard Cumulus Ensemble–GCE) models are used in a wide range of studies, including investigations of the dynamic and thermodynamic processes associated with cyclones and frontal rainbands, tropical and mid-latitude deep convective systems, surface (i.e., ocean and land, and vegetation and soil) effects on atmospheric convection, cloud-chemistry interactions, and stratospheric-tropospheric interaction. Other important applications include assessment of the potential benefits of assimilating satellite-derived water vapor, winds and precipitation fields into tropical and extra-tropical regional-scale (i.e., hurricanes and cyclones) weather simulations, and climate applications. The latter involves long-term integrations of the models that allow for the study of air-sea and cloud-radiation interactions and their role in cloud-radiation-climate feedback mechanisms. Such simulations provide an integrated systemwide assessment of important factors such as surface energy and radiative exchange processes, and diabatic heating and water budgets associated with tropical and mid-latitude weather systems.

Data collected during several major field programs, GATE (1974), PRESTORM (1985), TOGA COARE (1992–1993), SCSMEX (1998), TRMM LBA (1999), TRMM KWAJEX (1999) and CAMEX 3/4 (2000/2001), was used to improve as well as to validate the GCE and MM5 model. The MM5 was also improved in order to study regional climate variation, hurricanes and severe weather events (i.e., flash floods in the central U.S.). The models also are used to develop retrieval algorithms. For example, GCE model simulations are being used to provide TRMM investigators with four-dimensional cloud data sets to develop and improve TRMM rainfall and latent heating retrieval algorithms. Four-dimensional latent heating structures (1° by 1°, monthly) were retrieved from December 1997 to November 2000. For more information, contact Wei-Kuo Tao (WeiKuo.Tao.1@gsfc.nasa.gov).

Physical Parameterization in Atmospheric GCM

The development of physical submodels of the climate system is an integral part of climate modeling activity. Laboratory scientists are actively involved in developing and improving physical parameterizations of the major radiative transfer and moisture processes in the atmosphere. Both of these areas are extremely important for eliminating model biases and leading to a better understanding of the global water and energy cycles.

For atmospheric radiation, we are developing efficient, accurate, and modular longwave and shortwave radiation codes. The radiation codes allow efficient computation of climate sensitivities to water vapor, cloud microphysics, and optical properties. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

For atmospheric hydrologic processes, we are evaluating and improving a prognostic cloud liquid water scheme, which includes representation of source and sink terms as well as horizontal and vertical advection of cloud material. This scheme incorporates attributes from physically based cloud life cycles, including the effects of downdraft, cloud microphysics within convective towers and anvils, cloud-radiation interactions, and cloud inhomogeneity corrections. We are evaluating coupled radiation and the prognostic water schemes with in situ observations from the ARM and TOGA-COARE IOPs as well as satellite data. For land-surface processes, a new snow physics package is being evaluated with GEWEX GSWP data sets. It is currently in the GEOS GCMs. Moreover, the soil moisture prediction is extended down to 5m, which often goes through the groundwater table. All these improvements are found to better represent the hydrologic cycle in a climate simulation. For more information, contact Yogesh Sud (Yogesh.C.Sud.1@gsfc.nasa.gov).

Trace Gas Modeling

The Atmospheric Chemistry and Dynamics Branch has developed two- and three-dimensional models to understand the behavior of ozone and other atmospheric constituents. We use the two-dimensional models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, or solar proton events, and human effects, such as changes in chlorofluorocarbons (CFCs), nitrogen oxides, and hydrocarbons. The three-dimensional models simulate the evolution of ozone and trace gases that affect ozone. The constituent transport is calculated utilizing meteorological fields (winds and temperatures) generated by the DAO. These calculations are appropriate to simulate variations in ozone and other constituents for time scales ranging from several days or weeks to seasonal, annual, and interannual. The model simulations are compared with observations, with the goal of improving our understanding of the complex chemical and dynamical processes that control the ozone layer.

The modeling effort has evolved in four directions: (1) Lagrangian models are used to calculate the chemical evolution of an air parcel along trajectory. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations. (2) Two-dimensional (2-D) noninteractive models have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used in both data analysis and multidecadal chemical assessment studies. (3) Two-dimensional interactive models include interactions among photochemical, radiative, and dynamical processes, and are used to study the dynamical and radiative impact of major chemical changes. (4) Three-dimensional (3-D) models have a complete representation of photochemical processes and use input meteorological fields from either the data assimilation system or from a general circulation model for transport. The constituent fields calculated using winds from a new general circulation model developed jointly by the DAO and the National Center for Atmospheric Research exhibit many observed features. We are exploring coupling this GCM with the stratospheric photochemistry from the CTM with the goal of developing a fully interactive 3-D model that is appropriate for assessment calculations.

The Branch uses trace gas data from sensors on the UARS, on other satellites, from ground-based platforms, from balloons, and from various NASA-sponsored aircraft campaigns to test model processes. The integrated effects of processes such as stratosphere troposphere exchange, not resolved in 2-D and 3-D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass.1@gsfc.nasa.gov).

Support for National Oceanic and Atmospheric Administration Operational Satellites

In the preceding pages, we examined the Laboratory for Atmosphere's work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA's remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists assure scientific integrity throughout mission definition, design, development, operations, and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments flies on POES. Post-doctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

Laboratory members are actively involved in the NPOESS Internal Government Studies (IGS) and support the Integrated Program Office (IPO) Joint Agency Requirements Group (JARG) activities. Likewise, the Laboratory is supporting the formulation phase for the next generation GOES mission, known as GOES-R.

Geostationary Operational Environmental Satellites

NASA GSFC project engineering and scientific personnel support NOAA for the GOES operational satellites. GOES supplies images and soundings to study atmospheric processes, such as moisture, winds, clouds, and surface conditions. In particular, GOES observations are used by climate analysts to monitor the diurnal variability of clouds and rainfall and to track the movement of water vapor in the upper troposphere. In addition to high-quality imagery, the GOES satellites also carry an infrared multichannel radiometer that NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States. These mesoscale soundings are improving NOAA's numerical forecasts of local weather. The GOES project scientist at Goddard provides free public access to real-time weather images for regions all over the western hemisphere via the World Wide Web (http://rsd.gsfc.nasa.gov/goes/). For more information, contact Dennis Chesters (Dennis.Chesters.1@gsfc.nasa.gov).

Polar-Orbiting Environmental Satellites

Algorithms are being developed and optimized for the HIRS-3 and the Advanced Microwave Sounding Unit (AMSU) first launched on NOAA 15 in 1998. Near real-time analysis will be carried out thereafter, as was done with HIRS2/MSU data. For more information, contact Joel Susskind (Joel.Susskind.1@gsfc.nasa.gov).

Solar Backscatter Ultraviolet/2

NASA has the responsibility to determine and monitor the prelaunch and postlaunch calibration of the SBUV/2 instruments that are included in the payload of the NOAA polar-orbiting satellites. We further have the responsibility to continue the development of new algorithms to determine more accurately the concentration of ozone in the atmosphere.

The NOAA 16 SBUV/2 instrument was launched and has gone through testing. It has now been operational since March 2001. Because the EP TOMS instrument is undergoing a degradation of its scanning mirror, the NOAA 16 SBUV/2 is now our primary measurement for the long-term ozone record. We are in the process of integrating the data from this instrument into our long-term record. This is being accomplished by comparing its data to both EP TOMS and the NOAA 11 SBUV/2 to evaluate their relative calibrations.

We have previously produced a single merged data set with a common calibration that extends from November 1978 through the end of 2000. We have recently updated this record to include the NOAA 16 data through the end of 2001. The data are available on the Web at http://code916.gsfc.nasa.gov/Data_services/merged/. For more information, contact Richard Stolarski (Richard.S.Stolarski.1@gsfc.nasa.gov).

National Polar-Orbiting Environmental Satellite System

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the Source Evaluation Board, acting as technical advisors. Laboratory personnel were involved in evaluating proposals for the OMPS (Ozone Mapper and Profiler System) and the Crosstrack Infrared Sounder (CrIS), which will accompany ATMS, an AMSU-like crosstrack microwave sounder. Collaboration with the IPO continues through the Sounder Operation Algorithm Teams (SOAT) and the Ozone Operational Algorithm Team (OOAT), which will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. We have conducted numerous trade studies involving CrIS and ATMS, the advanced IR and microwave sounders, which will fly on NPP and NPOESS. Simulation studies were conducted to assess the ability of AIRS to determine atmospheric CO_2, CO, and CH_4. These studies indicate that total CO_2 can be obtained to 2ppm (0.5%) from AIRS under clear conditions, total CH_4 to 1%, and total CO to 15%. This shows that AIRS should be able to produce useful information about atmospheric carbon. For more information, contact Joel Susskind (Joel.Susskind.1@gsfc.nasa.gov).

For OMPS, Laboratory scientists continue to support the IPO through the OOAT. The team conducts algorithm research and provides oversight for the OMPS developer. An algorithm is being developed to analyze SAGE III data when SAGE III operates in a limb scattering mode, which will simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE/LORE shuttle mission conducted in 1997. The SOLSE/LORE payload was developed in the Laboratory for Atmospheres. The retrievals from this shuttle mission demonstrated the feasibility of employing limb scattering to observe ozone profiles with high vertical resolution down to the tropopause. This research is enabled by the advanced UV and visible radiative transfer models developed in the Laboratory. Laboratory scientists also participate in the Instrument Product Teams to review all aspects of the OMPS instrument development. The IPO is supporting a reflight of SOLSE/LORE on the Space Shuttle, in July 2002, as a risk mitigation effort related to the OMPS. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

CrIS is a high-spectral-resolution interferometer infrared sounder with capabilities similar to those of the Atmospheric Infrared Sounder (AIRS). AIRS will fly with AMSU A and HSB on the EOS Aqua platform to be launched in 2002. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. These data will be used in a pseudo-operational mode by NOAA/NESDIS and NOAA/NCEP. Simulation studies were conducted for the IPO to compare the expected performance of AIRS/AMSU/HSB with that of CrIS, as a function of instrument noise, together with AMSU/HSB. The simulations will help in assessing the noise requirements for CrIS to meet the NASA sounding requirements for the NPOESS Preparatory Project (NPP) bridge mission in 2005. Trade studies have also been done for the Advanced Technology Sounder (ATMS), which will accompany CrIS on the NPP mission and replace AMSU/HSB. For more information, contact Joel Susskind (Joel.Susskind.1@gsfc.nasa.gov).

Tropospheric wind measurements are the number one priority in the unaccommodated Environmental Data Records (EDR) identified in the NPOESS Integrated Operational Requirements Document (IORD-1). The Laboratory is using these requirements to develop new technologies and Direct Detection Doppler Lidar measurement techniques to measure tropospheric wind profiles on a global scale. The IPO is supporting the effort through their IGS program. For more information, contact Bruce Gentry (Bruce.M.Gentry.1@gsfc.nasa.gov).

The Instrument Incubator Program is supporting the development of a visible and infrared imaging radiometer based on advanced-technology array detectors. The goal is an imaging radiometer smaller, less costly, and more capable than previous instruments. The program is developing an instrument based on advanced microbolometer array (MBA) warm thermal detectors. A prototype MBA-based instrument, the ISIR, flew as a shuttle small-attached payload in August 1997. Its performance proved the capability and advantages for MBA detectors in space applications. The Compact Visible and Infrared Imaging Radiometer (COVIR) is an engineering model of an operational flight instrument and will be completed and tested in 2001. A shuttle flight experiment is planned for early 2003. For more information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The IPO supports the development of Holographic Scanning Lidar Telescope technology as a risk reduction for lidar applications on NPOESS, including, but not limited to, a direct detection (edge) wind lidar system. Currently used in ground-based and airborne lidar systems, holographic scanning telescopes operating in the visible and near infrared wavelength region have reduced the size and weight of scanning receivers by a factor of three. We are currently investigating extending the wavelength region to the ultraviolet, increasing aperture sizes to 1 meter and larger, and eliminating all mechanical moving components by optically addressing multiplexed holograms in order to perform scanning. This last development should reduce the weight of our current large aperture scanning receivers by another factor of three. For more information on the Holographic Optical Telescope and Scanner (HOTS), visit the Web site at http://virl.gsfc.nasa.gov/lazer/index.html or contact G. Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers, the project scientist and the project manager, who are the principal leaders of the project. The project scientist provides continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large.

Table III: Laboratory for Atmospheres Project, Deputy Project, and Mission and Study Scientists

PROJECT SCIENTISTS		DEPUTY PROJECT SCIENTISTS	
Name	**Project**	**Name**	**Project**
Pawan K. Bhartia	TOMS	Anne R. Douglass	EOS Aura ,UARS
Dennis Chesters	GOES	Ernest Hilsenrath	EOS Aura
Jay Herman	Triana	Arthur Hou	TRMM
		Si-Chee Tsay	EOS Terra
Robert Adler	TRMM	Marshall Shepherd	GPM
Charles Jackman	UARS		
Joel Susskind	POES		
Robert Cahalan	EOS SORCE		
Eric Smith	GPM		
EOS VALIDATION SCIENTIST		**MISSION AND STUDY SCIENTISTS**	
		Name	**Project**
David O'C. Starr	EOS	Matt McGill	Cloud Sat
		Matt McGill	CALIPSO
		Robert Atlas	GTWS

.

Interactions with Other Scientific Groups

Interactions with the Academic Community

The Laboratory depends on collaboration with university scientists to achieve its goals. Such relationships make optimum use of government facilities and capabilities and those of academic institutions. These relationships also promote the education of new generations of scientists and engineers. Educational programs include summer programs for faculty and students, fellowships for graduate research, and associateships for postdoctoral studies. A number of Laboratory members teach courses at nearby universities and give lectures and seminars at U.S. and foreign universities. The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community, as shown in Appendix 5.

NASA and non-NASA scientists work together on NASA missions, experiments, and instrument and system development. Similarly, several Laboratory scientists work on programs residing at universities or other federal agencies.

The Laboratory routinely makes its facilities, large data sets, and software available to the outside community. The list of refereed publications, presented in Appendix 7, reflects our many scientific interactions with the outside community.

Prime examples of collaboration between the academic community and the Laboratory include these cooperative agreements with universities (a complete list may be found at the Web site http://webserv.gsfc.nasa.gov/ESD/collab.html):

- Earth System Science Interdisciplinary Center (ESSIC), with the University of Maryland, College Park;

- Joint Center for Earth Systems Technology (JCET), with the University of Maryland, Baltimore County;
- Goddard Earth Sciences and Technology Center (GEST Center), with the University of Maryland, Baltimore County, (and involving Howard University);
- Center for Earth-Atmosphere Studies (CEAS), with Colorado State University;
- Cooperative Center for Atmospheric Science and Technology (CCAST), with the University of Arizona;
- Cooperative Institute for Atmospheric Research (CIFAR) Graduate Student Support, with UCLA;
- Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA), with Howard University;
- Joint Interdisciplinary Earth Science Information Center (JIESIC) with George Mason University;
- Joint Center for Geoscience (JCG) at MIT;
- Cooperative Institute for Meteorological Satellite Studies (CIMSS) with the University of Wisconsin, Madison; and,
- Joint Center for Observation System Science (JCOSS) with the Scripps Institution of Oceanography, University of California, San Diego.

These joint centers have been organized to increase scientific interactions between the Earth Sciences Directorate at GSFC and the faculty and students at the participating universities. One means of increasing these interactions is a new initiative the Earth Sciences Directorate has established that will increase our sponsorship of graduate students. The Laboratory for Atmospheres is participating in this program, which will partner Laboratory scientists with graduate students. Our scientists will advise the student, serve on the thesis committee, visit the university, host the student at GSFC, and collaborate with the student's thesis advisor.

In addition, university and other outside scientists visit the Laboratory for periods ranging from 1 day to as long as 2 years. (See Appendix 1 for list of recent visitors and Appendix 4 for seminars.) Some of these appointments are supported by Resident Research Associateships offered by the National Research Council (NRC) of the National Academy of Sciences; others, by the Visiting Scientists and Visiting Fellows Programs currently managed by the Goddard Earth Sciences and Technology (GEST) Center. Visiting Scientists are appointed for up to 2 years and carry out research in pre-established areas. Visiting Fellows are appointed for up to 1 year and are free to carry out research projects of their own design. (See Appendix 3 for a list of NRC Research Associates, GEST Center Visiting Scientists, Visiting Fellows, and Associates of the Joint Institutes during 2001.)

Interactions with Other NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with other NASA Centers and Federal laboratories.

Our ties with the other NASA Centers broaden our knowledge base. They allow us to complement each other's strengths, thus increasing our competitiveness while minimizing duplication of effort. They also increase our ability to reach the Agency's scientific objectives.

Our interactions with other Federal laboratories enhance the value of research funded by NASA. These interactions are particularly strong in ozone and radiation research, data assimilation studies, water vapor and aerosol measurements, ground truth activities for satellite missions, and operational satellites. An example of interagency interaction is the NASA/NOAA/NSF Joint Center for Satellite Data Assimilation (JCSDA), which is expanding prior collaborations between

NASA and NCEP to exploit the assimilation of satellite data for both operational and research purposes.

Interactions with Foreign Agencies

The Laboratory has cooperated in several ongoing programs with non-U.S. space agencies. These programs involve many of the Laboratory scientists.

Major efforts include the TRMM Mission, with the Japanese National Space Development Agency (NASDA); the Huygens Probe GCMS, with the ESA (CNES); the TOMS Program, with NASDA and the Russian Scientific Research Institute of Electromechanics (NIIEM); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, Africa, and Asia.

Laboratory scientists interact with about 20 foreign agencies, about an equal number of foreign universities, and several foreign companies. The collaborations vary from extended visits for joint missions to brief visits for giving seminars or working on joint science papers. As a result of the joint U.S.-Japan Workshop on Relationships and Intercomparison of Monsoon Climate Systems, held in our Laboratory in 2000, participants have agreed to develop pilot research projects involving the U.S. Global Change Research Program and the Japanese Frontier Research System for Global Change to enhance studies of teleconnections or globally connected climate systems.

Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government/industry partnerships, SBIRs, and technology transfer activities. In recent years two members of the Laboratory received the annual James J. Kerley Award for outstanding contributions to technology commercialization. The Laboratory was extremely proactive, and a key contributor, to development of the partnering process now used within Goddard. Through this process Government PIs can team with industry to produce credible and competitive proposals that satisfy CICA (Competition In Contracting Act) requirements. The Laboratory used this process under the ESSP Program and will continue to use this process on all major mission proposals. Industry or university Co-Is are important contributors on each program. Laboratory scientists also serve as Co-Is on proposals led by industry. These practices will continue on future proposals.

During 2001 Code 912 researchers obtained a patent on a holographic circle-to-point converter optic (U.S. Patent #6313908). Recognizing the potential of the holographic optic, Scientific Solutions, Inc., a small Massachusetts-based company, licensed the technology from GSFC. Scientific Solutions is interested in using the holographic optic in several applications, including instruments for atmospheric remote sensing, instruments for medical imaging, and use in multiplexing/demultiplexing for telecommunications. Based on initial successes, Scientific Solutions has renewed its license for 2002.

Successful technology transfer has occurred on a number of programs in the past and new opportunities will become available in the future. Past examples include the micro pulse lidar and holographic optical scanner technology. Industry now develops and markets micro pulse lidar systems to an international community. A licensing agreement with industry permits the continued use of government-patented holographic technology for commercial applications to topographic mapping. New research proposals involving technology development will have strong commercial partnerships wherever possible. The Laboratory hopes to devote at least 10% to 20% of its resources to joint activities with industry on a continuing basis.

6. HIGHLIGHTS OF LABORATORY FOR ATMOSPHERES ACTIVITIES IN 2001

In this section, you'll learn about some of the Laboratory's research accomplishments for 2001. We have divided this material into two groups. First, you'll see a branch-by-branch summary of highlights. Then, you'll see short articles presenting the results of specific science research highlights. The Branch Web sites can be accessed from the Laboratory for Atmospheres Web site at http://atmospheres.gsfc.nasa.gov/.

Summary of Branch Highlights

Data Assimilation Office (DAO), Code 910.3

The Data Assimilation Office (DAO) works to advance the state of the art of data assimilation. The DAO's objectives are:

- To produce research-quality assimilated data sets for addressing questions in studies of the Earth system and of global change.
- To make the best use of satellite data for climate assessment.
- To assist Earth Observing System science and instrument teams.

The DAO's accomplishments in 2001 include these—

1) We released the first version of DAO's next-generation data assimilation system. This system is based on a state-of-the-art general circulation model. The model consists of the finite-volume dynamical core developed at DAO, coupled to physical parameterizations from NCAR. This "finite-volume" data assimilation system (fvDAS) employs an adaptive statistical quality control, which examines the quality of the input data stream taking in consideration the "flow of the day." The system ingests data from a variety of conventional and remotely sensed data, including rawinsondes, TOVS Level 1B radiances, and scatterometers. The core assimilation algorithm is DAO's Physical-space Statistical Analysis System (PSAS), a global 3-D VAR class solver that combines model short-term forecast with observations to provide an optimal estimate of the atmospheric state. Compared to the GEOS-3.2 operational system, the fvDAS has better forecasts skills, an improved stratospheric circulation, more realistic representations of synoptic systems, and a faster throughput. The fvDAS is scheduled to replace GEOS-3 as DAO's real-time operational system in the first half of 2002.

2) The GEOS-3 operational system provided daily first-look and late-look data products to EOS Instrument Teams without serious production anomalies. The operational system was upgraded throughout 2001, including a smooth transition from RTOVS to ATOVS data in the operational input data stream. During TRACE-P and ACE–Asia chemistry missions, the DAO provided near real-time direct support to the science teams with customized assimilated data products, which received appreciative commendations from the mission scientists. The DAO also delivered to ECS data products that were created by reprocessing data of October to December 2000 using the latest operational system in support of MODIS data processing.

3) We conducted advanced data assimilation research in the use, retrieval, and full exploitation of remotely sensed data. In 2001, DAO scientists developed a 1D-variational scheme that simultaneously performs cloud clearing and retrieves information about temperature, humidity, ozone, and surface parameters including the surface skin temperature from TOVS. The implementation of this procedure in the fvDAS resulted in improved 5-day forecasts and in smaller biases and standard deviation errors in 6-hr forecast winds and heights verified against radiosonde data.

Mesoscale Atmospheric Processes Branch, Code 912

The Mesoscale Atmospheric Processes Branch seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. We conduct research on the physical and dynamical properties, structure, and evolution of meteorological phenomena, with a strong focus on the initiation, development, and effects of cloud systems. We investigate phenomena on a wide range of scales, from the synoptic scale to the microscale. A major emphasis is on energy exchange and conversion mechanisms, especially cloud microphysical development and latent heat release associated with atmospheric motions. The work is inherently focused on defining the atmospheric component of the global hydrologic cycle, especially precipitation, and its interaction with other components of the Earth system. Branch activities include satellite missions, advanced remote sensing technology development and application, modeling and analysis, and visualization.

1) Branch scientists retrieve precipitation estimates using satellite and ground observations. Satellite data comes from the Tropical Rainfall Measurement Mission (TRMM) and from earlier and continuing SSM/I and GOES observations. Ground-based data comes from rain-gauge networks and from radar. Branch scientists are engaged in all phases of field work to support validation of satellite-derived precipitation estimates, including application of an airborne (NASA ER-2) Doppler precipitation radar (EDOP). The Branch is also strongly engaged in future missions such as the AMSR-E on EOS Aqua, to be launched in 2002, and the developing Global Precipitation Mission (GPM). A major effort has been made to characterize the rainfall data products generated by different instruments on the TRMM satellite. This analysis is a key step toward a best estimate of precipitation climatology. Major accomplishments include—

- Extending the lifetime of TRMM through an orbit boost.
- Actively participating in the CAMEX-4 field campaign in August–September 2001 to study hurricanes.
- Developing a near real-time global-tropics 3-hourly rainfall analysis based on data from multiple satellites and sensors.
- Studying the effects of deforestation on rainfall distribution over the Amazon.
- Studying El Niño and other climate systems.
- Helping move the GPM mission into the formulation phase.

2) Branch members are engaged in research and development of lidar technology. The technology will enable us to characterize the profile structure of cloud systems (Cloud Physics Lidar–CPL), atmospheric aerosols (Micro Pulse Lidar–MPL), water vapor (Scanning Raman Lidar–

SRL), and winds (Goddard Lidar Observatory for Winds–GLOW) at fine temporal and/or spatial resolution. We can gather these lidar observations from airborne and satellite platforms and from ground-based systems. Of particular note are capabilities to characterize atmospheric structure in the planetary boundary layer and in high-level cirrus clouds, and support of NASA's planned Global Tropospheric Winds mission. In addition, the Cloud Radar System (CRS), a new millimeter-wavelength *radar* for profiling cloud systems, has been developed and will soon be integrated on NASA's high-altitude ER-2 research aircraft for use in sensing the microphysical properties of cirrus and other cloud types.

Branch scientists play a key role in developing the atmosphere-sensing capabilities of the Geoscience Laser Altimeter System (GLAS). GLAS will be launched on ICESat in late 2002. Major accomplishments include assembling, aligning, and testing the optics and detector hardware; and delivering and testing the at-launch algorithms for GLAS atmospheric data products, including aerosol and cloud profiling. Branch scientists also serve as Project Scientists for the Earth System Science Pathfinder (ESSP), CALIPSO (lidar), and CloudSat (mm-radar) missions that are planned for launch in 2004.

Another major accomplishment was the graduation to operational status of the MPL-Net project, with eight operational sites/systems. MPL-Net is a Goddard-based federation of lidar sites sharing a common data processing (algorithms), archive, and access system. The federation includes three sites of the Department of Energy Atmospheric Radiation Measurement (ARM) Program and two sites operated by Japan. GSFC maintains sites at the South Pole and at Goddard. GSFC also maintains systems used in field experiments, including ocean research cruises such as the Aerosol Characterization Experiment (ACE–Asia) in the spring of 2001. MPL-Net data products are now documented and routinely available to the community via the MPL-Net Web site (http://virl.gsfc.nasa.gov/mpl-net/). MPL observations have proven very useful for modeling GLAS algorithm performance and accuracy.

3) The mesoscale (MM5) and cloud-resolving Goddard Cumulus Ensemble (GCE) models are used in investigations of the dynamic and thermodynamic processes associated with numerous weather and climate phenomena. These include cyclones and frontal rainbands, tropical and mid-latitude deep convective systems, ocean-surface and land-surface (vegetation and soil moisture) effects on atmospheric convection and weather systems, cloud-chemistry interactions, and stratospheric-tropospheric interaction. Other important applications of the MM5 and GCE models include assessment of the potential benefits of assimilating satellite-derived water vapor and precipitation fields on tropical and extra-tropical regional-scale (i.e., hurricane and cyclone) weather simulations. Long-term integration of the models will allow study of air-sea and cloud-radiation interactions and their role in cloud-radiation climate feedback mechanisms. The simulations provide a basis for integrated systemwide assessment of important factors such as surface energy and radiative exchange processes, and diabatic heating and water budgets associated with tropical and mid-latitude weather systems. The models are also used to develop retrieval algorithms. For example, the GCE model is providing TRMM investigators with 4-dimensional data sets for developing and improving TRMM rainfall and latent heating retrieval algorithms.

The scientific output of the modeling activities was prodigious in 2001. We submitted nearly 20 papers for publication, and most have already been accepted. A major accomplishment was the publication of the first extensive analysis of vertical profiles of latent heating produced from TRMM data using model-derived algorithms. Another significant result was the identification and description of a dynamical instability leading to a secondary circulation that plays a key role in hurricane intensification. This work indicates that the hot towers concept is a viable description of eye wall convection and that explanations based on slant convection or broad ascent are not required. In the hot towers analysis, upward motion is concentrated in a small number of intense isolated thunderstorm updrafts.

Branch scientists actively participate in or lead various international model comparison and evaluation activities of the GEWEX Cloud System Study. These activities aim to increase confidence in these tools and facilitate research on the development and testing of cloud parameterizations used in large-scale climate and forecast models (GCMs). Of particular note is a model comparison study of microphysical development in cirrus clouds that identifies key parameters, such as deposition coefficient, to which the models are highly sensitive and for which additional information is required (e.g., laboratory studies).

4) The Branch has developed a world-class visualization lab that is being increasingly used in high-profile settings to reach out to scientists and, very importantly, to citizens and government organizations to stimulate understanding and support of NASA's Earth Science Enterprise and its missions. These capabilities are heavily utilized by the TRMM Outreach Office, Earth Observing System (EOS) Project Science Office, and NASA HQ in bringing the value of TRMM and EOS science to the forefront of U.S. global change research.

Climate and Radiation Branch, Code 913

The Climate and Radiation Branch conducts research to improve understanding of climate processes and their societal impacts, using space-based as well as in situ observations and modeling. Research focuses on physical processes underlying the formation of aerosols, clouds, and precipitation, and their interaction with atmospheric dynamics and radiation.

The Branch’s accomplishments in 2001 include the following:

1) Clouds, precipitation and the water cycle—

We discovered from satellite data a fundamental relationship between clouds, water vapor and sea surface temperature (SST), with a new interpretation on cloud water vapor-climate feedback processes.

We developed an improved rain retrieval method based on spatial structures of the TRMM microwave radiometer (TMI) observations. The method will provide better discrimination of convective and stratiform precipitation.

We developed a simple method of estimating mean squared random error in monthly rainfall estimates, based on quantities that can be directly computed from the satellite data. This method will have potential application in the design of the Global Precipitation Mission (GPM).

2) Aerosol climate interactions—

MODIS data collaborated previous findings with Landsat and AERONET that dust absorption of solar radiation is much smaller than previously estimated, implying possibly a stronger global cooling effect by desert dust.

The ACE–Asia campaign showed global transport of dusts and aerosols from central Asia to North America with possible climatic, ecological, and human impacts.

We demonstrated for the first time the feasibility of using a combination of aerosol measurements from MODIS and MISR, carbon monoxide measurements from MOPITT, and energy measurements from CERES to distinguish man-made combustion aerosol from natural aerosol.

We provided value-added capability to the Terra data system to allow the Forest Service to use MODIS images for monitoring the wildfires of the western U.S. during the dry seasons. This use of Terra data permitted unprecedented near real-time (within 15 hours) observations of fires, smoke, and the spread of pollution.

3) Climate variability and predictability—

We discovered a climate teleconnection pattern linking U.S. summertime severe droughts and floods to monsoon heat sources and sinks around the world.

We developed a canonical ensemble prediction system to identify new sources of potential predictability for U.S. seasonal precipitation, raising the skill bar for seasonal prediction.

We provided basic understanding and a new interpretation of monsoon and its interaction with the ITCZ.

We developed a new generation catchment-based land-surface model for use in climate studies, and carried out experimental dynamical seasonal predictions with a state-of-the-art production version of the NSIPP atmospheric GCM.

We developed a new parameterization for snow cover that includes separate predictions of the temperatures of snow and the ground underneath. These improvements have led to better climate simulations in atmospheric general circulation models.

We demonstrated that remote forcing from radiative cooling in the subsidence region exerts strong control on the cloudiness distribution in the warm pool region, and that the gradient of SST likely plays an important role in controlling cloud radiative feedback associated with global warming.

We organized 3-D radiation intercomparisons showing large plane parallel and IPA bias in radiation codes in climate models.

4) Technology development—

We developed versatile, mobile platforms to measure surface and atmospheric radiation, water vapor and aerosols (3S photometers, SMART, Leonardo airborne simulator) for deployment in major international field campaigns.

We fabricated a laboratory instrument, the THOR lidar, which is designed to measure cloud thickness from off-beam lidar returns. The instrument is being prepared for airborne deployment and for competitive award under the Instrument Incubator Program (IIP).

5) Advanced concepts and new visions—

We championed and submitted a proposal to NASA Headquarters for establishing a Center of Excellence for Aerosol Climate Research within the Laboratory, and lead the Directorate-wide Aerosol crosscutting team development.

We developed an advanced concept for AEROSAT— an aerosol satellite to include aerosol polarization and black carbon measurements to unravel and reduce uncertainties on effects of aerosols on global change.

We led a GSFC team to develop unified onboard processing and spectrometry aimed at building compact, low-power, low-cost detectors to allow a wide field-of-view of the Earth with onboard processing, programmable by ground commands.

Atmospheric Experiment Branch, Code 915

The Atmospheric Experiment Branch conducts experimental studies to increase our understanding of the chemical environment in our solar system during its formation and to study the physical processes that have continued to shape solar system bodies throughout time. To achieve this goal, the Branch has a comprehensive program of experimental research, developing instruments to make detailed measurements of the chemical composition of solar system bodies such as comets, planets, and planetary satellites that can be reached by space probes or satellites.

The Branch's accomplishments for 2001 include:

1) The Branch continued participation in the CONTOUR mission that will rendezvous with multiple comets and provide a more detailed understanding of cometary nuclei and the diversity among comets. CONTOUR is a mission in NASA's Discovery line of small mission programs for planetary studies. The CONTOUR PI is Professor Joseph Veverka of Cornell University. The Johns Hopkins University Applied Physics Laboratory (JHU/APL) in Laurel, Maryland, is managing the development of this spacecraft. The Neutral Gas and Ion Mass Spectrometer (NGIMS) is one of four instruments on this mission. CONTOUR was designed and fabricated in-house at GSFC with collaboration on the analog portion of the flight electronics by the Space Physics Research Laboratory (SPRL) of the University of Michigan. The instrument was delivered in late 2001 to JHU/APL for integration with the CONTOUR spacecraft. CONTOUR's launch is planned for July 2002. A significant activity for the NGIMS instrument team was the completion of the instrument calibration prior to delivery. The calibration was carried out for the numerous ions and neutral gases that are predicted to be present in the coma of comets. This was done using an array of solid, liquid, and gas sources for the ions and neutrals. Following this calibration, a series of environmental tests were carried out to establish the space worthiness of this hardware. The first comet encounter is planned for Encke on November 11, 2003.

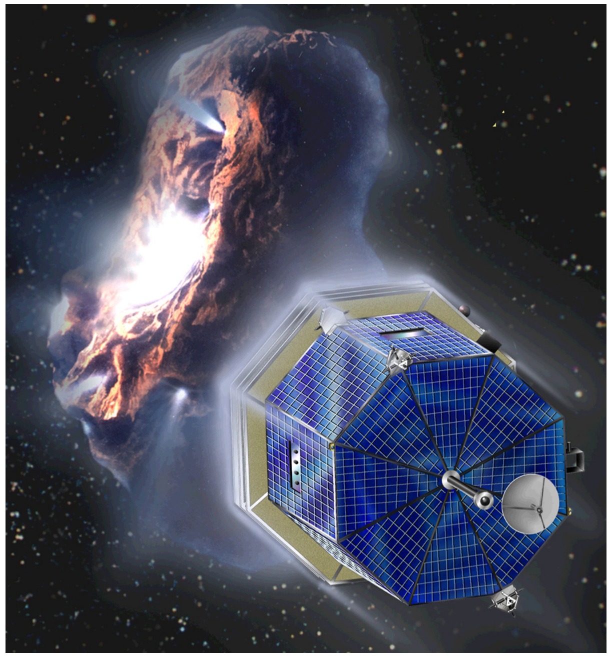


Figure 6-1. Artist's conception of CONTOUR spacecraft encountering a comet nucleus.

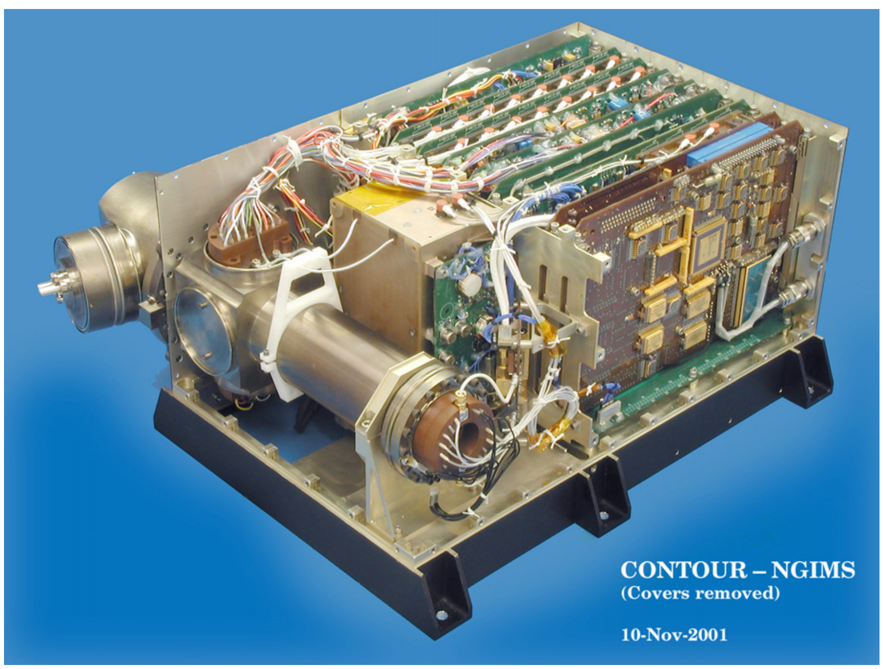


Figure 6-2. Neutral Gas and Ion Spectrometer instrument designed and fabricated in our Laboratory, one of four instruments on the CONTOUR spacecraft.

2) The Branch continued providing post-launch support for several key planetary missions. These include:

A Gas Chromatograph Mass Spectrometer on the Cassini Huygens Probe mission to explore the atmosphere of Saturn's moon Titan.

An Ion and Neutral Mass Spectrometer on the Cassini Orbiter to explore the upper atmosphere of both Saturn and Titan.
A Neutral Mass Spectrometer on the Japanese *Nozomi* mission to explore the upper atmosphere of Mars.

3) We continue to refine flight data from the Galileo Probe Neutral Mass Spectrometer and to compare the chemical and isotopic compositions determined at Jupiter with those measured at Saturn and the other giant planets.
4) We continue advanced development for measurements on future missions. These include the following:

- A probe of the deep atmosphere of Venus to perform precision measurements of isotopes designed to resolve questions of the origin and processing of this atmosphere;
- A detailed in situ rendezvous mission with the nucleus of a comet to better understand the complexity of organic molecules that might have been delivered to Earth over the course of its history;
- A landed experiment on Mars to sample isotopes and molecules from its atmosphere and below its surface that can address studies of past climate and the possibility of past life on the planet.

5) We continued the collaborative effort with GSFC's Engineering Directorate in a comprehensive program to achieve a significant reduction in the size and weight of present-day mass spectrometer systems. This includes reduction in the electronics system by utilizing Application Specific Integrated Circuits (ASICS) and other advanced packaging techniques as well as reductions in the mass spectrometer itself by utilizing MEMS (Micro Electro Mechanical Systems) techniques.

Atmospheric Chemistry and Dynamics Branch, Code 916

The Atmospheric Chemistry and Dynamics Branch conducts research in the distribution and variability of atmospheric ozone by making new measurements, by analyzing existing data, and by theoretically modeling the chemistry and transport of trace gases that control the behavior of ozone. An emerging research focus is the characterization of sources, sinks, and transport of aerosols, carbon dioxide, and ozone in the troposphere.

The Branch's accomplishments for 2001 include the following:

1) Several Branch scientists are playing key roles in the WMO/UNEP assessment of the stratospheric ozone depletion. This congressionally mandated assessment, held every 3 to 4 years, brings together experts in stratospheric research to assess the current health of the ozone layer and to make informed predictions about its future state. A key input to this assessment is the long-term global record of ozone created by combining ground-based and satellite data. Branch scientists continue to play a leading role in maintaining such a data set.

2) Several Branch scientists are members of the International OMI science team. OMI is a Netherlands-provided instrument, scheduled to fly on the EOS Aura satellite in 2003. This team recently completed a 4-volume description of the scientific algorithms that will be used to process OMI data to derive a variety of products relevant in atmospheric chemistry research. This document is currently undergoing peer review.

3) NASA Headquarters selected several Branch scientists to become members of the newly reconstituted TOMS science team. This included funding to continue the SHADOZ (Southern Hemisphere Additional Ozonesondes) program. This international program, managed by the

Branch, has greatly improved the quality and quantity of ozone vertical profile data in the region of the world that is experiencing rapid environmental change. These measurements have been extremely useful in validating satellite-derived estimates of tropospheric ozone.

4) The Branch started a major new initiative aimed at understanding the regional scale variability of carbon dioxide in the boundary layer. This includes the development of new modeling tools as well as new instruments to measure, with extremely high accuracy, column CO_2 and its vertical distribution in the boundary layer.

5) The Branch scientists developed a state-of-the-art capability to model global transport of desert dust. These models are not only helping in the interpretation of aerosol data derived from TOMS, SeaWiFS, and MODIS, but have also been used to plan field campaigns to study air quality in southeast Asia.

Scientific Research Highlights

Now that you've seen general summaries of our Branch accomplishments, let's have a closer look at some of the results of our research. The following pages present the Laboratory's scientific highlights for 2001, divided into three disciplines: Measurements, Data Analysis, and Modeling. Table IV lists the contents of these three sections. The authors and topics were selected by the respective Branch Heads.

Table IV: Summary of Scientific Research Highlights for 2001

Measurements	Data Analysis	Modeling
Ground-Based Measurements **South Pole MP Lidar Experiment** James Spinhirne, Code 912 **Micro Pulse Lidar Network** James Spinhirne, Code 912 **Instrument Development** **Unified Onboard Processing and Spectrometry** Si-Chee Tsay, Code 913 **GLAS Algorithm Development** James Spinhirne, Code 912 **ISIR/COVIR Project** James Spinhirne, Code 912	**Aerosol Studies** **Measuring Dust Absorption from MODIS and Landsat** Yoram Kaufman & Lorraine A. Remer, Code 913 **Climatic and Ecological Impacts of Asian Dusts** Si-Chee Tsay, Code 913 **Modeling of Tropospheric Aerosols** Mian Chin, 916 **Studies of Radiative Forcing of Saharan Dust Aerosols** Jay Herman, Code 916 **Atmospheric Chemistry** **Extremely Cold Temperatures and the Absence of Polar Stratospheric Clouds during SOLVE** John Burris, Code 916 **Measured Arctic Ozone Loss during the SOLVE Campaign** Thomas J. McGee, Code 916 **Changes in the Earth's UV Reflectivity from the Surface, Clouds, and Aerosols** Jay Herman, Code 916 **Global Mapping of Underwater UV Irradiances** Jay Herman, Code 916 **Simulating Global Distributions of CO_2** Randy Kawa & Aryln Andrews, Code 916	**Data Assimilation** **Impact of QuikSCAT Data on Numerical Weather Prediction** Robert Atlas, Code 910.3 **Monitoring of Observation Errors Using the GEOS Ozone Assimilation System** Ivanka Stajner, Code 910.3 **Assimilation of Cloud- and Land-Affected Satellite Sounding Data at the Data Assimilation Office** Joanna Joiner, Code 910.3 **A Simple Framework for Assessing the Information Content of Observations from a Satellite Doppler Wind Lidar** Lars Peter Riishojgaard, Code 910.3 **Water Vapor Tracers as Diagnostics of the Regional Hydrologic Cycle** M. Bosilovich, Code 910.3 **Retrospective Data Assimilation** Ricardo Todling, Code 910.3 **Can We Predict the Next Dust Bowl?** Siegfried Schubert, Code 910.3 **High-Efficiency High-Resolution Global Model Development at the Data Assimilation Office** S.-J. Lin, Code 910.3 **Improving Global Analysis and Forecasts Using Using TRMM and SSM/I Observations of Precipitation Processes** Arthur Hou, Code 910.3

	<u>Clouds and Precipitation</u> **Retrieved Vertical Profiles of Latent Heat Release Using TRMM Rainfall Products** Wei-Kuo Tao, Code 912 **The Effects of Amazon Deforestation on Rainfall** Andrew J. Negri, Code 912 **Sampling of the Diurnal Cycle of Precipitation Using TRMM** Andrew J. Negri, Code 912 **On Rainfall Modification by Major Urban Areas: Observations from Spaceborne Rain Radar on TRMM** J. Marshall Shepherd, Code 912 **Cirrus Cloud Microphysical Modeling** R.-F. Lin, Code 912 **<u>Climate Variability and Climate Change</u>** **Hydrologic Teleconnections during Northern Summer** W. K. M. Lau, Code 913 **Cloud, SST, and Climate Sensitivity Inferred from Satellite Radiance Measurements** M.-D. Chou, Code 913 **Global Warming: Evidence from Satellite Observations** P. Cuddapah, Code 913	**<u>Hurricanes</u>** **Simulation of the Cloud-Scale Structure of an Atlantic Hurricane** Scott Braun, Code 912 **Studies of Hurricanes During CAMEX-4** G.M Heymsfield, Code 912 **<u>Physical Processes</u>** **Global Solar Oscillations** Charles Wolff, Code 915

Measurements

Ground-Based Measurements

South Pole MP Lidar Experiment

The second full year of operations by the Micro Pulse Lidar at the U.S. South Pole Station was completed. We continue to acquire observational data on cloud structure, blowing snow layers, and detection and height of PSCs. The figure shows the detection of PSCs and other clouds during the winter season of 2000. The South Pole lidar measurements have been very important for modeling GLAS signals, algorithm performance, and accuracy.

An improved MP lidar experiment was installed at the South Pole in December. The new hardware will allow regular scanning through zenith angles to determine the effect of specular reflection from gravitationally aligned ice crystals on lidar signals. The effect must be understood for GLAS signal analysis.

An agreement was made with NOAA ERL for the MP lidar experiment to become one of the facility measurements at the NOAA Atmospheric Research Observatory at the South Pole Station.

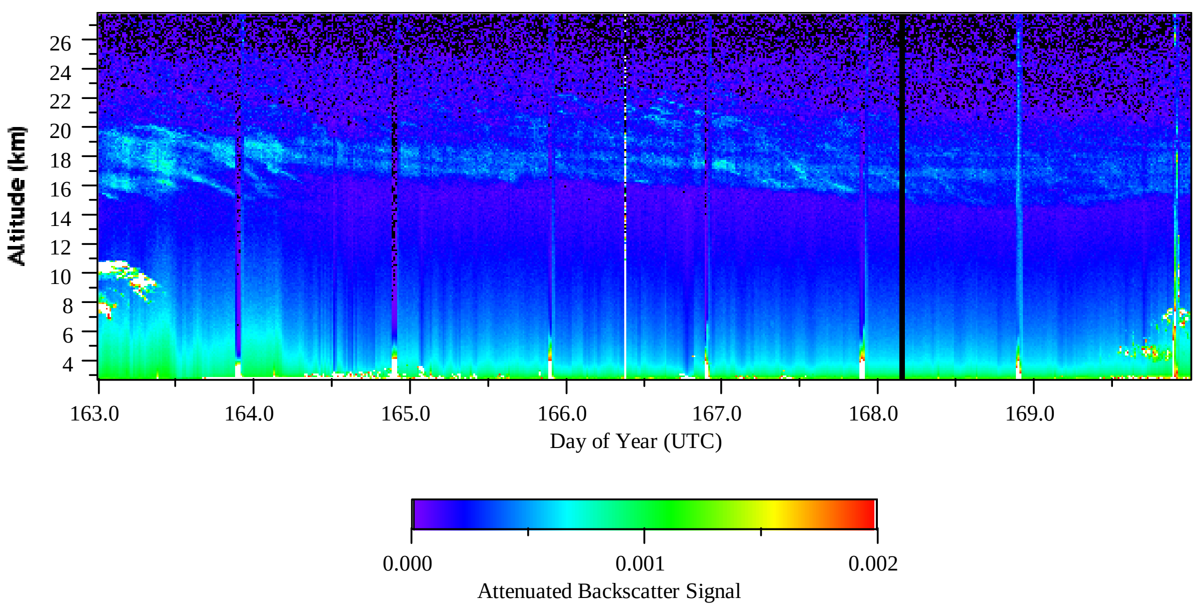


Figure 6-3. South Pole MPL data for 1 week in June of 2000. The layer at 16 to 18 km is Polar Stratospheric Clouds. At the surface is a persistent layer of blowing snow.

James Spinhirne, Code 912 (James.D.Spinhirne.1@gsfc.nasa.gov)

Micro Pulse Lidar Network

The Micro Pulse Lidar was developed in the Laboratory as the first eye-safe, stand-alone lidar capable of full-time monitoring of atmospheric clouds and aerosol. The MPL-Net project became operational in 2001 with eight sites, four supported by the DOE ARM program and two by a Japanese partner. The figure shows the location of the sites. The MPL-Net Web site also came into operation with both low-level and some high-level data products now available to the outside community.

In addition to the permanent sites, three MPL-Net instruments successfully participated in the Aerosol Characterization Experiment–Asia (ACE–Asia) in the spring of 2001. In an unusual occurrence, the GSFC MPL site observed Asian dust transported over the Pacific and the U.S. The sites in Oklahoma and Alaska and the systems deployed for ACE–Asia have also detected the dust. The monitoring of aerosol transport is an example of the application of data from the network. MPL-Net data products are available to the community via the MPL-Net Web site (http://virl.gsfc.nasa.gov/mpl-net/).

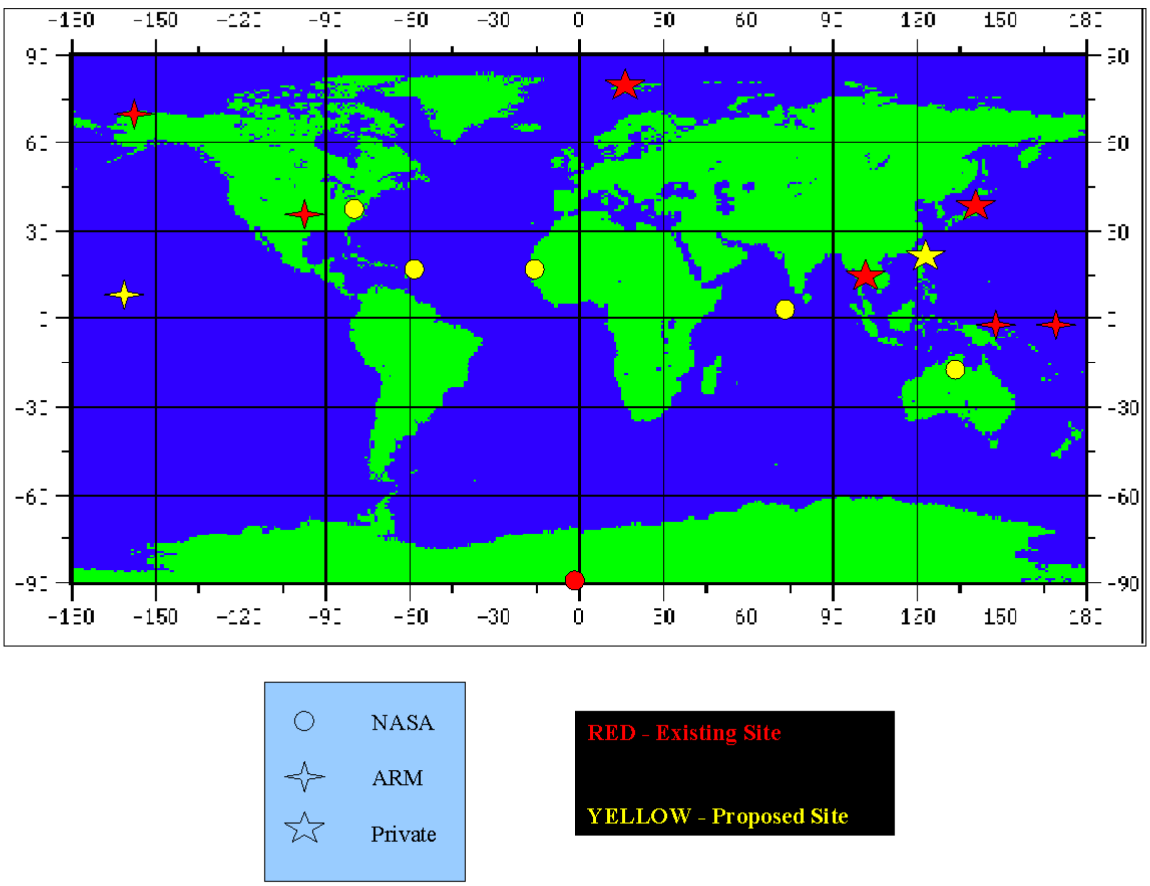


Figure 6-4. A map of the locations of existing and proposed MPL sites.

James Spinhirne, Code 912 (James.D.Spinhirne.1@gsfc.nasa.gov)

Instrument Development

Unified Onboard Processing and Spectrometry

Leading remote-sensing scientists are increasingly convinced that spectrometers are the wave of the future in passive Earth remote sensing. Spectrometers are becoming cheaper, simpler, and more robust than classical filter radiometers, and, indeed, they may soon become generic off-the-shelf space instruments. Spectrometers can satisfy the needs of many communities that heretofore felt compelled to build new custom radiometers for every new mission, at huge costs. However, a difficulty arises from the vast volume of data generated by an imaging spectrometer sampling in the spatial and spectral dimensions. Figure 6.5 shows a typical image cube. The radiance field acquired by a spectrometer contains seven dimensions: spectral (λ), spatial (x, y, z), angular (θ, ϕ), and temporal (t). Nearby samples and/or sequential data are often highly correlated. For example, at a given time and position, the spectral data (*cf*. Figure 6-5) generally reveal a high degree of correlation between closely spaced spectral bands. We urgently need to learn how to compress the data in an intelligent way that retains the information.

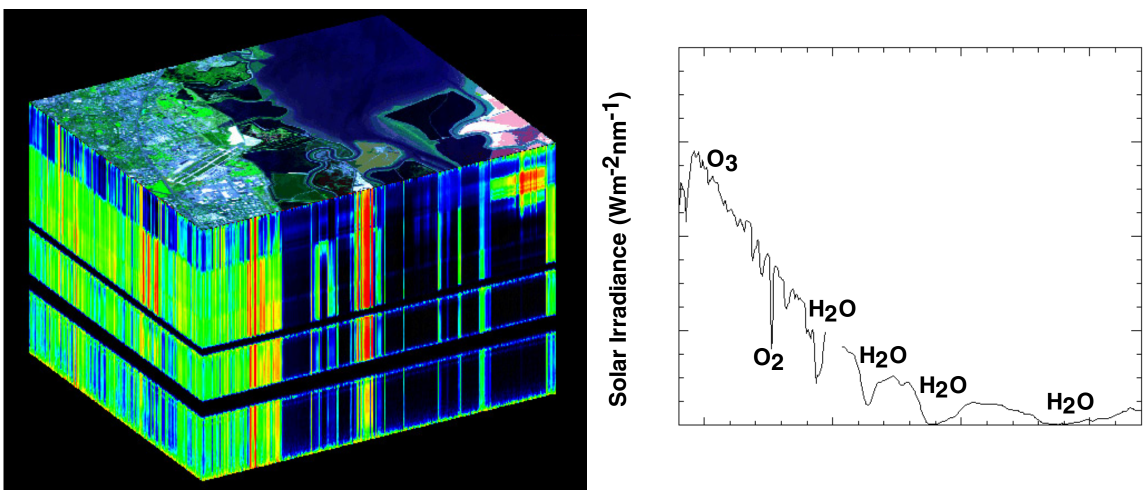


Figure 6-5. An image cube (left panel), horizontal for spatial and vertical for spectral data, acquired by the Airborne Visible/Infrared Imaging Spectrometer, which is a NASA facility instrument based at JPL. Downwelling solar irradiance spectra (right panel), collected by the Solar Spectral Flux Radiometer at NASA Ames Research Center, depict several absorption features by atmospheric gases.

With the surge of advanced spectrometry, sensor data accumulate at a rate and abundance that not only necessitates efficient data compression and storage but also imposes critical demands on the communication downlink and the ground data-management system. A typical hyperspectral spectrometer produces about 170 MB of data per second, or a total volume of 1 TB in one 94-min orbit. (This example assumes a spectrometer of 200 wavelengths on a 1K $\times$ 1K detector array, imaging the Earth every 100 km—or every 14 sec at 800 km altitude—with a 12-bit data system.) This rate of data capture requires 1.6 GB/sec downlink bandwidth for a 10-min communication window per orbit, or 10 times our current X-band capacity. Thus, with this new generation of instruments, the “archive all the raw bits” paradigm has reached the end of its utility. Keeping this paradigm would require either an EOSDIS 10 times bigger than the present one (i.e., something NASA simply cannot afford) or draconian restrictions on the amount of data taken by the instruments. Onboard data compression provides a viable alternative to both of these unpalatable choices.

A group of scientists (GSFC and Ames) and engineers (GSFC and JPL) is interested in this largely unexplored territory. We contend that spectrometry and its onboard processing algorithms must advance in unison and eventually unite seamlessly. This is a potentially revolutionary instrument concept with considerable spin-offs for many space missions. We envision a future in which archives of the spectrometer output will not be a monstrous data-dump of spectra, but rather the *information content* of those spectra, undoubtedly a much smaller and more valuable data stream. We propose to take full advantage of existing spectral observations to develop and refine two compression algorithms, named *proximate differencing* and *physics-based removal* techniques. Both are *reversible* (i.e., the information removed can be restored on the ground, as needed). The information removed from a measured spectrum can be of two types: (1) that which is known a priori, whether from theory or from measurements done off-line (e.g., extraterrestrial solar spectrum, known absorption/scattering spectra, etc.) and (2) that which is measured by the spectrometer itself, proximate in either space or time. Clearly an optimal combination of these two strategies needs to be sought. An example of method (2) is presented in Figure 6-6, which shows how spectra can be flattened (thus made more compressible) by dividing or subtracting out spectra contiguous in time.

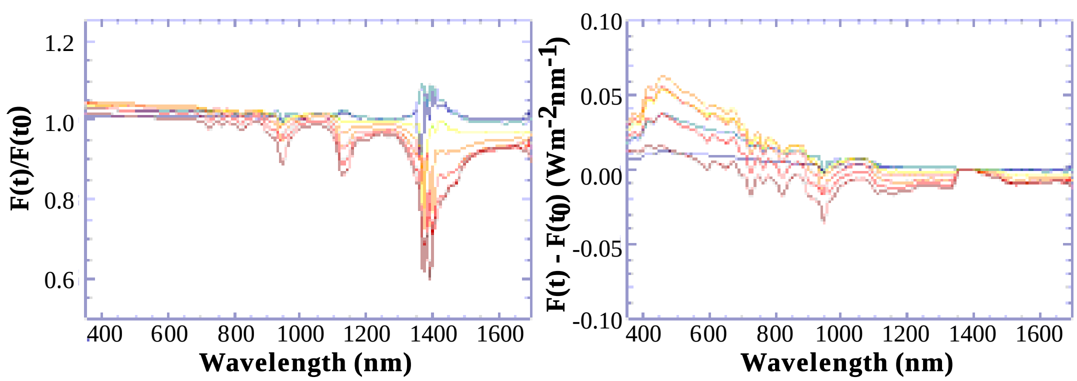


Figure 6-6. Used for illustration are six spectra of upwelling flux, similar to that shown in Figure 6-5, collected from above a stratus cloud deck over a 5-minute period during a recent field deployment. The left panel shows ratios and the right panel differences of each of the six spectra to one collected just prior to the start of this 5-minute period. Clearly the ratio method is useful except for the blowup that occurs in the nearly saturated water vapor absorption in the 1.4-µm region.

Si-Chee Tsay, Code 913 (Si-Chee.Tsay.1@gsfc.nasa.gov)

GLAS Algorithm Development

The launch of the Geoscience Laser Altimeter System (GLAS) aboard the Ice, Cloud, and Land Elevation Satellite (ICESat) in 2002 will mark the advent of global space-based laser profiling of the atmosphere and the planetary surface. For atmospheric science, GLAS cloud and aerosol measurements address critical applications not available from existing satellite observations. ICESat's unique lidar observations include the direct measurement of cloud heights, monitoring of aerosol distributions, and all-year coverage of clouds and aerosols in polar regions. Our lidar group is developing the launch algorithms for the Geoscience Laser Altimeter System (GLAS) atmospheric data products. The preliminary algorithms were delivered to the Science Computing Facility group for GLAS, and initial testing has been successful.

GLAS measurements will provide a global data set for direct detection of atmospheric cloud and aerosol layers with a high accuracy that has not been previously available. Detection is possible because atmospheric regions containing cloud or aerosol constituents have greater volume backscatter coefficients than clear regions. One of the data product algorithms analyses signals by filtering noise to delineate particle layers within the lidar profile. The figure below shows a simulation of GLAS data for a partial orbit with aerosol and cloud layers present. The algorithm successfully discriminates between cloud and aerosol layers.

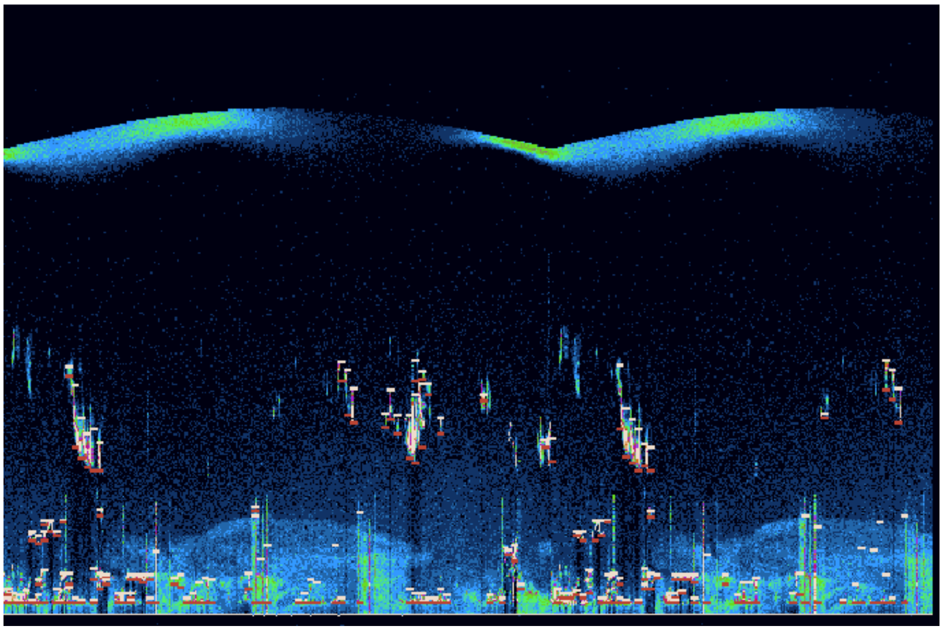


Figure 6-7. GLAS signal simulation showing algorithm retrievals of cloud heights. The white and red lines indicate clouds detected. Layers not detected are aerosol. The ability of the algorithm to discriminate between cloud and aerosol signals is demonstrated.

James Spinhirne, Code 912 (James.D.Spinhirne.1@gsfc.nasa.gov)

ISIR/COVIR Project

The Infrared Spectral Imaging Radiometer (ISIR) instrument was flown in space as a shuttle hitchhiker experiment. The goal of the experiment was to test a new type of infrared cloud sensor. The enabling new technology consisted of uncooled, microbolometer infrared array detectors. One advantage of the uncooled array detector was to enable imaging radiometers of smaller size and lower cost. Another advantage was that an imager could be made that would provide directionality of radiance in addition to spectral information. Since the shuttle experiment, ISIR data has been analyzed to test the application of the spatial information in data. Analysis was completed and a paper submitted on the results of infrared stereo cloud height retrieval. Figure 6-8 shows an example of stereo height retrieval.

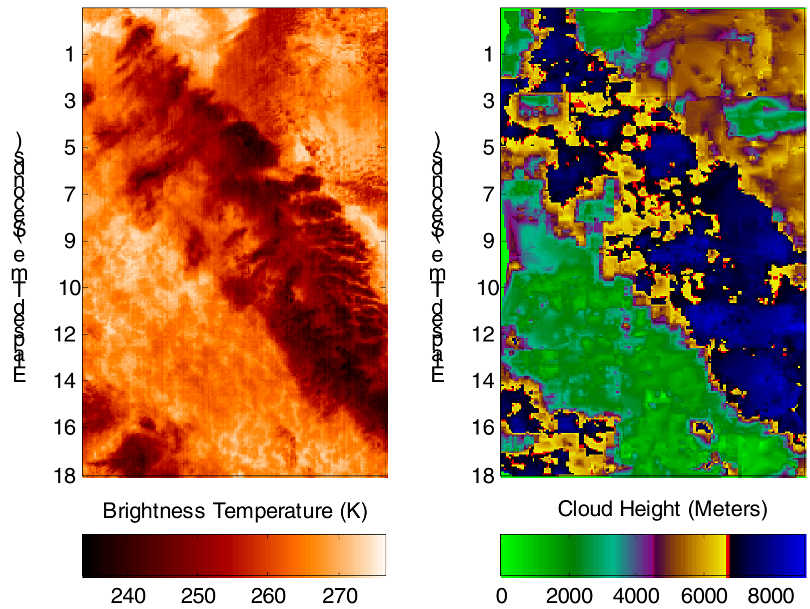


Figure 6-8. The panel on the left shows a sample of the imagery obtained using the ISIR instrument during mission STS-85. These data have been calibrated into units of brightness temperature, as measured through the 10.2 um channel of the instrument. The panel on the right shows the corresponding estimates of cloud height obtained stereoscopically. Here, a multilayered cloud system is seen that includes an aged contrail at an altitude near 8 km.

The Compact Visible and Infrared Radiometer (COVIR), supported by the IIP program, is a follow-on to the ISIR instrument. COVIR is intended as an engineering model of an operational satellite imager. Completion and testing of the instrument is awaiting delivery of the spectral filter arrays in 2002.

James Spinhirne, Code 912 (James.D.Spinhirne.1@gsfc.nasa.gov)

Data Analysis

Aerosol Studies

Measuring Dust Absorption from MODIS and Landsat

Airborne dust from Africa or the Gobi Desert in Asia intercepts incoming sunlight, reflecting a portion back to space and absorbing another fraction of the solar radiation. Reflection acts to cool the atmosphere by decreasing the amount of radiation retained by the system. Absorption acts to heat the atmosphere by keeping the radiation within the system. The balance between reflection and absorption determines if dust can heat or cool the climate.

There may be a feedback between dust emission and climate change, since large amounts of dust are emitted from the deserts in dry years, like the maximum El Niño year of 1987. Therefore, depending on the ability of dust to absorb sunlight, it can produce a positive or negative feedback on the climate system. What we mean is that in a hot year, when drier deserts emit large amounts of absorbing dust into the atmosphere, the additional dust will result in additional heating of the atmosphere and may result in even more dust being emitted. However, if dust is not very absorbing the situation may be reversed. Of course, this is a very simplistic way to look on the effect of dust since atmospheric circulation is not as simple as depicted, and detailed global climate models are needed to really assess the dust effect. The simple model described above only illustrates the profound importance of knowing exactly how much desert dust really absorbs.

Until recently, the scientific community believed Saharan dust to be a strong absorber of sunlight, because it includes rust (iron oxide) that gives the red color to soils in Africa. Bermuda also boasts red soils, which were brought to the islands from Africa by the easterly winds. Figure 6-9 (right panel) shows the dust caught up in the easterly wind that transports the dust across the Atlantic to the islands and continents of the Western Hemisphere. Working with visiting scientists from France and Israel on a totally unrelated problem, we found that dust models published in 1983 by the World Meteorological Organization cannot explain analysis of Landsat data from a 1987 French experiment in Western Africa. Using newer reports of dust models gave the same inconsistent results. Thus we decided to use the MODIS data to generate a new model of dust absorption. Using the data from the images in Figure 6-9, our analysis is demonstrated in Figure 6-10.

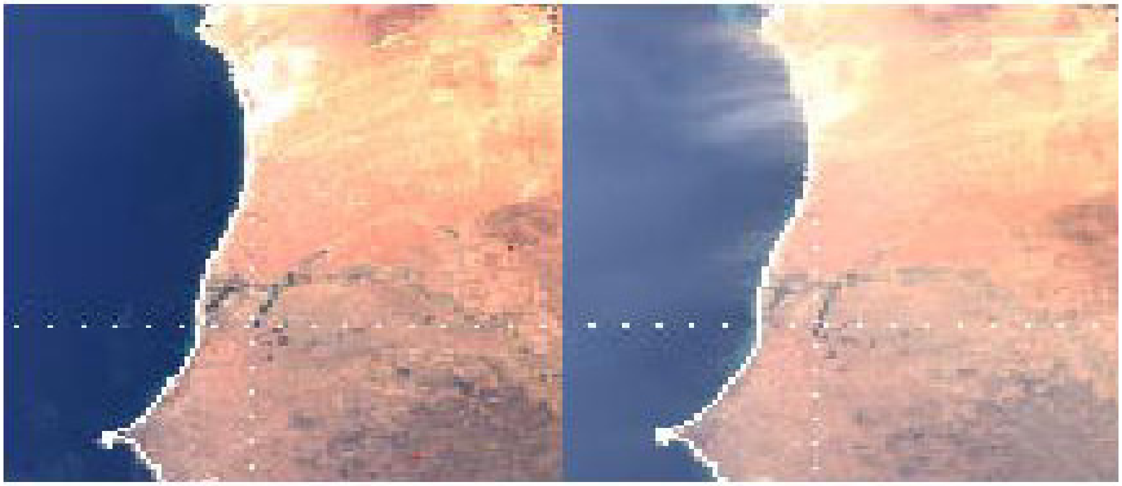


Figure 6-9. MODIS images of Western Africa and the Atlantic Ocean. (a) left image without dust, Jan. 27, 2001 (b) right image showing dust emitted from Africa over the Atlantic Ocean and moving toward the Americas, Feb. 12, 2001. These images illustrate the type of data set necessary for the dust absorption analysis shown in Figure 6-10. The clear day reflectance, the abscissa, is taken from Figure 6-9 left, while the dust reflectance, the ordinate, is obtained from the difference of Figures 6-9 right and left.

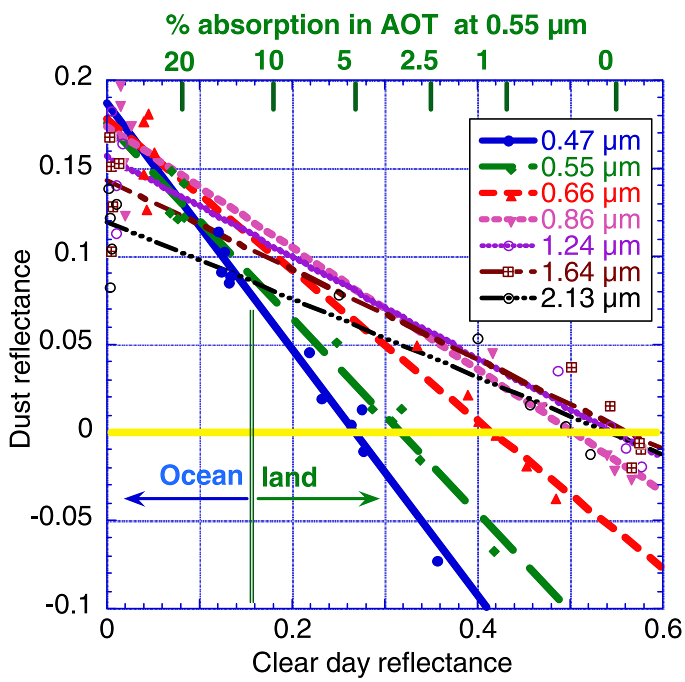


Figure 6-10. Dust reflectance of sunlight, meaning the difference in the reflectance measured by MODIS in a day with dust and a day with no dust, plotted as a function of the land reflectance in the day with no dust. The dust reflectance can be positive or negative, depending on the dust absorption and land reflectance. The brighter the land, the stronger the influence of dust absorption and the more negative the dust reflectance is. From the value of surface reflectance for which the dust reflectance is zero, we deduce the fraction of the dust optical thickness corresponding to absorption. The corresponding values of absorption percentage for the 0.55 µm channel are given at the top of the figure. The figure is plotted for all the relevant solar channels of MODIS from 0.47 µm to 2.1 µm.

Using the MODIS and Landsat data, we found that dust is not absorbing in the red to near IR channels (the green line in Figure 6-11). It is absorbing in the blue and UV parts of the spectrum, but much less than the absorption used in models currently accepted by the community. Once these new optical properties are included in numerical climate models, the significantly lower dust absorption and correspondingly higher dust reflection of sunlight will show that dust has a cooling effect. Meanwhile, in situ measurement techniques of dust absorption have improved. Preliminary measurements of dust outbreaks from Asia and Africa were presented recently in the IAMAS meeting in Austria and indicate similarly low dust absorption from the new in situ measurements.

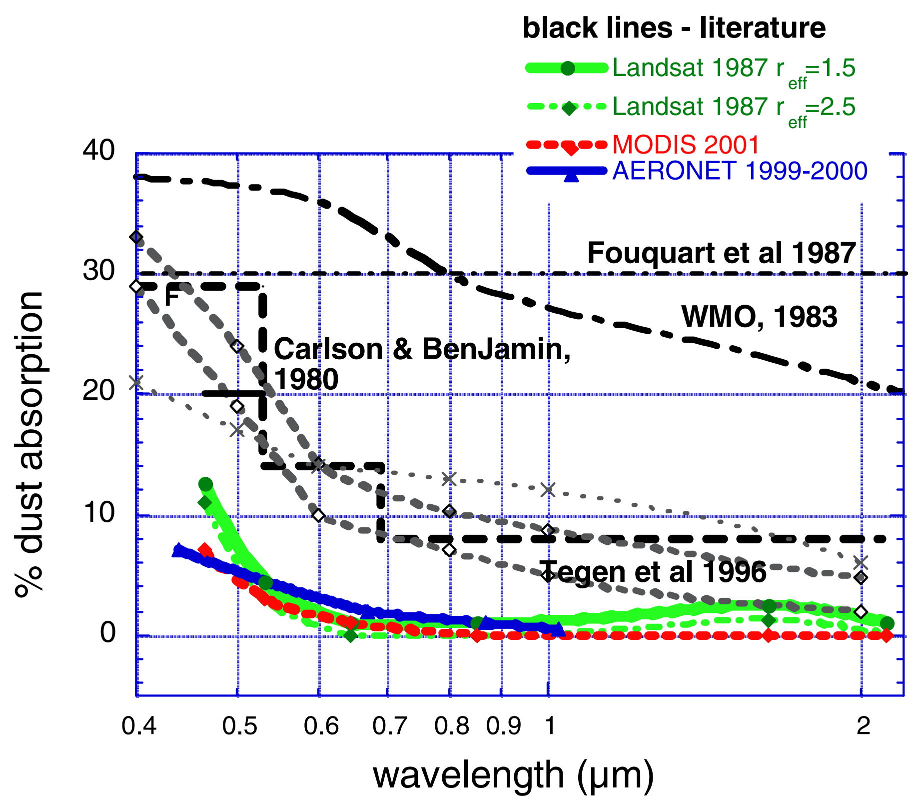


Figure 6-11. The spectral absorption of dust given as the % of the dust optical thickness. The green lines are the analysis of Landsat data for 1987 for two assumed sizes of the dust particles, the red line is the analysis of the MODIS data for 2001, and the blue line is the analysis of ground-based measurements by the Aerosol Robotic Network instruments in Capo Verde, an Island in the Atlantic Ocean off the African coast. All of them show very similar results. The black lines are different models from the World Meteorological Organization model (WMO) and from different papers published in the last few years.

Yoram Kaufman and Lorraine Remer, Code 913 (Yoram.Kaufman.1@gsfc.nasa.gov)

Climatic and Ecological Impacts of Asian Dusts

Recently intensified Asian dust storms have called attention to the topic of aerosol radiative forcing of climate, a phenomenon that constitutes a major source of uncertainty in climate change research. These dust storms occur frequently in arid and semi-arid areas of northwestern China in the springtime. To better understand the properties of dust aerosols, we deployed the SMART (Surface Measurements for Atmospheric Radiative Transfer) remote-sensing system during the ACE–Asia (March–May 2001) study.

Our work took place in the vicinity of Dun-Huang, China. Dun-Huang is located at one of the largest oases between the Taklimakan and the Gobi Deserts. It is in the source region of dust storms without much manmade contamination. Figures 6-12 & 6-13 demonstrate the sky conditions before, during, and after the impact of a dust storm.

Figure 6-12. Dust storm is approaching the Dun-Huang site (left panel) and the researchers have scrambled for shelter; photo taken at 3 p.m. local time on 28 April 28 2001. The fierce storm has generated a dense blanket of dust in the air, just 1 hour after the event (right panel).

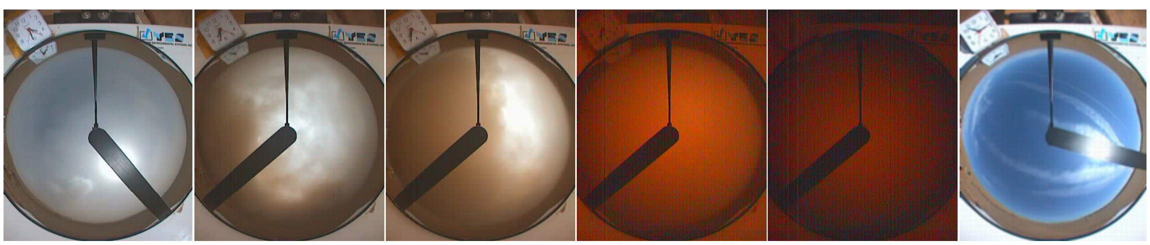


Figure 6-13. Time series of images captured by the Whole Sky Camera depict a dust storm passing through the Dun-Huang site. The last image reveals that many contrails streak across a clear blue sky.

Dust storms have the potential for enormous social impact. Nearly half the world's population resides in Asia, and China alone is home to roughly 1.3 billion people. These masses rely on crops produced from 8% of the world's farmland and on the yield from fisheries of the surrounding oceans. Airborne dust particles might alter regional hydrological cycles by direct and indirect radiative forcing. Dust storms might affect fisheries by influencing the nutrient deposition pattern. The storms might also produce adverse health effects on humans (e.g., irritating the eyes and respiratory system with aluminum, zinc, and iron contained in the dust aerosols). In addition, these dust clouds can transport swiftly across the Pacific reaching North America within a few days (*cf.* NASA press release in April 2001).

The seasonal incidence of dust storms peaks from March to May. The number of storms has tripled in recent years, from a 30-year average of 3.5 events per year to 10 events in 2000. ACE–Asia focused primarily on dust radiative forcing on regional to global climate. The optical depths (at 0.5 µm wavelength) of dusts during ACE–Asia (near the source region of Dun-Huang oasis, China) averaged about 0.8, with a maximum of greater than 2. The dust layers were almost always present at the surface. In Figure 6-14, all cloud-free data, based on Sun photometer and whole-sky camera observations, are used to quantify the radiative forcing of dust aerosols. Since atmospheric energetics requires integration over a period of time, the air mass (solar zenith angle) should be introduced as a parameter. The slopes ($\Delta F/\Delta\tau$, as shown in the right panel of Figure 6-14) of each slice of air mass depict the solar radiative forcing at the surface; their values clustered around -134 Wm^{-2} (cooling) at local solar noon.

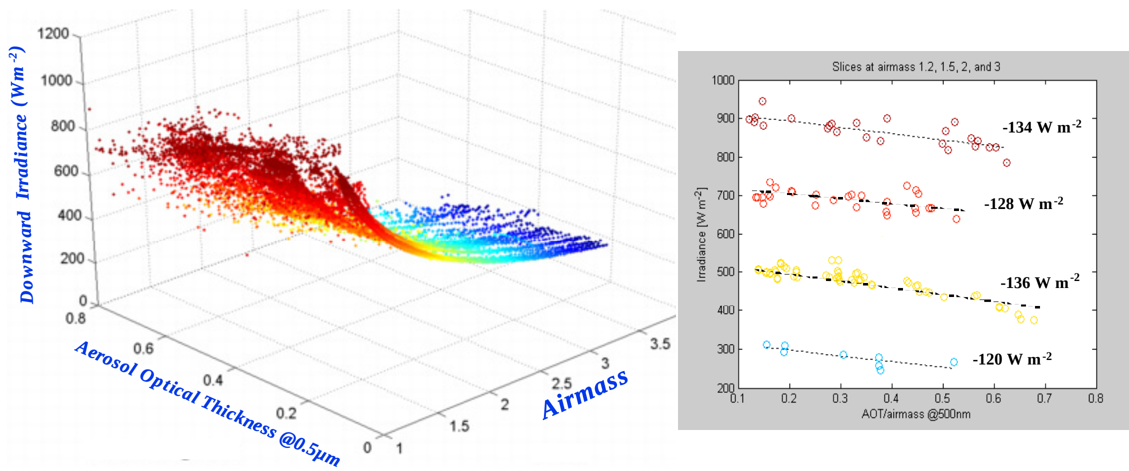


Figure 6-14. Three-dimensional representation of surface radiative forcing by dust aerosols during ACE–Asia from March to May 2001.

Si-Chee Tsay, Code 913 (Si-Chee.Tsay.1@gsfc.nasa.gov)

Modeling of Tropospheric Aerosols

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. We have recently developed an atmospheric aerosol model to help us understand the various processes that control aerosol properties and to understand the roles of aerosols in atmospheric chemistry and climate. The model is called the Georgia Tech/Goddard Global Ozone Chemistry Aerosols Radiation and Transport (GOCART) model.

GOCART uses the meteorological fields produced by the Goddard Data Assimilation Office (DAO), code 910.3, and includes major types of aerosols: sulfate, dust, black carbon, organic carbon, and sea salt. Among these, sulfate, black and organic carbon mainly originate from human activities, such as fossil fuel combustion and biomass burning. Dust and sea salt are mainly generated by natural processes; for example, uplift of dust from a desert by strong winds.

We have compared extensively the model results with satellite, aircraft, and surface observations. Our comparisons enable us to evaluate the model and, more importantly, to interpret the data. Figure 6-15 shows the comparison of total aerosol optical thickness calculated from the GOCART model with that retrieved from the satellite measurement by Total Ozone Mapping Spectrometer (TOMS). Here, the model reproduces the most prominent features as seen in the satellite data. Examples are biomass burning over equatorial northern Africa in January, a large dust plume originating in North Africa and transporting across the Atlantic Ocean in July, and biomass burning aerosols over southern Africa in July and over Brazil in October. The high optical thickness over Indonesia in October, revealed by both model and TOMS, is due to the unusually intensive biomass burning that occurred during fall 1997. Over the tropical or subtropical ocean, however, the aerosol optical thickness from the model is much lower than that from the TOMS. This difference occurs partly because of the difficulties involved in the TOMS retrieval when aerosols are optically thin. It is also possible that the model underestimates the aerosol source from the tropical ocean.

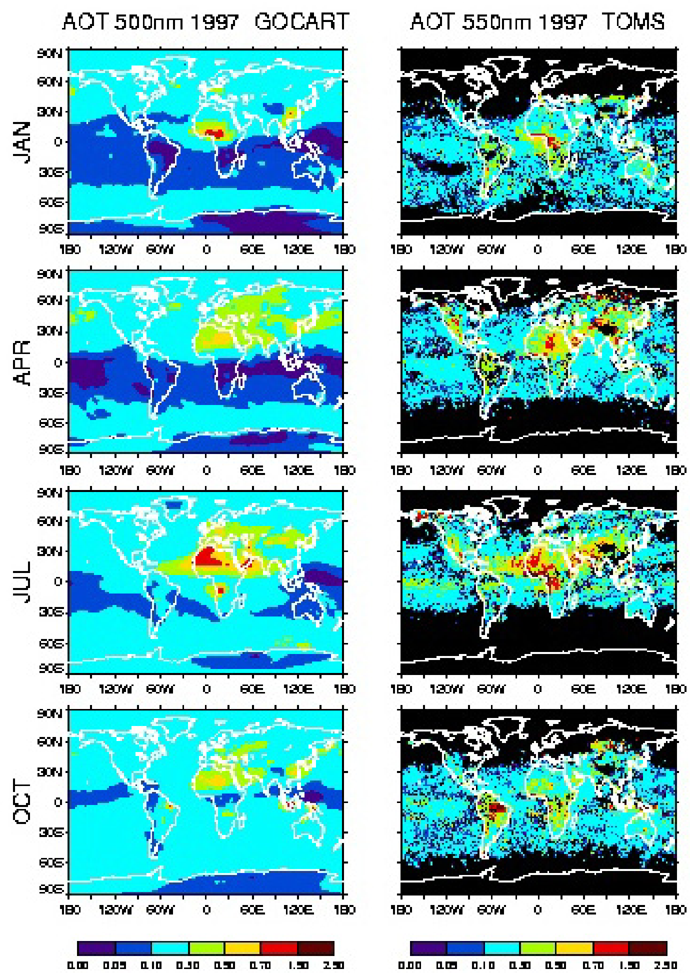


Figure 6-15. Aerosol optical thickness in 1997 from the GOCART model (left column) and the TOMS retrieval (right column). TOMS data are from Torres et al., 2001.

Figure 6-16 shows the comparison of model-calculated aerosol optical thickness with the quantities directly measured by the Sun photometer in the Aerosol Robotic Network (AERONET). Also shown in Figure 6-16 is the model-estimated aerosol composition. At Mongu (southern Africa), carbonaceous aerosol is the dominating aerosol from the biomass burning, which has a very strong seasonal variation and peaks in September. By contrast, almost all aerosols from Cape Verde (west coast off northern Africa) are dust from the Sahara region. At the NASA GSFC location, sulfate aerosol level is usually higher than other aerosol types, while the aerosol composition at Bermuda varies with the season.

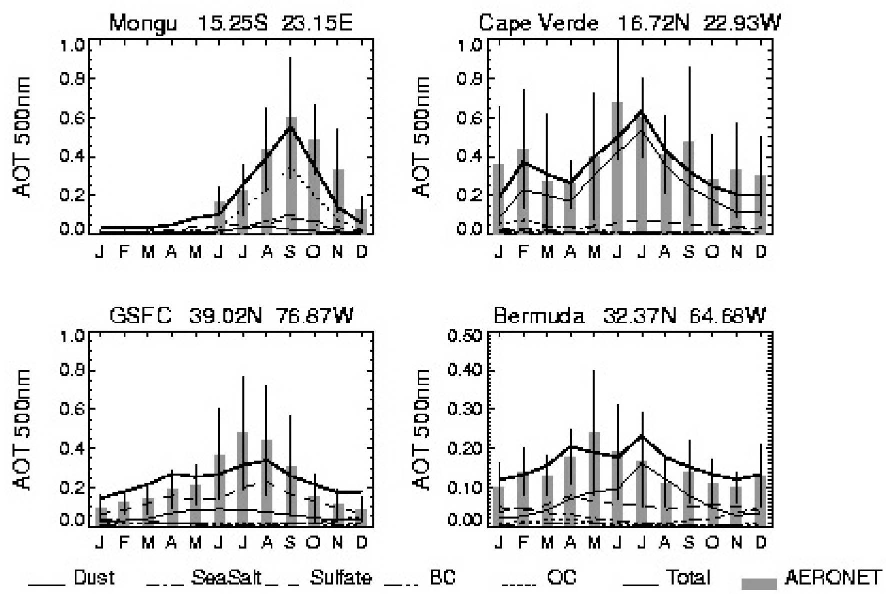


Figure 6-16. Comparison of aerosol optical thickness calculated in the model with that measured at four AERONET sites. Data are from Holben et al., 2001.

The detailed description of this work appears in the Special Issue of Global Aerosol Climatology of the Journal of the Atmospheric Sciences: Chin, M. and 9 others, 2001: Tropospheric aerosol optical thickness from the GOCART model and comparisons with satellite and sun photometer measurements.

The model assessment of aerosol's impact on future climate has been included in the 2001 Intergovernmental Panel on Climate Change (IPCC) report. Using the projected future emission change due to the change of human activities and emission controls, we have estimated the aerosol optical thickness and direct radiative forcing in the present and in 2030 and 2100. We have found that, on a global average, the direct aerosol forcing at the top of the atmosphere is almost linearly related to the emission of aerosols and their precursors.

In spring 2001, the intensive field phase for the ACE–Asia took place over the Asian-Pacific region. ACE–Asia is a multinational, multiagency-sponsored field program with a goal of improving our understanding of how aerosols, transported from the Asian continent, influence the chemical and radiative properties of the Earth's atmosphere. We have been actively involved in the ACE–Asia program. During the intensive field operation period (March–May 2001), we provided aerosol forecasts using the meteorological forecasts (including winds, temperature, clouds) from the DAO. Figure 6-17 gives an example of the GOCART model forecast of aerosol optical thickness for dust, sulfate (mainly from pollution), and black carbon (mainly from biomass burning), as well as the cloud forecast from DAO for April 8, 2001. These products were used every day at the field operation center for planning optimal flight routes.

We are currently working on model analysis of the ACE–Asia data to evaluate the controlling processes that determine the aerosol properties and distributions of Asian aerosols and their effects on the Earth's climate.

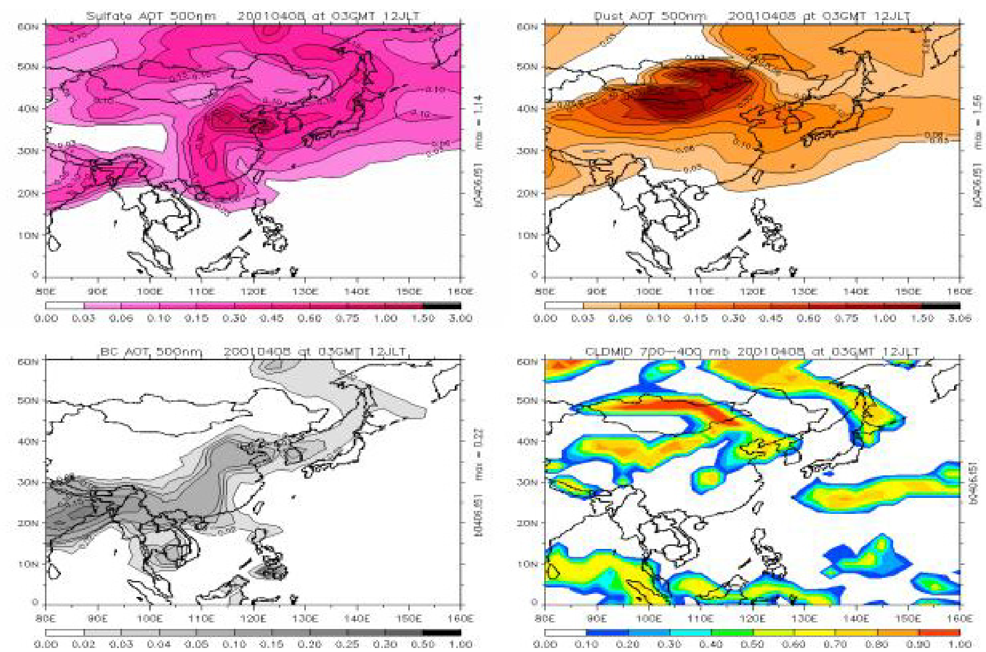


Figure 6-17. Model forecast of aerosol optical thickness of sulfate, dust, and black carbon at 500nm for April 8, 2001. Also shown is the midlevel cloud fraction forecasted by the DAO.

Mian Chin, Code 916 (Mian.Chin.1@gsfc.nasa.gov)

Studies of Radiative Forcing of Saharan Dust Aerosols

We used satellite data to determine the direct radiative forcing over Saharan dust. In our analysis, we combined aerosol information from Nimbus-7 TOMS with top of the atmosphere radiation (TOA) measurements from NOAA-9 ERBE. We used cloud and precipitable water information from NOAA-9 HIRS to screen for clouds and water vapor.

Our results indicate that under *cloud-free* and *dry* conditions a good correlation exists between the ERBE TOA outgoing longwave fluxes and the TOMS aerosol index measurements over both land and ocean in areas under the influence of airborne Saharan dust. We also found the ERBE TOA outgoing shortwave fluxes to correlate well with the dust loading derived from TOMS over ocean. However, the calculated shortwave forcing of Saharan dust aerosols is very weak and noisy over land for the range of solar zenith angle viewed by the NOAA-9 ERBE in 1985. Forcing efficiency of the TOA outgoing fluxes due to Saharan dust was estimated using a linear regression fit to the ERBE and TOMS measurements.

Figure 6-18 summarizes our results. The ratio of the shortwave-to-longwave response to changes in dust loading over the ocean is found to be roughly 2 to 3, but opposite in sign. It indicates a net cooling effect in the atmosphere over ocean. The effect can locally be as much as 15 Watts/m^2 in February and 25 Watts/m^2 in July. However, due to the weak response of the shortwave radiation to the change in dust loading over arid land, the net radiation budget is dominated by the longwave wavelength response, resulting a net warming.

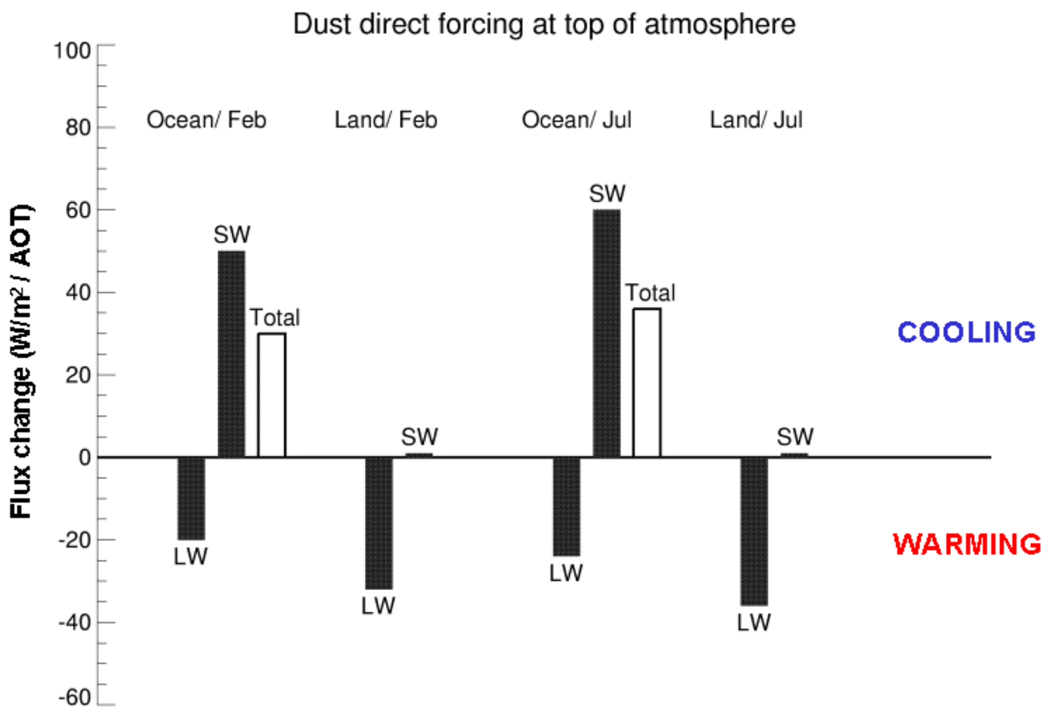


Figure 6-18. Summary of the estimated TOA longwave and shortwave direct forcing of dust per unit AOT over land and ocean surfaces for February and July.

Both the observational and theoretical analyses indicate that the underlying surface properties, the dust-layer height, the ambient moisture content, and the presence of clouds all play important roles in determining the TOA direct radiative forcing due to mineral aerosols.

During the past year, these techniques have been applied to the recent large Asian dust storm (The Perfect Dust Storm) originating in the Gobi and Taklamaken Deserts and reaching across the Pacific Ocean and into the U.S. (Figure 6-19). Another key result is that the amount of dust appearing over China has increased annually since the start of the TOMS data (1979) and most strongly in recent years according to data from Earth-Probe/TOMS. The radiative forcing for the ACE–Asia Perfect Dust Storm was comparable to that from the Saharan Dust, about 15 Watts/m^2.

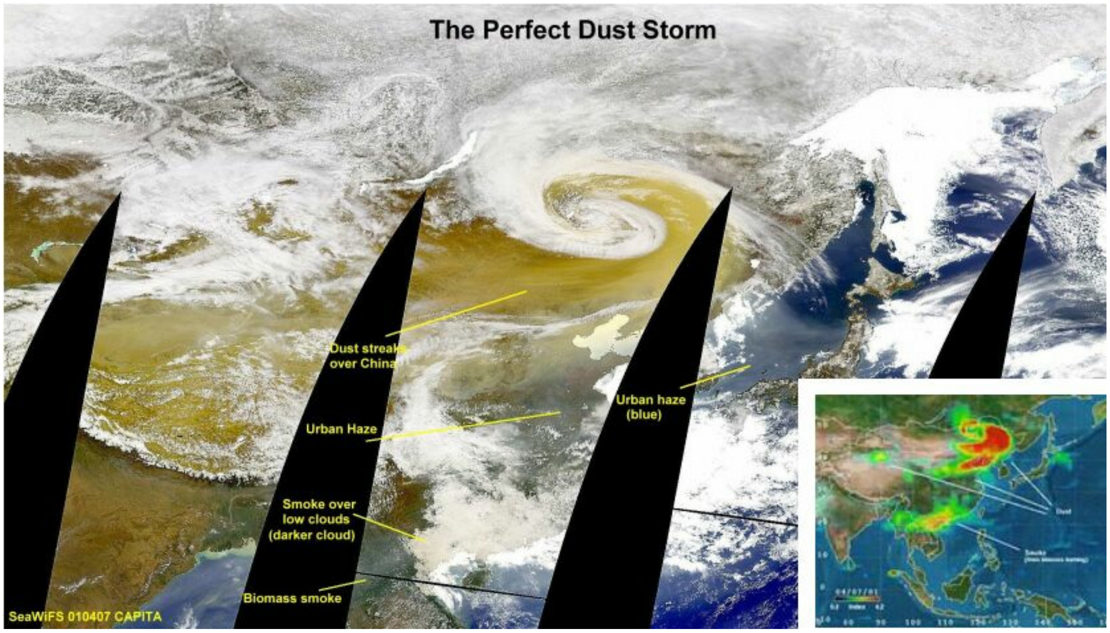


Figure 6-19. "The Perfect Dust Storm" from SeaWiFS observations and the aerosol observations from TOMS.

Hsu, N. Christina, Herman, J.R., and Clark Weaver, Determination of Radiative Forcing of Saharan Dust Using Combined TOMS and ERBE Data, J. Geophys. Res., **105**, 20649-20662, 2000.

Jay R. Herman and Christina Hsu, Code 916 (Jay.R.Herman.1@gsfc.nasa.gov)

Atmospheric Chemistry

Extremely Cold Temperatures and the Absence of Polar Stratospheric Clouds during SOLVE

The Airborne Raman Ozone Temperature and Aerosol Lidar (AROTEL) made observations that were both unexpected and significant during the recently concluded Sage III Ozone Loss and Validation Experiment (SOLVE) mission. AROTEL is a collaborative effort between Goddard Space Flight Center and Langley Research Center.

SOLVE took place during the winter of 1999/2000. The mission focused on processes controlling stratospheric ozone levels from the northern mid-latitudes to the North Pole. Polar stratospheric clouds, or PSCs, are a major component in the loss of polar ozone. PSCs provide the surfaces on which chemically inactive reservoir species convert to active species capable of destroying ozone.

Temperature plays a key role in the formation and lifetime of PSCs. In part because of temperature's pivotal role, AROTEL was selected to fly on NASA's DC-8 to provide high-resolution profiles of the arctic temperature fields. Lidar retrievals from the DC-8 offer distinct advantages over satellite data. They provide high-precision temperature profiles along with measurements of ozone, aerosols, clouds, and water vapor throughout the region of interest. These measurements were designed to help understand the conditions under which PSCs form and persist by identifying regions in the lower Arctic stratosphere where temperatures were low enough for PSCs to persist (195 K or lower).

AROTEL measured extremely cold temperatures during all three SOLVE deployments (December, 1999; January, 2000; and February–March, 2000). Temperatures were significantly below values observed in previous years, with large regions regularly below 191 K and frequent retrievals gave temperatures at or below 187 K. Temperatures were regularly encountered well below the saturation point of Type I PSCs, but their presence was not well correlated with PSC observations made by AROTEL. On December 12, extensive regions were observed having temperatures as cold as 185 K. Simultaneous observations on AROTEL's aerosol and polar stratospheric cloud (PSC) channels captured few, if any, PSCs within these extremely cold regions.

These observations are both surprising and important. Current theories on PSCs predict the occurrence of PSCs for measured values of nitric acid and water vapor at these temperatures. PSC formation depends critically on an air parcel's temperature and time history, its altitude, and the mixing ratio profiles of nitric acid and water vapor. The absence of PSCs where conditions appear favorable for their existence suggests that our current understanding of PSC formation is incomplete. The series of figures below illustrate this important conclusion.

Figure 6-20 displays over 7 hours of temperature data from the December 12th flight. This flight originated in Kiruna, Sweden, flying north of Russia and Scandinavia to ~80N. Only temperatures between 185 and 195 K are presented and extensive regions at or below 189 K are clearly seen.

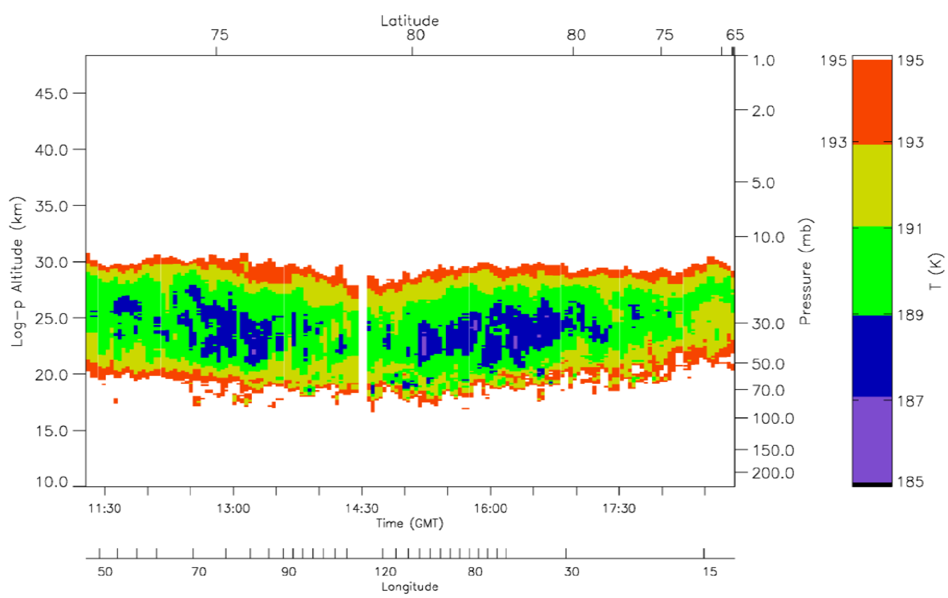


Figure 6-20. AROTEL temperatures between 185 and 195 K on flight of December 12, 1999.

Figure 6-21 shows the aerosol depolarization ratios measured on AROTEL's 532 nm channel. This data is used to identify PSCs that are nonspherical. Nonspherical PSCs are type 1a and type 2 PSCs, and Nat Rocks. Nat Rocks are very large particles >3 microns in diameter and having a very low number density. Nat rocks were first detected during SOLVE using in situ and AROTEL data. The figure shows that minimal depolarization was observed, meaning that nonspherical PSCs were absent.

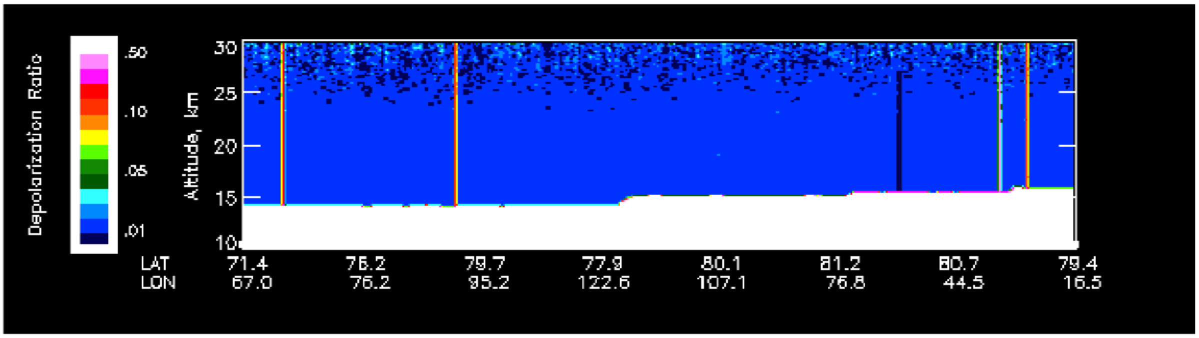


Figure 6-21. Aerosol depolarization on December 12th flight. The absence of depolarization indicates that nonspherical PSCs were absent between 15 to 30 km altitude on this flight.

Figure 6-22 presents aerosol backscattering as observed on AROTEL's 1064 nm channel. Mie scattering from PSCs and aerosols at this wavelength is typically much stronger than the weak molecular backscattering. Spherical PSCs (type 1b) are differentiated from background signals using this data and temperature. These observations are consistent with an aerosol background layer.

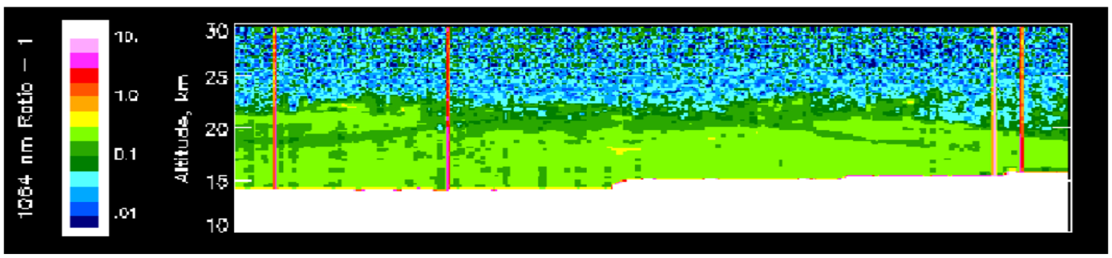


Figure 6-22. Aerosol backscattering at 1064 nm. Signal is consistent with only background aerosols being present.

Figure 6-23 displays four separate data sets addressing the December 12 observations. Aerosol/PSC backscattering as seen on the AROTEL 1064 nm channel appears in the upper left plot. AROTEL temperatures appear in the upper right plot. The bottom plots present calculations showing where Type 1 and 2 PSCs could exist as a function of temperature, nitric acid, and water vapor. (The lower left plot used AROTEL temperatures; the lower right plot used temperatures from Goddard's DAO). The dotted line in the bottom two plots separates data from regions where PSCs could exist (above line) from data that could not have originated from PSCs (below dotted line). In the lower left plot, only ~150 out of 168,000 acquired data points lie above the line. Below the line, the red dots represent temperatures where Type 1 PSCs should occur, but are not observed due to the low measured backscatter. Below the line, the yellow dots represent temperatures where Type 2 PSCs should occur, but also are not observed. The lower right panel uses DAO model temperatures, which are about 5 K higher than the measured AROTEL temperatures, and the red region below the dotted line indicates where PSCs should occur but are not observed.

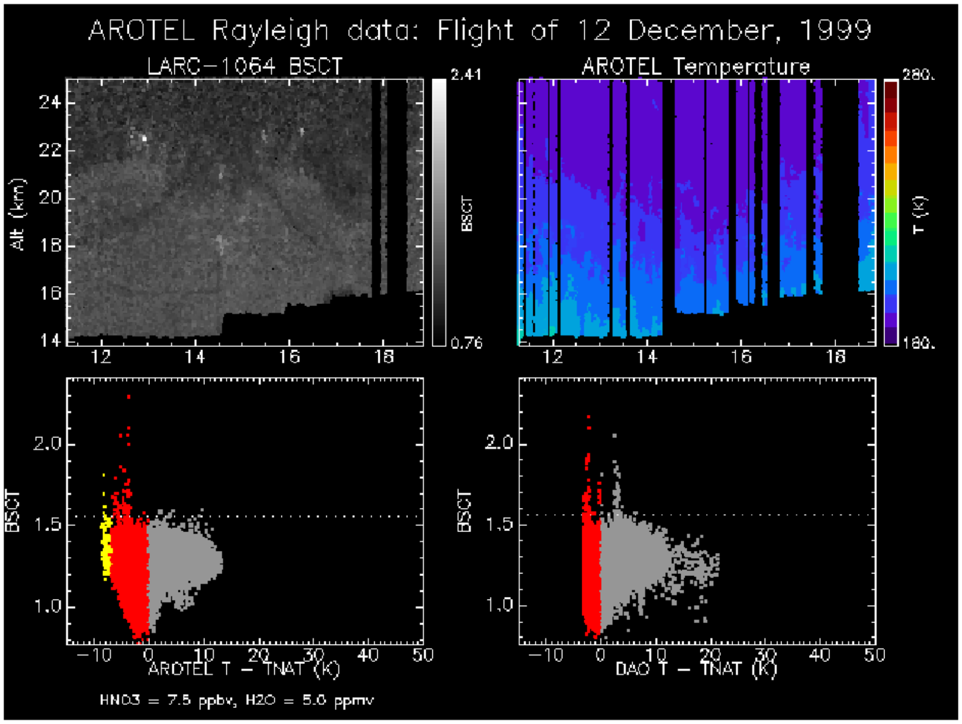


Figure 6-23. Upper left plot displays AROTEL 1064 nm backscatter data for December 12, 1999. Upper right plot shows AROTEL temperature data within the same region. Lower left plot shows where PSCs could exist as a function of measured AROTEL temperatures, water vapor, and nitric acid. Ordinate on the lower panels is the backscatter value and the abscissa is the difference between the AROTEL or DAO temperature and the Nat formation temperature. Data below the dotted line originated with aerosols and not PSCs; data above the dotted line originated with PSCs. The points above the dotted line consisted of only ~150 points out of a total of 168,000. The lower right plot is identical to the lower left one except that DAO temperatures were used in place of the measured values.

John F. Burris, Code 916 (John.F.Burris.1@gsfc.nasa.gov)

Measured Arctic Ozone Loss during the SOLVE Campaign

The SAGE III Ozone Loss and Validation Campaign (SOLVE) was conducted from Kiruna, Sweden, during the winter of 1999–2000. The campaign was an international effort and included the NASA DC-8 and the NASA ER-2 aircraft, both equipped to measure chemical and meteorological parameters. The Laboratory's Atmospheric Chemistry and Dynamics Branch (Code 916) flew the Airborne Raman Ozone Temperature and Aerosol Lidar (AROTEL) instrument on board the DC-8 for this mission. This instrument retrieves vertical profiles of ozone, temperature, aerosols, and clouds above the nominal flight altitude of 12 km.

One of the primary purposes of the mission was to document the concentration of stratospheric ozone as the Sun began to illuminate the Arctic vortex. The AROTEL instrument was an ideal instrument for this purpose, since it not only measures a vertical profile of ozone, but it also provides information as to the location and type of PSCs and the temperature environment as the PSCs form.

The campaign was made up of three deployments of the DC-8 to Kiruna. The first, in December 1999, sampled the prewinter Arctic atmosphere; a January deployment made measurements during the darkness of the winter; and the third deployment, in March 2000, observed large ozone losses and the breakup of the vortex. Figure 6-24 shows the ozone field above the aircraft during one of the flights in January, prior to any significant ozone loss. This flight took place almost entirely within the vortex and is indicative of the atmosphere within the vortex during January. For this reason all the data collected from within the vortex during all the January flights were averaged to obtain a "presunlight," vortex ozone profile. Figure 6-25 shows similar data from the flight of March 13, 2000, and shows significant chemically related ozone loss particularly in the 18 km region. Data from within the vortex during the DC-8 flights on March 11 and March 13 were averaged and then compared with the January baseline profile to retrieve an ozone loss rate profile, which is shown in Figure 6-26. This plot indicates that the maximum ozone loss rate occurred at about 460K (approximately 18 km). The maximum loss rate obtained in this manner is 0.029 ppm/day. Shortly after the March 13 flight, the vortex began to break up and the ozone-depleted air began mixing with mid-latitude stratospheric air parcels.

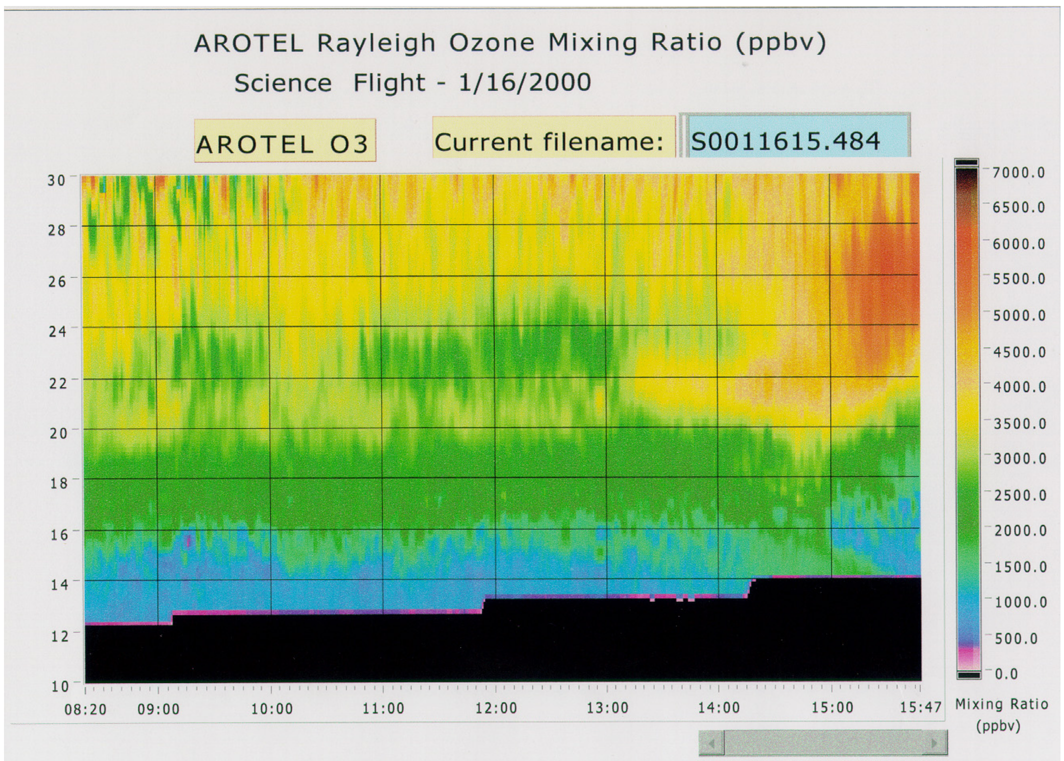


Figure 6-24. The vertical distribution of ozone above the NASA DC-8 during the flight of January 16, 2000.

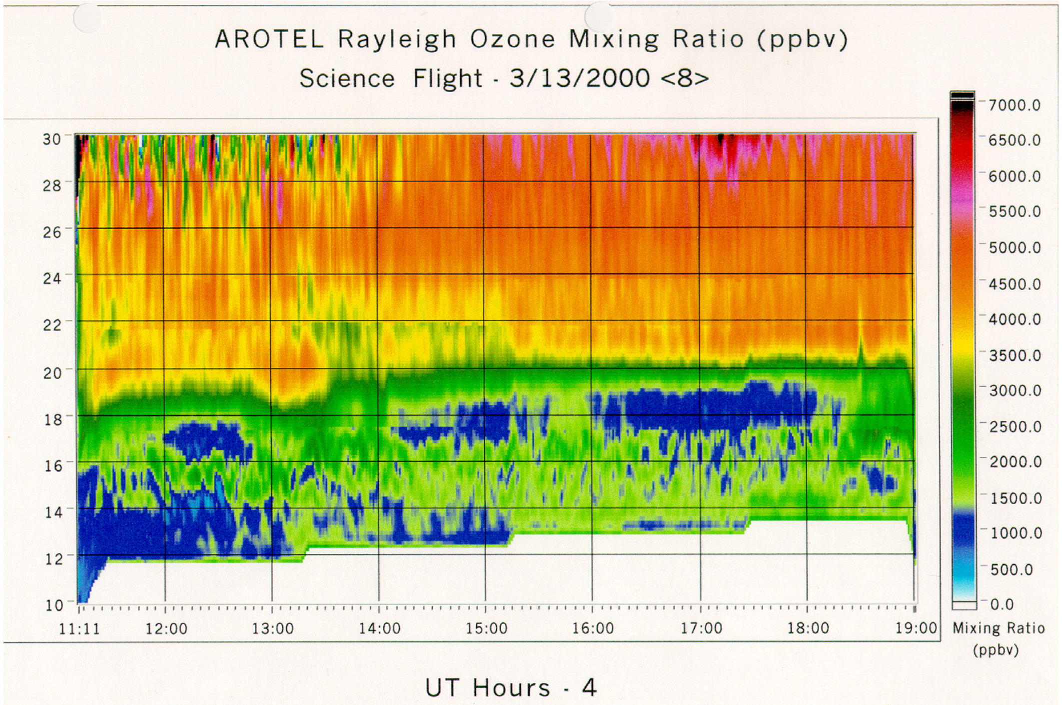


Figure 6-25. The vertical distribution of ozone above the NASA DC-8 for the flight of March 13, 2000.

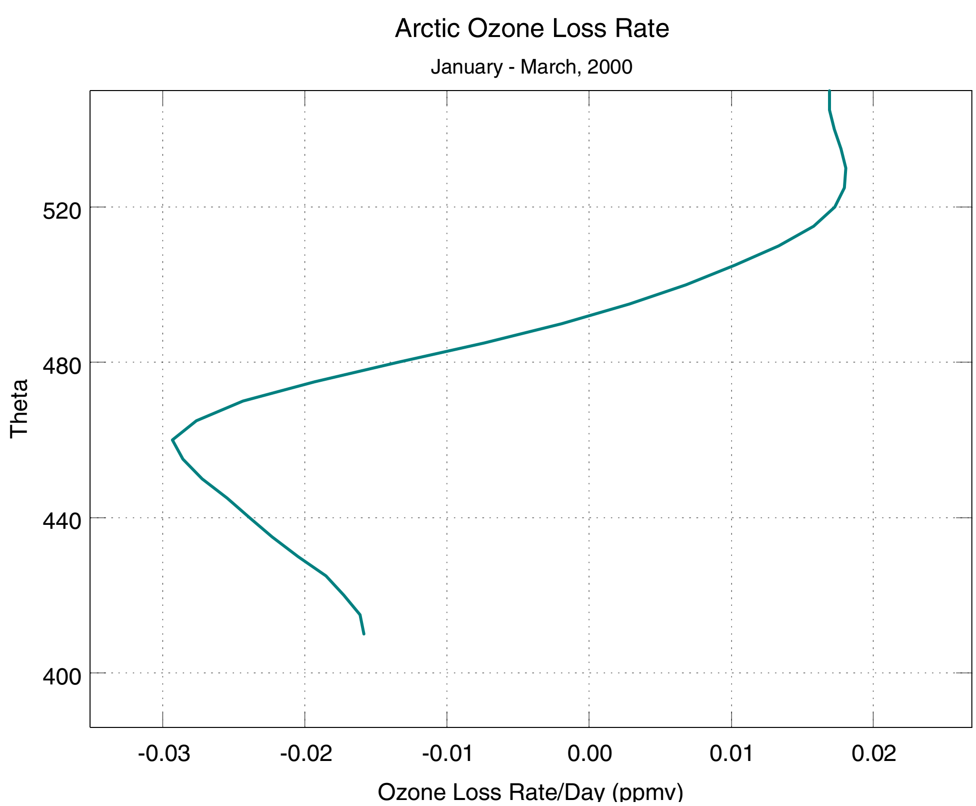


Figure 6-26. Plot showing the ozone loss rate from the January average vortex profile to the average of the vortex ozone during the flights of March 11 and 13, 2000.

Thomas J. McGee and John F. Burris, Code 916 (Thomas.J.McGee.1@gsfc.nasa.gov)

Changes in the Earth's UV Reflectivity from the Surface, Clouds, and Aerosols

Measurements of the Earth's 380 nm ultraviolet (UV) reflectivity combine the effects of surface reflectivity, aerosols, haze, cloud optical thickness and the fraction of the scene covered by clouds. Changes in UV cloud and aerosol reflectivity imply similar changes over a wide range of wavelengths—UV, visible, and near infrared (at least 0.31 to 2 microns). These changes affect both the transmission of radiation to the Earth's surface and the reflection back to space. TOMS (Total Ozone Mapping Spectrometer) 380 nm reflectivity data indicates that the 14-year annual mean power reflected back to space is 385.3±31 w/m^2. Most of the reflection is by clouds, aerosols, and snow/ice. Based on measured long-term changes in global reflectivity, it is estimated that there is an additional 2.8 ± 2.8 w/m^2 per decade reflected back to space (2 standard-deviation error estimate) during the TOMS observing period of 1979 to 1992. Since the 380 nm surface reflectivity is low (2% to 8%) over most surfaces, water and land, the observed reflectivity changes are mostly caused by changes in the amount of snow/ice, cloudiness, and aerosols.

Time-series analysis of TOMS reflectivity over the period from 1979 to 1992 shows that no significant changes occurred in annually averaged zonal-average reflectivity at latitudes within 60°S to 60°N, even though there were changes at higher latitudes (e.g., 3% per decade, in reflectivity units, between 60°N and 70°N). When the effects of the 11-year solar cycle and ENSO (El Niño Southern Oscillation) are removed from the data, we observe statistically significant reflectivity changes poleward of both 40°S and 40°N (Figure 6-27). The solar-cycle results suggest a possible Sun-weather relationship.

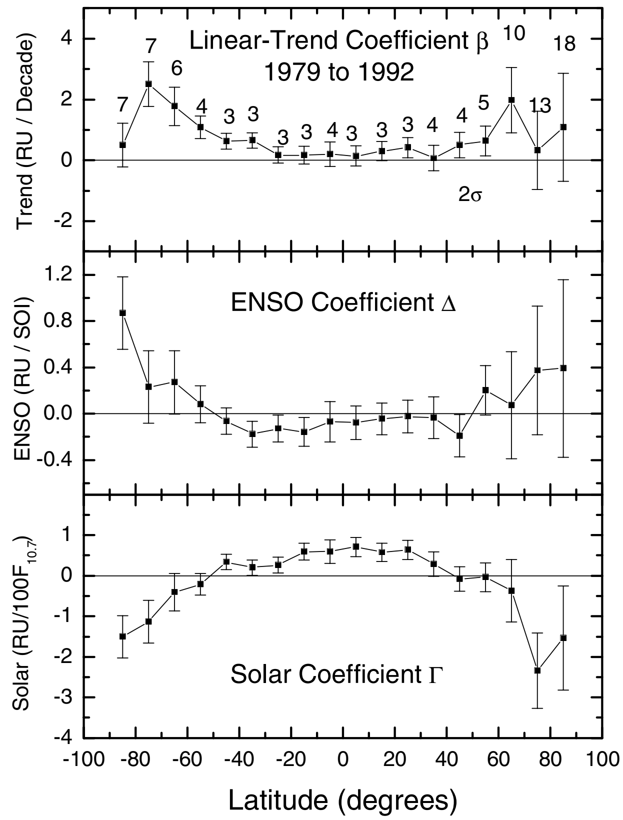


Figure 6-27. The linear-trend coefficient (upper panel) β ENSO coefficient Δ (middle panel), and the solar coefficient γ (lower panel) in units of RU per year, RU per SOI, and RU per 100 $F_{10.7}$, respectively. Error bars are 2σ standard deviations. 1 RU = 1% reflectivity.

There are significant regional changes over land and ocean areas that can affect the amount of solar radiation reaching the surface (Figure 6-28). The largest of these regions have decreases of 3 to 6± 1% per decade in central Europe, the western United States, central China, and western Russia. These decreases are offset by increases in the same latitude bands mostly over the oceans. The largest regions showing an increase in scene reflectivity are off the western coast of South America (near Chile and Peru), 5 to 8± 1 %/decade, and over the Weddell Sea in Antarctica, 10% /decade. Yet no change appears over the ice shelf and continent. The largest increase in reflectivity occurs over the ocean just to the north of Antarctica. This change is important because it reduces UV radiation overall (290 to 400 nm), and it partially offsets the effect of the increased amount of UVB radiation (290 to 320 nm) caused by decreasing Antarctic ozone.

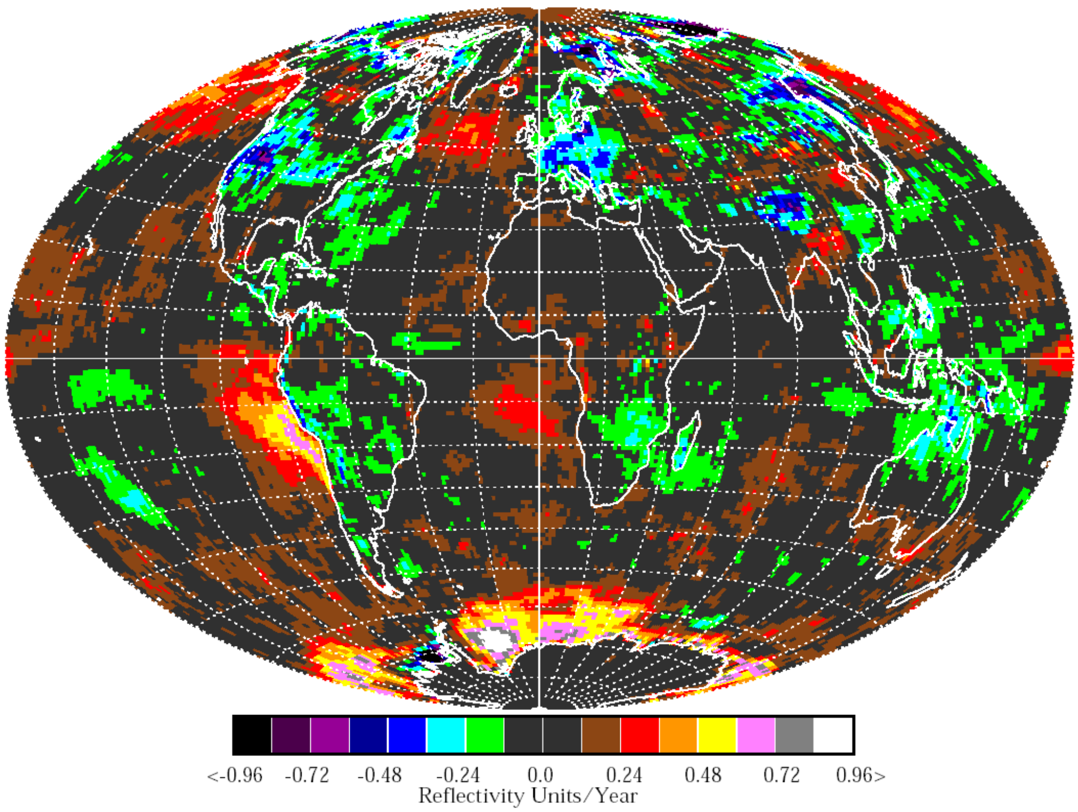


Figure 6-28. Contour plot of the linear slope coefficient (RU per year) for all causes (see Figure 6-27) showing a map of the global trends in annually averaged reflectivity for 1980 to 1992 for each 1° x 1° TOMS pixel from the gridded reflectivity data set.

Herman, J.R., D. Larko, and J. Ziemke, Changes in the Earth's Global UV Reflectivity from Clouds and Aerosols, J. Geophys. Res. **106**, 5353-5368, 2001.

Jay R. Herman, Code 913 (Jay.R.Herman.1@gsfc.nasa.gov)

Global Mapping of Underwater UV Irradiances

The global stratospheric ozone-layer depletion results in an increase in biologically harmful UV radiation reaching the surface and penetrating to ecologically significant depths in natural waters. Such an increase can be estimated on a global scale by combining satellite estimates of UV irradiance at the ocean surface from the TOMS satellite instrument with the SeaWiFS satellite ocean-color measurements in the visible spectral region. We have developed a model of seawater optical properties in the UV spectral region based on the Case 1 (open ocean) water model in the visible range. The inputs to the model are standard monthly SeaWiFS products: chlorophyll concentration and the diffuse attenuation coefficient at 490nm. The depth of penetration of solar UV radiation (to 10% of surface intensity, Z10) into ocean water is shown in Figure 6-29

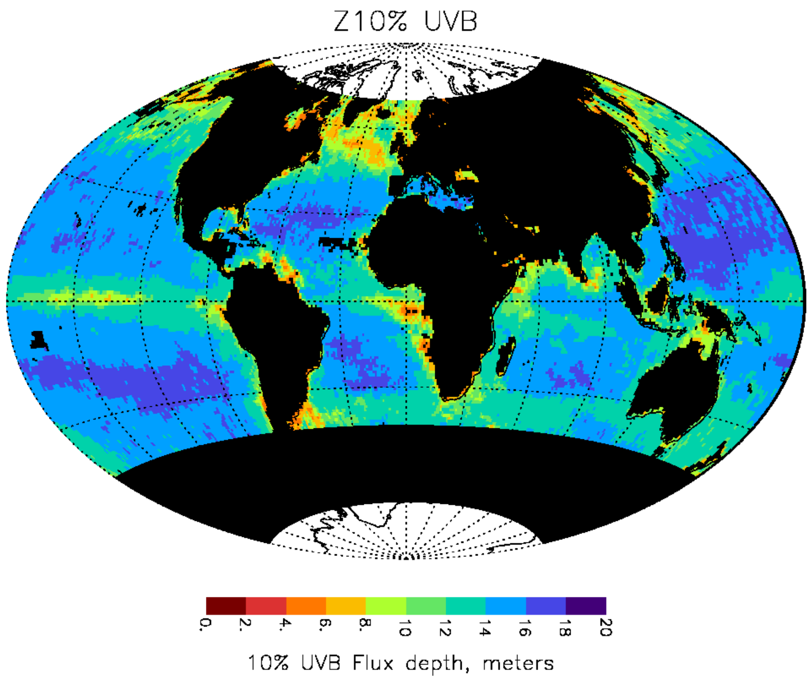


Figure 6-29. The depth of UVB penetration to level of 10% of the surface irradiance as a function of the input parameters: chlorophyll concentration and the diffuse attenuation coefficient at 490 nm.

Vasilkov, A., N. Krotkov, J. Herman, C. McClain, K. Arrigo, and W. Robinson, Global mapping of underwater uv fluxes and dna-weighted exposures using TOMS and SeaWifs data products, J. Geophys. Res. Vol. 106, 27,205, 2001.

Sensitivity studies of underwater UV irradiance to changes in atmospheric and oceanic optical properties show that solar-zenith angle, cloud transmittance, water optical properties, and total ozone are the main environmental parameters controlling absolute levels of UVB (280–320nm) and DNA-weighted irradiance underwater. Monthly maps of underwater UV irradiance and DNA-weighted exposure are calculated using monthly-mean SeaWiFS chlorophyll and diffuse attenuation coefficient, daily SeaWiFS cloud fraction data, and the TOMS-derived surface UV irradiance daily maps. The results include global maps of monthly average UVB irradiance and DNA-weighted daily exposures at 3m and 10m, and depths where the UVB irradiance and DNA-weighted dose rate at local noon are equal to 10% of their surface values.

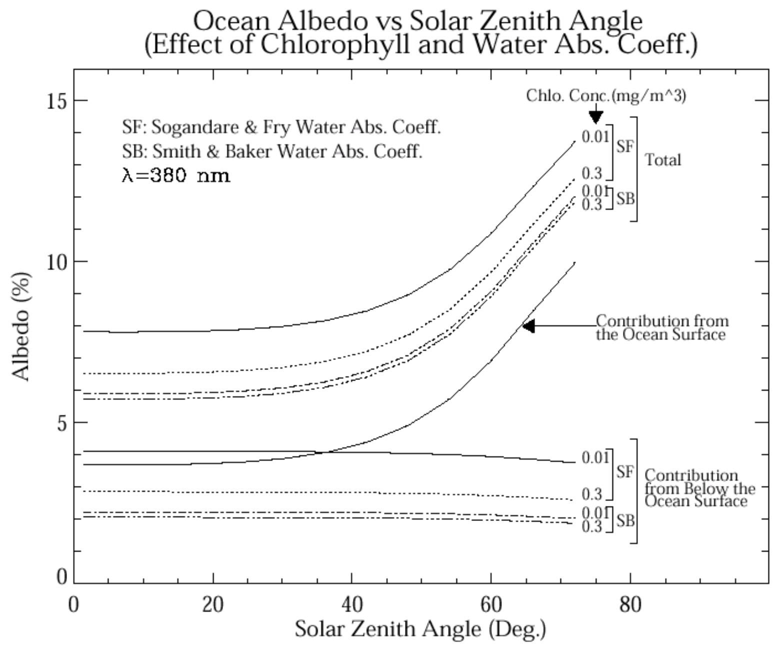


Figure 6-30. Ocean Albedo vs. Zenith Angle and Chlorophyll Concentration at 380 nm. This figure shows that the main contribution to the satellite-retrieved 380 nm radiances from the ocean comes from the surface reflection and from underwater in approximately equal amounts. Retrieval of new ocean properties using UV wavelengths requires knowledge of surface conditions and accurate radiative transfer modeling.

The relationship between chlorophyll concentrations and the 380 nm water-leaving radiances (Figure 6-30) enables us to deduce the amount of chlorophyll from radiance measurements. Of particular interest are recent findings that the ratio of 340 to 380 nm ocean reflectivities are reversed from that of clean water when chlorophyll-bearing phytoplankton is present and mycrosporine amino acids, minerals, and other UV-absorbing substances are absent (Figure 6-31). TOMS data indicate that this condition prevails throughout most of the open ocean. The results show that the UV channels can be used to distinguish between types of materials present in the ocean. This finding should lead the way towards future designs for ocean-observing satellite instruments.

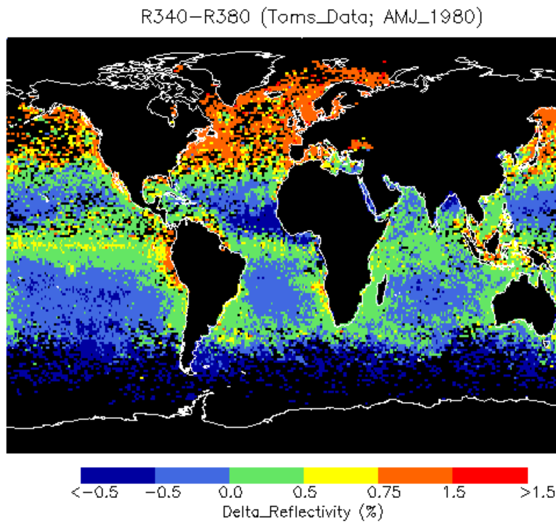


Figure 6-31. TOMS UV reflectivity difference showing chlorophyll patterns that match SeaWiFS data

Jay R. Herman, Code 913 (Jay.R.Herman.1@gsfc.nasa.gov)

Simulating Global Distributions of CO_2

The Earth's climate is changing as a result of human activity, including the emission of greenhouse gas chemicals. Carbon dioxide (CO_2) constitutes the largest current and projected manmade source of climate forcing [*Intergovernmental Panel on Climate Change*, 2001]. Yet, in spite of carbon dioxide's primary importance in climate forcing, large uncertainties exist in the global carbon budget. We must resolve these uncertainties before we can reliably predict the impact of greenhouse gas emissions and devise remedial strategies.

Determining the fate of manmade source gases requires numerical simulation of the transport of CO_2 (and other tracers such as CO, CH_4, and biomass burning tracers). Understanding the exchange of CO_2 between the ocean surface, the terrestrial biosphere, and the atmosphere is critical to understanding the global carbon cycle and what processes determine the atmospheric concentration of CO_2. We conduct transport simulations of CO_2 to better understand how meteorological variability contributes to changes in CO_2 and to better quantify the magnitudes of the surface sources and sinks. A further goal of the simulations is to provide realistic concentration profiles and spatial gradients for determining remote-sensing instrument requirements. The 3-D distributions of atmospheric CO_2 permit instrument developers to estimate sources of error and determine allowable bounds on instrument sensitivity for making meaningful measurements.

The simulation shown in Figure 6-32 was run using monthly average grids of surface fluxes and real-time 3-dimensional wind data from a prototype version (fvDAS) of the assimilation system run by Goddard's DAO. The example day shows the correspondence between the location of the surface sources and sinks and the resulting regions of enhanced and diminished CO_2 in the lower atmosphere (near 850 mbar or about 1500 m MSL). The effects of transport are also seen in the CO_2 distribution. Changes in the average column abundance of CO_2 are produced by the surface forcing as well, but the signal is attenuated relative to that near the surface.

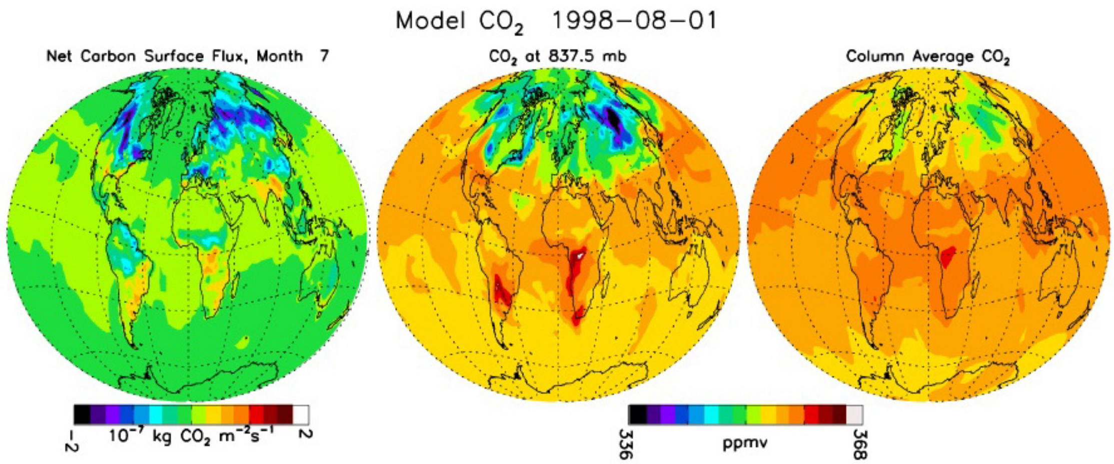


Figure 6-32. Global distribution of input net surface sources and sinks, calculated CO_2 distributions in the lower atmosphere, and column CO_2 for one example day of the simulation. Each color on the CO_2 scale represents 2 ppmv.

With meteorology from data assimilation, such transport runs provide the basic framework to analyze existing (and proposed) measurement data on a point-by-point basis. We compare our simulation with observed CO_2 concentration gradients on a daily, seasonal, regional, and interhemispheric basis to examine the consistency of sources and sinks. Figure 6-33 compares the simulation with surface data at four sites for 1 year. This comparison shows 1) the large seasonal cycle of CO_2 in the Northern Hemisphere driven by exchange with the terrestrial biosphere; 2) the difference in the interhemispheric gradient between the model and data, from which a “missing sink” for CO_2 has been inferred for the Northern Hemisphere; and 3) a significant correlation between the model and data for fluctuations on synoptic (3–5 day) time scales.

Satellite observations of CO_2 with adequate precision and resolution would substantially increase our knowledge of the atmospheric CO_2 distribution and thereby improve our understanding of the global carbon budget. The measurement requirements are challenging, however, since the variation in atmospheric CO_2 is small relative to background levels and most of the variability occurs near the Earth’s surface. Several instrument approaches with a wide range of sampling characteristics are under consideration for measuring CO_2 from space. The spatial and temporal variability of atmospheric CO_2 must be considered in designing potential satellite instruments and in evaluating the potential of proposed methods for inferring fluxes. CO_2 simulations are used as inputs to radiative transfer sensitivity studies needed for algorithm development. In addition, we have begun to investigate the ability of potential satellite instruments with a variety of orbits, horizontal resolutions, and vertical weighting functions to capture the variation in the modeled CO_2 fields. Finally, because our simulations use assimilated meteorology, they will be useful for relating satellite, ground-based, and aircraft observations for satellite calibration/validation and intensive field campaigns.

Future simulation work is aimed at exploiting these methods to better constrain CO_2 sources and sinks, to improve the formulation of transport in the model, and to refine the instrument requirements for remote sensing of atmospheric CO_2. Our long-term goal is assimilation of CO_2 data, including satellite-based CO_2 measurements. This approach is expected to lead to resolution of the global carbon budget and to improved prediction of future climate change and response.

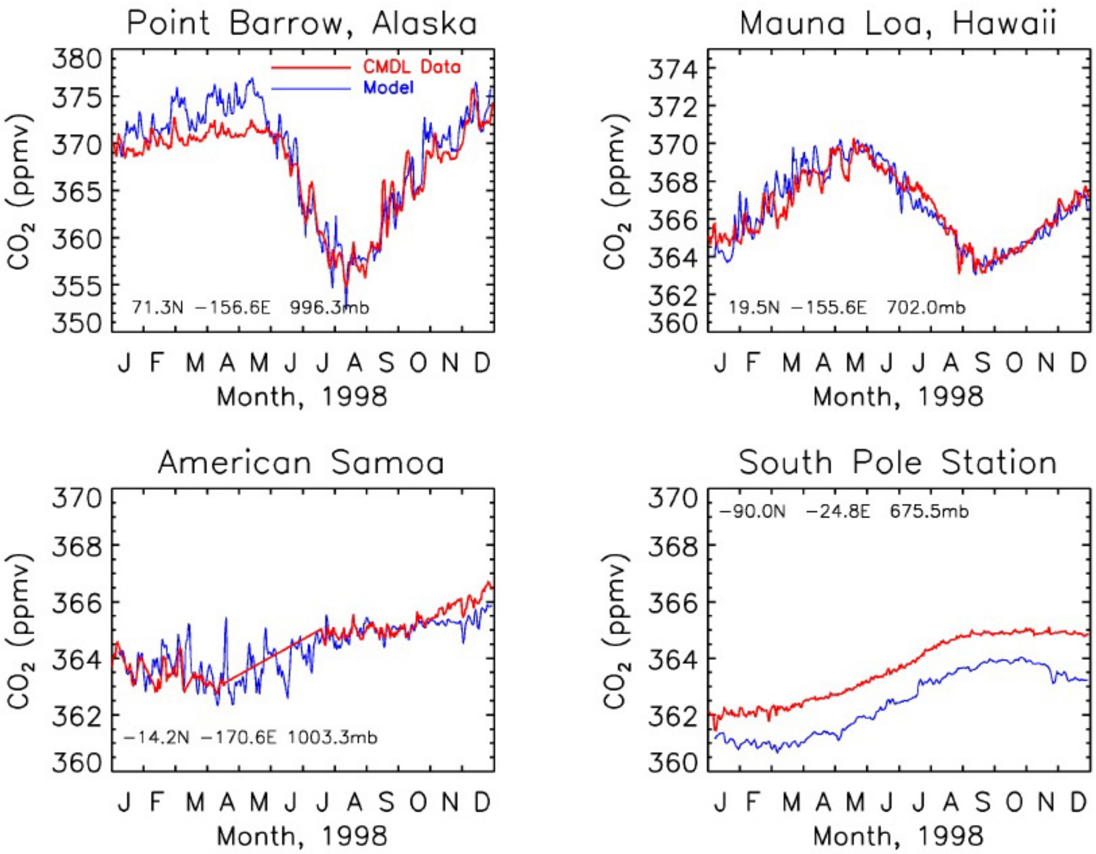


Figure 6-33. Comparison of model output for 1998 with daily measurement data at four sites. CO_2 data is provided by the National Oceanic and Atmospheric Administration, Climate Modeling and Diagnostics Laboratory, Carbon Cycle Group.

Randy Kawa and Arlyn Andrews, Code 916 (Stephan.R.Kawa.1@gsfc.nasa.gov)

Clouds and Precipitation

Retrieved Vertical Profiles of Latent Heat Release Using TRMM Rainfall Products

Rainfall is a key link in the hydrologic cycle and is a primary heat source that fuels the general circulation of the atmosphere. The vertical distribution of latent heat release, which is accompanied by rainfall, modulates the large-scale circulation of the tropics and in turn can affect mid-latitude weather. This latent heat release is a consequence of phase changes between vapor, liquid, and solid water. Present large-scale weather and climate models can simulate cloud latent heat release only crudely, thus reducing their confidence in predictions on both global and regional scales.

Laboratory scientists were the first to use NASA Tropical Rainfall Measuring Mission (TRMM) rainfall information to estimate the four-dimensional structure of latent heating on a global scale. We retrieved latent heating for 1 month (February 1998) over the global tropics, the coverage of the TRMM satellite. Figure 6-34 shows monthly mean latent heating at three different altitudes (2, 5 and 8 km) over the global tropics from the Goddard Convective-Stratiform (CSH) heating algorithm (developed by the Goddard mesoscale modeling group). The horizontal pattern of latent heat release coincides with areas of major convective activity such as the intertropical convergence zone (ITCZ) in the Pacific and Atlantic basins, the South Pacific Convergence Zone (SPCZ), and broad areas of precipitation events spread over the continental regions.

Heavy surface precipitation is associated with intense latent heating in the middle and upper troposphere. Upper tropospheric heating over the Pacific and Indian Oceans is much stronger than over Africa, South America, and the Atlantic Ocean. Higher stratiform amounts always contribute to higher maximum latent heating levels. Whether the higher stratiform proportions and more frequent vigorous convective events in the Pacific are related to the warmer SSTs needs to be studied using multiseason and multiyear retrieved latent heating profiles. Note that differential heating between the continents and oceans in the upper troposphere could generate strong horizontal gradients in the thermodynamic fields and could interact with the global circulation.

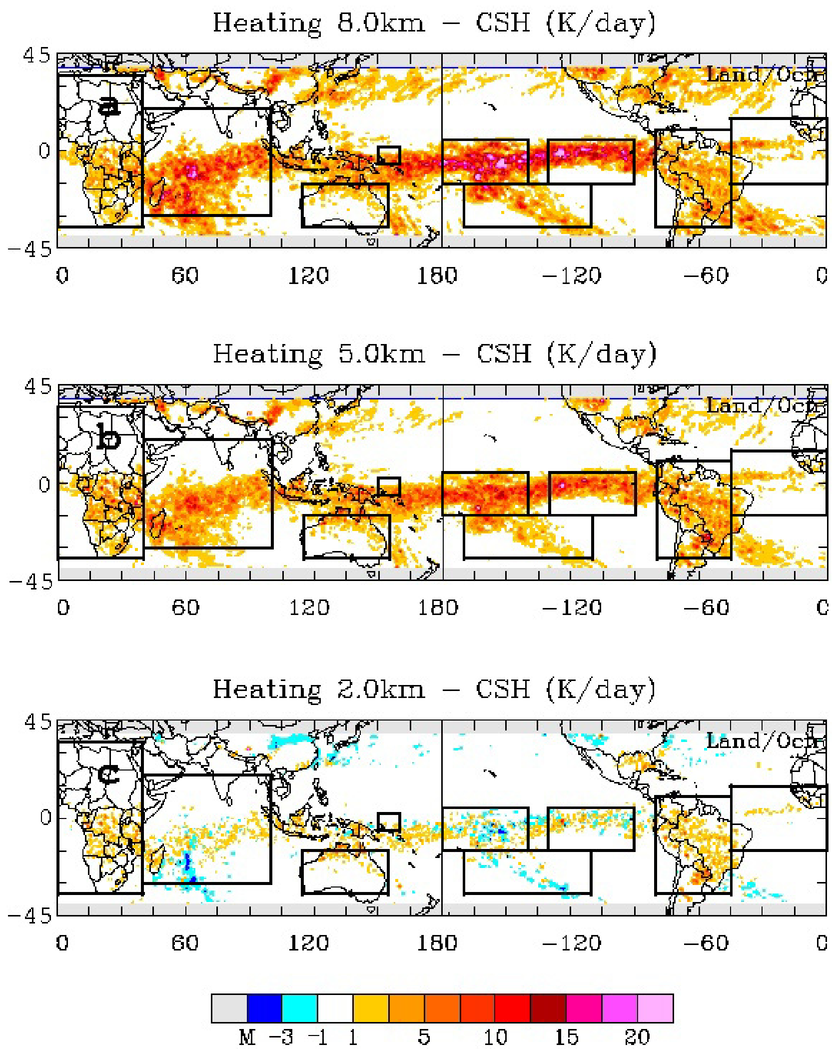


Figure 6-34. Monthly mean latent heating at 8, 5, and 2 km AGL over the global tropics derived from the Goddard Convective-Stratiform Heating (CSH) algorithm.

An interesting result from Figure 6-34 is the relatively strong cooling at 2 km over the Pacific (East, Central, and South) and Indian Oceans but not over Africa and South America. This result is unexpected, as the moisture content is higher over oceans. Cooling from rain evaporation in the lower troposphere should be stronger over drier areas. Several previous observational studies diagnosed the heating budgets from sounding networks located over the west Pacific warm pool region and the Amazon basin. The sounding budget showed weak, low-level cooling in the mean heating profile over the Pacific warm pool region for the month of February 1993. This cooling was induced by mesoscale downdrafts or evaporation by shallow cumuli. Observations also revealed that the relative humidity tended to be relatively low in the lower troposphere over the warm pool region. This would allow for more evaporative cooling. Budget results from the Amazon region did not exhibit low-level diabatic cooling. It has been suggested that the lower-most 2–3 km above the canopy of the Amazon rain forest is characterized by a strong diurnal cycle of evapotranspiration and upward convective fluxes of moisture, producing very large mixing ratios. The high moisture content during the wet season in the lower troposphere of the Amazon Basin may prevent or severely limit cooling below the cloud base. This indirect validation provides some confidence in our TRMM latent heating product. We are currently in the process of producing a multiyear latent heating data set using TRMM rainfall products.

Two other latent heating retrieval algorithms, the Goddard Profiling (GPROF) heating and the Hydrometeor heating (HH), were also used to estimate latent heating for February 1998. Their results were compared to those from the CSH algorithm. All three algorithms showed the same horizontal distribution pattern coincident with the major areas of convective activity in the tropics. The magnitudes of their estimated latent heating also agreed well with each other and with that determined from diagnostic budget studies. The major difference among the three algorithms was in the altitude of the retrieved maximum heating level. The latent heating profiles derived from the Goddard CSH heating algorithm agreed better with observations.

Two global climate models, from Goddard's DAO and from Florida State University, are currently using these data sets either to improve their cumulus parameterization schemes or to identify the problem in their parameterization schemes. Preliminary results indicate that these two global models have improved their energy and water cycles and their ability to forecast rainfall.

Wei-Kuo Tao, Code 912 (Wei-Kuo.Tao.1@gsfc.nasa.gov)

The Effects of Amazon Deforestation on Rainfall

This study began with the hypothesis that heavily deforested regions will experience increased surface heating, leading to local circulations that will ultimately *enhance* the rainfall. This would be an important finding because several modeling studies have concluded that widespread deforestation would lead to *decreased* rainfall. Toward that end, we analyzed rain estimates from a combined GOES infrared/TRMM microwave technique with respect to percent forest cover from Landsat data (courtesy of TRFIC at Michigan State University).

Figure 6-35 shows the area of interest in Rondonia (southwest Brazil). Five 1º x 1º areas of varying forest cover were examined during the "dry" season in Amazonia (July–Sept, 2000), when the effects of the surface would not be dominated by large-scale synoptic weather patterns.

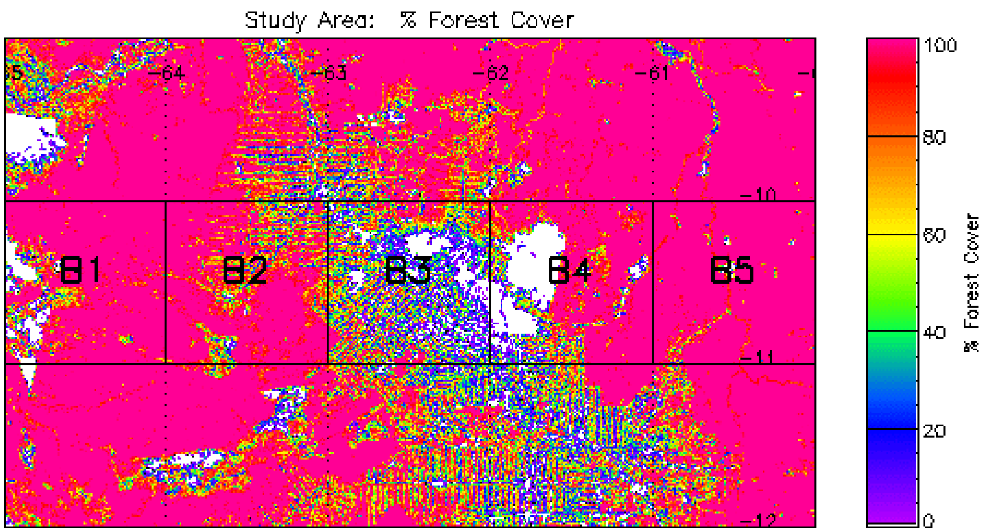


Figure 6-35. Five 1º x 1º areas of varying forest cover in Rondonia, southwest Brazil.

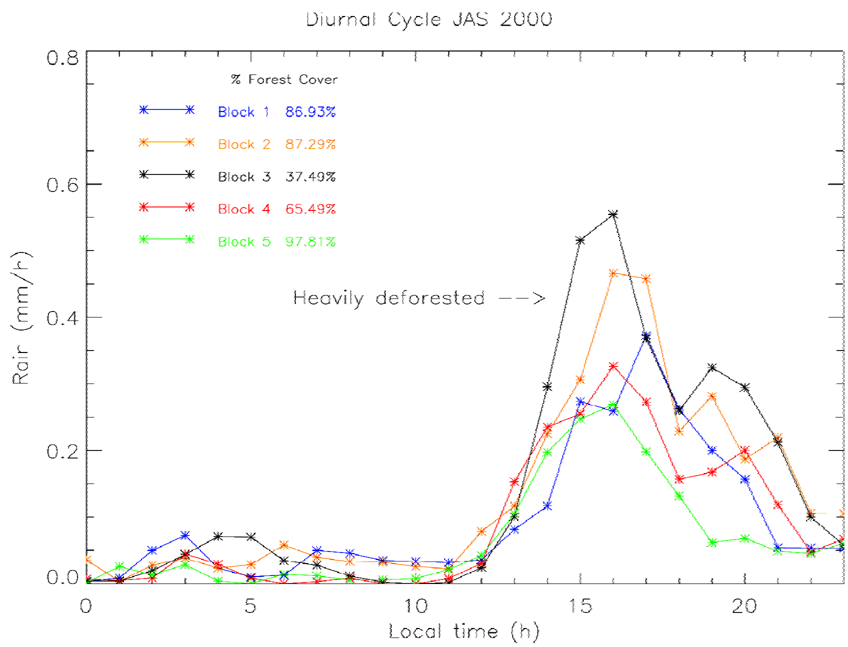


Figure 6-36. Rainfall amounts in the five regions versus local time.

Figure 6-36 presents results that show—

- Maximum rainfall fell in most deforested area (B3).
- Heavily forested areas (B1 and B5) received the least rainfall.
- Cloud development initiated at borders, and the diurnal cycle of precipitation may be a function of the surface cover.

These results should be viewed as preliminary, as only one season was examined and the error bars on the rain estimates are large.

Andrew J. Negri, Code 912 (Andrew.J.Negri.1@gsfc.nasa.gov)

Sampling of the Diurnal Cycle of Precipitation using TRMM

One of the priority science questions in the design of the Tropical Rainfall Measuring Mission (TRMM) was "What is the diurnal (daily) cycle of tropical rainfall and how does it vary in space?" To answer this question, TRMM's orbit was designed to precess (or make a complete cycle) through the 24 hours of the day during a period of 46 days. We have recently analyzed TRMM data to determine the optimal time period over which to accumulate the rainfall observations.

TRMM's sampling pattern affects our ability to understand the daily variation of the rainfall estimates produced by the satellite's two main instruments. These two instruments are the TRMM Microwave Imager (TMI) and Precipitation Radar (PR). These instruments have ground-track widths of 720 km and 220 km respectively. The combination of a long precession period and narrow ground-track results in peculiar patterns of sampling (the number of observations of any spot on the Earth).

Figure 6-37 shows the results from 3 years (1998–2000) of PR sampling at 1 hour of local time (00–01 LT). (The color scale highlights tropical sampling at the expense of the higher latitudes.) Note the absence of PR data over Australia due to an intergovernmental agreement. A checkerboard pattern in the hourly sampling at low latitudes is apparent. This pattern is examined in greater detail over a representative tropical region, the Amazon Basin (0–10º S, 75–50º W).

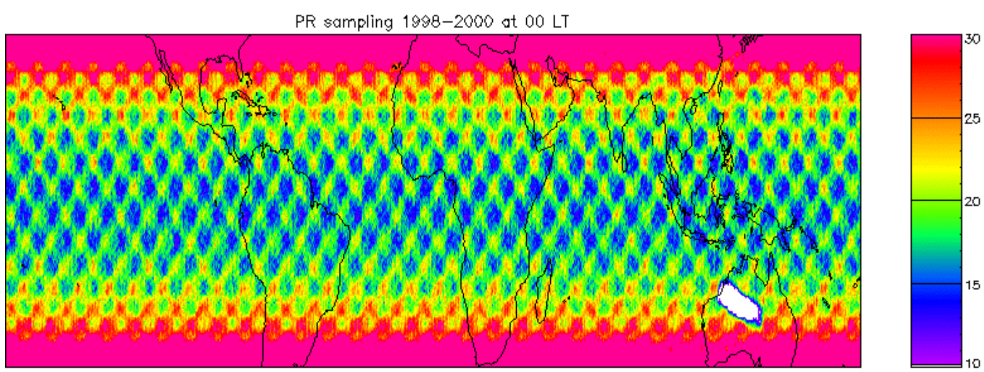


Figure 6-37. Observed Precipitation Radar sampling at 00 Local Time (1998-2000).

Figure 6-38 shows the PR sampling accumulated for periods from 1 to 6 h (plotted vertically) and for 1 year (2000) and 3 years (1998–2000) (plotted horizontally). The parameter sigma/mean is the standard deviation (s) divided by the mean (m) of the grid cells in each scene. This ratio attempts to quantify the homogeneity of each scene, with lower numbers indicating more uniform sampling. It is evident that 4-hour accumulations provide the most spatially even sampling pattern across this region. (Note that the scale changes from plot to plot.) Adding 2 more years of data, while tripling the sampling, does not appreciably smooth the pattern at any accumulation period. Further accumulation beyond 4 hours increases the unevenness of the sampling pattern.

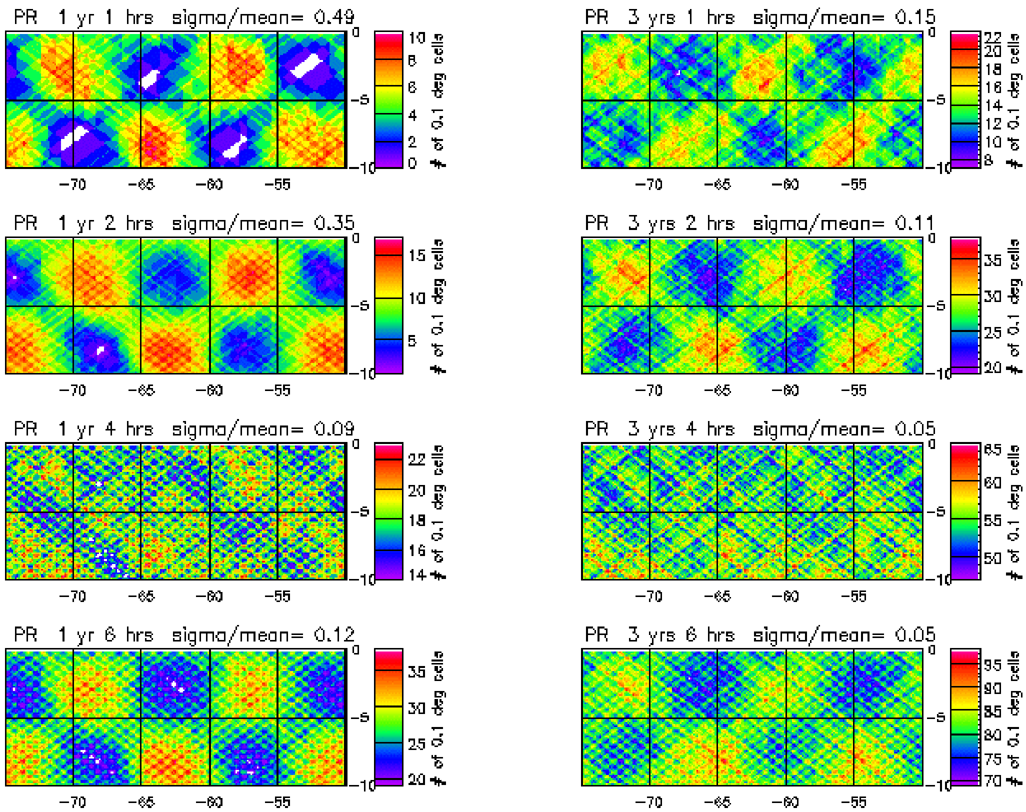


Figure 6-38. Cumulative observed sampling in the Amazon Basin.

One year (2000)

Three years (1998-2000)

Our study concluded that the optimal time period over which to accumulate the rainfall observations was 4 hours. That interval minimizes the spatial variation and the sampling error across any tropical region. These results are important for our understanding of the hourly variation of rainfall over remote regions such as the Amazon Basin, where conventional observations are not possible. The study also verified its observational results using a simple orbital model and demonstrated the sensitivity of the sampling pattern to the altitude of the TRMM satellite, an important consideration for future missions such as the Global Precipitation Mission.

Andrew J. Negri, Code 912 (Andrew.J.Negri.1@gsfc.nasa.gov)

On Rainfall Modification by Major Urban Areas: Observations from Spaceborne Rain Radar on TRMM

Most of us have watched local television weather forecasts. Observing the maps closely, we notice that the cities tend to be from 2 to 10 degrees (F) warmer than the surrounding suburbs and rural areas (Figure 6-39). This difference is due to the so-called “urban heat island” effect. Urban areas have numerous buildings, roadways, cars, and artificial surfaces. The heat-retaining properties of these surfaces contribute to the formation of this urban heat island. To understand this effect, think of how uncomfortable it is to walk on hot pavement without shoes. It is estimated that by 2025, 80% of the world’s population will live in cities. As cities continue to grow, urban sprawl creates unique problems related to land use, transportation, agriculture, housing, pollution, and development. Urban expansion also has measurable impacts on the environment.

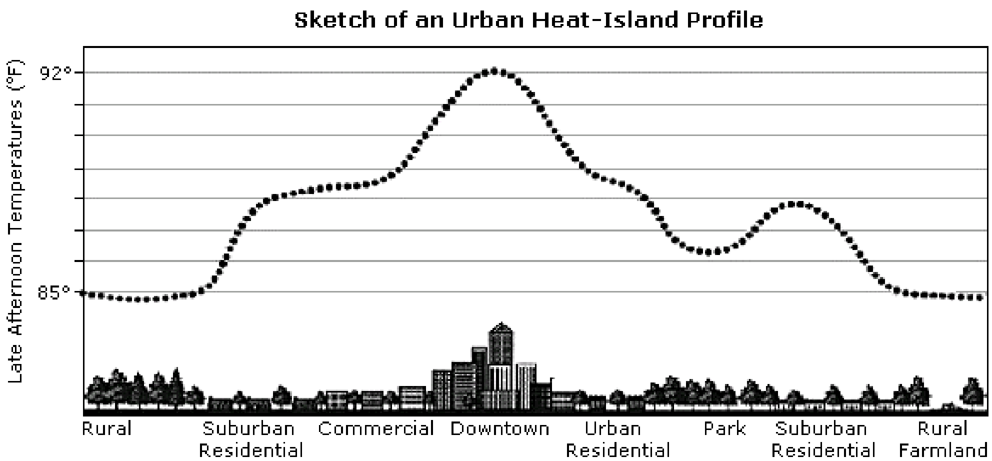


Figure 6-39. Typical Urban Heat Island (UHI) temperature profile (courtesy of The Heat Island Group, LBNL).

In fact, large cities may *create* their own weather and climate. The urban heat island creates a wind circulation that promotes rising air over the city. During the warmer months, researchers have discovered that the rising air can produce clouds or enhance existing ones. Under the right conditions, these clouds can evolve into rain-producers or storms. It is suspected that as air converges due to rougher city surfaces (e.g., buildings) the convergence contributes to the rising air needed to produce rainfall. Converging air forces air upward in the same manner that two colliding cars will be forced upward upon impact. Others have suggested that increased particles in the urban atmosphere from cars and smokestacks contribute to efficient cloud formation. Early studies using ground-based instruments around cities like St. Louis, Chicago, Mexico City, and Atlanta have shown that large cities can affect rainfall over and slightly downwind of metropolitan areas. These studies were limited in many ways, however.

Our recent work represents one of the first published attempts to identify rainfall modification by cities using space-based rain measurements. The work has implications for assessing this anomaly in the water cycle at locations around the globe. The study utilizes the world’s first space-based rain radar aboard NASA’s TRMM satellite. The instrument operates similarly to the Doppler radar seen on evening newscasts. Space-based observations overcome many limitations of ground-based observations and allow for investigation of urban rainfall in numerous cities simultaneously around the world.

This study suggests that major cities in the United States such as Atlanta, Dallas, San Antonio, Austin, and Nashville noticeably affect summer rainfall over and downwind of the urban centers. Our results reveal an average increase of ~28% in monthly rainfall rates within 30–60 km downwind of the metropolis with a modest increase of 5.6% over the metropolis (Figure 6-40.). Portions of the downwind area exhibit increases as high as 51%. The percentage changes are relative to an upwind control area (Figure 6-41.). Our results also show that maximum rainfall rates in the downwind impact area exceeded the mean value in the upwind control area by 48%–116%. The maximum value was generally found at an average distance of 39 km from the edge of the urban center or 64 km from the center of the city. Results are consistent with METROMEX studies of St. Louis almost 2 decades ago and with more recent studies near Atlanta and other cities. Our current research involves utilizing mesoscale models to investigate the impact of urban land surfaces on mesoscale circulations and precipitation.

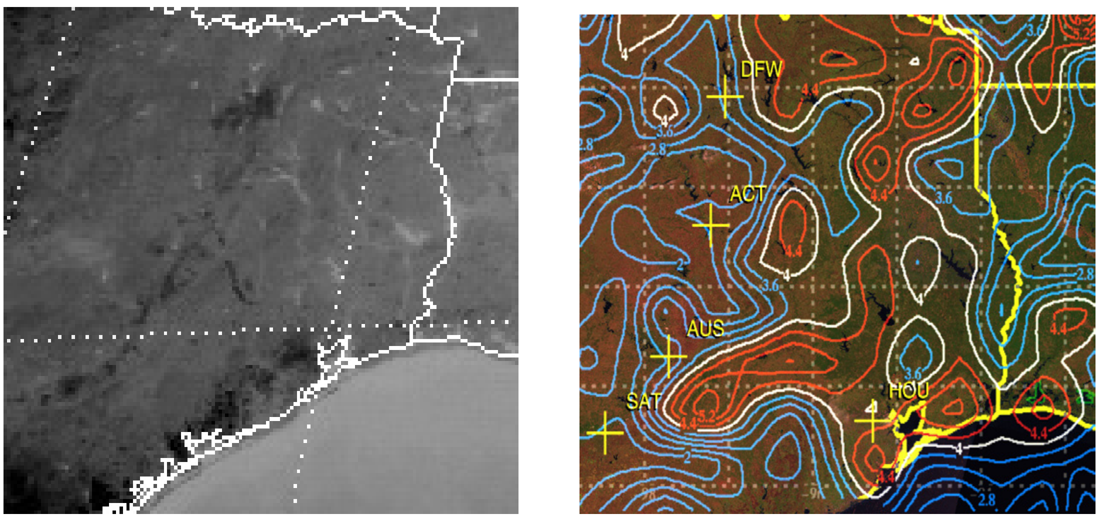


Figure 6-40 left panel is a GOES IR 3.9 micron image of Texas. Urban heat islands for Dallas, Waco, Austin, San Antonio, and Houston are observed as warm, dark regions. Figure 6-40 right panel represents a contour plot of the 3-year, warm season analysis of mean rainfall rates at a height of 2.0 km using the 0.5°-resolution TRMM PR data. The yellow crosses locate the five cities. Values in red are greater than or equal to 4.2 mm/day and demonstrate the increased rainfall downwind of the city heat islands. Values in blue are less than or equal to 3.6 mm/day.

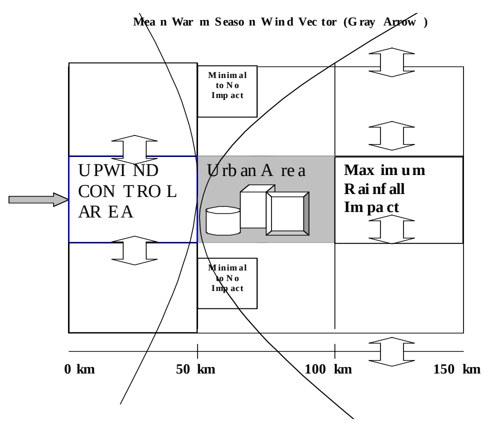


Figure 6-41. Theoretical coordinate system used to define upwind control (UCA), urban, and maximum rainfall impact (MIA) areas. Gray arrow depicts the mean prevailing wind and defines the reference axis for the coordinate system.

This work demonstrates the capability of spaceborne platforms to identify rainfall changes linked to cities and urban sprawl. The research has implications for policymakers, urban planners, water resource managers, and agriculture professionals. Such decision makers may use an understanding of urban rainfall in designing better drainage systems, planning land use, or identifying optimal areas for agricultural activity. Additionally, the results may alert meteorologists that urban surfaces must be considered in the sophisticated computer models that produce weather forecasts. Finally, the study further demonstrates the impact of human development on the environment.

J. Marshall Shepherd, Code 912 (James.M.Shepherd.1@gsfc.nasa.gov)

Cirrus Cloud Microphysical Modeling

The Cirrus Parcel Model Comparison Project (Lin et al., 2002) is an international effort to assess the current understanding of cirrus microphysical modeling. The effort is part of the GEWEX Cloud System Study Working Group on Cirrus Cloud Systems and is led by members of the Mesoscale Atmospheric Processes Branch (Code 912). The project involves the systematic comparison of seven state-of-the-art parcel models of cirrus cloud microphysical initiation and development including aerosol and ice crystal number concentrations and size distributions. Standardized sets of simulations were made for typical cirrus environments. The first set focused on the homogeneous freezing of H_2SO_4 aerosol particles acting alone as ice nucleating agents, while the second set studied the scenario that both H_2SO_4 aerosols and heterogeneous ice nuclei were present.

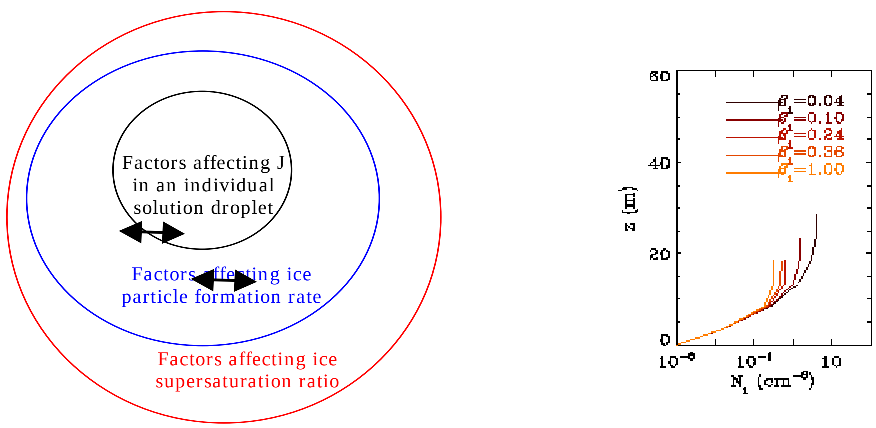


Figure 6-42. Left: A schematic of the microphysical process interactions. Right: Ice crystal number density as function of height above cloud base during the critical (short) initial ice nucleation period illustrating the strong sensitivity to deposition coefficient, β_i, where the range of values reflects those used in various models. Resultant values of predicted ice particle number concentration, N_i, range over an order of magnitude and these significant differences persist in the developing simulated cirrus cloud.

The paucity of knowledge on upper tropospheric (UT) heterogeneous nucleation resulted in major differences in the all-mode nucleation set. We then focused on comparing the homogeneous nucleation simulations. We found qualitative agreement; however, the quantitative disagreements were significant and resulted from a hierarchy of processes that interact and modulate the predicted cirrus microphysical properties. For an aqueous aerosol particle at a given temperature, the homogeneous freezing rate, J, is rather sensitive to solution concentration. Therefore, aerosol modeling, and formulation of J, are useful. Moreover, some frequently adopted assumptions in UT aerosol modeling must be modified for application to certain cirrus initiation conditions. For example, attention is needed for the curvature effect (Kelvin's effect), which is ignored in some models, and for the common assumption that the aerosol particles are in environmental equilibrium, which is violated for a parcel lifted by a fast updraft (1 m s^{-1}) at a cold temperature. Finally, water vapor uptake by nucleated ice crystals controls the maximum ice supersaturation ratio achieved by the parcel, and thus, the duration of active nucleation and the predicted ice particle number concentration. When ice crystals are still small, being just nucleated from aqueous solution, their diffusional growth rates are extremely sensitive to the poorly understood deposition coefficient, which is the probability that a vapor molecule impinging onto the ice surface becomes attached to the surface. The findings highlight the need for laboratory studies on these crucial yet still uncertain parameters.

Ruei-Fong Lin, Code 912/GEST (Ruei-Fong.Lin.1@gsfc.nasa.gov)

Climate Variability and Climate Change

Hydrologic Teleconnections during Northern Summer

Atmospheric teleconnection patterns linking continental-scale rainfall anomalies over North America and East Asia have been identified from 4-dimensional assimilated data. These teleconnection patterns appear to arise from intrinsic modes of climate variability linked to intrinsic fluctuations of sea surface temperature (SST) in the extratropical oceans. Two such intrinsic climate models have been identified.

Figure 6-43 shows the patterns of 850-hPa wind, rainfall, and SST associated with the most dominant mode (Mode-1) of U.S. rainfall. Mode-1 explains 32% of the co-variability between U.S. rainfall and 500 hPA geopotential height (not shown) and projects strongly on the disastrous flood over the U.S. midwest in 1993. It depicts a *Pan-Pacific*, zonally oriented rainfall/circulation pattern stretching from east Asia and Japan to North America. We see excessive rainfall over northern and northwestern North America and deficient rainfall over the eastern and southeastern U.S. The rainfall pattern is coupled to an anomalous low-level anticyclonic flow over the eastern U.S., which favors the transport of warm moist air from the Gulf coast to the midwest and dry air along the east coast. The band of excessive rainfall linking Canada and Japan coincides with regions of low-level cyclonic flow. Along the equator, we see a weaker signal indicating generally enhanced rainfall in a large fetch of enhanced westerlies in the central and eastern equatorial Pacific. The regressed SST anomaly pattern for Mode-1 (Figure 6-43b) suggests possible El Niño influence, as evident in the positive SST over the equatorial eastern and central Pacific. A prominent feature in the Figure 6-43b is the presence of an extensive area of below-normal SST in the extratropical Pacific (near 40ºN), coinciding with anomalous low-level westerlies and enhanced rainfall. These features suggest the importance of extratropical air-sea interaction in sustaining Mode-1.

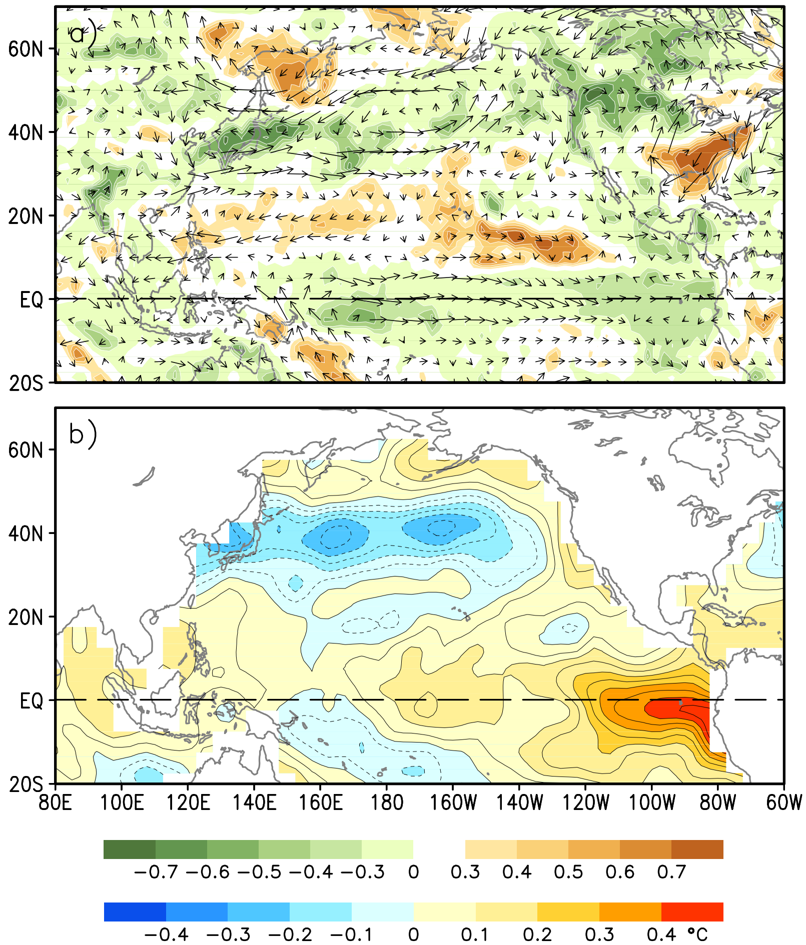


Figure 6-43. Spatial patterns of 850-hPa horizontal wind, CMAP rainfall, and SST anomalies related to Mode-1. (a) Regressed wind anomaly for the period of 1955-98. Correlation between PC1r and CMAP rainfall anomaly for the period of 1979-98 is shaded. (Green areas with negative correlation are above normal.). (b) Regressed SST anomaly for the period of 1955-98 (contour interval: 0.05ºC).

Mode-2 explains 30% of the co-variability between U.S. rainfall and global geopotential height. The associated 850-hPa wind and CMAP rainfall patterns suggest that U.S. summer rainfall variability may be associated with deep convection (heavy monsoon rainfall) in the IndoChina and western Pacific region (Figure 6-44a). The principal components (not shown) of this mode show a strong projection on the 1988 drought over the U.S. We see excessive rainfall over the west coast of Canada and below normal rainfall over the Great Plains and midwest. The associated low-level flow indicates a large anticyclone over northeastern North America coupled to a cyclone over the Gulf region. This anticyclone/cyclone couplet induces anomalous low-level easterlies in southern U.S. These easterlies effectively cut off the supply of moisture from the Gulf of Mexico, resulting in below-normal rainfall in the Midwest. A well-developed cyclonic circulation over northwestern North America, with southerly flow that feeds moist oceanic air into the region, may be responsible for the excessive rainfall along the west coast of Canada (Figure 6-44a). The continental wave pattern over North America appears to be a part of a much larger and well-organized wavetrain emanating from the subtropical western Pacific, in an arc across the north Pacific to North America. Regions of enhanced (reduced) rainfall appear to align along the direction of the wavetrain, coinciding with low-level cyclonic (anticyclonic) circulation that can be traced back to enhanced convection over Indo-China. The anticyclone over the subtropical western Pacific near the Philippines is of particular interest, because this circulation feature has been identified as one of the key features of the Asian summer monsoon variability affecting droughts and floods in China, Japan, and Korea (Lau et al. 2000). Mode-2 is associated with substantial changes in extratropical SST, with positive (negative) SST anomalies underlying the anticyclones (cyclones) (Figure 6-44b), suggesting that the atmospheric circulation pattern may be anchored in place by the SST anomalies. Since there is no significant SST signal in the tropical eastern Pacific, Mode-2 appears to be independent of El Niño/La Niña, but rather may have stemmed from fluctuations of heat sources and sinks associated with the Asian/West Pacific monsoon convection.

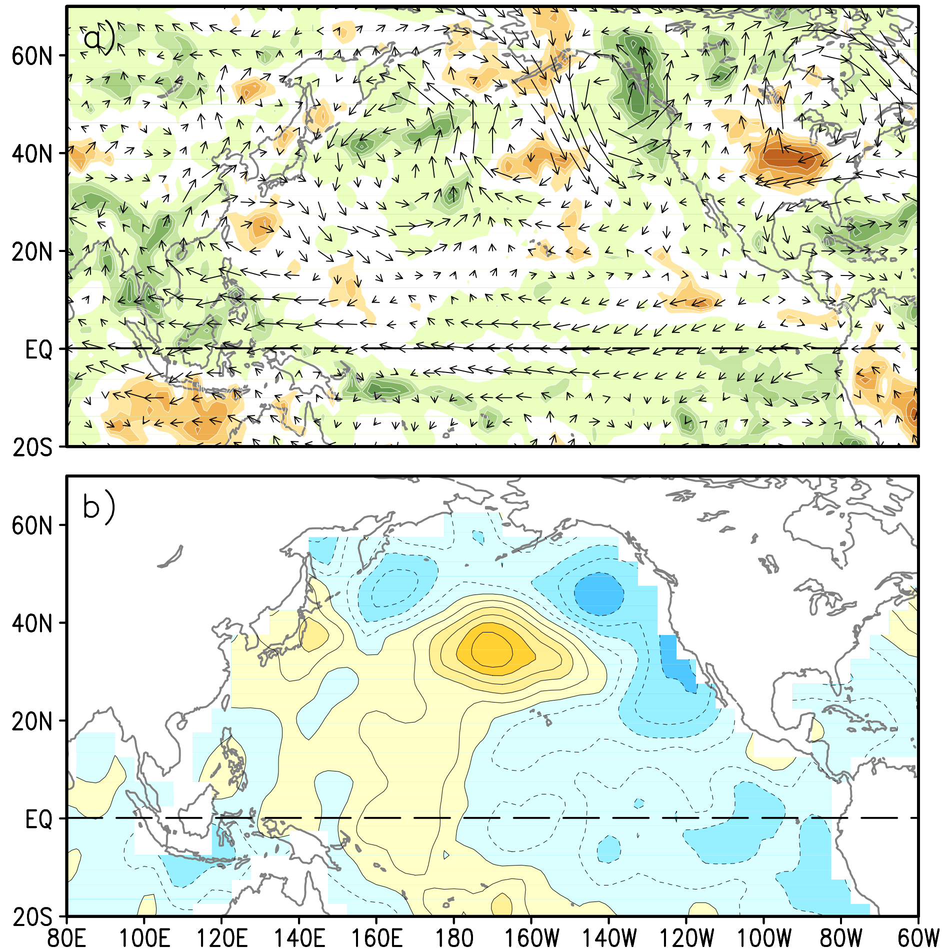


Figure 6-44. Same as Figure 6-43, except for Mode-2.

Lau, K.M. and H.T. Wu, 2001: Intrinsic modes of coupled rainfall/SST variability for the Asian summer monsoon: a re-assessment of monsoon-ENSO relationship. *J. Climate*, **14**, 2880-2895.

Lau, K.M. and H. Weng, 2000: Teleconnection linking summertime rainfall variability over North America and East Asia. *CLIVAR Exchanges*, **5**, 18-20.

William K.M. Lau, Code 913 (William.K.Lau.1@gsfc.nasa.gov)

Cloud, SST, and Climate Sensitivity Inferred from Satellite Radiance Measurements

High-level clouds have a significant impact on the radiation energy budgets and, hence, the climate of the Earth. Convective cloud systems, which are controlled by large-scale thermal and dynamical conditions, propagate rapidly within days (Figure 6-45). These cloud systems propagate over oceanic regions with spatially varying sea surface temperature (Figure 6-46).

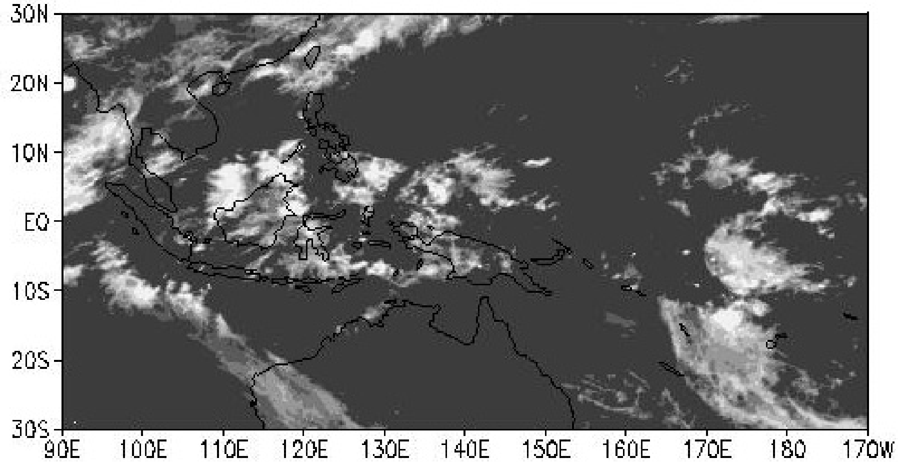


Figure 6-45. GMS satellite imagery showing the cloud clusters in the tropical western Pacific. Propagation of cloud systems is primarily in the zonal direction.

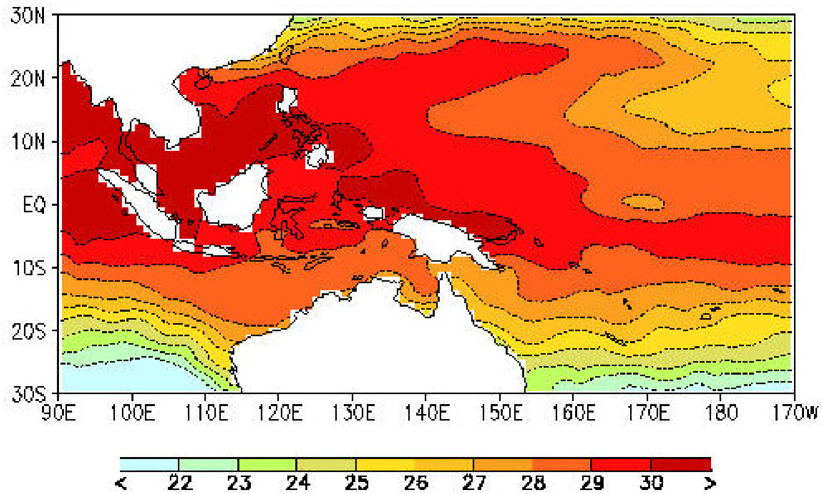


Figure 6-46. The weekly-mean sea surface temperature distribution for the period 7-13 June 1998 taken from NCEP data archive.

We use the radiances measured by Japan's Geostationary Meteorological Satellite (GMS) to study the response of high-level cirrus clouds to the sea surface temperature (SST) in the tropical western and central Pacific (30S–30N; 130E–170W), where the ocean is warm, and deep convection is intensive. Twenty months (January 1998–August 1999) of GMS data are used, which cover the second half of the strong 1997–1998 El Niño.

When deep convection moves to regions of high SST, the domain-averaged high-level cloud amount decreases. A +2 °C change of SST in cloudy regions results in a relative change of –30% in high-level cloud amount (Figure 6-47). Figure 6-48 shows that the amount of cirrus anvil clouds relative to the convection core decreases as the SST increases. The decrease in cloud amount is due to the reduced cumulus detrainment associated with an increase in precipitation efficiency when temperature is high. This large change in cloud amount is due to clouds moving through oceanic regions with varying SST.

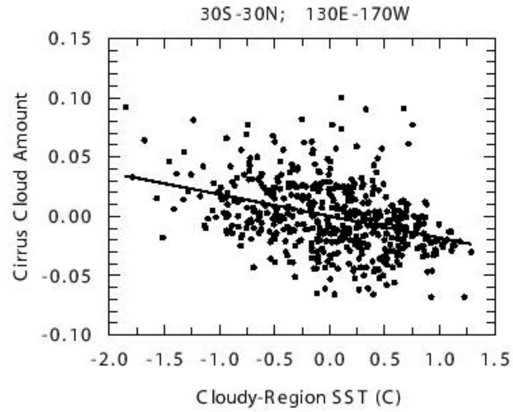


Figure 6-47. The relation between high-level clouds and the SST.

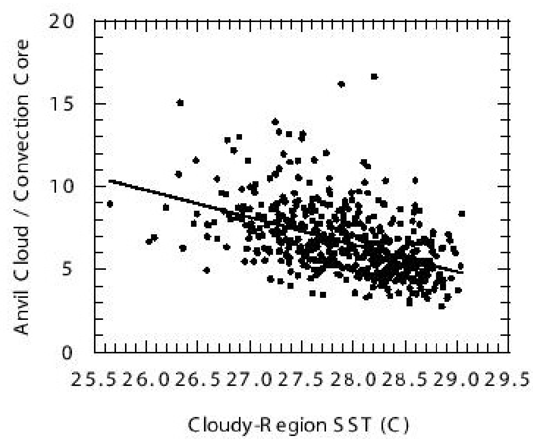


Figure 6-48. Relation between the SST and the ratio of the area of cirrus anvils to that of convection cores.

A reduction in high-level cloud amount in the equatorial region implies a drier upper troposphere in the off-equatorial region, and the greenhouse warming of high clouds and water vapor is reduced through enhanced longwave cooling to space. The results are important for understanding the physical processes relating SST, convection, and water vapor in the tropics. They are also important for validating climate simulations using global general circulation models.

Ming-Dah Chou, Code 913 (Ming-Dah.Chou.1@gsfc.nasa.gov)

Global Warming: Evidence from Satellite Observations

Meteorological measurements of air temperature over land, taken about a meter above the ground, and ocean surface temperature are commonly used in estimating global temperature and its long-term trend (e.g., Hansen et al., 1996, and Jones et al., 1999). However, since these conventional data represent point values (i.e., not spatial averages), they may overemphasize adverse effects due to urbanization (Hansen et al., 1999), land use, and deforestation.

Observations made by the Microwave Sounding Unit (MSU) radiometer on board NOAA operational polar-orbiting satellites represent averages over radiometer footprints, each of which has an area of about 10^4 km^2. Also, MSU data coverage is uniform over land and ocean. For these reasons, satellite data are potentially valuable in monitoring global temperature.

In a pioneering study, Spencer and Christy (1990) used the measurements made by the MSU radiometer in Channel 2 (Ch 2), centered over a narrow spectral interval near 53.74 GHz of the oxygen absorption band, to determine global temperature trend. Each Ch 2 observation reflects the vertically weighted mean temperature of the atmosphere, with a peak weight near the midtroposphere, and is highly correlated with the surface temperature. However, problems in creating the MSU Ch 2 global temperature time series, mainly due to instrument calibration errors introduced by slow satellite orbital drift over several years, have not been accounted for satisfactorily by these authors. We have developed an innovative technique to remove these errors with the help of the warm blackbody temperature data, which is used in calibrating the MSU.

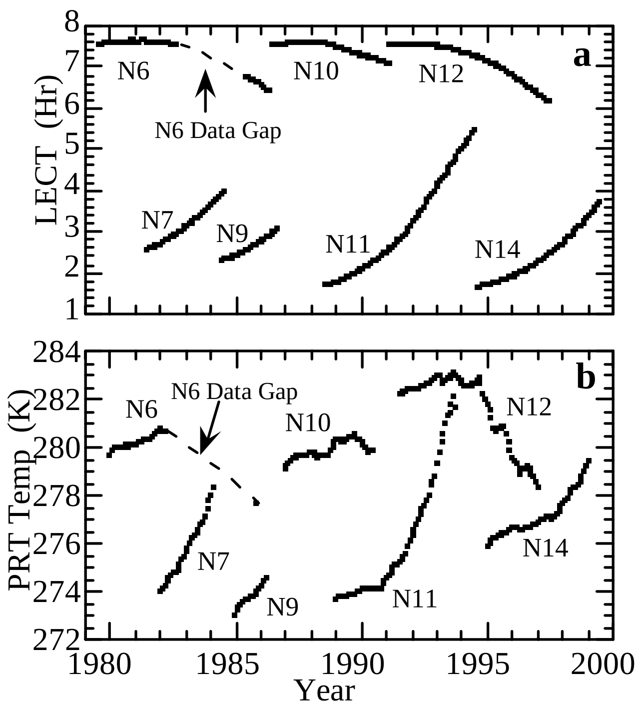


Figure 6-49. a) Temporal change in Local Equatorial Crossing Time (LECT) of each satellite, b) Temporal change in 12-month running-mean warm blackbody temperature of each satellite.

In Figure 6-49a, we show the manner in which the ***morning*** satellites (NOAA 6, 10, and 12) and ***afternoon*** satellites (NOAA 7, 9, 11, and 14) drift in Local Equatorial Crossing Time (LECT) over a period of several years. Similarly, in Figure 6-49b, we show that the 12-month running-mean of warm blackbody temperature changes gradually by a small amount (< 10 K) due to drift in LECT over the same time period. From these figures, it is clear that the warm blackbody temperature for the ***morning*** satellites ultimately decreases following the LECT. On the other hand, the warm blackbody temperature of the ***afternoon*** satellites steadily increases with time following the LECT. This time-dependence of the warm blackbody temperature is the key to our MSU Ch 2 calibration correction scheme.

When observations from two successive satellites overlap over an extended period of time (see Figure 6-49a), we expect that the 12-month running-mean of Ch 2 temperature from these satellites should track one another with only a constant calibration offset. If this offset is not constant during the overlap period, we infer it is because of the calibration errors. In the analysis of MSU data made by Prabhakara et al. (2000), this calibration error is quantified with the help of the 12-month running-mean warm blackbody temperature that is shown in Figure 6-49b.

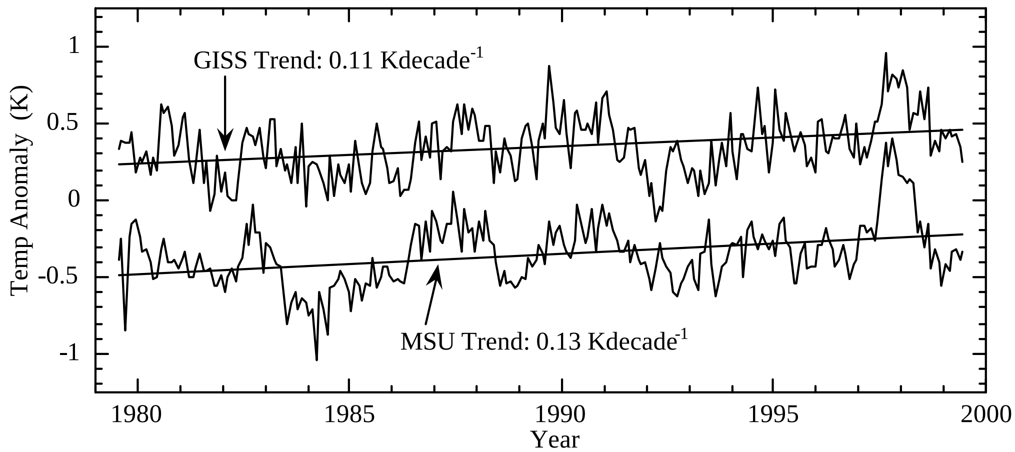


Figure 6-50. Anomaly time series and trend of MSU Ch 2 global monthly-mean temperature for the time period 1980 to 1999 is compared with corresponding information deduced from the conventional data analysis made by GISS. Note for clarity that the MSU and GISS time series are offset by 0.7 K.

In Figure 6-50, we show the monthly-mean MSU Ch 2 temperature anomaly time series after correcting for calibration errors. From this time series, we find that the vertically weighted global-mean temperature of the atmosphere, with a peak weight near the midtroposphere, increased by 0.13 K/decade during the period 1980 to 1999.

We estimate the total error in the global temperature trend to be 0.05 K/decade. This error includes uncertainties in the overlap adjustment between NOAA 9 and 10, and our procedure to improve the calibration. It also includes errors introduced by variations of hydrometeors in the atmosphere and surface emissivity. With this error, the MSU estimate of the global temperature trend is 0.13 ± 0.05 K/decade.

In Figure 6-50, we also show the surface temperature anomaly time series deduced by Goddard Institute for Space Studies (GISS) from conventional data corrected for urbanization effects (see Hansen et al., 1999). This time-series, also presented in Prabhakara et al. (2000), has a trend of 0.11 K/decade. The two time series shown in Fig. 6-50 have similar interannual variability. From this analysis, we find the global warming estimated from conventional meteorological data that have been corrected for urbanization effects is in reasonable accord with the satellite-deduced result. This demonstrates the potential of the satellite data to monitor the global temperature.

Hansen, J., R. Ruedy, M. Sato, and R. Reynolds, 1996: Global surface air temperature in 1995: Return to pre-Pinatubo levels. *Geophys. Res. Lett.*, **23**, 1665-1668, 1996.

Hansen J., R. Ruedy, J. Glascoe, and M. Sato, 1999: GISS analysis of surface temperature change. *J. Geophys. Res.*, **104**, 30997-31022. (For more information, visit http://www.giss.nasa.gov/data/update/gistemp/GLB.Ts.txt)

Jones, P.D., M. New, D.E. Parker, S. Martin, and I.G. Rigor, 1999: Surface air temperature and its change over the past 150 years. *Rev. Geophys.*, **37**, 173-199.

Prabhakara, C., R. Iacovazzi, Jr., J.-M. Yoo, and G. Dalu, 2000: Global warming: Evidence from satellite observations. *Geophys. Res. Lett.*, **27**, 3517-3520.

Spencer, R.W. and J.R. Christy, 1990: Precise monitoring of global temperature trends from satellites. *Science,* **247**, 1558-1562.

Prabhakara, C. and R. Iacovazzi, Jr., Code 913 (Prabhakara.Cuddapah.1@gsfc.nasa.gov)

Modeling

Data Assimilation

Impact of QuikSCAT Data on Numerical Weather Prediction

One of the important applications of satellite surface wind observations is to increase the accuracy of weather analyses and forecasts. Satellite surface wind data can improve numerical weather prediction (NWP) model forecasts in two ways. First, these data contribute to improved analyses of the surface wind field, and, through the data assimilation process, of the atmospheric mass and motion fields in the free atmosphere above the surface. Second, comparisons between the satellite-observed surface wind data and short-term (6-hr) forecasts can provide information to improve model formulations of the planetary boundary layer, as well as other aspects of model physics.

The SeaWinds scatterometer on the QuikSCAT satellite was launched in July 1999, and it represents a dramatic departure in design from the other scatterometer instruments launched during the past decade (ERS-1 and 2 and NSCAT). The NASA DAO was the first data assimilation center to assimilate QuikSCAT SeaWinds data and evaluate their impact on numerical weather prediction. Following the launch of QuikSCAT, a detailed evaluation of the initial surface wind data sets was performed as part of a collaborative project between the Environmental Modeling Center of NCEP, NESDIS and the DAO. The first component of this evaluation consisted of both subjective and objective comparisons of QuikSCAT winds to ship and buoy observations, GEOS and NCEP wind analyses, ERS-2 wind vectors, and SSM/I wind speeds. This was then followed by a series of data assimilation and forecast experiments using the GEOS and operational NCEP data assimilation systems (DAS). The experiments were aimed at comparing the impact of QuikSCAT with that previously obtained with NSCAT (NASA Scatterometer), and at assessing the relative utility of QuikSCAT, SSM/I, and ERS-2 winds, the relative contributions of QuikSCAT directional and speed information, and the effectiveness of the QuikSCAT ambiguity removal algorithms.

For each DAS used, a control assimilation was generated using all available data with the exception of satellite surface winds. Then assimilations were generated that added one of the following: SSM/I wind speeds, QuikSCAT wind speeds, ERS-2 unique wind vectors, QuikSCAT ambiguous wind vectors, QuikSCAT unique wind vectors, or the combination of QuikSCAT with ERS-2 and SSM/I. This initial evaluation of QuikSCAT demonstrated potential for QuikSCAT data to improve meteorological analyses and forecasts. However, the evaluation also indicated ambiguity removal and rain contamination problems that were limiting the application of QuikSCAT winds to data assimilation.

As an illustration of the impact of QuikSCAT data, Figure 6-51 shows anomaly correlations for a limited sample of Control and QuikSCAT 500 mb height forecasts. From this figure, it can be seen that there is a slight positive impact of QuikSCAT in the Northern Hemisphere and a larger positive impact in the Southern Hemisphere.

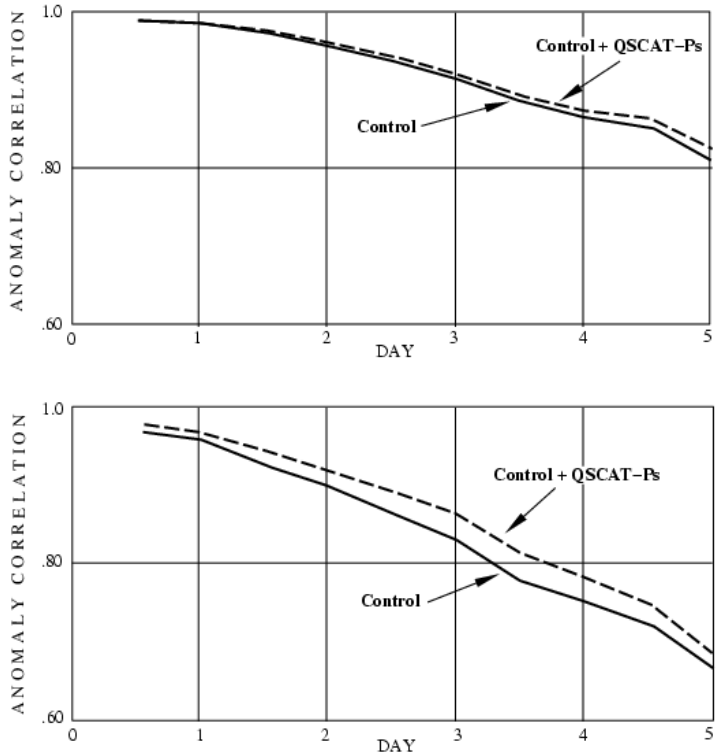


Figure 6-51. Anomaly correlations for a limited sample of Control and QuikSCAT 500 mb height forecasts. Upper panel Northern Hemisphere, lower panel Southern Hemisphere.

Robert Atlas Code 910.3 (Robert.M.Atlas.1@gsfc.nasa.gov)

Monitoring of Observation Errors Using the GEOS Ozone Assimilation System

We used the ozone assimilation system at the DAO to monitor error characteristics of ozone observations. This system assimilates the Total Ozone Mapping Spectrometer (TOMS) total column ozone and the Solar Backscatter UltraViolet/2 (SBUV/2) instrument ozone profiles into an off-line transport model. The system is providing near real-time global 3-dimensional ozone fields. In addition, the system routinely produces observed minus-forecast (O-F) residuals, i.e., the differences between observations and a short-term forecast. We used the O-F residuals to evaluate how well an observational data set agrees with the prediction model forecast and with other observational data. We found several examples of changes in observation error characteristics from time series of the O-F statistics.

One of the first examples was an abrupt change that occurred in the NOAA-14 SBUV/2 O-F residuals on March 31, 2000. Figure 6-52 shows the global mean of the O-F residuals for the ozone layer between 16 and 32 hPa. The sharp increase on March 31 was caused by a change in the SBUV/2 instrument calibration. After the SBUV/2 instrument team readjusted the calibration coefficients and reprocessed the data, we used the reprocessed SBUV/2 data in the assimilation. We found that the change in the global mean O-F value was significantly smaller with the reprocessed data. The change was almost within the typical variability of daily statistics. This finding indicates that reprocessed SBUV/2 data are more consistent with the SBUV/2 data before the calibration change. The calibration coefficients used in the reprocessing were later implemented by NOAA in the operational retrievals.

Another monitoring example shows the cross-track differences in Earth Probe TOMS data. TOMS is a scanning instrument that measures total column ozone. The observing geometry is unique for each scan angle, and some of the ozone errors are related to the scan angle at which a measurement is made. This scan-angle dependence increased in the beginning of 2001. The dependence is easiest to see in the tropics where natural zonal variability of the total column ozone is small. This scan-angle dependence is also evident in the O-F residuals from the assimilation system. A scatter plot of TOMS O-F residuals at 2 degrees south latitude reveals a larger cross-track bias in 2001 than in 2000 (Figure 6-53). This work demonstrates the use of the assimilation system to monitor TOMS data quality.

We have implemented monitoring of ozone observations from the Upper Atmosphere Research Satellite Microwave Limb Sounder. We plan to extend the monitoring and include ozone data from instruments on future satellites: EOS Aqua, EOS Aura, and European Space Agency Environment Satellite (Envisat).

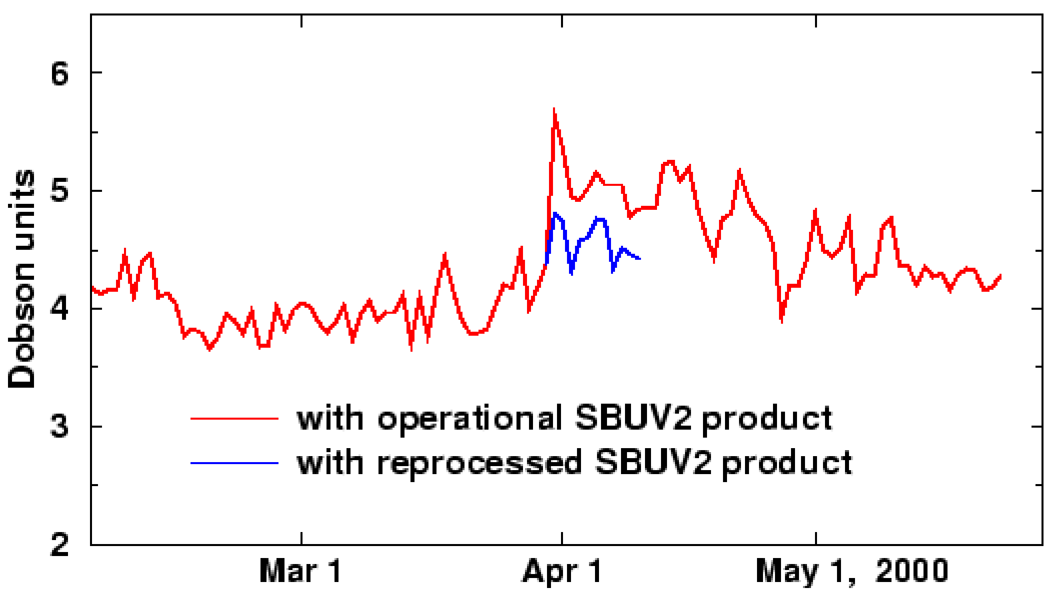


Figure 6-52. Time series of a daily global mean of O-F residuals for ozone column between 16 and 32 hPa from NOAA-14 SBUV/2 instrument is shown (red). The calibration changed on March 31. The mean of O-F residuals for SBUV/2 data reprocessed using a different calibration is shown in blue.

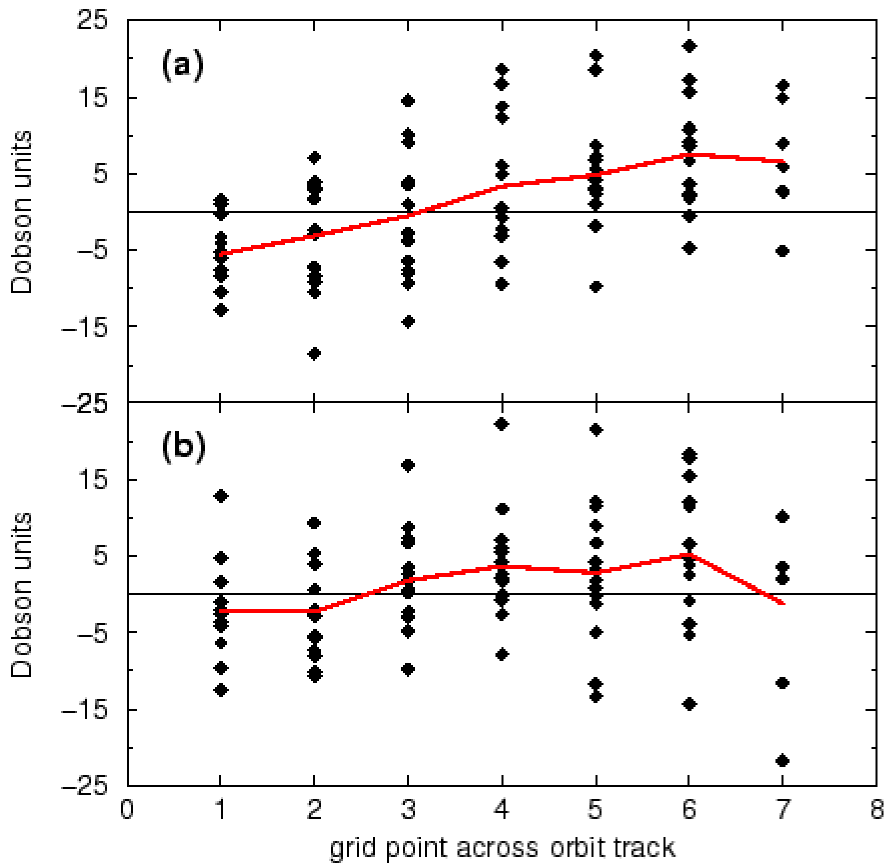


Figure 6-53. The TOMS O-F residuals at 2 degrees south latitude were binned by model grid points across the orbit track. The westernmost grid point is denoted by 1 and the easternmost one by 7. The residuals from 14 orbits on January 28 are shown by black diamonds for 2001 in a), and 2000 in b). The mean of residuals for each grid point is shown by the red curve. Across-track variability of the mean increased from 7.6 DU in 2000 to 13.1 DU in 2001.

Ivanka Stajner, 910.3 (Ivanka.Stajner.1@gsfc.nasa.gov)

Assimilation of Cloud- and Land-Affected Satellite Sounding Data at the Data Assimilation Office

Satellite data from passive microwave and infrared sounders consistently improve forecasts and analyses in data assimilation systems. However, most numerical weather prediction (NWP) centers use only a small fraction of the data available from these instruments. In particular, NWP centers often exclude data from infrared instruments, which are affected by clouds more than are microwave sensors. Similarly, most NWP centers omit data from land-affected channels.

Sensitive areas for medium-range forecasts are frequently cloudy. Clouds affect ~80% of infrared pixels from the Advanced TIROS Operational Vertical Sounder (ATOVS) flying on NOAA weather satellites. Conservative cloud detection schemes may declare 90% or more pixels as cloud-contaminated.

The next generation of infrared kilo-channel sounders offers more information than the current ATOVS infrared sounding instruments. This next generation includes the Atmospheric Infrared Sounder (AIRS), which will fly on the NASA EOS Aqua satellite. Our ability to use land- and cloud-affected data from these instruments may increase their impact on forecasting capabilities.

Several methods exist for utilizing cloud-affected data in a data assimilation system. These include (1) directly assimilating the cloudy radiances and (2) assimilating cloud-cleared radiances. Direct assimilation of cloudy radiances is very challenging, as it requires reasonably accurate model-generated clouds and a fast and accurate radiative transfer model. At the NASA DAO, we examined the latter approach.

Assimilating cloud-cleared radiances involves estimating the clear-column radiance that would have been observed in the absence of cloud. We examined the effectiveness of this approach using the DAO's next-generation finite-volume Data Assimilation (fvDAS) with a 1D variational radiance assimilation scheme. This system simultaneously performs cloud-clearing and retrieves information about temperature, humidity, ozone, and surface parameters including the surface skin temperature. The fvDAS experimental setup was at a resolution of 2° latitude × 2.5° longitude for the month of August 1999 with a 2-week spin-up. We conducted a series of experiments using different ATOVS data: (1) DAO CC (includes cloud-cleared data), (2) DAO CLR (clear data only), and (3) NESDIS (operational retrievals). One major caveat is that the DAO experiments used the NOAA 15 satellite with the Advanced Microwave Sounding Unit (AMSU) whereas the NESDIS experiment did not.

Figure 6-54 shows the spatial RMS of the bias and the standard deviation of the radiosonde observed minus 6-hour forecast residuals for heights. Figure 6-55 shows the standard deviations of the same for zonal and meridional winds. Both the DAO CC and DAO CLR have substantially less height bias. The DAO CC has a smaller bias in height in all regions except Asia (NE), where the type of radiosonde used has known temperature bias. The 6-hour forecast fit to radiosonde winds is best for the DAO CC case. Improvements in 5-day forecasts with DAO CC were also achieved.

Similar experiments were conducted with and without land-affected channels. A positive but smaller impact was shown on the 6-hour forecast heights and winds.

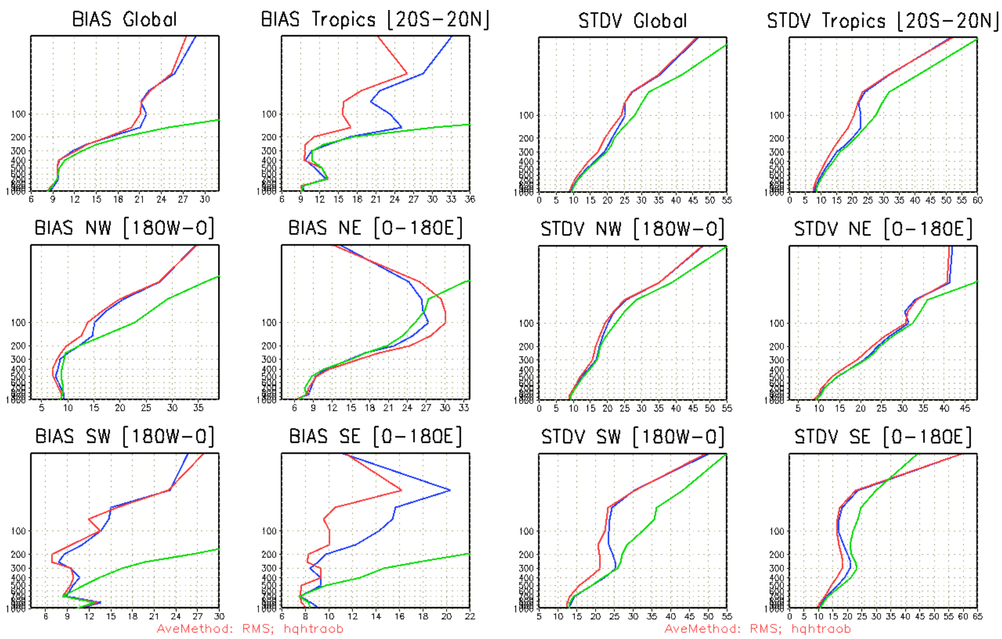


Figure 6-54. Spatial RMS of the bias (left) and standard deviation (right) of radiosonde observed heights minus 6 hour forecast residuals averaged over August 1999. Red: DAO CC; Blue: DAO CLR; Green: NESDIS.

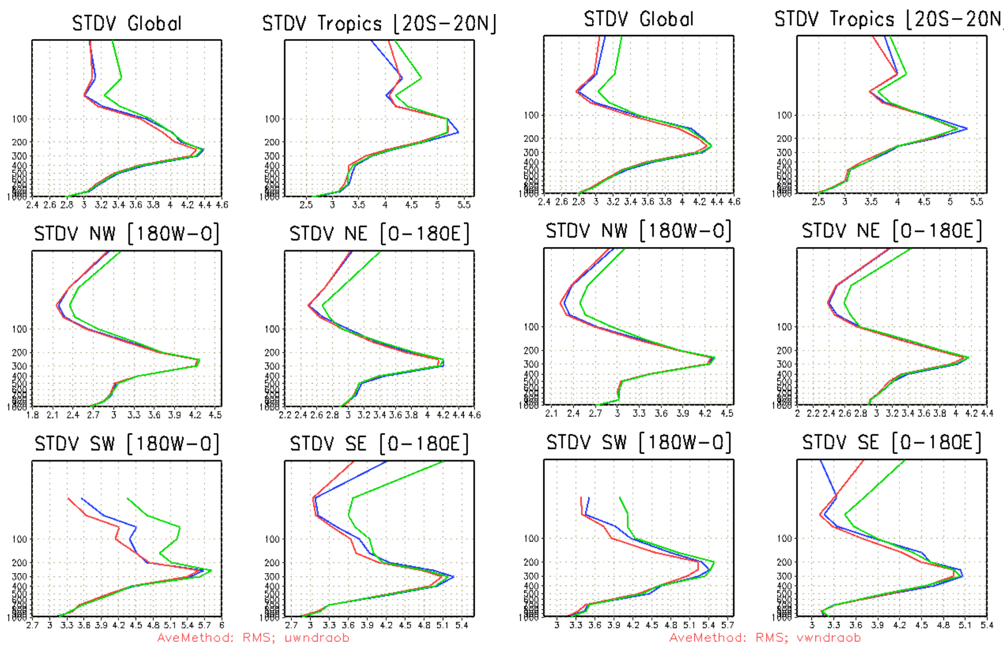


Figure 6-55. Standard deviation of radiosonde observed winds minus 6-hour forecast averaged over August 1999; Left: zonal (U) winds, Right: meridional (V) winds. Red: DAO CC; Blue: DAO CLR; Green: NESDIS

Joanna Joiner, Donald Frank, and Arlindo da Silva, Code 910.3 (Joanna.Joiner.1@gsfc.nasa.gov)

A Simple Framework for Assessing the Information Content of Observations from a Satellite Doppler Wind Lidar

It is by now well documented that perhaps the most important missing piece of observational information about the atmosphere is a global set of independent (i.e., nonmass-derived) vertical wind profiles in the free atmosphere, especially away from the regions of reasonably dense radiosonde coverage. Since the goal is to achieve a fairly high and uniform horizontal resolution, this can only realistically be achieved with a satellite system. A spaceborne Doppler Wind Lidar (DWL) is a candidate instrument, but numerous issues remain to be resolved before a final decision can be made.

In general, the design, development, deployment, and subsequent operation of a satellite instrument represent substantial investment. Therefore, decision makers are eager for tools that can help them assess the value and impact of a proposed new instrument as early as possible in its life cycle. This capability can provide input not only to the overall decision process on whether or not to proceed with a given instrument, but it can also support trade-off studies in the instrument-definition phase.

The established technique for doing such assessments in the field of Numerical Weather Prediction (NWP) is through Observing System Simulation Experiments (OSSEs). In OSSEs, observations are simulated from the proposed system and from the components of the already existing observing systems. These observations are then assimilated into a numerical model. Such experiments are expensive and time-consuming to set up and carry out. They therefore allow for only a limited amount of experimentation. Certain aspects of an instrument can be studied in simpler, less expensive frameworks that offer the possibility of a wider range of experiments while still maintaining some of the essential characteristics of the full testing environment.

In the DAO, we have developed such a framework specifically to measure the information content of a proposed Doppler Wind Lidar instrument in the context of a simplified meteorological analysis. The main target application of a DWL instrument is data assimilation. Thus, we have decided to judge the value of various simplified, idealized configurations of the instrument by their respective contributions to reducing the uncertainty of our knowledge of the state of the atmosphere; i.e., the *analysis error* in data assimilation terminology.

In this simplified testing framework, the user specifies a “true” wind field as well as a background wind field. The system then simulates and analyzes DWL observations at a given resolution and with given error characteristics. Since we know the true field, we can calculate the analysis error directly. Figure 6-56 shows an example of a simple true state (zonal flow with single eddy).

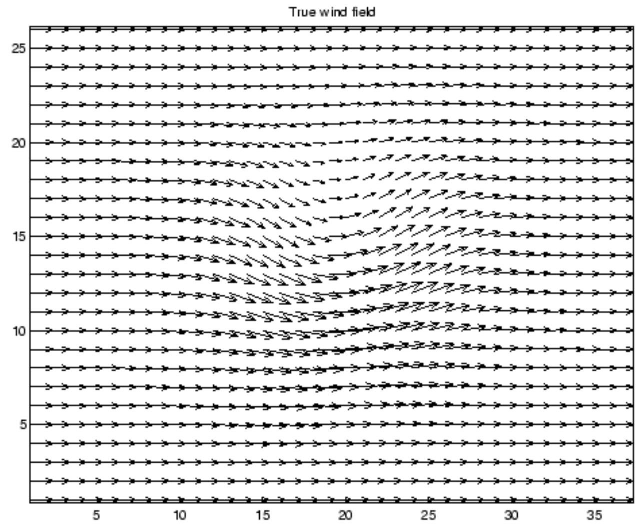


Figure 6-56. Example of a simple true state zonal flow with single eddy.

One of the most important issues studied with the system is the relative information content of single- vs. dual-perspective observations. A DWL only measures a single component of the flow; namely, the one that falls along a line of sight from the instrument down to the air parcel for which the flow is measured. It would thus take two independent measurements along different directions to uniquely determine the horizontal wind vector at a given point. This requirement would complicate the design of the instrument. We must, therefore, test whether—and in that case how—we might relax the requirement for two independent measurements per location.

Our experiments show clearly that single-perspective observations along parallel lines of sight are insufficient for retrieving the correct flow field with the given background field (compare the resulting analysis in Figure 6-57 with the true state from Figure 6-56). When both components of the wind are observed, the analysis quality improves dramatically (Figure 6-58). Interestingly enough, however, our results indicate that it is not necessary to obtain full knowledge of the wind vector at every single location, as long as the general flow field is observed along two separate directions. This finding demonstrates that the instrument must be able to observe along different directions, but not necessarily along more than one direction at any given location.

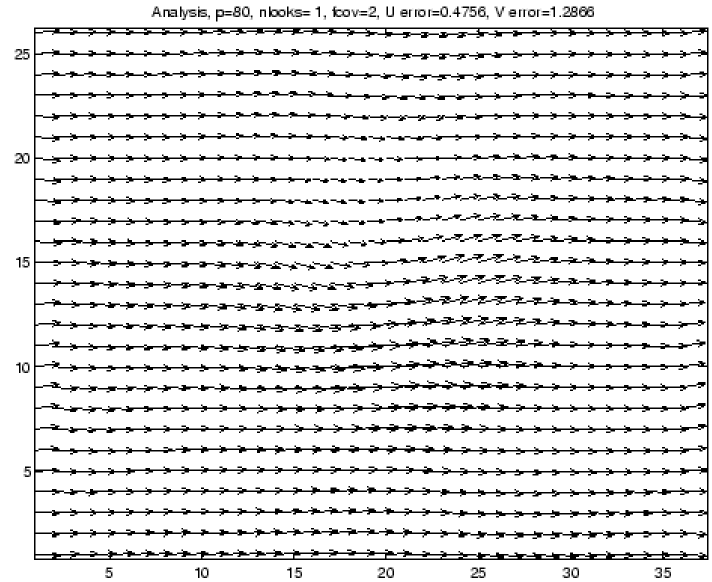


Figure 6-57. Flow field resulting from single-perspective observations along parallel lines of sight is shown to be insufficient for retrieving the correct flow field with the given background field (compare this with the true state from Figure 6-56).

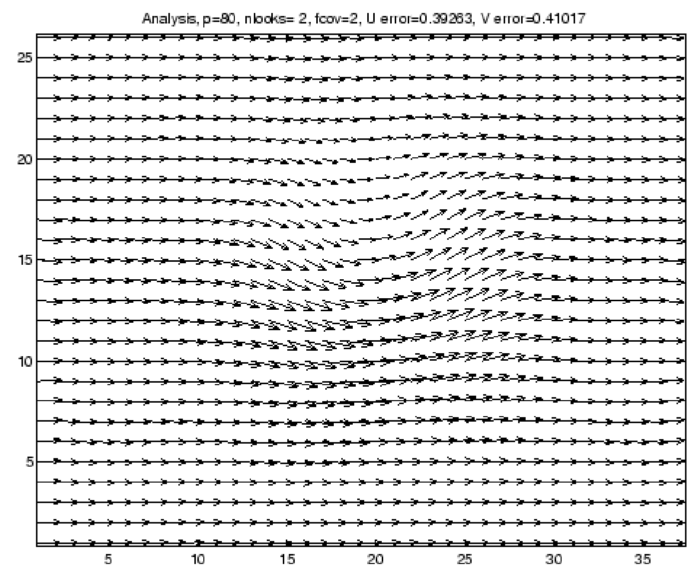


Figure 6-58. Flow field resulting from observation of both components of the wind, demonstrating a dramatic improvement of the analysis quality.

Satellite observation technology often involves a trade-off between the number and the accuracy of observations. Figure 6-59 illustrates how such a trade-off can be viewed from an analysis point of view. The isolines show the analysis error as a function of the number of observations (abscissa) and observation error (ordinate). Clearly, a given target analysis error can be obtained for a range of different combinations of measurement accuracy/number of measurements.

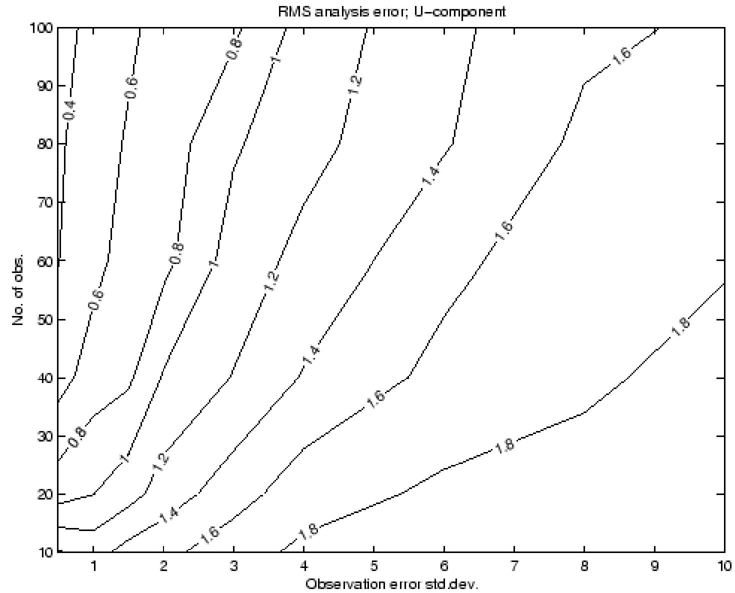


Figure 6-59. This figure illustrates how a trade-off between the number and the accuracy of observations can be viewed from an analysis point of view. The isolines show the analysis error as a function of the number of observations (abscissa) and observation error (ordinate).

Lars Peter Riishojgaard, Data Assimilation Office (Lars.P.Riishojgaard.1@gsfc.nasa.gov)

Water Vapor Tracers as Diagnostics of the Regional Hydrologic Cycle

NASA and other research institutions are deeply involved in assessing the effect of climate change on the water cycle. A key question remains: “Is the water cycle intensifying?” In other words, are climatic extreme events such as flood and drought increasing in frequency and intensity? Also, what are the local and remote sources of water for precipitation? This research addresses these questions by use of a diagnostic approach to quantitatively identifying the geographic source of water for precipitation in a general circulation model (GCM) and data analysis system (DAS).

We begin by implementing into the most recent Goddard Earth Observing System (GEOS) GCM a methodology for tracking regional water vapor (termed Water Vapor Tracers, WVTs). This methodology was originally developed at NASA GISS for global purposes (in mid-1980s). GEOS has state-of-the-art dynamical and physical processes and can be operated with much higher spatial resolution than the original GISS models (required to study precipitation and regions of the Earth). Regional WVTs provide quantitative information on the geographic sources of water for precipitation, including local and remote sources. The local source of water refers to water that is evaporated from a region, but precipitates before it leaves the region. This process is also known as “precipitation recycling” and is considered a potentially important feedback mechanism in the Earth’s climate system.

Figure 6-60 shows several nearby geographical sources of water that supply Mexico and the North American monsoon system. As water enters the atmosphere from the surface of these regions, the WVT diagnostics maintain a mass balance that allows for the computation of precipitation from each region. For example, Figure 6-61 shows the simulated monthly mean annual cycle of precipitation area averaged for all of Mexico (from a 10-year GCM simulation). In addition, the figure shows the quantity of precipitation that occurs as a result of surface evaporation occurring from the nearby regions. The Mexico (MX) precipitation identifies the amount of precipitation recycling in this simulation. Recycling is considerable during most of the year, but largest during June, July, and August. The cross-equatorial transport of water from the South Pacific contributes to Mexican precipitation only during September and October.

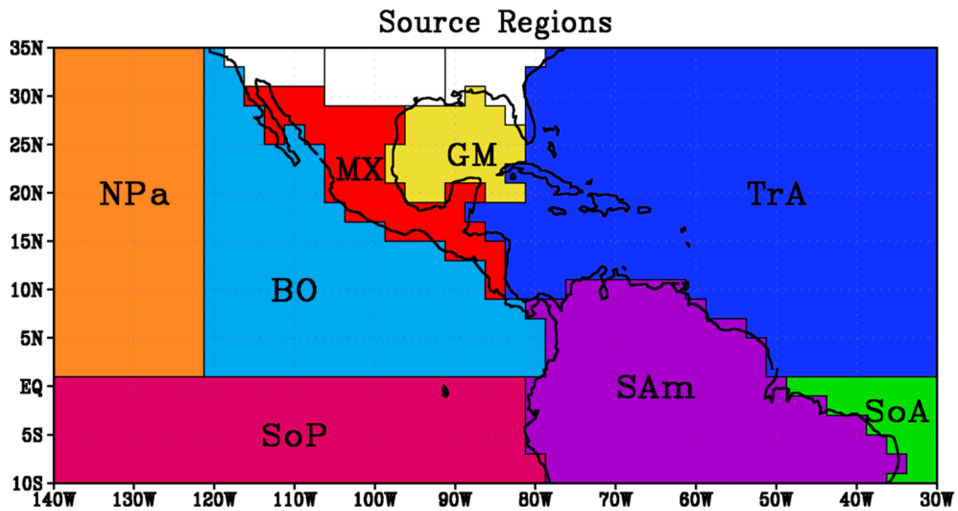


Figure 6-60. Geographic source regions of water that contributes to precipitation in Mexico. MX – Mexico, GM – Gulf of Mexico, TrA – Tropical Atlantic, SoA – South Atlantic, Sam – South America, SoP – South Pacific, BO – Baja Oceanic and NPa – North Pacific.

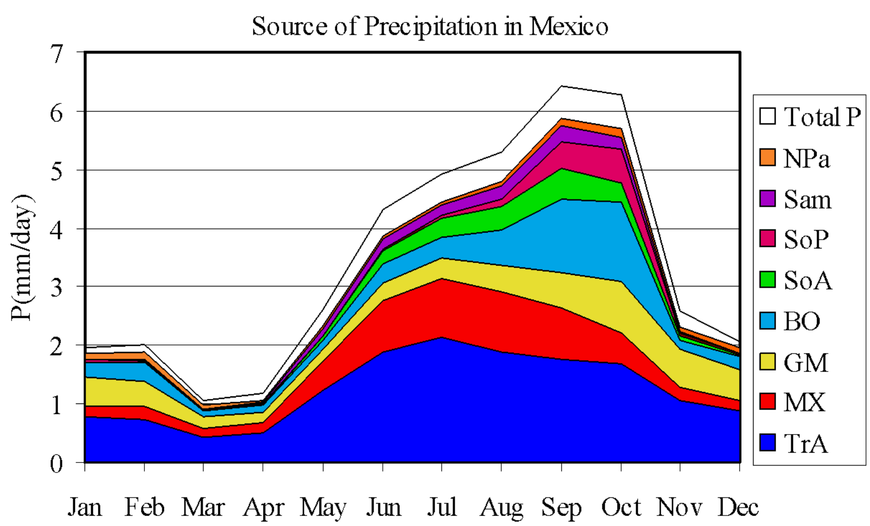


Figure 6-61. Amount of precipitation that fell in Mexico (MX) from nearby regions, as shown in Figure 6-60. All sources from the globe have been categorized, but only the eight largest sources are shown here. The largest sources are at the bottom and the smallest are at the top.

The full potential of this diagnostic method is only now being realized. The basic formulation has been validated and presented to the community (Bosilovich and Schubert, 2002). A project to better understand the hydrology of the North American Monsoon is ongoing. We are also attempting to use this methodology to identify the sources of water that contribute to the development and maintenance of hurricanes. We will use water vapor tracers to study the impact of remotely sensed water vapor on data assimilation.

Bosilovich, M.G. and S.D. Schubert, 2002: Water Vapor Tracers as Diagnostics of the Regional Hydrologic Cycle. *Journal of Hydrometeorlogy* (accepted, to appear in early 2002).

M.G. Bosilovich and S.D. Schubert, DAO, Code 910.3 (Michael.G.Bosilovich.1@gsfc.nasa.gov)

Retrospective Data Assimilation

The Laboratory for Atmospheres has developed a retrospective data assimilation system (RDAS) that we expect will produce data sets of a quality superior to that currently available for climate research. Retrospective data assimilation implements an advanced data assimilation technique that is an extension of the more common 3-dimensional variational procedure used operationally in the Laboratory and elsewhere.

Retrospective data assimilation is similar to four-dimensional variational assimilation. It uses the adjoint of the tangent linear of the dynamical atmospheric model to propagate observation and model information back in time. Thus, it allows users to refine estimates of the state of the atmosphere that are generated through standard procedures.

We illustrate in Figure 6-62 the potential benefits of retrospective data assimilation by comparing its results with those from our standard 3-dimensional variational assimilation system. We choose as a case study the meteorologically challenging French storm of 27 December 1999.

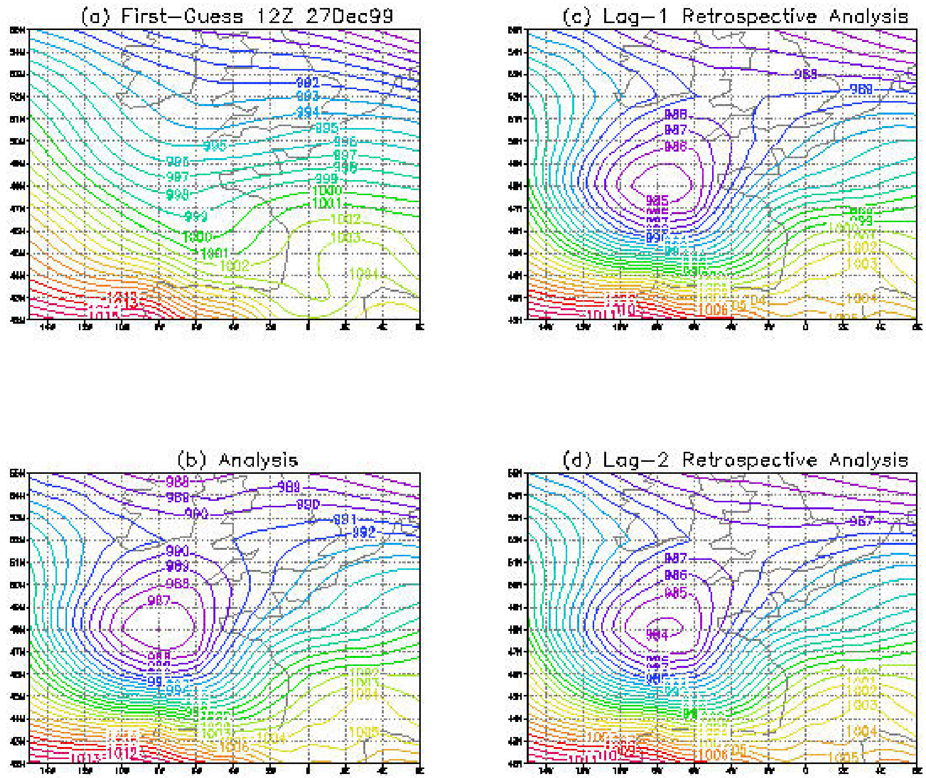


Figure 6-62 shows contours of sea level pressure, at 1 mb intervals, for 12 GMT 27 December 1999. The panels correspond to differently obtained estimates of the state of the atmosphere 6 hours before the peak of the storm. Panels (a) and (b) on the left are respectively the forecast and analysis generated by the standard assimilation system. The forecast is simply a 6-hour model prediction and does not contain any observational information. The analysis blends the 6-hour model prediction and the observations at 12 GMT. Because the analysis combines both model predictions and observations, it is generally a better estimate of what actually happens in the atmosphere than the forecast. Panels (c) and (d) on the right are the estimates of the state of the atmosphere obtained with the RDAS. These analyses are essentially a "redo" of the normal analysis [in panel (b)], and still valid at 12 GMT, but now are obtained using observational data taken after 12 GMT. For this reason, we call them retrospective analyses.

In ideal circumstances, when all assumptions in the theory are met, we expect retrospective analyses to be more accurate than the regular analysis, since they use an extended data set with observational data taken after the time of the event. Here, in the French storm illustration, we produce the lag-1 retrospective analysis of panel (c) using observations taken from 12 GMT to the time of the storm's peak at 18 GMT. We produce the lag-2 retrospective analysis of panel (d) using observations from 12 GMT to 00 GMT of the following day. An after-the-fact evaluation indicates that the regular analysis [panel (b)] overestimates the minimum of the low-pressure system by almost 9 mb. Therefore, the lag-2 RDAS analysis shows an improved low-pressure system. This improvement arises from the use of data taken after the time of the event and from the use of the adjoint of the tangent linear model of the atmospheric model that propagates this extra observational information back in time.

One of the goals of the Laboratory for Atmospheres is to generate an accurate, global, and continuous record of the state of the atmosphere. This record must be of very high quality. We consider retrospective data assimilation one possible technique to help us accomplish this goal.

Cohn, S.E., N.S. Sivakumaran, and R. Todling, 1994: A fixed-lag Kalman smoother for retrospective data assimilation. *Mon. Wea. Rev*., 122, 2838-2867.

Todling, R., S.E. Cohn, and N.S. Sivakumaran, 1998: Suboptimal schemes for retrospective data assimilation based on the fixed-lag Kalman smoother. *Mon. Wea. Rev.*, 126, 2274-2286.

Ricardo Todling, Code 910.3/SAIC (Ricardo.Todling.1@gsfc.nasa.gov)

Can We Predict the Next Dust Bowl?

Multiyear droughts are a regular feature of the Great Plains climate, having occurred once or twice a century over the last 400 years (Woodhouse and Overpeck, 1998). Laboratory scientists have recently gained insight into the nature and predictability of these events.

Our results are based on an ensemble of nine 70-year (1930–1999) simulations. We ran these simulations using the NASA Seasonal-to-Interannual Prediction Project (NSIPP-1) atmospheric-land general circulation model (AGCM). The simulations were run at a horizontal resolution of 2° latitude by 2.5° longitude and were forced by observed sea surface temperatures (SSTs). We also present results from some runs with idealized SST forcing. The model is part of the NSIPP coupled atmosphere-land-ocean model. However, for these experiments, we ran the model uncoupled from the ocean. Our focus is on assessing whether the model produces droughts in the Great Plains similar to those observed and, if so, to assess the nature and predictability of the simulated droughts.

The nine 70-year runs were forced with identical SSTs (the observed) and differ only in their initial atmospheric conditions: the initial conditions were chosen arbitrarily from previously completed simulations. Since all runs “see” the same SST forcing, the degree to which they produce similar results is an indication of predictability (assuming we have perfect knowledge of the SST). For example, if all runs produce identical precipitation variations in the Great Plains, we would conclude that precipitation in that region is perfectly predictable if we could somehow perfectly predict the SST.

Figure 6-63 shows the simulated precipitation over the Great Plains from all nine runs. The results are filtered to isolate time scales longer than about 6 years. Clearly, the nine ensembles produced varied results. The variation suggests that SST does not have a strong control on the precipitation in that region. Nevertheless, the runs do show some similarities. For example, during the 1930s almost all the runs show a tendency for dry conditions, consistent with the observations. This is followed, in the early 1940s, by wet conditions, again consistent with the observations. On the other hand, during the 1950s, the runs show a mixture of dry and wet conditions. Only one of the nine runs is as dry as observed. In general, the model results do agree with the observations in that the observations tend to fall within the spread of the ensemble members.

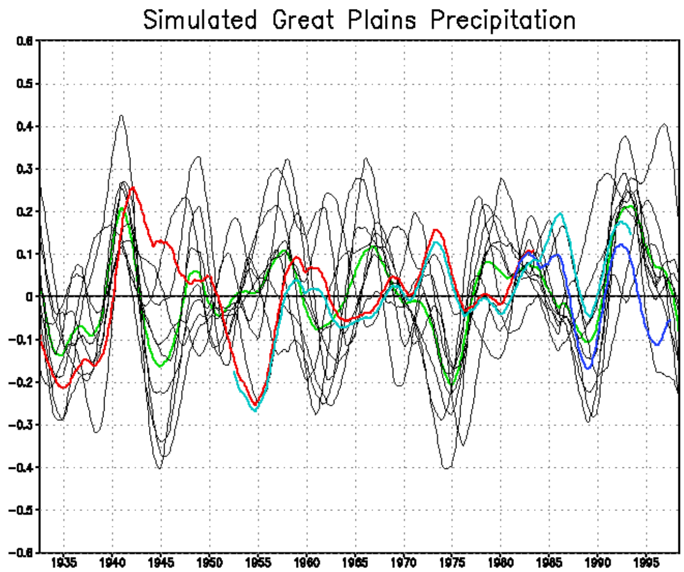


Figure 6-63. Time series of precipitation anomalies over the Great Plains (30°-50°N, 95°-105°W). A filter is applied to remove time scales shorter than about 6 years. The black curves are the results from the nine ensemble members produced with the NSIPP-1 model forced by observed SST. The green curve is the ensemble mean. All the other colored curves are various observational estimates.

We can obtain some idea of the connection between the Great Plains precipitation and the SST by correlating the ensemble-mean-filtered Great Plains precipitation (green curve in Figure 6-63) with the similarly filtered SST at all points. The correlations, with a sign change to emphasize the connection with dry conditions over the Great Plains (lower panel of Figure 6-64), show a large-scale coherent structure that has some similarity to the cold phase of an El Niño/Southern Oscillation (ENSO) event. Reduced precipitation in the Great Plains on these long time scales is associated with negative SST anomalies throughout the central tropical Pacific Ocean, extending northward toward the west coast of North America. The negative SST anomalies are flanked by positive anomalies that extend poleward and eastward from the western tropical Pacific.

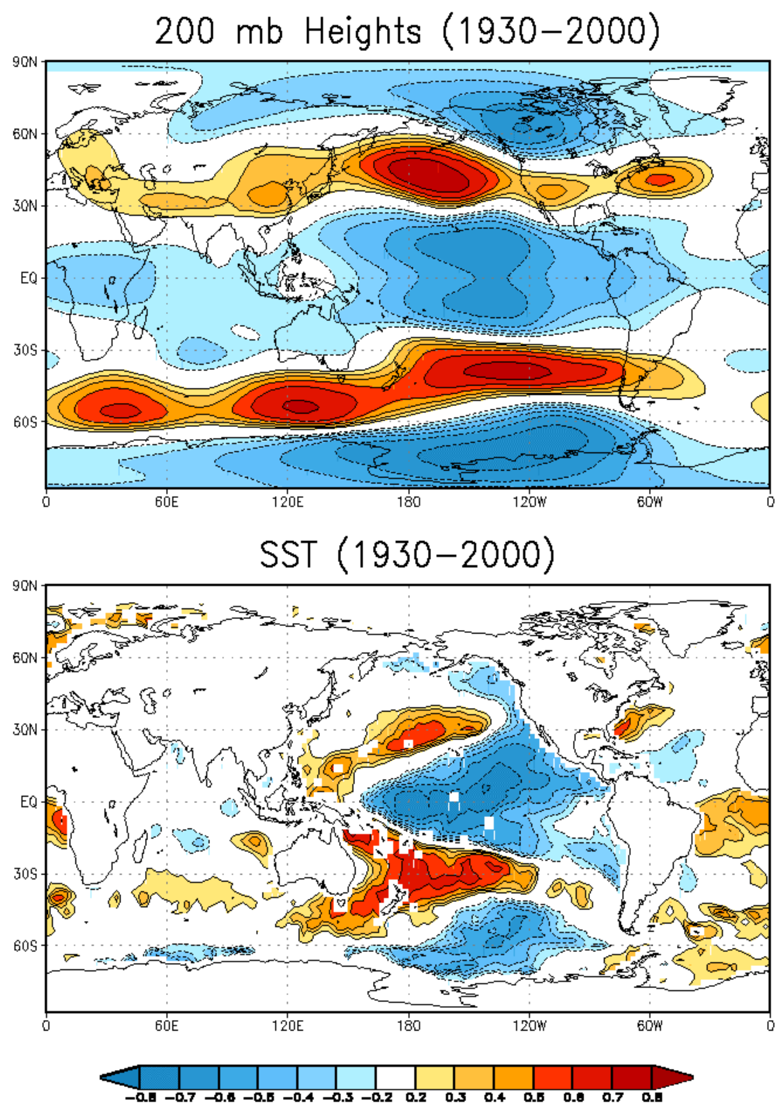


Figure 6-64. The negative of the correlation between the low-pass filtered ensemble mean simulated precipitation anomalies over the Great Plains (green curve in Figure 6-63) and 200mb height (top panel), and SST (bottom panel) for the period 1930–1999.

Figure 6-64 top panel shows the correlation between the filtered ensemble mean Great Plains precipitation and the filtered ensemble mean 200mb height field at all points. This shows that Great Plains precipitation is associated with global-scale height anomalies. Dry conditions are associated with positive height anomalies in the middle latitudes of both hemispheres, and reduced heights in the tropics and the high latitudes. We note that the zonally symmetric structure of the height anomalies found here is similar to that found on interannual time scales during northern summer (Schubert et al., 2001).

The above results suggest that low-frequency variations in Great Plains precipitation are, at least in part, controlled by large-scale pan-Pacific SST anomalies that resemble the correlation pattern shown in Figure 6-64 bottom panel. It turns out that the pan-Pacific SST pattern shown here is the dominant pattern of SST variability on these very long time scales (based on an empirical orthogonal function analysis–not shown). To further support this Great Plains/SST link, we have carried out several additional AGCM simulations in which the model is forced for 40 years by the positive and negative versions of the pan-Pacific SST anomalies shown in Figure 6-64 bottom panel. (We actually use +/- 2 standard deviations of the dominant SST empirical orthogonal function.) A third 40-year run was done with seasonally varying climatological SSTs (no anomalies). The results, shown in Figure 6-65, confirm that the cold phase of the pan-Pacific SST pattern tends to produce drier than normal conditions in the Great Plains, while the warm phase tends to produce wetter than normal conditions. Here, normal is defined as the average of the case with no SST anomalies (the straight black line in Figure 6-65).

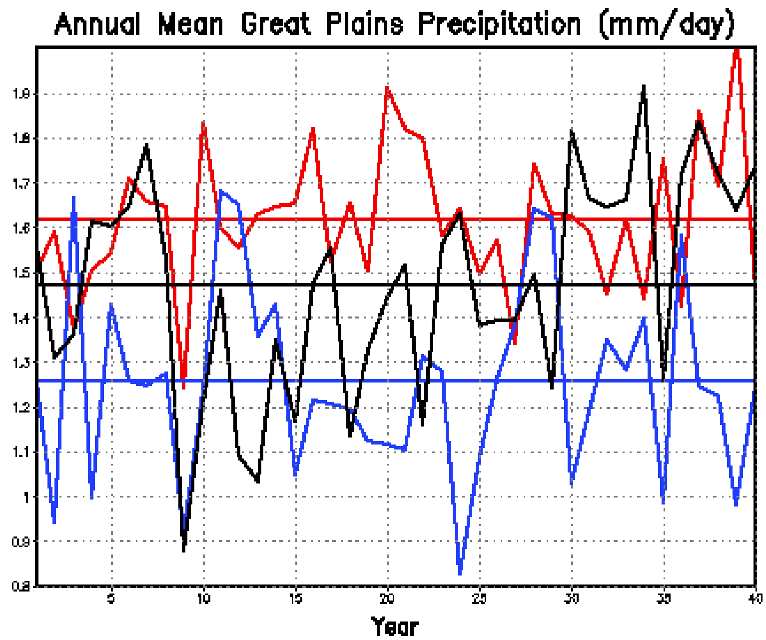


Figure 6-65. Model simulations of the annual mean precipitation over the United States Great Plains region (30°-50°N, 95°-105°W). In these idealized runs the model is forced by the global SST anomalies resembling those shown in Figure 6-64 (+/- 2 standard deviations). The red curve shows the results for the run forced by SST with positive anomalies in the tropical central Pacific (the warm phase). The blue curve shows the results for the run forced by SST with negative anomalies in the tropical central Pacific (the cold phase). The black curve is for the case with no anomalies. The straight lines are the corresponding 40-year means.

One rather remarkable and unexpected result from these idealized SST runs is that the case without SST anomalies (the black curve) exhibits rather pronounced multiyear precipitation variations. For example, during years 10–20 the Great Plains are nearly as dry as for the cold SST run, while during years 30–40 the Great Plains are wetter than that for the warm SST run. This suggests that the model is capable of producing multiyear (even decade-long) droughts in the absence of any nonseasonal SST variations.

This study shows that the NSIPP-1 model, when forced by observed SSTs, does produce low-frequency (multiyear) variations in the Great Plains precipitation similar to those observed. In particular, the model produces the dry conditions of the 1930s “dust-bowl” era. On the other hand, the model does not show a strong tendency for the dry conditions that were observed during the early 1950s (only one of the nine ensemble members reproduced the dry conditions). A correlative analysis suggests that the low-frequency variations in the Great Plains precipitation are linked to variations in a pan-Pacific decadal SST pattern. This was confirmed by further AGCM simulations, in which the model was forced by the 2 polarities of the Pacific SST pattern. These runs, as well as the nine 1930–1999 runs, show that when the Pacific decadal SST pattern is in its warm phase, the Great Plains tends to have above normal precipitation, while there is a tendency for drought during the cold phase.

The results suggest that our ability to predict the next dust bowl in the Great Plains will require predicting the long-term behavior of the pan-Pacific SST pattern. This is, however, only part of the story since the SSTs do not provide a strong constraint on the precipitation: this is clear from the spread in the curves shown in Figure 6-63. In other words, even if we could predict the SST perfectly, our precipitation forecast would still bear uncertainty that results from processes unrelated to the SST. In fact, our results suggest that precipitation in the Great Plains can exhibit very low-frequency (decadal time scale) variations even in the absence of SST anomalies. The nature of these variations and the implications for the predictability of drought in the Great Plains are currently under investigation.

Bark, D.L., 1978: History of American Droughts. *North American Droughts*. AAAA Selected Symposia Series. Westview Press, Boulder Colorado, N.J. Rosenberg, Ed., pp 9-23.

Borchert, J.R., 1971: The dust bowl in the 1970’s. Assoc.Amer.Geogr.Ann., 61, 1-22.

Felch, R.E., 1978: Drought: Characteristics and assessment. *North American Droughts*. AAAA Selected Symposia Series. Westview Press, Boulder Colorado, N.J. Rosenberg, Ed., pp 25-42.

Felch, R.E., 1978: Drought: Characteristics and assessment. *North American Droughts*. AAAA Selected Symposia Series. Westview Press, Boulder Colorado, N.J. Rosenberg, Ed., pp 25-42.

Hughes, P., 1976: Drought: The land killer. American Weather Stories, U.S. Dept. Commerce, NOAA-EDS, Washington, D.C., pp 77-87.

Schubert, S.D., M.J. Suarez, P.J. Pegion, M.A. Kistler, and A. Kumar, 2001: Predictability of zonal means during boreal summer. To appear in *J. Climate*.

Woodhouse, C.A. and J.T. Overpeck 1998: 2000 years of drought variability in the central United States. *Bull.Amer.Meteor.Soc*., 79, 2693-2714.

Worster, D., 1979: Dust Bowl: The Southern Great Plains in the 1930s. Oxford University Press, New York, 277 pp.

Siegfried D. Schubert, Max J. Suarez, and Philip J. Pegion, Code 910.3 (Siegfried.D.Schubert.1@gsfc.nasa.gov)

High-Efficiency High-Resolution Global Model Development at the Data Assimilation Office

The DAO is leading the effort in the development of a new generation of ultrahigh-resolution GCMs that is suitable for 4-D data assimilation, numerical weather predictions, and climate simulations. These three areas of the model's application have conflicting requirements. For 4-D data assimilation and weather predictions, it is highly desirable to run the model at the highest possible spatial resolution (e.g., 55 km or finer) so as to be able to resolve and predict socially and economically important weather phenomena such as tropical cyclones, hurricanes, and severe winter storms. For climate change applications, the model simulations need to be carried out for decades, if not centuries. To reduce uncertainty in climate change assessments, the next generation model would also need to be run at a fine enough spatial resolution that can at least marginally simulate the effects of intense tropical cyclones. Scientific problems (e.g., parameterization of subgrid scale clouds) aside, all three areas of application require the model's computational performance to be dramatically enhanced as compared to the previous model generation.

Using a hybrid distributed-shared memory programming paradigm that is portable to virtually any of today's high-end parallel super computers, scientists at DAO have achieved unprecedented computing performance on the NCCS's SGI Origin-3000 machine. Figure 6-66 demonstrates the computational throughput (in model simulation days per wall clock day) of DAO's 55-level finite-volume GCM (fvGCM) at the 55 km horizontal resolution. Using this next generation high-resolution model for numerical weather predictions, a 10-day forecast can be done in 1 hour on the SGI Origin-3000 machine. Scientists at DAO are currently exploring ways to further increase the model's spatial resolution to 28 km while at the same time keeping the throughput at a rate that is still operationally feasible.

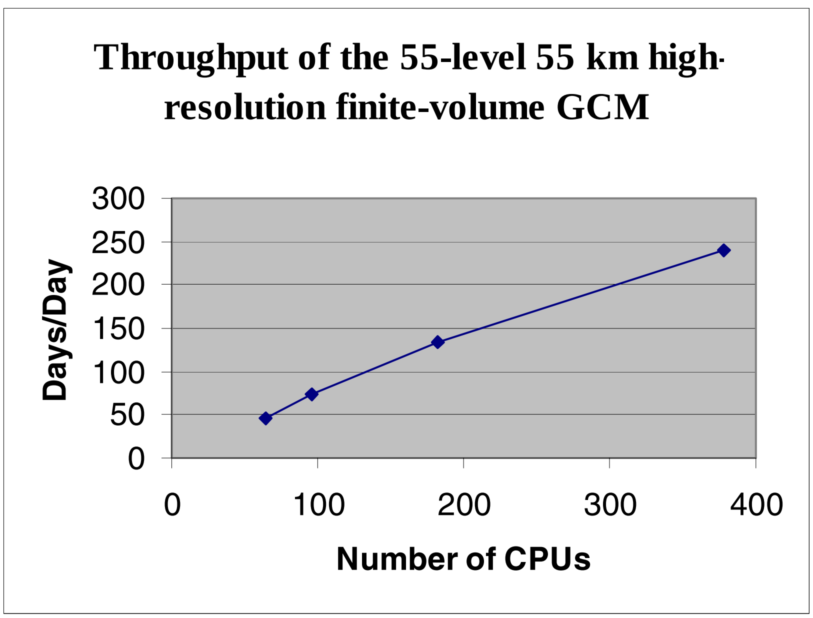


Figure 6-66 shows the computational throughput (in model simulation days per wall clock day) of DAO's 55-level finite-volume GCM (fvGCM) at the 55 km horizontal resolution.

Shian-Jiann Lin, Code 910.3 (Shian-Jiann.Lin.1@gsfc.nasa.gov)

Improving Global Analysis and Forecasts Using TRMM and SSM/I Observations of Precipitation Processes

Scientists at the Laboratory for Atmospheres have developed innovative techniques to assimilate, into global models, rain rates and total precipitable water (TPW) derived from space-based passive microwave sensors. Our results show that we can significantly improve the quality of GEOS analyses and short-range forecasts through variational assimilation of surface rain rates and TPW from TRMM Microwave Imager (TMI) and SSM/I using, as a control variable, the moisture tendency produced by the model physics.

Figure 6-67 shows the impact of assimilating 6-hour averaged TMI and SSM/I rainfall and TPW on GEOS analysis at 1° x 1° horizontal resolution for January 1998. The improved precipitation in the tropics effectively reduces the monthly-mean bias and standard deviation errors in the outgoing longwave radiation (OLR). OLR was not assimilated but was used for independent verification. Current global analyses contain significant errors in hydrological parameters. Thus, we see important implications in the result that rainfall assimilation improves not only precipitation but also related fields such as cloud and radiation. This work identifies precipitation as a key observation for improving the quality and usefulness of global analyses for understanding the Earth’s water and energy cycles.

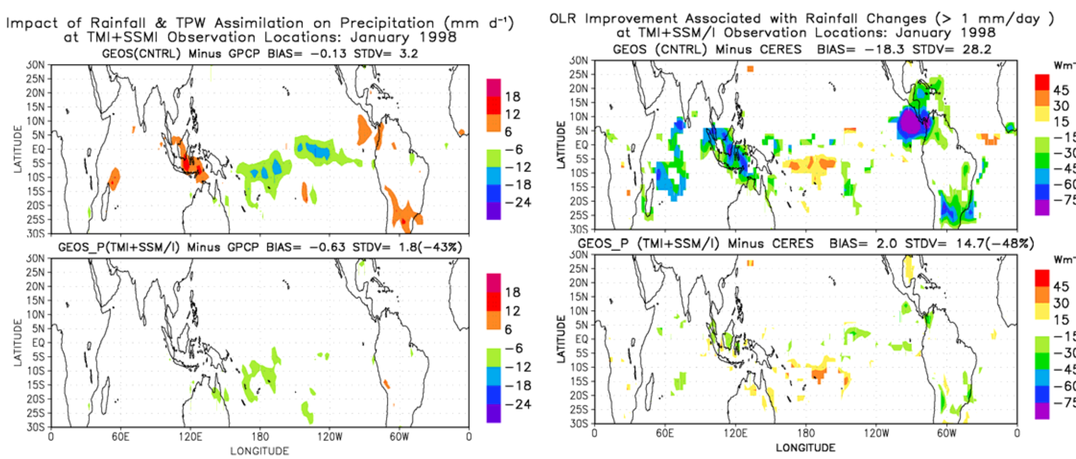


Figure 6-67. GEOS assimilation results with and without TMI and SSM/I observations for January 1998. Left panels show errors in the monthly-mean tropical precipitation fields verified against GPCP combined satellite-gauge estimate. Top is the difference between the GEOS control (without rainfall and TPW data) and GPCP. Bottom is the corresponding error in GEOS assimilation with rainfall and TPW data. Right panels show the impact on the outgoing longwave radiation (OLR) verified against CERES/TRMM measurements. Percentage changes in the tropical-mean error standard deviation relative to the GEOS control are given in parentheses.

The improved analysis with rainfall data also provides better initial conditions for storm-track and quantitative precipitation forecasts (QPF), as shown in Figure 6-68 for Hurricane Bonnie. Results from 5-day ensemble forecasts show systematic improvements in precipitation, divergent winds, and geopotential heights in the tropics. These results suggest that rainfall assimilation has the potential to significantly improve weather forecasting skills.

Laboratory scientists are currently developing techniques to assimilate the latent heating information together with precipitation data derived from microwave instruments into global models. This work will further improve short-range forecasts and assimilated global data sets for climate analysis.

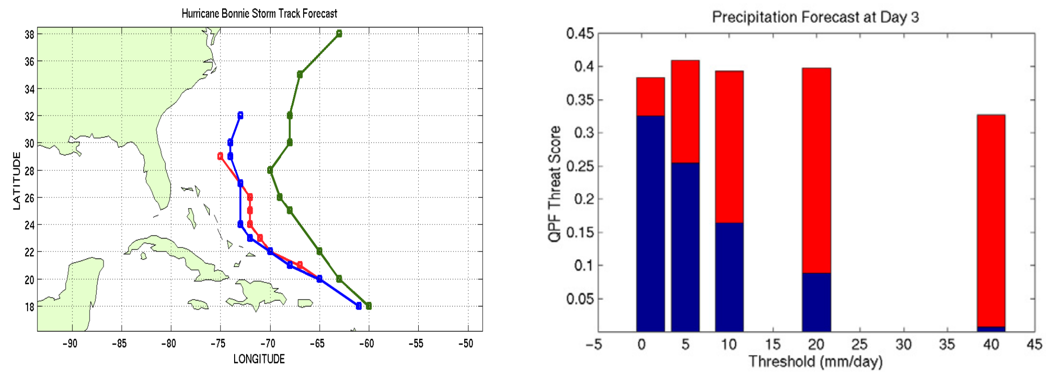


Figure 6-68. Improved storm track forecasts and QPF Equitable Threat Scores for Hurricane Bonnie. The left panel shows that the 5-day storm track forecast initialized with 1° x 1° GEOS analysis containing TMI and SSM/I rainfall data (blue) is in close agreement with the best track analysis from NOAA. The track from the control experiment is shown in green. The forecasts are initialized at 12:00 on 20 August 1998. The right panel shows the consistently higher Equitable Threat Scores for Day 3 precipitation forecast (red) initialized by the analysis with rainfall data. Results for the control experiment are shown in blue. A higher Threat Score corresponds to greater forecast skills.

Hou, A.Y., S. Zhang, A. da Silva, W. Olson, C. Kummerow, J. Simpson, 2001: Improving global analysis and short-range forecast using rainfall and moisture observations derived from TRMM and SSM/I passive microwave instruments. *Bulletin of Amer. Meteor. Soc.*, 82, 659-679.

Arthur Y. Hou, Code 910.3 (Arthur.Y.Hou.1@gsfc.nasa.gov)

Hurricanes

Simulation of the Cloud-Scale Structure of an Atlantic Hurricane

Hurricanes are well known for their high winds, heavy rainfall, and damaging storm surges. Along with the tolls they take in human lives and in property damage, they can also severely disrupt local economies, lead to housing and food shortages, cause problems with disease in flooded areas, and require massive disaster relief. Our ability to observe and forecast hurricanes has improved tremendously in recent decades as a result of satellite measurements and improved numerical models. We can now observe the occurrence of hurricanes all over the planet and can provide reasonably good forecasts of hurricane tracks. Yet we are still far from being able to accurately forecast rapid changes in storm intensity, partly because of insufficient observations of the processes that contribute to intensification as well as a lack of knowledge about how such intensification occurs.

We have simulated a hurricane using a numerical weather prediction model for the purpose of examining the processes that contribute to storm structure and intensification. Unlike many previous simulations of hurricanes in which clouds were either completely parameterized or only coarsely resolved, this simulation uses a horizontal grid spacing that is capable of resolving individual clouds.

The model produces a realistic hurricane (Figure 6-69) that intensifies slowly during the period of simulation and provides insight into factors influencing storm structure. The hurricane wind field is composed of a primary circulation that is associated with the strong, damaging winds that move tangentially around the storm center. A secondary circulation includes a circuit with radial inflow near the surface, rising motion in the wall of thunderstorms that surrounds the eye (known as the eyewall), and outflow in the upper troposphere. We find that the general structure of the storm is determined partly by characteristics of the storm's environment and also by dynamical instabilities induced by the hurricane's primary circulation. Vertical and horizontal variations in the environmental winds influence the structure of the storm by favoring near-surface inflow, rising motion in the eyewall, and precipitation on the west-northwestern side of the storm. While the storm's environment favors one side of the storm, a dynamical instability develops in the eyewall associated with radial changes in the primary circulation. This instability produces a pair of lower- and higher-pressure regions in the eyewall (Figure 6-69) that rotate around the center at about half the speed of the vortex winds. Counter-clockwise and clockwise wind perturbations occur with these low- and high-pressure anomalies, respectively, and influence the patterns of inflow and outflow, upward motion, and precipitation in the eyewall.

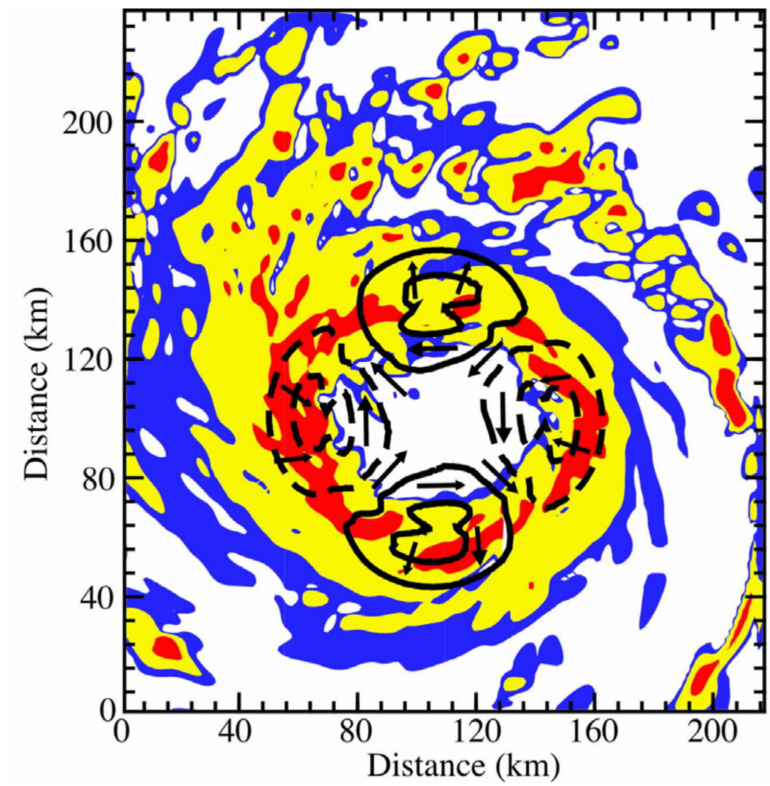


Figure 6-69. Simulated low-level radar reflectivity (shading), with warmer colors indicating heavier precipitation. Contours and vectors indicate pressure and wind perturbations associated with a dynamical instability in the eyewall. Pressure contours are drawn at values of 0.5 and 1.5 mb with positive values indicated by solid lines, negative values by dashed lines.

We identify key aspects of the secondary circulation that play important roles in storm intensification. The inflow into the eyewall is very intense within the shallow boundary layer near the ocean surface, but transitions to strong outward flow just above the boundary layer as the air begins its fairly rapid rise within the eyewall (Figure 6-70). As described below, this outflow appears to play an important role in allowing thunderstorms to occur in the eyewall. While many simplified models of hurricanes envision the eyewall as a ring of gradually rising air, our calculations indicate that most of the upward motion in the hurricane eyewall is associated with a small number of intense but isolated thunderstorm updrafts instead of a broader region of more gentle upward motion, consistent with the concept of hot cloud towers.

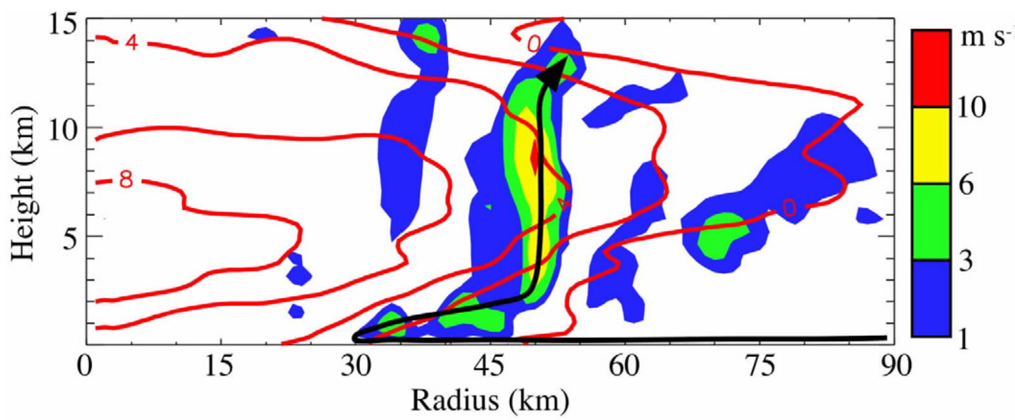


Figure 6-70. Vertical cross section extending outward from the storm center and showing upward vertical motions (shading) and temperature perturbations (red contours, 2 K intervals). The temperatures are perturbations from the model domain average values at each height. The long black arrow shows a hypothetical air parcel trajectory in which the near-surface air penetrates well inside the eyewall so that it resides underneath the warm air in the eye, where convection is suppressed. It then begins to rise slowly and move rapidly outward, eventually moving far enough out from under the warm air that convective instability is released (e.g., near a radius of 50 km).

The eye of the hurricane contains very warm air at upper levels that is generally believed to reduce or prevent the release of thermodynamic instabilities that produce thunderstorms. Some hypotheses suggest that the instability, rather than being released in the vertical direction, is instead released only along a slanted path outward and upward. Figure 6-70 shows that the low-level outward flow in the eyewall displaces the rising air sufficiently far away from the warm air in the eye so that the instability can be released in the vertical direction to produce thunderstorms rather than requiring that the air rise along a slanted path. The energy for these thunderstorms comes from the exchange of heat and moisture from the ocean surface to the low-level inflowing air and is manifested as tongues of warm, moist air within the low-level outward flow that feed into the eyewall thunderstorms.

Scott A. Braun, Code 912 (Scott.A.Braun.1@gsfc.nasa.gov)

Studies of Hurricanes During CAMEX-4

During August and September 2001, NASA sponsored the Convection and Moisture Experiment 4 (CAMEX-4). Camex-4 focused on hurricane research in the eastern Atlantic region. NASA conducted the campaign jointly with NOAA and university scientists. The effort was part of the U.S. Weather Research Program (USWRP) hurricane landfalling program.

The main CAMEX-4 objective was to obtain a comprehensive mapping of the full 3-dimensional structure of hurricanes. The mapping will be used in studies and modeling of processes related to intensification (and weakening) and tracking of hurricanes, especially near landfall. NASA and NOAA scientists designed five experiments to address CAMEX-4 objectives, the USWRP hurricane landfalling objectives, and the NOAA operational tropical storm forecast requirements.

One of the high-priority goals of the Goddard and collaborating UMBC/JCET and GEST scientists was to measure high-altitude temperature and wind simultaneously with radar measurements of the hurricane. As hurricanes mature, heat is produced by condensation as air expands and rises. This process in turn causes a lowering of the hurricane's surface pressure. Lower surface pressures result in air accelerating toward the hurricane center. This movement intensifies the hurricane circulation through the Coriolis force. The heat carried aloft by the rising air produces a characteristic "warm core" in the upper tropopause. In 1998, the CAMEX-3 campaign measured the relation of this warm core to the hurricane's wind and precipitation structure. These measurements were limited to the DC-8's altitude (12 km). Thus, little was known about the temperature and wind structure above that altitude. During CAMEX-4, more emphasis was placed on measuring the full vertical extent of the warm core.

The NASA ER-2 and DC-8 aircraft were instrumented with numerous remote sensing and in situ instruments to provide high-resolution, detailed measurements of the structure of hurricanes. The two NOAA P3 aircraft flew in a coordinated fashion with the NASA aircraft. Two instruments played a key role in measuring the warm core of a mature hurricane. The Goddard ER-2 Doppler Radar (EDOP) is a downward-looking instrument that measures radar reflectivity and vertical velocity in precipitation regions. The ER-2 High-altitude Dropsonde system (EHAD) was a joint effort between JCET's Jeff Halverson and NCAR.

For the first time during CAMEX-4, high-altitude dropsondes were released by EHAD into a hurricane while simultaneous radar measurements were taken by EDOP. Figure 6-71 shows a pass across Hurricane Erin on 10 September 2001 with EDOP. Erin was a mature storm with an unusually clear eye and eyewall. The reflectivity and Doppler measurements provide a clear indication of the outwardly sloping eyewall in the storm. During this pass and others, the ER-2 and DC-8 aircraft launched dropsondes to map Erin's temperature and wind structure. Figure 6-72 provides a temperature and moisture sounding from one of the first high-altitude ER-2 dropsondes, which was launched into a hurricane eye. These data sets are being analyzed to more fully understand the dynamics related to hurricane intensification.

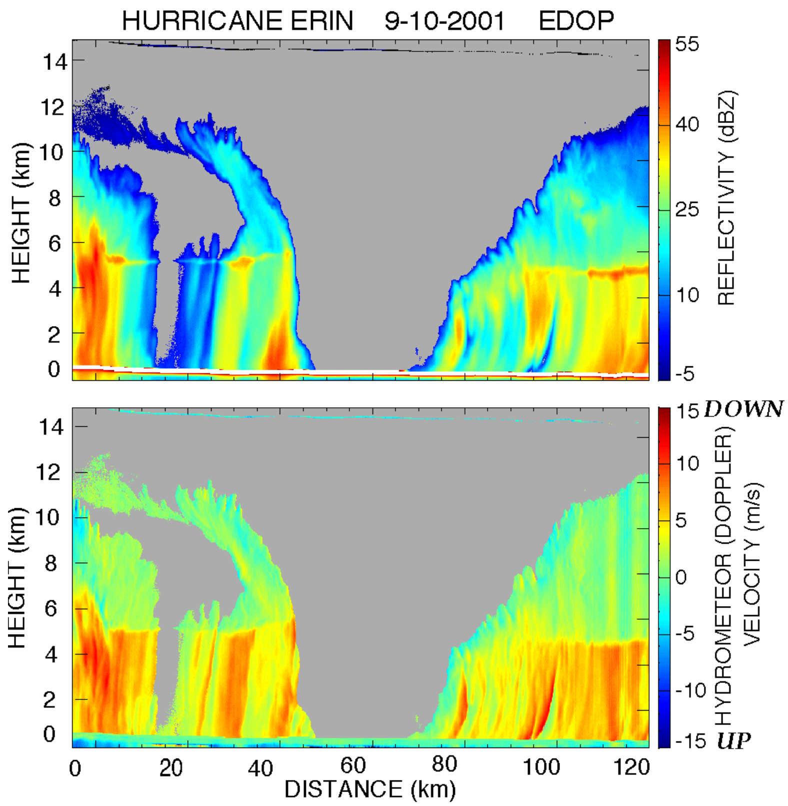


Figure 6-71. EDOP measured vertical structure of Hurricane Erin. The top panel shows the radar reflectivity and the bottom panel shows the Doppler velocity.

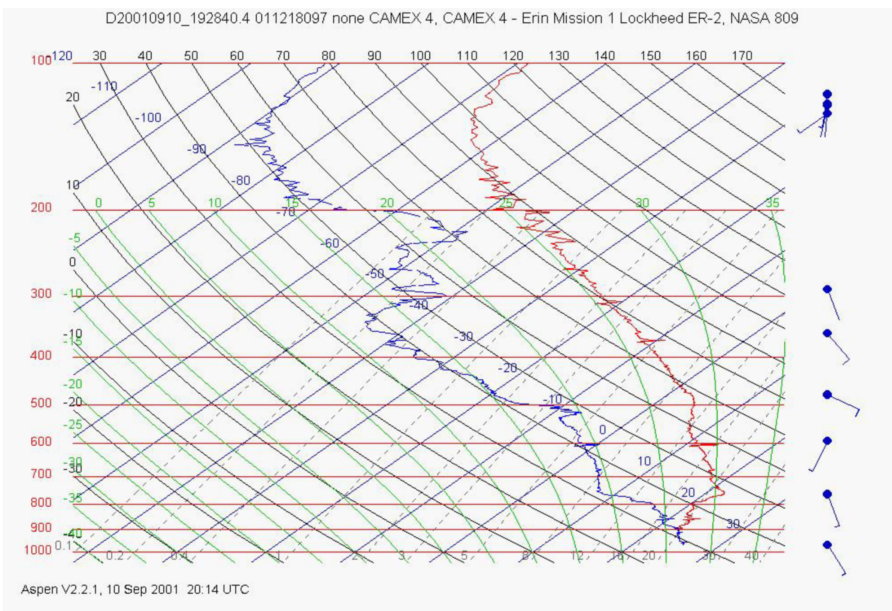


Figure 6-72. First dropsonde released by the ER-2 High Altitude Dropsonde (EHAD) into the ER-2 into the eye of a hurricane during Hurricane Erin .

Gerald Heymsfield, Code 912 (Gerald.M.Heymsfield.1@gsfc.nasa.gov)

Physical Processes

Global Solar Oscillations

A wide variety of oscillation modes can exist inside the Sun. Most cover the entire globe. Modes with short oscillation periods are easiest to detect and have been recorded by the thousands. Beat periods between various modes range from minutes to many years. Long beat periods that affect solar luminosity might affect the Earth's climate.

The family of Rossby modes propagate in the Sun's convection region, which occupies the outer third of its radius. Astronomers call these *r-modes*. The Rossby *waves* of meteorology are local approximations to the Rossby *mode* of a sphere. All are driven by the Coriolis force. Rossby modes rotate more slowly than the fluid in which they oscillate—they drift "backwards." This behavior normally distinguishes them from the other solution to the same equations—a stationary geostrophic flow. But the distinction is weakened by solar differential rotation (i. e., an altitude-dependent zonal wind). Such a wind makes Rossby and geostrophic motion more similar. A geostrophic flow begins to drift backwards too, and, with increasing wind strength, it eventually becomes identical to a Rossby mode[1].

Gravity modes are another type of oscillation that also defines long beat periods of months or years in the Sun. These beats with precisely known periods affect the timing of fluctuations in solar activity (sunspots, flares, and ejections of mass into the planetary system).[2] Thus, danger levels for astronauts and space equipment should become a bit more predictable by taking into account these very stable modes. Whether their long-term modulation of the solar energy output is large enough to affect the Earth's climate is under investigation.

Finally, the prominence of beats means that nonlinear amplitudes are involved, causing gravity modes to deposit considerable energy in layers just below the solar convection zone. This would drive a significant reversing zonal flow, analogous to the QBO (Quasi-Biennial Oscillation) in the Earth's atmosphere, that is conjectured to possibly be a main energy source for the 11-year solar activity cycle. [3]

Charles L. Wolff, Code 915 (Charles.L.Wolff.1@gsfc.nasa.gov

[1] C.L. Wolff, Astrophysical Journal, 502, 961, 1998
[2] C.L. Wolff, Astrophysical Journal, 264, 667, 1983
[3] H.G. Mayr, C.L. Wolff, & R.E. Hartle, Geophysical Research Letters, 28, 463, 2001

7. EDUCATION AND PUBLIC OUTREACH

The Laboratory for Atmospheres actively participates in NASA's efforts to serve the education community at all levels and to provide information to the general public. The Laboratory's educational outreach component is consistent with the Agency's objectives to enhance educator knowledge and preparation, supplement curricula, forge new education partnerships, and support all levels of students. Laboratory activities include addressing public policy, establishing and continuing collaborative ventures and cooperative agreements; providing resources for lectures, classes, and seminars at educational institutions; and mentoring or academically advising all levels of students. Through our public outreach component, we seek to make our scientific and technological advances broadly accessible to all members of the public and to increase their understanding of why and how such advances affect their lives.

Public Policy

High End Climate Science: Development of Modeling and Related Computing Capabilities (known as the *Rood Report*) was released early in 2001 and is available on http://www.usgcrp.gov/ under "What's new." This report is the result of a panel chaired by Richard Rood of the Data Assimilation Office and written at the request of the White House Office of Science and Technology Policy. Other panel members were Jeff Anderson (GFDL), Dave Bader (DOE), Maurice Blackmon (NCAR), Tim Hogan (DOD), and Pat Esborg (Organizational Consultant).

Interaction with Howard University and Other Historically Black Colleges and Universities

A part of NASA's mission is to initiate broad-based aerospace research capability by establishing research centers at the nation's Historically Black Colleges and Universities (HBCUs). The Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA) was established in 1992 at Howard University (HU) in Washington, D.C., as a part of this initiative. The Laboratory for Atmospheres started a close collaboration with CSTEA in the second 5-year period of NASA funding under a cooperative agreement grant. It is the goal of NASA and the mission of CSTEA to establish at Howard University a self-supporting, world-class facility for the study of terrestrial and extraterrestrial atmospheres, with special emphasis on recruiting and training African Americans for careers in Earth and space science.

The Laboratory continues its research and educational activity with Howard University's CSTEA program. A Technical Review Committee site visit has been held yearly to evaluate the CSTEA program, to make recommendations for the program's research and collaborative interactions with the Laboratory, to help the program with its strategic planning for future growth, and to help the program develop new funding sources. The Laboratory works closely with CSTEA faculty to promote the Howard University Program in Atmospheric Sciences (HUPAS). HUPAS is the first M.S.- and Ph.D.-granting program in atmospheric sciences at an HBCU and the first interdisciplinary academic program at Howard University. Scientists from our Laboratory contribute to the HUPAS program as lecturers, advisors to students, and adjunct professors teaching courses. Laboratory for Atmospheres Adjunct Professors Dean Duffy and Richard Stewart wrote parts of the first Ph.D. candidacy exams for HUPAS. In another example of collaboration, a video on the origin of UV-B and its health implications for the people of Madagascar was prepared at the Howard University TV station for presentation on Madagascar national TV with the aid of a Laboratory scientist and using our Laboratory's TOMS data. Dr. A. Aikin prepared the script, which was delivered in French and Malagasy by M. Robjohn, a student from Madagascar studying atmospheric sciences at HU.

The Laboratory continues its enthusiastic support for the Goddard/Howard University Fellowship in Atmospheric Sciences (GoHFAS) program. GoHFAS was established in 1999 to broaden and strengthen the research and educational opportunities of underrepresented minorities. The students attend a summer program at Howard University where they engage in research with mentors at HU, GSFC, or NOAA. They attend a for-credit class in atmospheric science and a technical writing and presentation class. They receive fellowships at their home institutions during their senior year and are given an opportunity to come to HU during the winter break to continue their research. A significant number of GoHFAS students have successfully transitioned into CSTEA and HUPAS graduate degree programs.

Another example of efforts by our Laboratory scientists to encourage underrepresented minorities to enter the sciences is given by the activities of Dr. J. Marshall Shepherd. Dr. Shepherd participated in the Quality Education for Minorities (QEM) Ask a Scientist Activity in February in Washington, D.C., with roughly 25 professional scientists from various disciplines fielding questions from over 100 students and parents attending the conference. He participated in a NASA Awareness Program at Jackson State University in October. Dr. Shepherd also gave a seminar entitled "TRMM Observations and Numerical Investigations of Urban-Induced Rainfall Anomalies" at Clark Atlanta University to spur development of a partnership with Clark Atlanta in support of his current urban rainfall research initiatives.

Summer Mentoring Programs

Our Laboratory participates in a number of programs that bring graduate and undergraduate students to work one-on-one with scientists and engineers in the Laboratory for Atmospheres as well as in other Laboratories and Directorates at Goddard. The GoHFAS collaboration with Howard University was mentioned in the previous section. The Summer Institute on Atmospheric and Hydrologic Sciences program is the longest running program. This past year 16 students were hosted in the Earth Sciences Directorate with 8 in the Laboratory for Atmospheres. This program is now administered by the GEST Center as the Visiting Student Enrichment Program (VSEP). Information on VSEP can be found on the World Wide Web at http://www.umbc.edu/gest/ under Student Opportunities. Student projects in the past have included simulating neural networks, preparing image analysis algorithms on supercomputers, developing computational science applications, and creating interactive World Wide Web sites. Two other programs that are bringing students to our Laboratory for mentoring are the GSRP (Graduate Student Researchers Program), funded by NASA, and the SOARS (Significant Opportunities in Atmospheric Research and Science) program, funded by UCAR. All these programs are designed to stimulate interest in interdisciplinary Earth science studies by enabling selected students to pursue specially tailored research projects with Goddard scientific mentors.

University Education

At the university level, Laboratory scientists have taught undergraduate and graduate courses, given seminars and lectures, and advised degree-seeking students. Over 20 Laboratory scientists supervise graduate students and have official affiliations (i.e., adjunct or visiting professor) with various universities, and 14 regularly teach university-level courses. As an example of our scientists' mentoring of graduate students, David Starr participated in the Ph.D. dissertation defense of students at Colorado State University and Pennsylvania State University, and the students followed up their graduate work with visits to our Laboratory. Alexander Marshak served on the Ph.D. committee for two dissertations at Boston University Department of Geography on these topics: “Evaluation of the Performance of the MODIS LAI and PFAR Algorithm with Multiresolution Satellite Data” and “Application of Stochastic Radiative Transfer to Remote Sensing of Vegetation.”

Our scientists give seminars in a variety of national and international settings. Dr. Song Yang was invited to Nanjin and Beijin, China, in July and visited two universities (Nanjin Institute of Meteorology and Nanjin University) and three research institutes (Institute of Atmospheric Physics, National Satellite Meteorological Center, and the Meteorological Center of China Meteorological Administration) where he presented 7 TRMM seminars. This peer outreach helps extend the impact of TRMM on atmospheric sciences in China with the expectation that research scientists in China will increasingly apply TRMM data to advance our understanding of weather systems and climate. Anne Thompson gave a seminar in the Oceanography Department at Dalhousie University (Halifax, Nova Scotia) on July 23 and discussed SHADOZ (Southern Hemisphere Additional Ozonesondes) and the forthcoming SOLAS (Surface Ocean Lower Atmosphere Studies) international project with department members.

In an example of outreach to universities in areas outside of our specific basic research focus, Anne Thompson and Jay Herman (916), Nancy Maynard (900), Elissa Levine and Dan Kimes (923) attended the Workshop on Human Health, Urbanization, and Remote Sensing, held at the Emory University Rollins School of Public Health (Atlanta) in May. As a result of the workshop, five specific health and urbanization issues that can be approached through remote sensing were selected for follow-up study by NASA, university, EPA, NIEHS (National Institute of Environmental Health Sciences), and CDC (Centers for Disease Control) researchers.

K–12 Education

Laboratory staff participated in K–12 education in a variety of ways. Laboratory scientists routinely present lectures and demonstrations to K–12 schools and youth groups to help develop an early interest in science. Many Laboratory scientists have also mentored students in grades K–12. The Eleanor Roosevelt High School Science and Technology Internship Program enables high school students to perform research under the mentorship of Laboratory scientists. As an example, Candice Chan, a student at Eleanor Roosevelt High School, was mentored by Drs. Gerald Heymsfield and Lin Tian and competed in the Prince George’s Area Science Fair (including Prince George’s, Calvert, Anne Arundel, and Charles Counties), taking third place in the Earth Sciences category. Her project was titled “Characteristics of the Radar Bright Band” and involved analysis of ER-2 Doppler Radar (EDOP) observations. She has received awards from The Johns Hopkins Applied Physics Lab, National Space Club, Friends of Agricultural Research, and TRW. Members of the Laboratory have served as judges for local science fairs and made presentations at high school career days to foster interest in NASA-related research. This educational outreach teaches students how many of us chose our scientific careers and what steps we took to achieve our positions. In another example, Dr. George Huffman and Mark Malanoski presented Earth Science demos to four groups (totaling approximately 130) of 5th–8th graders and their teachers in the D.C. Public Schools Higher Achievement/Scholar program during their site visit to GSFC in August.

In a significant example of K–12 outreach outside of the U.S., Richard Stolarski participated in the “Ozone Awareness Program” at Cannock Chase High School in October. The teachers and students at the high school spent the previous year developing an ozone awareness program and a

Web site, http://www.cannockchase-high.staffs.sch.uk/ozone/ozoneindex.htm The site was inspired in large part by the ozone research carried out in our Laboratory, and made extensive use of the TOMS data. As part of its program, the school obtained funds from a number of educational sources within the U.K. to bring a NASA scientist to the school to talk about ozone science and to stimulate students into following science as a career choice. Dr. Stolarski spoke to over 300 students and was interviewed by BBC news. In an email, Mina Patel, who organized the student project and lobbied for the NASA visit, wrote: “I would like to let you know on behalf of the Headmaster at Cannock Chase High school, just how much of a pleasure it was for us to have Rich Stolarski come to speak to our pupils. He was truly inspirational to so many of our youngsters. Thank you so very much for supporting my school and me. Regards, Mina.”

Presentation to about 170 students in their 8th year at Cannock Chase High School, U.K. Quote from Dr. Stolarski’s report: “I talked to them for about 40 minutes about the excitement of doing science. They were excited and fun and asked lots of questions. Overall, it was a fun experience. The teachers and students were enthusiastic. I was reminded that people consider being a NASA scientist as something special. I hope that I contributed positively towards the eventual career decisions of some of the students.”

Public Outreach

Informing the public of how their tax dollar investments are working for them within the Laboratory is a critical subset of the Center and Agency public outreach mission. Laboratory scientists, working with other Laboratories at Goddard and outside institutions, continue to pass their knowledge and interest in Earth and space science to the general public via public information and education programs. Our scientists and engineers have been interviewed by the news media, have appeared in press conferences, have generated Web sites, CDs and educational material oriented toward the general public, and have participated in public forums.

Some of our outreach addressed the CAMEX project. Dr. J. Marshall Shepherd participated in a NASA Press Briefing at the Naval Air Station-Jacksonville, FL, in August. The press briefing, organized by NASA HQ, kicked off the CAMEX-4 Field Experiment. CAMEX-4 employed NASA and NOAA aircraft, satellites, and ground assets to study Atlantic Basin hurricanes from August through September. Dr. Shepherd spoke about the role of TRMM in extending knowledge of hurricane intensification and evolution processes and how field campaigns like CAMEX-4 contribute to TRMM validation and calibration efforts. The press briefing also included remarks by NASA program manager Dr. Ramesh Kakar, Robbie Hood (MSFC), Dr. Ed Zipser (University of Utah), and Dr. Frank Marks (NOAA). At another time, Gerry Heymsfield was interviewed by Fox Morning News on the CAMEX field program in Florida.

Some of our public outreach addressed the topic of ozone. Dr. Paul Newman gave a talk to the Montgomery County Science Teachers Association in Lansdale, Pennsylvania, on stratospheric ozone. About 100 attendees were present. Jay Herman and Paul Newman were interviewed for an article on ozone in Discover Magazine. Paul Newman and Scott Janz were interviewed by Allison Aubrey of National Public Radio on the Antarctic ozone hole. She was shown the SSBUV instrument in the clean room and the tunable diode laser in the laser lab. Jay Herman was interviewed, live and delayed, by CNN on August 15 concerning the distribution and trends in UV radiation reaching the Earth’s surface. CNN showed the images on the GSFC Web site pertaining to TOMS data.

Dr. W. Lau (Code 913) and Dr. P.K. Bhartia served as panelists on an Asian Pacific Media Workshop in June at GSFC. Dr. Lau presented a talk on “Rainfall and Climate,” and Dr. Bhartia a talk on “Ozone and Atmospheric Chemistry.” The event was organized by the GSFC Asian American Advisory Committee, in conjunction with the Public Affairs Office, to promote science and engineering outreach to the Asian-Pacific-American and the larger community. More than 10 representatives from Asian-Pacific-sponsored newspapers, magazines, and TV stations participated in the workshop. The presentations were followed by questions and answers, and a tour of the GSFC facilities.

On Sunday, May 6, Lorraine Remer (913) delivered the keynote address to the Girl Scouts of Central Maryland Gold Award Banquet. This event honors the 61 high school Girl Scouts within the Council who have earned Girl Scouting’s highest honor during the past year. Lorraine spoke of her own Girl Scout experiences and how these early challenges have helped her succeed as a woman scientist in a male-dominated field.

TRMM Outreach/Education

TRMM continues its comprehensive Education/Outreach program, in which Laboratory personnel promote TRMM science and technology to the public under the leadership of the TRMM Project Scientist Robert Adler (910) and TRMM Education and Outreach Scientist Jeffrey Halverson (912/JCET). TRMM has included the development of broadcast visuals and educational curriculum focusing on the Tropical Rainfall Measuring Mission. These packages are available on the TRMM Web site (http://trmm.gsfc.nasa.gov/) and have been reviewed as a part of the ESE Education product review. They are currently under revision. TRMM scientists regularly appear on major media outlets (Earth and Sky Radio, CBS, NBC, ABC, and CNN) in support of the mission. In addition, Laboratory personnel have spoken at and conducted several outreach workshops in support of TRMM. Dr. J. Marshall Shepherd released a new Web site highlighting current mesoscale and TRMM-related research on rainfall modification by urban areas. The Web site address is http://rsd.gsfc.nasa.gov/912/urban. This Web site was completely designed and implemented by one of the Mesoscale Atmospheric Processes Branch's summer high school interns as a part of the Branch and Laboratory's outreach initiatives.

GOES Web Server

This Web server continues to provide GOES images online, including full-resolution images of all sectors of the United States for the most recent 2 days. In addition, there are extensive scrapbooks of digital movies and pictures of important weather events observed by the GOES-8 and GOES-9 satellites since they were launched in 1994 and 1995, respectively. The Remote Sensed Data (RSD) server (http://rsd.gsfc.nasa.gov) has been judged by NASA HQ to be one of the 20 most popular NASA Web sites during the year 2000. The science administrator of RSD supplies GOES-derived high-quality graphics and severe storm animations to the Visualization Analysis Laboratory (VAL), to GSFC Public Affairs Office (PAO), and directly to the public via the Internet. During active hurricanes, the GOES section of the RSD Web server is accessible to the general public.

EOS Terra/Aqua Outreach Synopsis

The EOS coordinated outreach effort—under the direction of Yoram Kaufman (Code 913), Claire Parkinson (Code 971), and David Herring (Code 913)—is a coordinated effort to foster greater cooperation and synergy among the various outreach groups within the EOS community. A sampling of these activities, described below, represents contributions from the diverse EOS community.

The Terra Project Science Office (Code 900) produced a Terra mission overview brochure. The brochure, as well as many more images, animations, and information, is available on the Terra Web site (http://terra.nasa.gov/), which is also maintained by the Terra Project. The Aqua project scientist and outreach scientist have also developed an EOS Aqua overview brochure.

The Terra and Aqua project teams created NASA's Earth Observatory Web site (http://earthobservatory.nasa.gov/). This Web environment is the NASA Web portal where the general public goes to learn about the Earth. It showcases new images and science results from EOS missions. All resources produced for the Earth Observatory are freely available for use by the EOS community, museums, educators, public media, regional "stakeholders," environmental awareness groups, and interested members of the general public. While leadership for this site resides in Code 913, significant contributions to its development come from Codes 900, 902, 912, 921, 922, 923, 935, 971, and 3200 at the Jet Propulsion Laboratory, as well as the American Museum of Natural History and East Carolina University.

To provide overarching guidance and review for the Terra outreach activities, as well as to flag mature new science results ready for public release, an Executive Committee for Science Outreach (ECSO) continues to operate. This committee is chaired by Dr. V. Ramanathan, of the Scripps Institute's Center for Clouds, Chemistry, and Climatology. The purpose of this committee is to harvest new Terra science results that are ready for public release, as well as to help temper the presentation of new results with respect to socio-political implications they may have. The major EOS outreach Web sites are (1) the Terra homepage (http://terra.nasa.gov/), (2) the Earth Observatory (http://earthobservatory.nasa.gov/), and (3) the Visible Earth (http://visibleearth.nasa.gov/). The Visible Earth site provides access to THE SUPERSET of all Earth science images, animations, and data visualizations produced by NASA for public release.

The Terra Project formed a Rapid Response Network to meet the media's requirements for quick access to satellite imagery relevant to newsworthy Earth events (e.g., severe storms, floods, El

Niño, volcanic eruptions, wildfires, etc.). The Network is headed by David Herring (Code 913), assistant Terra project scientist. This network enables us to access and produce remote-sensing imagery over targets of interest within hours to days after acquisition. As an example, MODIS fire detection was used during the 2001 fire season for the first time on an operational basis by the Forest Service to detect fires and smoke and to distinguish old from new fires. In a collaboration between the GSFC DAAC (Chris Lynnes et al.), MODIS processing team (Ed Masouka et al.), Terra outreach group (D. Herring et al), MODIS fire team (Chris Justice–UMD, Yoram Kaufman–GSFC et al.), and the U.S.D.A. Forest Service fire laboratory (Wei-Min Hao et al.), we had started an experimental delivery of MODIS data at the end of the 2000 fire season. Therefore, the Forest Service invested in a direct broadcast station and software for optimal use of the MODIS fire information. With the launch of Aqua there will be 4 MODIS observations of fires in 24 hours (2 observations of smoke and burn scars). Combined with the GOES fire observations, they make a powerful tool for scientific investigation and operational use. Terra's rapid response story received good play in the news media, including a short stint in the news block of ABC's Good Morning America. Most of the stories appeared on ABC affiliates and independent stations. Washington's WTTG Fox affiliate came out to the center and interviewed some of the rapid response team.

A Terra Engineering Competition was held in April at DuVal High School. There were teams of students competing from five different high schools around the state. David Herring played a lead role in defining both Round 1 and Round 2 problems, judging the entries of the students, and presiding over the last day's activities. The Competition was supported by Paul Ondrus, Code 500, EOS Operations Manager, and planned in collaboration with Ron Erwin, Technology Education Specialist, Code 100. The team from Westminster High School won the competition, with the Technology Magnet Program of the Howard County Public School System taking first runner up, and Perry Hall High School taking second runner up.

EOS Aura Education and Public Outreach Synopsis

The Laboratory for Atmospheres has responsibility for conducting the Education and Public Outreach program for the EOS Aura mission. Aura's Education and Public Outreach program has four objectives. The first objective is to educate students about the role of atmospheric chemistry in geophysics and the biosphere. The second objective is to enlighten the public about atmospheric chemistry and its relevance to the environment and their lives. The third objective is to inform geophysics investigators of Aura science, and thus enable interdisciplinary research. The final objective is to inform industry and environmental agencies of the ways Aura data will benefit the economy and contribute to answering critical policy questions regarding ozone depletion, climate change, and air quality.

To accomplish these objectives, the Laboratory has partnered with several institutions, which have established infrastructures that reach large audiences through formal and informal education. The GLOBE program and the American Chemical Society (ACS) will carry out formal EOS Aura education outreach effort. Grants are now in place with the American Chemical Society (ACS), the Smithsonian's NMNH, and the GLOBE Program, via Drexel University, for the various educational and public outreach activities relating to atmospheric chemistry and the Aura mission. The grants will result in educational material that will reach tens of thousands of students and millions of members of the general public over the next 3 years through the Aura launch.

GLOBE is a worldwide network of students, teachers, and scientists working together to study and understand the global environment. Students and teachers from over 9,500 schools in more than 90 countries are working with the science community to learn more about the environment by making observations at or near their schools and reporting their data through the Internet. A protocol is being developed for students to measure UVB and overhead aerosols in collaboration with Aura research. The protocol will help students understand the implications of ozone and aerosol changes and their relationship to incident UVB. This student data could also be valuable for validating Aura data. Since the Aura mission involves partners from Europe, their education and public outreach programs will also support the GLOBE international components.

The ACS distributes its teaching magazine, *ChemMatters*, to 30,000 high school teachers. Over the next 3 years, the ACS will produce four issues of *ChemMatters* highlighting topics related to atmospheric chemistry, including space-flight technology, remote-sensing methods, ozone and climate observations, and forthcoming results from Aura measurements. Teachers are also provided with a lesson plan that describes atmospheric chemistry in relation to ozone depletion, air quality and climate. The first issue of *ChemMatters* was published in 2001. Electronic versions of the magazine and a teachers guide appear at http://www.acs.org/education/curriculum/chemmatt.html. Click on the September 2001 issue and teachers guide.

Our outreach to the general public will also include an exhibit at the Smithsonian's NMNH. The museum has millions of visitors per year. Our exhibit will include a large display that illustrates the connections among land, ocean, and atmosphere. The exhibit will also include an interactive module that deals with Aura's three main science questions. The Laboratory's VAL will develop the digital interactive displays. The museum will also develop a tool kit that will allow the display to be portable and, thereby, available to other museums in the U.S. and abroad. For further information, see the Aura Web site at http://eos-aura.gsfc.nasa.gov/outreach/, and for visualization visit the Web site at http://rsd.gsfc.nasa.gov/rsd/.

NASA/NOAA: Earth Science Electronic Theater 2001

The NASA/NOAA/AMS Earth Science Electronic Theater (E-Theater) uses interactive computer-driven displays at near-IMAX size to deliver a powerful tool for promoting Earth science. Scientists from the various Earth science disciplines work directly with the VAL team to develop scientifically accurate visualizations. E-Theater visualizations are rendered at High Definition TV (HDTV) quality, the highest resolution possible. The visualizations can be used in a host of other applications (i.e., National Television Standards Committee (NTSC) TV, QuickTime movies, Web graphics, etc.). QuickTime versions of each E-Theater visualization are being added to the E-Theater Web page (http://Etheater.gsfc.nasa.gov/index.html/) along with an explanation of the scientific significance and the origin of the data.

Our Laboratory's VAL, as well as other Goddard and NASA groups, has produced visualizations using NASA, NOAA, ESA, and NASDA Earth science data sets. These visualizations continue to be shown around the world using new display technologies. The E-Theater has been presented at universities, high schools, museums, and government laboratories to scientists and the general public. An HDTV video was run on the 42" plasma screen at the NASA/HQ showing Landsat mosaics and panels explaining ESE's Science, Missions, Technology, and Applications. NASA/NOAA/AMS Earth Science Electronic Theater presentations were made at the AMS Satellite Conference in Madison, Wisconsin, and to middle- and high school students from all over Wisconsin in four daytime presentations. Presentations were also shown in the IMAX Theater of the Science Museum of Minnesota (SMM) in a public presentation in conjunction with the Earth Science Institute GIS Conference for Science Museums in November 2001. Fritz Hasler (VAL/912) and Steve Brill (EOS Program Office/420) made a successful NASA/NOAA/AMS

"Digital Earth Science" presentation in February 2001, at the Digital Theater Division of Evans & Sutherland in Salt Lake City, where the concept "Blue Marble Olympics" was put forth to the Salt Lake Organizing Committee and others. Subsequently, E-Theater presentations were made during the Winter Olympics in 2002.

We continue to demonstrate methods for visualizing and interpreting immense HyperImage remote-sensing data sets and 3-dimensional numerical models. We call the data from many new Earth-sensing satellites *HyperImage* data sets, because they have such high resolution in the spectral, temporal, and spatial domains. The traditional numerical spreadsheet paradigm has been extended to develop a scientific visualization approach for interactively processing HyperImage data sets and 3-D models. The advantages of extending the powerful spreadsheet style of computation to multiple sets of images and organizing image processing were demonstrated using the Distributed Image SpreadSheet (DISS). The DISS is being used as a high-performance testbed application for the Next Generation Internet (NGI).

Museum Support

The VAL actively works with several museums in creating new, innovative Earth science displays. A short list of some of these museums includes the Smithsonian's NMNH, the National Air and Space Museum, the American Museum of Natural History in New York, the Virginia Science Center, and the Houston Museum of Natural History. In conjunction with large museums, we are developing science presentations that will be made accessible and available to smaller museums.

One successful museum activity is the "Earth Today" exhibit. This exhibit evolved from an earlier Smithsonian exhibit, the "HoloGlobe." The Earth Today is a permanent exhibit in the National Air and Space Museum. It contains all of the original information contained in the "HoloGlobe" exhibit, and it has expanded the focus to include near real-time data displays. These near real-time data presently include global cloud cover, global water vapor, sea surface temperature, sea surface temperature anomalies, biosphere, and earthquakes. VAL personnel continue to actively promote advancements in this exhibit. These refinements include improved computer coding; new, high-resolution data sets (such as products from TRMM, TOMS, Terra and in the future, Aqua); a new version of Earth Today that will run on many mid-level PCs; and a version that will run on the Web.

Another effort is "Global Links." Global Links is an exhibition in the planning phase at the Smithsonian's NMNH. This exhibit will feature the four main Earth science spheres: atmosphere, biosphere, hydrosphere, and geosphere. The exhibit will focus on these different systems and explain what we know about the interdependency and delicate balance among these systems. VAL staff worked closely with the museum and NASA scientists to develop the initial concepts used in this exhibit. VAL personnel continue to work with the museum in refining those concepts. The Global Links exhibit provides the perfect opportunity to develop strong content to explain Earth science concepts.

8. ACKNOWLEDGMENTS

We thank all the Laboratory members whose work motivated this report and generates its substance. We especially thank the Branch Heads and Branch Secretaries for helping to gather and write some of the text.

We'd also like to thank Don Swenholt for his counsel on the tone and organization and for his work in editing the many contributions of a variety of authors. We thank Renee Boudreau for constructing the cover and Joseph Ardizzone for supplying and perfecting the cover picture.

Laura Rumburg turned her keen proofreader's eyes on our copy. In addition to the normal proofreading function, Laura diligently researched, edited, and checked factual items, figures, and tables, and spent a considerable effort in collecting input.

Charles Cote chose the cover design, helped to gather material, insured the accuracy of our instrument and project descriptions, and edited much of the material. Walter Hoegy designed the scheme for collecting input, set the arbitrary deadlines, and edited the final content.

APPENDIX 1. 2001 SHORT-TERM VISITORS

LABORATORY FOR ATMOSPHERES

Keith Cole La Trobe University	April 16–May 15

DATA ASSIMILATION OFFICE

Mark Leidner Atmospheric and Environmental Res., Inc.	January 3
Russel P. Morison CEMAP	January 9–11
James R. Taft NAS	February 15–16
Scott Weaver University of Maryland	February 16–May 31
Melanie B. Follette University of Maryland	February 16–May 31
Lesley Ott University of Maryland	February 16–May 31
Ron Errico NCAR	March 1–2
Joseph Tribbia NCAR	March 1–2
Mark Murrin University of Maryland	March 1–May 31
Michael Prather University of California, Irvine	March 6–8
Daryn Waugh Johns Hopkins University	March 6–8
Randall Friedl JPL	March 6–8
Jose Rodriquez University of Miami	March 6–8
Douglas Rotman Lawrence Livermore National Laboratory	March 6–8
Richard Bevilacqua NRL	March 6–8
Ed Baker Naval Research Laboratory	March 9
Nancy Baker Naval Research Laboratory	March 9
Roger Daley Naval Research Laboratory	March 9
Robert Ciotti NAS	March 14–15
Ron Errico NCAR	March 26–28
Scott Weaver University of Maryland	April 16–May 31
Vladimir Krasnopolsky NOAA/NCEP	April 19–October 19
Timothy DelSole COLA	April 23–October 23
Tsann Wang Yu NOAA/National Weather Service	April 26
Pat Pauley Naval Research Laboratory	April 26
Peter Bauer ECMRWF	May 18
Yoshihiko Tahara Japan Met. Res. Inst.	May 18
Jennifer Logan Harvard University	May 21
John Austin Atmospheric Processes Research Group, UK	May 21
Mathew McNamara HALCYON	May 25–October 31
Keiju Tani Japan Atomic Energy Research Institute	May 31
Ralf Giering FastOpt	June 4–5

James Snyder June 11–September 7
Northwestern University

Kirill Strunin July 9–August 31
UCLA

David Larry July 23–26
GEST

Luis Kornblueh August 4–11
Max-Planck Institute for Meteorology

Neil Whitney September 29–31
EPS Software Consultants, Inc.

Kenneth Holmlund October 10
EUMETSAT

Jean-Noel Thepaut June 19
ECMWF

Niels Bormann June 19
ECMWF

Christina Kopken June 19
ECMWF

Tufa Dinku July 1–December 31
University of Connecticut

Ki-Hong Min August 10
Student from Purdue University

Martin D Mueller September 5–11
Center for Solar Energy and Hydrogen Res.

Geoffrey Ng October 10–12
EPS Software Consultants, Inc.

Pete Colarco November 5
University of Colorado

Ron Errico November 5–9
National Center for Atmospheric Research

Joel Tenenbaum November 16
SUNY at Purchase

Hiroo Hayashi November 16
NIES, Tsukuba, Japan

Wei Wu Tan November 19
State Univ. of NY at Stony Brook

Angela Benedetti November 19
Colorado State University

Tijana Janjic December 3–7
Institut fur Physik, Universitat Hohenheim,Germany

Chung-Kyu Park December 19–21
Director, Climate Prediction Division,
Korea Meteorological Administration

Kirill V. Strunin December 17–January 11
UCLA

Nigel Daley December 18
Sun Microsystems

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

Dr. Denis O'brien, January 22–3
CSIRO
Melborne, Australia

Andrew Heymsfield January 22
NCAR

Dr. Edward Eloranta February 13–14
Univ. of Wisconsin

Richard E. Carbone March 6
NCAR

Leonard J. Pietrafesa April 3
North Carolina State University

Thomas Ackerman April 22
PNNL

Jose Fuentes April 25–30
University of Virginia May 10–1

Valerie Worth May 2
University of South Africa

Marco Marcovina May 5–November 2
Politecnico di Torino, Italy

Christian Kummerow May 10–11
Colorado State University

Minghua Zhang May 10–11
SUNY

Shinsuke Sato May 10–11
Communications Research Laboratory

Courtney Schumacher May 10–11
University of Washington

Mitchell Moncrieff May 10–11
NCAR/MMM

R. Johnson May 10–11
Colorado State University

Jeffery Stith May 23
NCA

David Parsons May 24
NCAR

Robert Pasken June 11
St Louis University

Karen Mohr June 11–26
University of Albany, N.Y.

David Baker June 18–July 18
Austin College, Texas

Phillip Brown June 25–July 6
Cloud Physics Research Meteorology Office

Emmanuoil Anagnostou July 26
University of Connecticut

Sonia Garcia Jul 9–Aug 18
US Naval Academy

Jorge Cabrera September 5
NCAR

CLIMATE AND RADIATION BRANCH

Brian Stocks January 18
Canadian Forest Service
Ontario, Canada

Jelle Hielkema January 18
FAO/SDRN
Rome, Italy

Tetsuo Nakazawa January 19
Japan Meteorological Society
Tsukuba, Japan

Andrew Shaw January 23
ESYS Consulting Guildford Surrey, UK

Anthony Davis January 29
Los Alamos National Laboratory
Los Alamos, NM

Jeffrey Reid January 30
SPAWAR System Center, San Diego
San Diego, CA

Darold Ward February 9
USDA Forest Service
Missoula, MT

Dave Thompson February 28
Colorado State University
Ft. Collins, CO

Gian Carlo Gobbi March 12
Consiglio Nazionale delle Richerche (CNR)
Rome, Italy

Francesca Barnaba March 12
Consiglio Nazionale delle Richerche (CNR)
Rome, Italy

Richard Sikorski March 23
University of Miami
Miami, FL

Venkatachala Ramaswamy March 28
NOAA/GFDL
Princeton, NJ

Michael Mishchenko April 4
NASA/GISS
New York, NY

Ryoko Iguchi April 9
Marcom Visual Creation
New York, NY

Haiyan He April 25
Zhongshan University
Guangzhou, China

Karla Longo de Freitas April 30
NRC NASA/Ames
Moffett Field, CA

Anatoli Chaikovski May 1
Belarus National Academy of Science
Minsk, Belarus

Annarita Mariotti-Zeng May 9
University of Maryland
College Park, MD

Kerry Cook May 16
Cornell University
Ithaca, NY

Nazario Ramirez May 21
Summer Faculty Fellowship Program
University of Puerto Rico
San Juan, Puerto Rico

John Roads May 23
University of California, San Diego
San Diego, CA

Ning Zeng May 24
University of Maryland
College Park, MD

Shea Burns May 29
Summer Faculty Fellowship Program
North Carolina A&T State University
Greensboro, NC

Melinda Schwasinger June 1
NASA Academy
Greenbelt, MD

Zhanqing Li June 4
University of Maryland
College Park, MD

Toshihisa Matsui June 4
University of South Carolina
Graduate Student Summer Program
Spartanburg, SC

Anandu Verneker June 12
University of Maryland
College Park, MD

Stephen Klein June 13
Princeton University/GFDL
Princeton, NJ

Andrea de Almeida Castanho June 15
GEPA-Instituto de Fisica, USP
Sao Paulo, Brazil

Jason Furtado June 15
Lyndon State College
NASA Summer Institute
Lyndonville, VT

Maeng-Ki Kim June 18
Kongju National University
Kongju, S. Korea

Richard Hansell June 25
University of California, Los Angeles
Graduate Student Summer Program
Los Angeles, CA

Kyu-Tae Lee July 1
National Kangnung University
Kangnung, Kangwon-do, S. Korea

Po-Hsiung Lin July 15
National Taiwan University
Taipei, Taiwan

Kung-Hwa Wang July 19
Central Weather Bureau
Taipei, Taiwan

Manoel Cardoso July 23
University of New Hampshire
Durham, NH

Jorge Gonzalez August 3
University of Puerto Rico
San Juan, Puerto Rico

Zhanqing Li August 13
University of Maryland
College Park, MD

Claude Williams August 28
NOAA/NESDIS
Silver Spring, MD

Christopher Cattrall September 5
University of South Florida
St. Petersburg, FL

Kingtse Mo October 3
NOAA/Climate Prediction Center
Camp Springs, MD

Stuart Piketh October 9
University of Witwatersrand
Johannesburg, South Africa

Antonio Queface October 9
University of Witwatersrand
Johannesburg, South Africa

Tatiana Zhuravleva October 15
Russian Academy of Sciences
Tomsk, Russia

Alexander Ignatov October 17
NOAA/NESDIS
Silver Spring, MD

Istvan Lazlo October 17
NOAA/NESDIS
Silver Spring, MD

Jeffrey Reid October 17
SPAWAR System Center, San Diego
San Diego, CA

Igor Podgorny October 18
University of California, San Diego
San Diego, CA

Russell Dickerson November 7
University of Maryland
College Park, MD

William Collins November 28
National Center for Atmospheric Research
Boulder, CO

Wei-Min Hao November 28
USDA Forest Service/Fire Sciences Lab
Missoula, MT

Vladimir Kovalev November 28
USDA Forest Service/Fire Sciences Lab
Missoula, MT

Claude Williams November 29
NOAA/National Climate Data Center
Asheville, NC

Yuri Knyazikhin December 19
Boston University
Boston, MA

Brian Cairns December 20
NASA/Goddard Inst. for Space Studies
New York, NY

ATMOSPHERIC EXPERIMENT BRANCH

Glen Benson March 28
Aker Industries
Oakland, CA

David Johnson March 28
TiNi Alloy Co.
San Leandro, CA

William Brinckerhoff June 15
JHU/Applied Physics Laboratory
Laurel, MD

Tim Cornish June 15
JHU/Applied Physics Laboratory
Laurel, MD

John Maurer Various Times
University of Michigan
Ann Arbor, Michigan

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

Wookap Choi January 30
Seoul National University, Seoul, Korea

Francisco Valero February 6
Scripps Institution of Oceanography
San Diego, California

Mark Wenig February 13–19
University of Heidelberg
Heidelberg, Germany

Leonid Kalachev February 23
University of Montana
Missoula, Montana

Randall V. Martin March 1–2
Harvard University
Cambridge, Massachusetts

Christopher Sioris March 5–7
York University
Toronto, Canada

Miriam von Koenig March 5–23
University of Bremen
Bremen, Germany

Brooke Hemming April 6
EPA, Washington, DC

Bill Stockwell April 20
Desert Research Institute, Nevada

John Austin May 21
UK Met Office Climate Research Program

Lisa Neef Various times
Valparaiso University, Valparaiso, Indiana

Mohan Gupta July 27
Electric Power Research Institute
Palo Alto, California

James W. Elkins August 3
NOAA/CMDL
Boulder, Colorado

Kelly Chance August 15–16
Smithsonian Astrophysical Observatory
Cambridge, MA

Thomas P. Kurosu Smithsonian Astrophysical Observatory Cambridge, MA	August 15–16
Ian Folkins Dalhousie University Canada	October 12
Jorg Gumbel USRA, Naval Research Laboratory	October 18
Nataly Chubarova Moscow State University	Oct 22–Nov 23
Andreas Behrendt Radio Science Center for Space and Atmosphere (RASC), Kyoto University, Japan	October 24
Wouter Peters University of Utrecht, Netherlands	Nov–Dec
David H. Rind NASA Goddard Institute for Space Studies New York, New York	November 7
Harold Annegam University of Witwatersrand, South Africa	November 14
Edward C. DeFabo George Washington University, Washington, DC	December 5
Warwick Norton Oxford University, Oxford, England	December 11

APPENDIX 2. 2001 COMPOSITION OF THE VISITING COMMITTEES FOR THE LABORATORY

LABORATORY VISITING COMMITTEE (OCTOBER 1993)

Alan K. Betts, Chairperson
Atmospheric Research Corporation, Pittsford, VT

Michael Ghil
Department of Atmospheric Science
University of California at Los Angeles, CA

Donald R. Johnson
Space Science and Engineering Center
University of Wisconsin, Madison, WI

Timothy L. Killeen
Space Physics Research Laboratory
University of Michigan, Ann Arbor, MI

Jose M. Rodriguez
AER, Inc., Cambridge, MA

Edward Westwater
CIRES, Boulder, CO

DATA ASSIMILATION OFFICE ADVISORY PANEL (OCTOBER 1992, OCTOBER 1993, JANUARY 1995, JUNE 1996, MAY 1998)

Roger Daley, Chairperson
Naval Research Laboratory, Monterey, CA
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Jeffrey Anderson
GFDL/NOAA
Princeton University, Princeton, NJ
(served Advisory Panel 1995, 1996, 1998)

Andrew F. Bennett
College of Oceanography
Oregon State University, Corvallis, OR
(served Advisory Panel 1995, 1996, 1998)

Guy Brasseur*
National Center for Atmospheric Research, Boulder, CO
(served Advisory Panel 1992, 1993, 1995)

Phillippe Courtier
Laboratoire d'Ocêanographie Dynamique et de Climatologie (LODYC), Paris, France
(served Advisory Panel 1995, 1996, 1998)

Robert E. Dickinson
Department of Atmospheric Science
University of Arizona, Tucson, AZ
(served Advisory Panel 1995, 1996, 1998)

Anthony Hollingsworth*
European Centre for Medium-Range Weather Forecasts (ECMWF), Reading England
(served Advisory Panel 1992, 1993)

Daniel J. Jacob
Division of Engineering and Applied Science
Harvard University, Cambridge, MA
(served Advisory Panel 1995, 1996, 1998)

Donald R. Johnson
Space Science and Engineering Center
University of Wisconsin, Madison, WI
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Kikuro Miyakoda*
GFDL/NOAA
Department of Commerce
Princeton University, Princeton, NJ
(served Advisory Panel 1992, 1993, 1995)

James J. O'Brien
Professor of Meteorology and Oceanography
Florida State University, Tallahassee, FL
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Alan O'Neill
The Center for Global Atmospheric Modelling
Department of Meteorology
University of Reading, Reading, England
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

DATA ASSIMILATION OFFICE COMPUTER ADVISORY PANEL (MARCH 1996, AUGUST 1997)

William E. Farrell, Chairperson
SAIC, San Diego, CA

Tony Busalacchi
Laboratory for Hydrospheric Processes, Code 970
NASA Goddard Space Flight Center, Greenbelt, MD

Bill Dannevik
L262, Environmental Programs
Lawrence Livermore National Laboratory,
Livermore, CA

Alan Davis
Center for Ocean-Atmosphere Prediction Studies
Florida State University, Tallahassee, FL

Geerd-R. Hoffmann, Head
Computer Division
European Centre for Medium-Range Weather
Forecasts (ECMWF), Reading, England

Menas Kafatos
University Professor of Interdisciplinary Science
Director, Institute for Computational
Sciences and Informatics
George Mason University, Fairfax, VA

Reagan W. Moore
Enabling Technologies Group
San Diego Supercomputer Center, San Diego, CA

John Sloan*
NCAR/SCD, Boulder, CO

Thomas Sterling*
Lawrence Livermore National Laboratory, Livermore, CA

MESOSCALE ATMOSPHERIC PROCESSES BRANCH, EXTERNAL REVIEW COMMITTEE REPORT, NASA GSFC, NOVEMBER 9, 1999

Dr. Robert Gall, Chair
Mesoscale Microscale Meteorology Division
National Center for Atmospheric Research
Boulder, CO

Dr. Michael Hardesty
Environmental Technology Laboratory
National Oceanic and Atmospheric Administration
Boulder, CO

Dr. Frank Marks
Hurricane Research Division
National Oceanic and Atmospheric Administration
Miami, FL

Dr. Eric Smith
Department of Meteorology
Florida State University
Tallahassee, FL

EDGE TECHNIQUE REVIEW COMMITTEE, NASA GSFC AUGUST 6-7, 1997

R. Michael Hardesty (Chair)
NOAA ERL, Boulder, CO

Edwin Eloranta
University of Wisconsin, Madison, WI

Chester Gardner
University of Illinois, Urbana, IL

Robert Menzies
NASA Jet Propulsion Laboratory, Pasadena, CA

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH REVIEW, NASA GSFC, APRIL 16-18, 1997

Dr. William L. Chameides
School of Earth and Atmospheric Sciences
Georgia Institute of Technology, Atlanta, GA

Douglas D. Davis
School of Geophysical Science
Georgia Institute of Technology, Atlanta, GA

Matthew H. Hitchman
Dept. of Atmospheric and Oceanic Sciences
University of Wisconsin, Madison, WI

David J. Hoffman
Climate Monitoring and Diagnostics Laboratory
National Oceanic and Atmospheric Administration
Boulder, CO

Susan Solomon
Environmental Research Laboratory
National Oceanic and Atmospheric Administration,
Boulder, CO

Joe W. Waters
Microwave Atmospheric Science Group
NASA Jet Propulsion Laboratory, Pasadena, CA

* *No longer on the committee*

APPENDIX 3. 2001 VISITING SCIENTISTS AND ASSOCIATES OF JOINT CENTERS

DISTINGUISHED VISITING SCIENTIST

David Atlas

ESSIC

Christian Alcala
David Considine
Andrew Dessler
Michael Fox-Rabinovitz
Peter Lyster
Vikram Mehta
Kenneth Pickering
Maria Tzortziou

GEORGE MASON UNIVERSITY

Dave Augustine
Bart Kelley
Mark Kulie
David Marks
Michael Robinson
David Silberstein

GEORGIA TECH.

Mian Chin
Paul Ginoux

GEST CENTER

Julio Bacmeister
Tim Berkoff
Eric Bucsela
Yehui Chang
Baode Chen
Jiun-Dar Chern
Artemio Fattori
Rosana Nieto Ferreira
Santiago Gasso
Charles Gatebe
Dirceu Luis Herdies
Christina Hsu
Dan Johnson
Nickolay Krotkov
Prasun Kundu
Redgie Lancaster
David Lary
Lihua Li
Shuhua Li
Ruei-Fong Lin
Xin Lin
Ashwin Mahesh
Peter Norris
Steven Pawson
Zhaoxia Pu
Anil Rao
Oreste Reale
Jerome Riedi
Lars Peter Riishojgaard
Joan Rosenfield
Chung-Lin Shie
Dan Stillman
Susan Strahan
Didier Tanre
Lin Tian
Guiling Wang
Clark J. Weaver
Judd Welton
Marcia Yamasoe
Keven Yeh
Jiayu Zhou

HOWARD UNIVERSITY

Vernon Morris

JCET

Eyal Amitai
Chris Barnet
Scott Curtis
Belay Demoz
Keith Evans
Jeffrey Halverson
Yong Li
Alexander Marshak
J. Vanderlei Martins
Amita Mehta
William Olson
Lazaros Oraiopoulos
Steven Platnick
Paul Poli
Jens Reichardt
Susanne Reichardt
Thomas Rickenbach
Alexander Sinyuk
Lynn Sparling
Andrew Tangborn
Ali Tokay
Omar Torres
Tamas Varnai
J. J. Wang

Yansen Wang
Guoyong Wen
Song Yang

JOHNS HOPKINS UNIVERSITY
Jun Ma

LAOR
Joe Otterman

NRC
Moyses Nussenzveig
Mark Olsen
Anna Rozwadowska
Sam Shen

NSF
Sankar-Rao Mopidevi

UNIVERSITY OF ARIZONA
Robert Loughman
Liming Xu

URF
Liela Garcia
Willis Wilson

APPENDIX 4. 2001 SEMINARS

LABORATORY FOR ATMOSPHERES SEMINAR SERIES

Dr. Peter Lyster, University of Maryland Earth System Science Interdisciplinary Center, “High Performance Computing and Kalman Filter Development for Data Assimilation,” January 9.

Dr. Mian Chin, Virginia Tech—Visiting Scientist w/Code 916, “Tropospheric Aerosol Composition and Radiative Forcing: A Global Model Study,” January 22.

Dr. Francisco Valero, Scripps Institution of Oceanography, “Triana: The First Deep Space Climate Observatory,” February 6.

Dr. Siegfried D. Schubert, NASA Goddard Space Flight Center, “Are Droughts and Floods Predictable on Seasonal and Longer Time Scales?” February 20.

Dr. Richard E. Carbone, National Center for Atmospheric Research, “Inferences of Predictability Associated with Warm Season Precipitation Episodes in North America,” March 6.

Dr. Bernard Marty, Centre de Recherches Petrographiques et Geochimiques, “Nitrogen Isotope Heterogeneity in the Solar System: Solar Versus Planetary,” March 20.

Professor Leonard J. Pietrafesa, North Carolina State University, “Wind-Driven Coastal Ocean Circulation Simulated by Using a Coupled Wave-Current Modeling System,” April 3.

Dr. Jay Herman, NASA Goddard Space Flight Center, “Triana: Earth Science from Deep Space,” April 17.

Dr. Michael King, NASA Goddard Space Flight Center, “Remote Sensing of Smoke, Land, and Clouds During the SAFARI 2000 Experiment in Southern Africa,” May 1.

Professor Robert Pepin, University of Minnesota, “On the Isotopic Composition of Primordial Xenon in Terrestrial Planet Atmospheres,” May 15.

Dr. Winston Chao, NASA Goddard Space Flight Center, “ITCZ, Monsoon, and Monsoon Onset: Toward an Interpretation of Tropical Large-Scale Rainfall Patterns,” May 22.

SOUNDER RESEARCH TEAM

Dr. Amita Mehta, JCET, “Variability of Global Water Vapor Observed from Satellite Measurements,” Department of Geography, University of Maryland Baltimore County, April 13.

Dr. Chris Barnet, “Passive Remote Sensing of CO_2 (and other trace gases),” 2001 GEST Graduate Summer Program, NASA GSFC, Greenbelt, Md., June 7.

DATA ASSIMILATION OFFICE

Mark Leidner, Atmospheric and Environmental Research, Inc., “Use of NASA SeaWinds Scatterometer Data at ECMWF,” January 3.

Peter Lyster, DAO and Univ. of Maryland Earth System Science Interdisciplinary Center, “High Performance Computing and Kalman Filter Development for Data Assimilation,” January 9.

Ricky Rood, DAO, “Evaluation of Upper Tropospheric and Lower Stratospheric Ozone Profiles From a Global Ozone Data Assimilation System,” January 12.

Kikuro Miyakoda, George Mason University, “Analysis of the Connection From the South Asia Monsoon to ENSO by Using Precipitation and Circulation Indices,” January 23.

Steven Pawson, DAO, “Does the 11-year Solar Cycle Really Influence the Lower Stratosphere? A Review of Some Observations and a Look at Some New Model Studies From GRIPS,” February 2.

Ricky Rood, DAO, chaired a White House OSTP Working Group on Climate Modeling and will regale us with “inside” stories from his summer at the White House, February 15.

Siegfried Schubert, DAO, “Are Droughts and Floods Predictable on Seasonal and Longer Time Scales?” February 20.

Group presentation led by Larry Coy, “Performance of fvDAS in the Stratosphere: Meteorology,” February 23.

Group presentation led by Susan Strahan, “Performance of fvDAS.1 in the Stratosphere: Transport,” March 9.

Robert Ciotti, NAS, “Recent Developments on the fvDAS Optimization at NAS,” March 15.

Ronald M. Errico, NCAR, “The Problem of Developing Adjoints of Model Physics,” March 26.

Bob Hudson, UMCP, “Separation of the Total Ozone Field at Mid-Latitudes by Meteorological Regime,” March 30.

Tonushree Kundu, Dept. of Mechanical Engineering, Univ. of Calif., Berkeley, “The Creation of Large-Scale Zonal Flows and Eddies From Small-Scale Forcing,” April 3.

Pat Pauley, Naval Research Lab, “Operational Aircraft Data for Numerical Weather Prediction—Characteristics and Quality Control,” April 26.

Keiji Tani, Japan Atomic Energy Research Institute, presents “Earth Simulator System,” May 31.

Jean-Noel Thepaut, Niels Bormann, Christina Kopken, ECMWF, “Assimilation of Satellite Data in the ECMWF 4-D VAR System,” June 19.

S.J. Lord, M. Masutani, J.S. Woollen, J.C. Derber, (NOAA/NWS/NCEP/EMC), R. Atlas, J. Terry (NASA GSFC/DAO), G.D. Emmitt, S.A. Wood, S. Greco, (Simpson Weather Associates), “Observing Systems Simulation Experiments for NPOESS,” July 12.

David Lary, University of Cambridge, UK, “Chemical Data Assimilation: Satellite Validation and Optimum Observation System Design,” Special Seminar, July 24.

Mohan Gupta, Electric Power Research Institute (EPRI), Palo Alto, California, “Atmospheric Simulations of Radon: Regional Sources,” GEST seminar, July 27.

Paul Poli, JCET, (DAO) “GPS: Climate Modelling and Forecast Skill,” Joint Center, EMC series, August 13.

Adrian Simmons, Environmental Modeling Center, NOAA, “Some Aspects of the Recent Improvement of Skill of NWP,” EMC seminar, August 13.

Jean Thiebaux, NOAA, “New Sea-Surface Temperature Analysis Implemented at NCEP,” DAO seminar, September 4.

Martin Mueller, Center for Solar Energy and Hydrogen Research (ZSW), Stuttgart, Germany, “Real-Time Total Ozone and Ozone Profiles from TOVS and GOME Data Using Neural Networks,” September 7.

Ross Hoffman, Atmospheric and Environmental Research, Inc. “Applications of Feature Calibration and Alignment,” DAO seminar, October 10.

Ken Holmlund, EUMETSAT, “Generation and Utilisation of Quality Indicators for Satellite-Derived Atmospheric Motion Vectors,” DAO Seminar, October 11.

Ian Folkins, Dalhousie University, “Tropical Convection and Ozone,” Fridays Seminar Series, October 12.

Daiwen Kang, North Carolina State University, “Non-Methane Hydrocarbons and Ozone in the Rural Southeast United States National Parks: A Model Sensitivity Analysis and Its Comparison With Measurement,” Fridays Seminar Series, October 12.

Mike Kalb, OGST, “Infrastructure Requirement for Weather Forecasting in 2025,” DAO Special Seminar, October 16.

X.-P. Tom Zhao, CIRA/CSU visiting scientist at NOAA/NESDIS/ORA, “AVHRR Aerosol Retrieval, Products, and Validation,” October 17.

Michael Fox-Rabinovitz, ESSIC, “Simulation and Data Assimilation of Anomalous Regional Climate Events With the GEOS Stretched-Grid (SG) GCM and SG-DAS,” DAO Seminar, October 26.

Pete Colarco, University of Colorado, “Determining the UV Imaginary Index of Refraction and Single Scatter Albedo of Saharan Dust Using EP-TOMS Data and a Three-Dimensional Dust Transport Model,” November 5.

Ron Errico, National Center for Atmospheric Research to discuss ongoing and future work with the DAO, “Adjoint Model Development and NCAR-DAO Collaborative Work in Predictability Research Related to Data Assimilation,” November 8.

Hiroo Hayashi, from NIES in Tsukuba, Japan, “An Observational Study of Inertial Instability in the Equatorial Middle Atmosphere,” November 16.

Wei Wu Tan, NY University at Stony Brook, “A Comparison of Lower-Stratospheric Subtropical Transport Between GEOS-DAS and GEOS-GCM,” November 19.

Angela Benedetti, Colorado State University, “Toward Assimilation of Cloud Radar Data for Improvements in Mesoscale Forecasts,” November 19.

Tijana Janjic, Institut fur Physik, Universitat Hohenheim, “Error Due to Unresolved Scales in Estimation Problems for Atmospheric Data Assimilation,” Dec. 3 and Dec 7.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

V. Chandrasekar, Colorado State University, “TRMM Precipitation Radar: Attenuation Estimation, Cross-Validation of Underlying Physical Models and Cross-Calibration of Radars,” January 8.

Andrew Heymsfield, “Observations and Parameterizations of Tropical Stratiform Particle Size Distributions: Results From TRMM Field Campaign,” January 22.

Eyal Amitai, UMBC/JCET, “Rainfall Studies for the TRMM Validation Program,” Microwave Sensors Branch Seminar, Laboratory for Hydrospheric Processes, February 20.

Sergey Y. Matrosov, University of Colorado, “X-Band Radar Polarimetric Studies of Rainfall at NOAA ETL,” March 12.

Ralf Bennartz, University of Kansas, “Active and Passive Microwave Response to Ice Particle Size Distributions,” March 20.

Lihua Li, University of Massachusetts at Amherst, “Millimeter-Wave Cloud Radars and Their Application in Atmospheric Attenuation Retrieval,” April 27.

Eric A., Smith, NASA GSFC, “Synopsis of Global Precipitation Mission Development,” May 9.

Jeffrey L. Stith, Research Aviation Facility, “Microphysical Observations of Tropical Clouds,” May 23.

David Parsons, NCAR, “A New Look at an Old Problem: An Explanation for the Diurnal Cycle of Rainfall over Tropical Oceans,” May 24.

Robert Pasken, Saint Louis University, “Investigations of TOGA COARE Convection Using Long Dual Doppler Baseline Techniques,” June 11.

Steven Sherwood, Yale University, “Aerosols, Cumulonimbus, and Water Vapor in the UT/LS,” June 12.

Philip R. A. Brown, Cloud Physics Research, U.K. Meteorological Office, “Ice Nucleation in Lee-Wave Clouds: Observations and Numerical Modelling Studies From the Intacc Field Campaign,” June 29.

David Atlas, “Anatomy of a Tropical Thunderstorm: A Synthesis of Observations During LBA,” Distinguished Visiting Scientist, Goddard Space Flight Center, October 11.

Judd Welton, UMBC/GEST Center, "Overview of the Micro Pulse Lidar Worldwide Observation Network (MPL-Net)," November 7.

Dr. Guojun Gu, Columbia University, "Synoptic-Scale Convective Components of the ITCZ," Goddard Visitor Center Auditorium, December 6.

CLIMATE AND RADIATION BRANCH

Scott Curtis, Univ. of Maryland (JCET), Code 912, "Extending Our Understanding of ENSO, Monsoons, and Climate Change Through Global Observations of Precipitation," January 10.

In-Sik Kang, Seoul National University, "Impacts of Cloud-Radiation Interaction in AGCM Simulations of Tropical ISO," January 24.

Jiayu Zhou, EITI, Climate and Radiation Branch, NASA/GSFC, "Contribution to Understanding South American Summer Monsoon System Climatology, Variability, Simulation and Predictability," January 24.

David Thompson, Colorado State University, "Regional Climate Impacts of the Arctic Oscillation and Associated Climate Trends," February 28.

V. Ramaswamy, NOAA/GFDL, "Quantifying the Radiative Forcing of Global Climate Change and Its Implications," March 28.

Michael Mishchenko, NASA, Goddard Institute for Space Studies, "Retrievals of Aerosol and Cloud Particle Microphysics Using Polarization and Depolarization Techniques," April 11.

Shian-Jiann Lin, NASA/Goddard Space Flight Center, "The Research and Development of the Finite-volume Community Climate Model (fvCCM) and Its Applications in Data Assimilation and Numerical Weather Predictions," April 25.

Kerry H. Cook, Department of Earth and Atmospheric Sciences, Cornell University, "Mechanisms of Tropical Precipitation Variability: Case Studies for Africa," May 16.

John Roads, Scripps Institution of Oceanography, "Global Water and Energy Budgets," May 23.

Stephen Klein, Geophysical Fluid Dynamics Laboratory/NOAA, "A Parameterization of the Statistical Moments of Total Water for Large-Scale Models," June 13.

Christopher Cattrall, University of South Florida, "Retrieval of Columnar Aerosol Phase Function and Single-Scattering Albedo From Sky Radiance over the Ocean: Measurements of African Dust," September 5.

H. Moyses Nussenzveig, Federal University of Rio de Janeiro, "Mie Resonances and Cloud Absorption," September 19.

Kingtse Mo, Climate Prediction Center/NOAA, "Impact of Soil Moisture on the North American Monsoon Systems," October 3.

Christina Hsu, UMBC/GEST, "Satellite Characterization of Tropospheric Aerosols During ACE–Asia," October 3.

Stuart Piketh, University of Witwatersrand, "Special Seminar," October 10.

John Reagan, University of Arizona, "Toward Establishing an Aerosol Extinction-to-Backscatter Climatology," October 16.

Zhanqing Li, U of M Department of Meteorology and Earth System Science Interdisciplinary Center, "Remote Sensing of Cloud, Aerosol and Radiation and Understanding Their Interactions," October 17.

Alexander Ignatov, NOAA, "Aerosols from AVHRR: Signal, Errors, Information Content," October 17.

Paul Ginoux, Georgia Tech, "Simulations of Global Transport and Deposition of Mineral Dust with the GOCART Model, and Applications to Climate and Biogeochemical Processes," October 31.

Russell R. Dickerson, University of Maryland, "Black Carbon: Global Budget and Impacts on Climate," November 7.

Alexander Smirnov, Science Systems and Applications, Inc., "Aeronet Results," November 14.

Alexander Marshak, UMBC/Joint Center for Earth Systems Technology, "A Correct Treatment of Large Droplets in Radiative Transfer and Its Effect on Cloud Absorption," November 28.

William D. Collins, National Center for Atmospheric Research, "Modeling Aerosols with Assimilation of Observations," November 28.

Robert F. Cahalan, NASA/Goddard Space Flight Center, "Satellite Observations of Solar Irradiance and Sun-Climate Impacts," December 5.

Judd Welton, UMBC/GEST Center, "Aerosol Observations Using the Micro Pulse Lidar Network (MPL-Net)," December 5.

Brian Cairns, Columbia University and NASA/Goddard Institute for Space Studies, "Using and Abusing Polarization," December 20.

ATMOSPHERIC EXPERIMENT BRANCH

Dr. Bernard Marty, NASA GSFC/Centre de Recherches Petrographiques Geochimiques (CRPG), "Nitrogen Isotope Heterogeneity In The Solar System: Solar Versus Planetary," March 20.

Prof. Robert Pepin, NASA GSFC/University of Minnesota, "On The Isotopic Composition of Primordial Xenon in Terrestrial Planet Atmospheres," May 15.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

Mian Chin, NASA GSFC/Georgia Tech, "Tropospheric Aerosol Composition and Radiative Forcing: A Global Model Study," January 22.

Omar Torres, NASA GSFC/JCET, "A New Tool for Measuring Aerosol Properties From Space: The Near UV Method," January 31.

Clark Weaver, NASA GSFC/Caelum Corporation, “Radiative Forcing of Saharan Dust. GOCART Model Simulations Compared with ERBE Data,” February 28.

Anne Thompson, NASA GSFC, “Studies of TOMS Smoke Aerosol and Tropospheric Ozone in the Tropics,” March 14.

Brooke Hemming, EPA, “Thermodynamics of Aerosol-Phase Atmospheric Organics: Temperature and Humidity Effects,” April 6.

Anne Thompson, NASA GSFC, “Tracking Pollution from Space,” Emory University, Atlanta, Georgia, April 9.

Jun Ma, NASA GSFC/Johns Hopkins University, “Model Measurement Comparison With Modified Lagrangian Mean Diagnostics,” April 13.

Jay Herman, NASA GSFC, “Earth Observations from Lagrange Points—Triana and Beyond,” April 17.

Bill Stockwell, Desert Research Institute (Nevada), “Coupling Atmospheric Chemistry With a Convective Boundary Layer Model,” April 20.

Alan R. Bandy, Drexel University, “Determination of Scalar Fluxes using Eddy Correlation and Isotope Dilution Atmospheric Pressure Ionization Mass Spectrometry,” June 20.

Mian Chin, NASA GSFC/Georgia Tech, “Model-Measurement Comparisons From Our Recently Submitted JAS Paper (GOCART Model Simulated AOT and Comparisons with TOMS, AVHRR, AERONET) and Model Support for the Recent ACE–Asia Mission,” June 20.

Mohan Gupta, Electric Power Research Institute (Palo Alto, CA), “Atmospheric Simulations of Radon: Characterization of Regional Sources,” July 27.

James W. Elkins, NOAA/CMDL, Boulder, Colorado, “Source Gas Emissions along the Trans-Siberian Railway During the Summer of 2001,” August 31.

Ian Folkins, Dalhousie University, Canada, “Tropical Convection and Ozone,” October 12.

Jorg Gumbel, USRA, NAVAL Research Laboratory, “The Coupling of Ion Chemistry and Ice Particles Near the Summer Mesopause,” October 18.

Andreas Behrendt, Radio Science Center for Space and Atmosphere (RASC), Kyoto University, Japan, “Combined Elastic Pure-Rotational Raman Lidar for the Measurement of Temperature and Optical Particle Properties: Design and Performance of the RASC Raman Lidar at Shigaraki (34.8° N, 136.1° E), Japan,” October 24.

David H. Rind, NASA Goddard Institute for Space Studies, “Global Climate Benchmarks: Data to Test Climate Models,” November 7.

Edward C. DeFabo, George Washington University, “Potential Impacts on Human Health and the Biosphere From Increased UV-b Radiation Associated with Stratospheric Ozone Depletion,” December 5.

Warwick Norton, Oxford University, "Dynamics and Tracer Transport in the Tropical Lower Stratosphere," December 11.

APPENDIX 5. 2001 SCIENCE POLICY MEETINGS, SCIENCE TEAM MEETINGS, AND WORKSHOPS

SCIENCE POLICY MEETINGS

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

WMO/UNEP Assessment of Ozone Meeting of Chapter 4 Authors and Co-authors, Boulder, Colo., August 27–29.

Management Technical Review (MTR), Review Meeting, NASA GSFC, September 28.

Women in Science Symposium: Status and Future Opportunities – “Where are we today?” Bryn Mawr, Pa., Anne Thompson, Panelist, October 26–27.

SCIENCE TEAM MEETINGS

SOUNDER RESEARCH TEAM

CrIS SOAT, Algorithm PDR Integrated Program Office Meeting, Boston, Mass., January 29–30.

Optical Remote Sensing of the Atmosphere, Coeur d’Alene, Idaho, February 5–8.

AIRS Science Team Meeting, Courtyard Marriott, Old Town Pasadena, Calif., hosted by Jet Propulsion Laboratory, February 21–23.

CrIS Interferometer PDR Integrated Program Office Meeting, Quebec, Canada, March 26–28.

ITT Integrated Program Office Meeting, Ft. Wayne, Ind., April 25–27.

PMR CrIS Integrated Program Office Meeting, Ft. Wayne, Ind., May 31–June 1.

AIRS Science Team Meeting, Courtyard Marriott, Old Town Pasadena, Calif., hosted by Jet Propulsion Laboratory, June 19–21.

CloudSat CDR Panel, Arcadia, Calif., July 31–August 2.

Ground Demo 3 Integrated Program Office Meeting, Denver, Colo., September 10–14.

Ground Demo 3 Integrated Program Office Meeting, Melbourne, Fla., October 16–17.

AIRS Science Team Meeting, Pasadena, Calif., November 6–9.

EOS-Aura HIRDLS Pre-Environmental Review, Palo Alto, Calif., December 4–7.

DATA ASSIMILATION OFFICE

23rd CERES Science Team Meeting, hosted by Dr. Bruce Wielicki, Williamsburg, Va., January 23–25.

CloudSat Science Team Meeting, Ottawa, Canada, February 12–14.

AIRS Science Team Meeting, Courtyard Marriott, Old Town Pasadena, Calif., hosted by Jet Propulsion Laboratory, February 21–23.

24th CERES Science Team Meeting, hosted by Dr. Bruce Wielicki, Newport News, Va., May 1–3.

TRACE-P Products and ACE–Asia Product Science Meeting, hosted by A. Hou, NASA GSFC, May 21.

OMI Science Team Meeting, Holland, June 16–21.

AIRS Science Team Meeting, Courtyard Marriott, Old Town Pasadena, Calif., hosted by Jet Propulsion Laboratory, June 19–21.

GTWS Science Definition Team Meeting sponsored by R. Atlas, Boulder, Colo., July 23.

The DOE PI Meeting, Climate Change Prediction Program, San Diego, Calif., sponsored by DOE, October 1–3.

TRMM Science Team Meeting, Fort Collins, Colo., October 29–31.

Ozone Monitoring Instrument (OMI)/Total Ozone Mapping Spectrometer (TOMS) Science Team Meeting, Seabrook, Md., November 1–2.

U.S.-Japan Joint Science Team Meeting, Fort Collins, Colo., November 2.

AIRS Science Team Meeting, Pasadena, Calif., November 6–9.

MODIS Science Team Meeting, Baltimore, Md., December 18.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

NASA SIMBIOS Science Team Meeting, “Micro-pulse Lidar Measurements of Aerosols over the Indian Ocean During INDOEX 1999,” NASA GSFC, January.

AMS Annual Meeting, Albuquerque, N.M., January 14–19.

Earth Sciences Review Panel, NASA High Performance Computing and Communications Program, Washington, D.C., February.

FTS/Optical Remote Sensing of Atmosphere Meeting, Coeur d’Alene, Idaho, February 2–8.

USWRP Science Symposium, Orlando, Fla., March 5–7.

ARM Science Team Meeting, Atlanta, Ga., March 19–23.

XXVI General Assembly of the European Geophysical Society, Nice, France, March 25–30.

GSFC Tropical Rainfall Measurement Mission (TRMM) Re-entry Review Panel, Greenbelt, Md., April.

ESSP3 Satellite Lidar Project's Science Team Meeting, NASA LaRC, Hampton, Va., April.

Sixth Conference on Polar Meteorology and Oceanography, "Arctic and Antarctic Cloud Properties from Simultaneous Lidar and Spectral Observations," San Diego, Calif., May.

11th Conference on Interaction of the Sea and Atmosphere, San Diego, Calif., May 14–18.

TRMM/LBA-Eurocs, Lisbon, Portugal, May 28–June 1.

ESSP3 Satellite Lidar Project Science Team Meeting, NASA LaRC, Hampton, Va., June.

7th International Conference on Precipitation, "On Rainfall Modification by Major Urban Areas—Part I: Observations from Space-borne Rain Radar aboard TRMM," Rockport, Maine, June 30–July 2.7th International Conference on Precipitation, Rockport, Maine, June 30–July 3.

IGARSS 2001 Meeting, Sydney, Australia, July 9–13.

Eighth Scientific Assembly of the International Association of Meteorology and Atmospheric Sciences, Innsbruck, Austria, July 10–8.

30th International Conference on Radar Meteorology, Munich, Germany, July 19–25.

46th Annual SPIE Meeting, "Time Resolved 3-D Mapping of Atmospheric Aerosol and Clouds during the Recent ARM Water Vapor IOP," San Diego, Calif., July 29–August 30.

AMS 9th Conference on Mesoscale Processes, 14th Conference on Numerical Weather Prediction, and 18th Conference on Weather and Forecasting, Ft. Lauderdale, Fla., July 30–August 2.

SAFARI 2000 Science Team Meeting, Zambia, August.

1st International Conference on Global Warming, Halifax, Canada, August 19–24.

NASA Earth Science Technology Conference, College Park, Md., August 28–30.

4th International Conference on the Global Energy and Water Cycle, Paris, France, September 10–14.

5th Airborne Remote Sensing Conference, San Francisco, Calif., September 17–20.

International Conference on Mesoscale Meteorology, Taiwan, China, September 26–29.

11th Conference on Meteorology and Oceanography, Madison, Wis., October 15–18.

NASA Global Water and Energy Research Initiative Panel Meeting, Linthicum, Md., November.

TRMM Science Team Meeting, Ft. Collins, Colo., October 28–November 1.

Fifth International Symposium on Hydrologic Applications of Weather Radar, Kyoto, Japan, November 19–22.

AGU Fall Meeting, San Francisco, Calif., December 10–14.

CLIMATE AND RADIATION BRANCH

EOS/International Working Group Meeting, Fort Lauderdale, Fla., January 29– February 1.

CAGEX Science Team Meeting, Hampton, Va., February 1–2.

ARESE II Science Team Meeting, LaJolla, Calif., February 7–9.

COBRA Team Meeting, New York, N.Y., March 15–16.

International Conference on the Forecasting of Monsoon from Days to Years, New Delhi, India, March 17–23.

ARM Program Science Team Meeting, Atlanta, Ga., March 20–22.

European Geophysical Society 2001, Nice, France, March 24–30. Convener: Robert F. Cahalan.

ACE–Asia Science Meeting, Iwakuni, Japan, April 4.

PICASSO-CENA, Hampton, Va., April 4–6.

South China Sea Monsoon Experiment (SCSMEX), Shanghai, China, April 16–20.

The First Panel Meeting of the U.S. CLIVAR Asian-Australian Monsoon Working Group, Washington, D.C., May 7–8. Convener: William K. Lau.

Ultra Long Duration Balloon (LDB) Project Meeting, Hampton, Va., May 8–10.

Landsat Science Team Meeting, Honolulu, Hawaii, May 21–25.

MISR Science Team Meeting, Los Angeles, Calif., June 4.

PRIDE Science Team Meeting, San Diego, Calif., June 5–8.

International Association of Meteorology and Atmospheric Sciences (IAMAS), Innsbruck, Austria, July 10–18. Convener: Robert F. Cahalan.

Instantaneous Radiative Fluxes (IRF) Working Group, Richland, Wash., October 8–12.

TRMM Science Team Meeting, Fort Collins, Colo., October 29–31.

GEWEX Radiation Panel Meeting/EOS-Source Meeting, Boulder, Colo., November 12–16.

U.S. CLIVAR Scientific Steering Committee Meeting, Princeton, N.J., December 3–5.

ATMOSPHERIC EXPERIMENT BRANCH

Cassini Ion and Neutral Spectrometer Team Meeting, University of California, Berkeley, Calif., January 18–19.

Mars 2007 Lander Science Definition Team Meeting, Pasadena, Calif., June 11–12.

Mars 2007 Lander Science Definition Team Meeting, Crystal City, Va., July 18–19.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

A Millennium Symposium on Atmospheric Chemistry, 81st AMS Annual Meeting, American Meteorological Society, Albuquerque, N.M., January.

Triana Science Team Meeting, NASA GSFC, January 25–26.

10th ILAS Data Evaluation & Validation Analysis Review Meeting, National Institute for Environmental Studies, Tsukuba, Japan, March 24–29.

2001 Spring AGU Meeting, Boston, Mass., May 29–June 2.

5th OMI Science Team Meeting, KNMI, De Bilt, Netherlands, Dr. P.K. Bhartia, Organizer, June 18–21.

Eighth Scientific Assembly of the International Association of Meteorology and Atmospheric Sciences, Innsbruck, Austria, July 10–18.

UARS 10th Anniversary of Launch, NASA GSFC and Computer Sciences Corp., Dr. Charles Jackman, Organizer , September 11–13.

6th International CO_2 Conference, Sendai, Japan, October.

Global Aerosol Climatology Database Symposium, Portland, Oregon, October 14–15.

POAM Science Team Meeting, Gettysburg, Pa., October 24–26.

Science Teacher’s Association Annual Meeting, Lansdale, Pa., October 25.

TOMS Science Team Meeting, Greenbelt, Md., November 1.

TRACE-P Science Team Meeting, Norfolk, Va., November 13–15.

2001 Fall AGU Meeting, San Francisco, Calif., December 10–14.

WORKSHOPS

SOUNDER RESEARCH TEAM

Carbon Cycle Science Workshop #1, NASA GSFC, January 9–11.

NPP/NewDISS Retreat, Manassas, Va., March 6–7.

Carbon Cycle Science Workshop #2, NASA GSFC, March 20–23.

Carbon Cycle Science Workshop #3, University of Maryland Conference Center, College Park, Md., May 2–4.

Global Precipitation Measurement (GPM) Planning Workshop, NASA, NASDA, University of Maryland, College Park, Md., May 16–18.

AIRS Assimilation Workshop #2, NOAA/NESDIS World Weather Building, Camp Springs, Md., May 17–18.

AIRS Assimilation Workshop #3, NOAA/NESDIS World Weather Building, Camp Springs, Md., September 20–21.

Overarching OAT Workshop Integrated Program Office Meeting, Redondo Beach, Calif., December 18.

DATA ASSIMILATION OFFICE

NASA/NOAA Global Tropospheric Wind Sounder Requirements Workshop, sponsored by Robert Atlas, Greenbelt Marriott Hotel, February 26–28.

ACMAP Review Panel Workshop hosted by Richard Rood, Data Assimilation Office, NASA GSFC, Greenbelt, Md., March 6.

Data Assimilation Class (Workshop in Data Assimilation Methods hosted by ECMWF), Oxford, England, March 12–23.

DARPA/DSRC Workshop on Dimension Reduction in Data- and Model-Based Systems, held by the Defense Advanced Research Projects Agency, Arlington, Va., March 19–20.

Workshop on Regional Climate Research: Needs and Opportunities, sponsored by NSF and DOE, Boulder, Colo., April 2–4.

Predictability Workshop at the Naval Postgraduate School in Monterey, Calif., April 23–25.

TRMM 1st Workshop at NASA GSFC, Greenbelt, Md., May 10–11.

ENVISAT ACVE Workshop, Holland, May 14–20.

Workshop on the Solution of Partial Differential Equations on the Sphere, Montreal, Quebec, Canada. Sponsored by DOE and Canadian Meteorological Service, May 15–18.

Workshop on Global Precipitation Mission (GPM) Measurement/Science Requirements for NWP (Numerical Weather Prediction) and Data Assimilation, hosted by A. Hou, NASA GSFC, May 16–18.

AIRS Assimilation Workshop #2, NOAA/NESDIS World Weather Building, Camp Springs, Md., May 17–18.

NCAR/DAO Joint Modeling Workshop, hosted by Richard Rood, NASA GSFC, June 19–20.

GPS Radio Occultation, organized by JCSDA and EMC, hosted by Paul Poli, NASA GSFC, Greenbelt, Md., August 13.

AIRS Assimilation Workshop #3, NOAA/NESDIS World Weather Building, Camp Springs, Md., September 20–21.

TRMM 2nd Workshop at NCAR, Boulder, Colo., October 10–11.

New Modeling System Workshop, sponsored by Ron Gelaro, NASA GSFC, Greenbelt, Md., November 30.

First Cumulus Parameterization Workshop, NASA GSFC, Greenbelt, Md., December 3–5.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

ARM Cloud Processes Working Group Meeting Algorithm Development and Archive Reprocessing for ARM Micropulse Lidar Data, Boulder, Colo., January.

Working Group on Spaced-based Lidar Winds, Oxnard, Calif., February 7–9.

Workshop on Rain Algorithms, an Overview on TRMM Rain Algorithms. EURAINSAT, Frascati, Italy, April 12–13.

SAFARI 2000 Workshop, NASA GSFC, May.

The first TRMM Latent Heating Workshop, Hydrometeor Profiling Heating Algorithm, NASA GSFC, May 10–11.

The GPM Workshop Precipitation Processes Simulated by the Goddard Cumulus Ensemble (GCE) Model, College Park (U. of Maryland), Md., May 16–18.

WCRP/SCOR Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields, Bolger Center, Potomac, Md., May 21–24.

MM5 Users Workshop, A Study of Heavy Precipitation Events in Taiwan During 10–13 August, 1994: Mesoscale Model Simulations, Boulder, Colo., June 25–27.

Working Group on Spaced-based Lidar Winds, Frisco, Colo., July 25–27.

CLIMATE AND RADIATION BRANCH

NASA/IPRC CLIVAR Workshop, Manoa, Hawaii, January 8–12.

FTS/ORSA Meeting, Coeur d'Alene, Idaho, February 5–8.

Puerto Rico Workshop, San Juan, Puerto Rico, February 11–13.

Gordon Conference, Los Angeles, Calif., March 12–14.

SBIR/ITS, Honolulu, Hawaii, March 12–16.

Intraseasonal to Interdecadal Variability of East Asian Monsoon Workshop, Taipei, Taiwan, March 14–17.

CLIVAR Monsoon Panel Meeting/International Conference on Forecasting, New Delhi, India, March 18–25.

EGS-2000 Special Session on TRMM, Nice, France, March 25–30.

International Workshop on SCSMEX, Shanghai, China. Co-organizer: William Lau. April 17–20.

Cloud Mask Workshop, Madison, Wisc., May 7–9.

3rd International Workshop on Remote Sensing and Geographic Information Systems, Champs-sur-Marne, France, May 14–18.

Italian Research Institute/Joint Research Center/Space Applications Institute, Ispra, Italy, June 13–27.

MM5 Modeling Systems Users Workshop, Boulder, Colo., June 24–26.

7th International Conference on Precipitation, Rockport, Maine, July 2–6.

Aerosol-Cloud-Radiation Meeting, Taipei, Taiwan, July 16–20.

Aerosol-Cloud-Radiation Workshop, Chongqing, China, July 23–27.

CLAMS Field Experiment, Wallops, Va., July 23–31.

Chapman Conference on Atmospheric Absorption of Solar Radiation, Estes Park, Colo., August 13–16.

SAFARI First Data Workshop, Siavonga, Zambia, August 27–31.

8th International Symposium on Remote Sensing, Toulouse, France, September 19–21.

26th Annual Climate Diagnostic Workshop, LaJolla, Calif., October 22–26.

ACE–Asia Data Workshop, Los Angeles, Calif., October 29–31.

ATMOSPHERIC EXPERIMENT BRANCH

Nozomi-Mars Express Joint Working Group Meeting, Institute of Space and Astronautical Science (ISAS), Sagamihara, Japan, January 24–26.

NASA MEMS Fabrication Workshop, JHU Applied Physics Laboratory, Laurel, Md., April 6.

Encke Workshop, Smithsonian Astrophysical Observatory, Cambridge, Mass., May 17–18.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

Carbon Cycle Initiative Workshop 1, NASA GSFC, Dr. S. Randolph Kawa, Atmospheres Discipline Discussion Leader, January 9–11.

SPARC-IOC Workshop, University of Maryland, College Park, Md., March 7–9.

Workshop on Nitrogen Oxides in the Lower Stratosphere and Upper troposphere, University of Heidelberg, Heidelberg, Germany, March 19–22.

The 3rd International Workshop on Aerosol-Cloud Radiation Interaction (IWACRI 2001), Chongqing, China, July.

Pilot Coastal Ocean Carbon Workshop, Wallops Flight Facility, Wallops Island, Va., September 11.

ACE–Asia Data Workshop, Pasadena, Calif., October.

Cumulus Parameterization Workshop, NASA GSFC, Dr. Paul A. Newman, Chairman, December 3–5.

APPENDIX 6. 2001 NASA TECHNICAL REPORTS AND OTHER PUBLICATIONS

SOUNDER RESEARCH TEAM

J.Susskind, C.D. Barnet, and J.M. Blaisdell, 2002, Determination of Atmospheric and Surface Parameters from AIRS/AMSU/HSB Data, IRS 2000: Current Problems in Atmospheric Radiation, A. Deepak Publishing, William L. Smith and Yurly M. Timofeyev, Editors, Hampton, Virginia, pp. 85-88.

DATA ASSIMILATION OFFICE

Milliff, R.F., M.H. Freilich, W.T. Liu, R. Atlas and W.G. Large, 2001: Global ocean surface vector wind observations from space. Chapter 2.2 in Koblinsky, C.J. and N.R. Smith, editors. *Observing the Ocean in the 21st century, Australian Bureau of Meteorology and GODAE publishers*, Melbourne, Australia, p. 604.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

Berkoff, T.A., H. Plotkin, D.N. Whiteman, G. Schwemmer, R. Rallison and L. Ramos-Izquierdo, 2001: Holographic optical element raman lidar. *Advances in Laser Remote Sensing*, Alain Dabas, Claude Loth and Jacques Pelon, Editors, pp.77-80, Ecole Polytechnique, France.

Shu-Hsien Chou, Chung-Lin Shie, Robert M. Atlas, Joe Ardizzone, and Eric Nelkin. A 7.5-Year Dataset of SSM/I-Derived Surface Turbulent Fluxes Over Global Oceans, August 7, 2001 http://www.soc.soton.ac.uk/JRD/MET/WGASF, Title of proceedings: WCRP/SCOR Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields, Bolger Center, Potomac, Md., May 21-24, 2001.

Demoz B., K. Evans, D. Starr, D. Whiteman, G. Schwemmer and D. Turner, 2001: Raman observations of lifting at a convergence line. *Advances in Laser Remote Sensing*, A. Dabas, C. Loth, J. Pelon, eds., Ecole Polytechnique, Cedex, France, 483-486.

Evans, K.D, B.B. Demoz, D.N. Whiteman, D. O'C. Starr, G.K. Schwemmer, F.J. Schmidlin, W. Feltz, D. Tobin and S. Gutman, 2001: A new calibration technique for raman lidar water vapor measurements. *Advances in Laser Remote Sensing*, A. Dabas, C. Loth, J. Pelon, eds., Ecole Polytechnique, Cedex, France, 289-292.

Huffman, G.J., 2001: Selections in the NASA/EOS Earth Observatory web site's Ask A Scientist dept. http://earthobservatory.nasa.gov/Library/AskScientist/index.html

Korb, C.L., C. Flesia, S.Lolli, and C. Hirt, 2001: Double-Edge Molecular Measurement of Lidar Wind Profiles at the Observatoide de Haute Provence.

Palm, S.P., D.O. Miller and G. Schwemmer, 2001: The estimation of surface latent heat flux over the ocean and its relationship to Marine Atmospheric Boundary Layer (MABL) structure. *Advances in Laser Remote Sensing*, Alain Dabas, Claude Loth and Jacques Pelon, Editors, pp. 459-462, Ecole Polytechnique, France.

Quante, M., and D.O'C. Starr, 2001: Dynamical Processes in Cirrus Clouds: A Review of Observational Results. in *Cirrus*, D.K. Lynch, K. Sassen, D.O'C. Starr and G. Stephens (ed), Oxford University Press, 346-374.

Schwemmer, Geary K., “Shared-Aperture Multiplexed Holographic Scanning Telescopes,” Photonics Tech Briefs, Vol. 25. No. 7, p. 18a, July 2001.

Schwemmer, G.K., T.D. Wilkerson, J.A. Sanders, D.V. Guerra, D.O. Miller and S.E. Moody, 2001: Ground based operational testing of holographic scanning lidar. *Advances in Laser Remote Sensing*, Alain Dabas, Claude Loth and Jacques Pelon, Editors, pp. 69-72, Ecole Polytechnique, France.

Starr, D.O'C., and M. Quante, 2001: Dynamical Processes in Cirrus Clouds: Concepts and Models. in *Cirrus*, D.K. Lynch, K. Sassen, D.O'C. Starr and G. Stephens (ed), Oxford University Press, 375-396.

Welton, E.J., J.R. Campbell, T.A. Berkoff, J.D. Spinhirne, S. Tsay, and B. Holben, “First Annual Report: The Micro-pulse Lidar Worldwide Observational Network,” Project Report, 2001. available at: http://virl.gsfc.nasa.gov/mpl-net/

Whiteman, D.N., D.O'C. Starr, G. Schwemmer, K. Evans, B. Demoz, M. Cadirola, S.H. Melfi and G.J. Jedlovic, 2001: Study on the influence of thin cirrus clouds on satellite radiances using raman lidar and GOES data. *Advances in Laser Remote Sensing*, A. Dabas, C. Loth, J. Pelon, eds., Ecole Polytechnique, Cedex, France, 271-274.

CLIMATE AND RADIATION BRANCH

Ming-Dah Chou, Max J. Suarez, Xin-Zhong Liang, and Michael M.-H. Yan, “A Thermal Infrared Radiation Para meterization for Atmospheric Studies,” a Technical Report Series on Global Modeling and Data Assimilation, *Max J. Suarez, Editor*. NASA/TM—2001–104606, Vol. 19, July 2001.

Mocko, D.M., and Y.C. Sud, 2001: Refinements to SSiB with an emphasis on snow-physics: Evaluation and validation using GSWP and Valdai data. Earth Interactions, 5(5-001), 31 pp. Web Site : http://EarthInteractions.org/

Nussenzveig, H.M., 2001: Time Delay and Tunneling. Modern Challenges in Quantum Optics, Eds. M. Orszag and J. Retamal, Springer Verlag, 229-243.

Samuel S.P. Shen, William K.M. Lau, Kyu-Myong Kim, and Guilong Li, “A Canonical Ensemble Correlation Prediction Model for Seasonal Precipitation Anomaly.” NASA/TM-2001-209989, September 2001.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

N.A. Krotkov, J. Herman, P.K. Bhartia, Colin Seftor, A. Arola, J. Kaurola, L. Koskinen, S. Kalliskota, P. Taalas OMI Surface UV Irradiance Algorithmn, *OMI ATBD:, vol 3 , chapter 5, KNMI, 2001.*

Reichardt, J., T.J. McGee, M. Hess, and A. Macke Multiple-Scattering Parameters in Cirrus Clouds with Variable Particle Extinction Profiles, 263-266, in Advances in *Laser Remote Sensing*, A. Dabas, C. Loth and J. Pelon, eds., *Editions de L'Ecole Polytechnique*, 91128, Palaiseux Cedex, France, 2001.

APPENDIX 7. 2001 REFEREED PUBLICATIONS

LABORATORY FOR ATMOSPHERES

Adler, R.F., C. Kidd, G. Petty, M. Morrissey and H.M. Goodman, 2001: Intercomparison of global precipitation products: The Third Precipitation Intercomparison Project (PIP-3). *Bull. Amer. Meteor. Soc*., **82** (7), 1377-1396.

Atlas, D., 2001: Fallstreaks and their parent generators. *BAMS*, **82** (3), 477-480.

Hartle, R.E., D.S. Intriligator and J.M. Grebowsky, 2001: Ionospheric flow and escape of ions from Titan and Venus. *Adv. Space Res.*, **27**, 1869-1874.

Krishnamurti, T.N., S. Surendran, D.W. Shin, R.J. Correa-Torres, T.S. V.V. Kumar, E. Williford, C. Kummerow, R.F. Adler, J. Simpson, R. Kakar, W.S. Olson and F.J. Turk, 2001: Real-time multianalysis-multimodel superensemble forecasts of precipitation using TRMM and SSM/I products. *Mon. Wea. Rev.*, **129** (12), 2861-2883.

Kummerow, C., Y. Hong, W.S. Olson, S. Yang, R.F. Adler, J. McCollum, R. Ferraro, G. Petty, D.-B. Shin and T.T. Wilheit, 2001: The evolution of the Goddard Profiling Algorithm (GPROF) for rainfall estimation from passive microwave sensors. *J. Appl. Meteor.*, **40**, 1801-1820.

Kummerow, C., J. Simpson, O. Thiele, W. Barnes, A.T.C. Chang, E. Stocker, R.F. Adler, A. Hou, R. Kakar, F. Wentz, P. Ashcroft, T. Kozu, Y. Hong, K. Okamoto, T. Iguchi, H. Kuroiwa, E. Im, Z. Haddad, G. Huffman, B. Ferrier, W.S. Olson, E. Zipser, E.A. Smith, T.T. Wilheit, G. North, T. Krishnamurti and K. Nakamura, 2001: The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit. *J. Appl. Meteor.*, **39** (12), 1965-1982.

Lakshmi, V. and J. Susskind, 2001: Utilization of satellite data in land surface hydrology: Sensitivity and assimilation. *Hydrol. Process,* 15, 877-892.

Lakshmi, V., K.P. Czajkowski, R.O. Dubayah and J. Susskind, 2001: Land surface air temperature mapping using TOVS and AVHRR. *Int. J. Remote Sensing*, **22**, 643-662.

Rodgers, E.B., R.F. Adler and H.F. Pierce, 2001: Contribution of tropical cyclones to the North Atlantic climatological rainfall as observed from satellites. *J. Appl. Meteor.*, **40** (11), 1785-1800.

DATA ASSIMILATION OFFICE

Amodei, M., S. Pawson, A.A. Scaife, U. Langematz, W. Lahoz, D.M. Li and P. Simon, 2001: The SAO and Kelvin waves in the EuroGRIPS GCMS and the UK Met. Office analyses. *Annales Geophysicae*, **19**, 99-114.

Atlas, R., R.N. Hoffman, S.M. Leidner, J. Sienkiewicz, T.W. Yu, S.C. Bloom, E. Brin, J. Ardizzone, J. Terry, D. Bungato and J.C. Jusem, 2001: The effects of marine winds from scatterometer data on weather analysis and forecasting. *Bull. Amer. Meteor. Soc.*, **82** (9), 1965-1990.

Bennett, A.C. and K. Omidvar, 2001: Alternative method for the thermospheric atomic oxygen density determination. *Middle Atmosphere Temporal and Spatial Structures Advances in Space Research*, **27** (10), 1685-1690.

Bosilovich, M. and S. Schubert, 2001: Precipitation recycling over the Central United States diagnosed from the GEOS-1 data assimilation system. *J. Hydrometeorology*, **2**, 26-35.

Chen, T.-C., M.-C. Yen and S. Schubert, 2001: Diurnal variation of pressure-heights: A vertical phase shift. *J. Climate*, **14**, 3793-3797.

Conaty, A. L., J. C. Jusem, L. Takacs, D. Keyser and R. Atlas, 2001: The structure and evolution of extratropical cyclones, fronts, jet streams, and the tropopause in the GEOS general circulation model. *Bull. Amer. Meteor. Soc.*, **82** (9), 1853-1867.

Dee, D.P., L. Rukohovets, R. Todling, A.M. da Silva and J.W. Larson, 2001: An adaptive buddy check for observational quality control. Q. J. R. Meteorol. Soc., **127**, 2451-2472.

Ferraris, L., O. Reale and B. Turato, 2001: Synoptic and hydrological analysis of a flood event. *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere*, **26** (9), 655-661.

Fox-Rabinovitz, M.S., L.L. Takacs, R.C. Govindaraju and M.J. Suarez, 2001: A variable resolution stretched grid GCM: Regional climate simulation. *Mon. Wea. Rev.*, **129**, 453-469.

Garand, L., D.S. Turner, M. Larocque, J. Bates, S. Boukabara, P. Brunel, F. Chevallier, G. Deblonde, R. Engelen, M. Hollingshead, D. Jackson, G. Jedlovec, J. Joiner, T. Kleespies, D.S. McKague, L. McMillin, J.L. Moncet, J.R. Pardo, P.J. Rayer, E. Salathe, R. Saunders, N.A. Scott, P. van Delst and H. Woolf, 2001: Radiance and Jacobian intercomparison of radiative transfer models applied to HIRS and AMSU channels. *JGR (Atmospheres)*, **106** (D20), 24,017-24,031.

Hou, A.Y., S.Q. Zhang, A.M. da Silva, W.S. Olson, C. Kummerow and J. Simpson, 2001: Improving global analysis and short-range forecast using rainfall and moisture observations derived from TRMM and SSM/I passive microwave sensors. *Bull. Amer. Meteoological,* **82**, 659-679.

Hou, A.Y., S.Q. Zhang, A.M. da Silva and W.S. Olson, 2001: Improving assimilated global datasets using TMI rainfall and columnar moisture observations. *J. Climate*, **13**, 4180-4195.

Otterman, J., J. Ardizzone, R. Atlas, D. Bungato, J. Cierniewski, J.C. Jusem, R. Przybylak, S. Schubert, D. Starr, J. Walczewski and A. Wos, 2001: The variability of winter air temperature in mid-latitude Europe. *Geographia Polonica*, **74,** 67-77.

Pawson, S., L. Takacs, A. Molod, S. Nebuda, M. Chen, R. Rood, W.L. Read and M. Fiorino, 2001: The tropical upper troposphere and lower stratosphere in the GEOS-2 GCM. *High Latitude Studies and Upper Atmospheric Processes including Climate Change Advances in Space Research*, **27** (8), 1457-1465.

Ramaswamy, V., M.-L. Chanin, J. Angell, J. Barnet, D. Gaffen, M. Gelman, P. Keckhut, Y. Koshelkov, K. Labitzke, J.-J.R. Lin, A. O'Neill, J. Nash, W. Randel, R. Rood, K. Shine, M. Shiotani and R. Swinbank, 2001: Stratospheric temperature changes: Observations and model simulations. *Reviews of Geophysics*, **39**, 77-122.

Reale, O. and R. Atlas, 2001: Tropical cyclone-like vortices in the extratropics: Observational evidence and synoptic analysis. *Weather and Forecasting*, **16**, 7-34.

Reale, O., L. Feudale and B. Turato, 2001: Evaporative moisture sources during a sequence of floods in the Mediterranean region. *Geophys. Res. Lett.*, **28** (10), 2085-2088.

Reynolds, C.A., R. Gelaro and J. Doyle, Relationship between singular vectors and transient features in the background flow. *Q.J.R. Meteor. Soc.,* **127**, 1731-1761.

Reynolds, C.A. and R. Gelaro, 2001: Remarks on Northern Hemisphere forecast error sensitivity from 1996-2000. *Mon. Wea. Rev.*, **129**, 2145-2153.

Riishojgaard, L.P., 2001: Deterministic prediction of the ensemble variance for a barotropic vorticity-equation model. *QJRMS,* **127** (575) 1761-1773.

Rotman, D.A., J.R. Tannahill, D.E. Kinnison, P.S. Connell, D. Bergmann, D. Proctor, J.M. Rodriguez, S.J. Lin, R.B. Rood, M.J. Prather, P.J. Rasch, D.B. Considine, R. Ramaroson and S.R. Kawa, 2001: Global modeling initiative assessment model: Model description, integration, and testing of the transport shell. *JGR*, **106**, 1669-1691.

Schubert, S.D., M.J. Suarez, Y. Chang and G. Branstator, 2001: The impact of ENSO on extratropical low-frequency noise in seasonal forecasts. *J. Climate*, **14**, 2351-2363.

Schubert, S.D. and M.L. Wu, 2001: Predictability of the 1997 and 1998 south Asian summer monsoon low-level winds. *J. Climate,* **14** (15), 3173-3191.

Stajner, I., L.P. Riishojgaard and R.B. Rood, 2001: The GEOS ozone data assimilation system: Specification of error statistics. *QJRMS*, **127**, 1069-1094.

Tippett, M.K. and S.E. Cohn, 2001: Adjoints and low-rank covariance representation. *Nonlinear Processes in Geophysics*, **8**, 331-340.

Wang, K.Y., D.J. Lary, D.E. Shallcross, S.M. Hall, and J.A. Pyle, A review on the use of the adjoint method in four-dimensional atmospheric-chemistry data assimilation. *Q. J. Roy. Meteor. Soc.*, **127** (576), 2181-2204 Part B.

Wu, Man Li C., S. Schubert, C.I. Lin, and Stajner, A method for assessing the quality of model-based estimates of ground temperature and atmospheric moisture using satellite data. *J. Geophys. Res.*, **106**, D10, 10129-10144.

Xue, M. and S.J. Lin, 2001: Numerical equivalence of advection in flux and advective forms and quadratically conservative high-order advection schemes. *Mon. Wea. Rev.*, **129** (3), 561-565.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

Bauer, P., P. Amayenc, C.D. Kummerow and E.A. Smith, 2001: Over-ocean rainfall retrieval from multisensor data of the Tropical Rainfall Measuring Mission. Part II: Algorithm implementation. *J. Atmos. and Oceanic Tech.*, **18** (11), 1838-1855.

Baker, R.D., B.H. Lynn, A. Boone, W.-K. Tao and J. Simpson, 2001: The influence of soil moisture, coastline curvature, and land-breeze circulations on sea-breeze initiated precipitation. *J. Hydrometeorology*., **2** (2), 193-211.

Chang, D.-E., J.A. Weinman, C.A. Morales and W.S. Olson, 2001: The effect of spaceborne microwave and ground-based continuous lightning measurements on forecasts of the 1998 groundhog day storm. *Mon. Wea. Rev.*, **129**, 1809-1833.

Crawford, T.M., D.J. Stensrud, F. Mora, J.W. Merchant and P.J. Wetzel, 2001: Value of incorporating satellite-derived land cover data in MM5/PLACE for simulating surface temperatures. *J. Hydrometeorology*, **2**, 453-468.

Curtis, S., R. Adler, G. Huffman, E. Nelkin and D. Bolvin, 2001: Evolution of tropical and extratropical precipitation anomalies during the 1997-1999 ENSO cycle. *Int. J. Climatol*., **21**, 961-971.

Doelling, D.R., P. Minnis, D.A. Spangenberg, V. Chakrapani, A. Mahesh, S.K. Pope and F.P.J. Valero, 2001: Cloud radiative forcing during FIRE ACE derived from AVHRR data. *JGR (Atmospheres)*, **106**, 15,279-15,296.

Duda, D.P., J.D. Spinhirne and E.W. Eloranta, 2001: Atmospheric multiple scattering effects on GLAS altimetry. Part I: Calculations of single pulse bias. *IEEE Trans. Geo. Rem. Sens*., **39**, 92-101.

Heymsfield, G.M., B. Geerts and L. Tian, 2001: TRMM precipitation radar reflectivity profiles compared to high-resolution airborne and ground-based measurements. *J. Appl. Meteor.*, **39** (12), 2080-2102.

Heymsfield, G.M., J.B. Halverson, J. Simpson, L. Tian and T.P. Bui, 2001: ER-2 Doppler radar investigations of the eyewall of Hurricane Bonnie during the convection and moisture experiment –3. *J. Appl. Meteor.*, **40** (8), 1310-1330.

Huffman, G.J., R.F. Adler, M.M. Morrisey, D.T. Bolvin, S. Curtis, R. Joyce, B. McGavock and J. Susskind, 2001: Global precipitation at one-degree resolution from multi-satellite observations. *J. Hydrometeorology*, **2**, 36-50.

Joyce, R.J., J.E. Janowiak and G.J. Huffman, 2001: Latitudinal and seasonal dependent zenith angle corrections for geostationary satellite IR brightness temperatures. *J. Appl. Meteor*., **40** (4), 689-703.

Keil, M.M. Heun, J. Austin, W. Lahoz, G.P. Lou and A. O'Neill, 2001: The use of long-duration balloon data to determine the accuracy of stratospheric analyses and forecasts. *JGR (Atmospheres)*, **106** (D10), 10,29-10,312.

Lynn, B.H., W.-K. Tao and F. Abramopoulos, 2001: A parameterization for the triggering of landscape generated moist convection. Part I: Analyses of high resolution model results. *J. Atmos. Sci*., **58**, 575-592.

Lynn, B.H. and W.-K. Tao 2001: A parameterization for the triggering of landscape generated moist convection. Part II: Zero order and first order closure. *J. Atmos. Sci*., **58** (6), 593-607.

Lynn, B.H., D. Stauffer, P. Wetzel, W.-K. Tao, P. Alpert, N. Perlin, R.D. Baker, R. Munoz, A. Boone and Y. Jia, 2001: Improved simulation of Florida summer convection using the PLACE land model and a 1.5-order turbulence parameterization coupled to the Penn State/NCAR mesoscale model. *Mon. Wea. Rev*., **129** (6), 1441-1461.

Mahesh, A., V.P. Walden and S.G. Warren, 2001: Ground-based infrared remote sensing of cloud properties over the Antarctic Plateau. Part I: Cloud base heights. *J. Appl. Meteor.*, **40**, 1265-1278.

Mahesh, A., V. Walden and S. Warren, 2001: Ground-based infrared remote sensing of cloud properties over the Antarctic Plateau. Part II: Cloud optical depths and particle sizes. *J. Appl. Meteor.*, **40**, 1279-1294.

McGill, M. and R. Rallison, 2001: Holographic optics convert rings to points for detection. *Laser Focus World*, **37** (3), 131.

Meneghini, R., L. Liao, S.W. Bidwell and G.M. Heymsfield, 2001: On the feasibility of a differential-frequency Doppler weather radar. *IEEE Trans. Geo. Rem. Sens.*, **39**, 2203-2316.

Michaels, M., J.M. Shepherd, S. Aberson and K. Murphy, 2001: Survey results of society membership: The face of our profession at the threshold of the new millennium. *Bull. Am. Meteor. Soc*., **82**, 1331-1352.

Olson, W.S., P. Bauer, N.F. Viltard, D.E. Johnson, W.-K. Tao, R. Meneghini, and L. Liao, 2001: A melting layer model for passive/active microwave remote sensing applications- Part I: Model formulation and comparison with observations. *J. Appl. Meteor.*, **40** (7), 1145-1163.

Olson, W.S., P. Bauer, C.D. Kummerow, Y. Hong and W.-K. Tao, 2001: A melting layer model for passive/active microwave remote sensing applications—Part II: Simulation of TRMM observations. *J. Appl. Meteor.*, **40** (7), 1164-1179.

Olson, W.S., Y. Hong, C. Kummerow, and J. Turk, 2001: A Texture-Polarization Method for Estimating Convective-Stratiform Precipitation Area Coverage from Passive Microwave Radiometer Data. *J. Appl. Meteor.*, 40, (9), 1577–1591.

Peng, L., C.-H. Sui and W.-K. Tao, 2001: Genesis and evolution of super cloud clusters in a 2-d numerical cloud resolving model. *J. Atmos. Sci.*, **58** (8), 877-895.

Pu, Z.-X. and S.A. Braun, 2001: Evaluation of bogus vortex techniques with four-dimensional variational data assimilation. *Mon. Wea. Rev*., **129** (8), 2023–2039.

Quante, M. and D.O'C. Starr, 2001: Dynamical processes in cirrus clouds: A review of observational results. *Cirrus*, 346-374.

Quinn, P.K., D.J. Coffman, T.S. Bates, T.L. Miller, J.E. Johnson, K.J. Voss, E.J. Welton and C. Neusüss, 2001: Dominant aerosol chemical components and their contribution to extinction during the aerosols99 cruise across the Atlantic. *JGR*, **106**, 20783-20810.

Sassen, K. and J.R. Campbell, 2001: A mid-latitude cirrus cloud climatology from the facility for atmospheric remote sensing. I.: Macrophysical and synoptic properties. *J. Atmos. Sci*., **58** (5), 481-496.

Shepherd, J.M., B.S. Ferrier and P.S. Ray, 2001: Rainfall morphology in Florida convergence zones: A numerical study. *Mon. Wea. Rev*., **129**, 177-197.

Sohn, B.J., H.S. Chung, D.H. Kim, D. Perkey, F.R. Robertson and E.A. Smith, 2001: Use of satellite-derived water vapor data to investigate northwestward expansion of North Pacific subtropical high during 1995 summer. *J. Meteor. Soc. of Japan*, **79** (5), 1059-1075.

Srivastava, V., J. Rothermel, A.D. Clarke, J.D. Spinhirne, R.T. Menzies, D.R. Cutten, M.A. Jarzembski, D.A. Bowdle and E.W. McCaul, 2001: Wavelength dependence of backscatter by use of aerosol microphysics and lidar data sets: Application to 2.1-mu m wavelength for space-based and airborne lidars. *Applied Optics*, **40** (27), 4759-4769.

Starr, D. O'C. and M. Quante, 2001: Dynamical processes in cirrus clouds: Concepts and models. *Cirrus*, 375-396.

Tao, W.-K., C.-L. Shie and J. Simpson, 2001: Comments on the sensitivity study of radiative-convective equilibrium in the tropics with a convective resolving model. *J. Atmos. Sci*., **58** (10), 1328-1333.

Tao, W.-K., S. Lang, J. Simpson, W.S. Olson, D. Johnson, B. Ferrier, C. Kummerow and R. Adler, 2001: Vertical profiles of latent heat release and their retrieval for TOGA COARE convective systems using a cloud resolving model, SSM/I, and ship-borne radar data. *J. Meteor. Soc. Japan*, **78**, 333-355.

Tao, W.-K., S. Lang, W.S. Olson, R. Meneghini, S. Yang, J. Simpson, C. Kummerow, E. Smith, and J. Halverson, 2001: Retrieved vertical profiles of latent heat release using TRMM Products. *J. Appl. Meteor*., **40**, 957-982.

Voss, K.J., E.J. Welton, P.K. Quinn, R. Frouin, M. Miller and M. Reynolds, 2001: Aerosol optical depth measurements during the aerosols99 experiment. *J. Geophys. Res.*, **106,** 20811-20820.

Voss, K.J., E.J. Welton, P.K. Quinn, J. Johnson, A. Thompson and H. Gordon, 2001: Lidar measurements during aerosols99. *J. Geophys. Res.*, **106**, 20821-20832.

Wang, J.R., G. Liu, J.D. Spinhirne, P. Racette and W.D. Hart, 2001: Observations and retrievals of cirrus cloud parameters using multichannel millimeter-wave radiometric measurements. *JGR (Atmospheres)*, **106** (D14), 15,251-15,263.

Whiteman, D.N., G. Schwemmer, T. Berkoff, H. Plotkin, L. Ramos-Izquierdo and G. Pappalardo, 2001: Performance modeling of an airborne Raman water-vapor lidar. *Applied Optics*, **40** (3), 375-390.

Whiteman, D.N., K.D. Evans, B. Demoz, D.O'C. Starr, D. Tobin, W. Feltz, G.J. Jedlovic, S.I. Gutman, G.K. Schwemmer, M. Cadirola, S.H. Melfi and F. Schmidlin, 2001: Raman lidar measurements of water vapor and cirrus clouds during the passage of Hurricane Bonnie. *JGR*, **106** (D6), 5211-5225.

Whiteman, D.N., G. Schwemmer, T. Berkoff, H. Plotkin, L. R.-Izquierdo and G. Pappalardo, 2001: Performance modeling of an airborne raman water-vapor lidar. *Applied Optics*, **40** (3), 375-390.

CLIMATE AND RADIATION BRANCH

Baran, A.J., P. Yang and S. Havemann, 2001: Calculation of the single-scattering properties of randomly oriented hexagonal ice columns: A comparison of the t-matrix and the finite-difference time-domain methods. *Applied Optics*, **40** (24), 4376-4386.

Baran, A.J., P.N. Francis, S. Havemann and P. Yang, 2001: A study of the absorption and extinction properties of hexagonal ice columns and plates in random and preferred orientation, using exact t-matrix theory and aircraft observations of cirrus. *J. of Quant. Spectr. & Rad. Transfer*, **70**, 505-518.

Barker, H. and A. Marshak, 2001: Inferring optical depth of broken clouds above green vegetation using surface solar radiometric measurements. *J. Atmos. Sci*., **58**, 2989-3006.

Basist, A., C. Williams Jr., N. Grody, T.F. Ross, S.S.P. Shen, A.T.C. Chang, R. Ferraro and M.J. Menne, 2001: Using the special sensor microwave imager to monitor surface wetness. *J. Hydrometeorology*, **2**, 297-308.

Bell, T.L., P. Kundu and C.D. Kummerow, 2001: Sampling errors of SSMI/I and TRMM rainfall averages: Comparison with error estimates from surface data and a simple model. *J. Appl. Meteor.*, **40**, 938-954.

Cahalan, R.F., L. Oreopoulos, G. Wen, A. Marshak, S.C. Tsay and T.P. DeFelice, 2001: Cloud characterization and clear sky correction from Landsat 7. *Rem. Sens. Environ.*, **78**, 83-98.

Chao, W.C. and B. Chen, 2001: On the role of surface friction in tropical intraseasonal oscillation. *Mon. Wea. Rev*., **129**, 896-904**.**

Chao, W.C. and B. Chen, 2001: Multiple quasi equilibria of the itcz and the origin of monsoon onset. Part II: Rotational ITCZ attractors. *J. Atmos. Sci.*, **58**, 2820-2831.

Chao, W.C. and B. Chen, 2001: On the origin of monsoon. *J. Atmos. Sci*., **58**, 3497-3507.

Chou, M.D., P.-K. Chan and M. Yan, 2001: A sea-surface radiation data set for climate applications in the tropical western pacific and south china sea. *JGR,* **106**, 7219-7228.

Davis, A. and A. Marshak, 2001: Multiple scattering in clouds: Insights from three-dimensional diffusion theory. *Nuclear Science and Engineering*, **137**, 251-280.

Feingold, G., L.A. Remer, J. Ramaprasad and Y.J. Kaufman, 2001: Analysis of smoke impact on clouds in brazilian biomass burning regions: An extension of Twomey's approach. *JGR*, **106** (D19), 22907-22922.

Folland, C.K., N.A. Rayner, S.J. Brown, T.M. Smith, S.S.P. Shen, D.E. Parker, I. Macadam, P.D. Jones, R. Jones, N. Nicholls and D.M.H. Sexton, 2001: Global temperature change and its uncertainties since 1861. *Geophys. Res. Lett.*, **28**, 2621-2624.

Gao, Y., Y.J. Kaufman, D. Tanre and P.G. Falkowski, 2001: Seasonal distribution of aeolian iron fluxes to the global ocean. *Geophys. Res. Lett.*, **28**, 29-33.

Gatebe, C.K., M.D. King, S.-C. Tsay, Q. Ji, G.T. Arnold and J.Y. Li, 2001: Sensitivity of off-nadir zenith angles to correlation between visible and near-infrared reflectance for use in remote sensing of aerosol over land. *IEEE Trans. Geos. Remote. Sens.*, **39** (4), 805-819.

Gatebe, C.K., P.D. Tyson, H.J. Annegarn, G. Helas, A.M. Kinyua and S. Piketh, 2001: Characterization and transport of aerosols over equatorial Eastern Africa. *Global Biogeochemical Cycle*, **15** (3), 663-672.

Gerber, H., J. Jensen, A. Davis, A. Marshak and W. Wiscombe, 2001: Spectral density of cloud liquid water content at high frequencies. *J. Atmos. Sci*., **58**, 497-503.

Holben, B.N., D. Tanre, A. Smirnov, T.F. Eck, I. Slutsker, N. Abuhassan, W.W. Newcomb, J.S. Schafer, B. Chatenet, F. Lavenu, Y.J. Kaufman, J.V. Castle, A. Setzer, B. Markham, D. Clark, R. Frouin, R. Halthore, A. Karnieli, N.T. O'Neill, C. Pietras, R.T. Pinker, K. Voss and G. Zibordi, 2001: An emerging ground based aerosol climatology: Aerosol optical depth from AERONET. *Geophys. Res. Lett.*, **106** (D11), 12067-12097.

Hu, Y.-X., D. Winker, P. Yang, B. Baum, L. Poole and L. Vann, 2001: Identification of cloud phase from PICASSO-CENA lidar depolarization: A multiple scattering sensitivity study. *J. of Quant. Spectr. & Rad. Transfer*, **70,** 569-579.

Karnieli, A., Y.J. Kaufman, L.A. Remer and A. Wald, 2001: AFRI-aerosol free vegetation index. *Rem. Sens. Environ.*, **77**, 10-21.

Kaufman, Y.J., D. Tanre, O. Dubovik, A. Karnieli and L.A. Remer, 2001: Absorption of sunlight by dust as inferred from satellite and ground-based remote sensing. *JGR*, **28** (8), 1479-1482.

Kaufman, Y.J., A. Smirnov, B.N. Holben, and O. Dubovik, 2001: Baseline Maritime Aerosol: Methodology to derive the Optical Thickness and Scattering Properties. *Geophys. Res. Lett.* **28**, (No. 17), 3251-3254.

Kim, K.-M. and K.M. Lau, 2001: Dynamics of monsoon-induced biennial variability in ENSO. *Geophys. Res. Lett*., **28** (2), 315-318.

Kreidenweiss, S.M., L.A. Remer, R. Bruintjes, R. Kleidman, and O. Dubovik, 2001: Smoke Aerosol from Biomass Burning in Mexico: Hygroscopic Smoke Optical Model. *J. Geophys. Res.*, **106**, 4831-4844.

Lau, K.M., and H.T. Wu, 2001: Intrinsic coupled ocean-atmosphere modes of the asian summer monsoon: A re-assessment of monsoon-ENSO relationships. *J. Climate*, **14**, 2880-2895.

Lau, K.M. and H. Weng, 2001: Coherent modes of global SST and summer rainfall over China: An assessment of the regional impacts of the 1997-98 el nino/la nina. *J. Climate*, **14**, 1294-1308.

Li, Z., Y.J. Kaufman, C. Ichoku, R. Fraser, A. Trishchenko, L. Giglio and J. Jin, 2001: A review of satellite fire detection algorithms: Principles, limitations, and recommendations. *Rem. Sens. Environ., A Special Issue on GOFC-FIRE*, 199-225.

Lindzen, R.S., M.-D. Chou and A. Hou, 2001: Does the Earth have an adaptive infrared iris? *BAMS*, **82**, 417-432.

Lyapustin, A.I. and Y.J. Kaufman, 2001: The role of adjacency effect in the optical remote sensing of aerosol. *JGR*, **106**, 11909-11916.

Nussenzveig, H.M., 2001: Time delay and tunneling. Modern Challenges in Quantum Optics, Eds. M. Orszag and J. Retamal, Springer Verlag, 229-243.

Peng, L. and W.K. Tao, 2001: Genesis and evolution of super cloud clusters in a two-dimensional cumulus resolving model. *J. Atmos. Sci.,* **58**, 877-895.

Platnick, S., M.D. King, H. Gerber and P.V. Hobbs, 2001: A solar reflectance technique for cloud retrievals over snow and ice surfaces. *JGR,* **106**, 15185-15199.

Platnick, S., 2001: A superposition technique for deriving mean photon scattering statistics in plane-parallel cloudy atmospheres. *J. Quan. Spectro. & Rad. Trans.,* **68**, 57-73.

Platnick, S., 2001: Approximations for horizontal photon transport in cloud remote sensing problems. *J. Quan. Spectro. & Rad. Trans.,* **68**, 75-99.

Prabhakara, C., R. Iacovazzi and J.-M. Yoo, 2001: TRMM observations of polarization difference in 85 GHZ: Information about hydrometeors and rain rate. *Meteor. Soc. of Japan,* **79**, 101-107.

Remer, L., A.E. Wald and Y.J. Kaufman, 2001: Angular and seasonal variation of spectral surface reflectance ratios: Implications for the remote sensing of aerosol over land. *IEEE Trans. on Geoscience and Rem. Sens.,* **39**, 275-283.

Sabbah, I., C. Ichoku, Y.J. Kaufman and L.A. Remer, 2001: Full year cycle of desert dust spectral optical thickness and precipitable water vapor over Alexandria, Egypt. *JGR,* **106**, 18305-18316.

Sokolik, I.N., D. Winker, G. Bergametti, D. Gillette, G. Carmichael, Y.J. Kaufman, L. Gomes, L. Schuetz and J. Penner, 2001: Introduction to special section on mineral dust: Outstanding problems in quantifying the radiative impact of mineral dust. *JGR*, **106**, 18015-18027.

Stieglitz, M., A. Ducharne, R.D. Koster and M.J. Suarez, 2001: The impact of detailed snow physics on the simulation of snow cover and subsurface thermodynamics at continental scales. *J. Hydrometeorology*, **2**, 228-242.

Sud, Y.C., D.M. Mocko, G.K. Walker and R.D. Koster, 2001: Influence of land surface fluxes on precipitation: Inferences from simulations forced with four ARM-CART SCM datasets. *J. Climate*, **14**, 3666-3691.

Tanre, D., Y.J. Kaufman, B.N. Holben, B. Chatenet, A. Karnieli, F. Lavenu, L. Blarel, O. Dubovik, L.A. Remer and A. Smirnov, 2001: Climatology of dust aerosol size distribution and optical properties derived from remotely sensed data in the solar spectrum. *JGR*, **106**, 18205-18217.

Tyson, P.D. and C.K. Gatebe, 2001: The atmosphere, aerosols, trace gases and biogeochemical change in Southern Africa: A regional integration. *South African J. of Science,* **97** (3-4), 106-118.

Várnai, T. and A. Marshak, 2001: Statistical analysis of the uncertainties in cloud optical depth retrievals caused by three-dimensional radiative effects. *J. Atmos. Sci.*, **58**, 1540-1548.

Walliser, D.E., Z. Zhang, K.M. Lau and J.-H. Kim, 2001: Interannual sea surface temperature variability and the predictability of tropical intraseasonal variability. *J. Atmos. Sci.*, **58**, 2596-2615.

Wang, B., R. Wu and K.M. Lau, 2001: Contrasting interannual variations between the Indian and the western North Pacific summer monsoons. *J. Climate*, **14**, 4073-4090.

Wen, G., R.F. Cahalan, T.-S. Tsay and L. Oreopoulos, 2001: Impact of cumulus cloud spacing on landsat atmospheric correction and aerosol retrieval. *JGR (Atmospheres)*, **106**, 12129-12138.

Yang, P., B.C. Gao, B. Baum, Y. Hu, W. Wiscombe, M. Mishchenko. D.M. Winker, S.L. Nasiri, 2001: Asymptotic Solutions for Optical Properties of Large Particles with Strong Absorption. *Appl. Optics*, **40**, No. 9, 1532-1547.

Yang, P., B.-C. Gao, B.A. Baum, Y.X. Hu, W.J. Wiscombe, S.-C. Tsay, D.M. Winker and S.L. Nasiri, 2001: Radiative properties of cirrus clouds in the infrared (8-13 μm) spectral region. *J. of Quant. Spectroscopy and Radiative Transfer*, **70**, 473-504.

Zhou, J. and K.M. Lau, 2001: Principal modes of interannual and decadal variability of summer rainfall over South America. *Int. J. Climatology*, **21**, 1623-1644.

ATMOSPHERIC EXPERIMENT BRANCH

Cabane, M., P. Coll, C. Rodier, G. Israel, F. Raulin, R. Sternberg, H. Niemann, P. Mahaffy, A. Jambon and P. Rannou, 2001: In situ inorganic and organic analysis (Pyr/CD-GC/MS) of the Martian soil, on the Mars 2005 mission. *Planetary and Space Science,* **49** (5), 523-531.

Owen, T., H. Niemann and P. Mahaffy, 2001: Nitrogen on the Moon: What does it tell us? *Earth Moon and Planets,* **85-6**, 343-350.

Owen, T., P.R. Mahaffy, H.B. Niemann, S. Atreya and M. Wong, 2001: Protosolar nitrogen. *Astrophys. J.,* **553** (1), L77-L79.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

Andrews, A.E., K.A. Boering, S.C. Wofsy, B.C. Daube, D.B. Jones, S. Alex, M. Loewenstein, J.R. Podolske and S.E. Strahan, 2001: Empirical age spectra for the mid-latitude lower stratosphere from in situ observations of CO_2: Quantitative evidence for a subtropical “barrier” to horizontal transport. *JGR (Atmospheres),* **106**, 10,257-10,274.

Andrews, A.E., K.A. Boering, B.C. Daube, S.C. Wofsy, M. Loewenstein, H. Jost, J.R. Podolske, C.R. Webster, R.L. Herman, D.C. Scott, G.J. Flesch, E.J. Moyer, J.W. Elkins, G.S. Dutton, D.F. Hurst, F.L. Moore, E.A. Ray, P.A. Romashkin, and S.E. Strahan, Mean ages of stratospheric air derived from in situ observations of CO_2, CH_4 and N_20. *J. Geophys. Res*., **106**, D23. 32,295, 2001.

Beyerle, G., M.R. Gross, D.A. Haner, N.T. Kjome, I.S. McDermid, T.J. McGee, J.M. Rosen, H.J. Schafer and O. Schrems, 2001: A lidar and backscatter sonde measurement campaign at

Table Mountain during February–March 1997: Observations of cirrus clouds. *J. Atmos. Sci.*, **58** (10), 1275-1287.

Deland, M.T. and R.P. Cebula, 2001: Spectral solar UV irradiance data for cycle 21, *J. Geophys. Res.*, **106**, 21,569-21,583.

DeLand, M.T., R.P. Cebula, L.K. Huang, S.L. Taylor, R.S. Stolarski and R.D. McPeters, 2001: Observations of "hysteresis" in backscattered ultraviolet ozone data. *J. Atmos. and Oceanic Tech.*, **18** (6), 914-924.

Doernbrack, A., M. Leutbecher, J. Reichardt, A. Behrendt, K.-P. Mueller, and G. Baumgarten, Relevance of mountain wave cooling for the formation of polar stratospheric clouds over Scandinavia: Mesoscale dynamics and observations for January 1997. *J. Geophy. Res*., **106**, 1569-1581, 2001.

Douglass, A.R., M.R. Schoeberl, S.R. Kawa and E.V. Browell, 2001: A composite view of ozone evolution in the 1995-96 northern winter polar vortex developed from airborne lidar and satellite observations. *JGR (Atmospheres)*, **106**, 9879-9895.

Eck, T.F., B.N. Holben, D.E. Ward, O. Dubovik, J.S. Reid, A. Smirnov, M.M. Mukelabai, N.C. Hsu, N.T. O'Neill, and I. Slutsker, Characterization of the optical properties of biomass burning aerosols in Zambia during the 1997 ZIBBEE field campaign. *J. Geophy. Res*., **106**, 3425-3448, 2001.

Fleming, E.L., C.H. Jackman, D.B. Considine and R.S. Stolarski, 2001: Sensitivity of tracers and a stratospheric aircraft perturbation to two-dimensional model transport variations. *JGR (Atmospheres)*, **106** (D13), 14,245-14,263.

Gao, R.S., E.C. Richard, P.J. Popp, G.C. Toon, D.F. Hurst, P.A. Newman, J.C. Holocek, M.J. Northway, D.W. Fahey, M.Y. Danilin, B. Sen, K. Aikin, P.A. Romashkin, J.W. Elkins, C.R. Webster, S.M. Schauffler, J.B. Greenblatt, C.T. McElroy, L.R. Lait, T.P. Bui and D. Baumgardner, 2001: Observational evidence for the role of denitrification in Arctic stratospheric ozone loss. *Geophys. Res. Lett.*, **28** (15), 2879-2882.

Ginoux, P., M. Chin, I. Tegen, J.M. Prospero, B. Holben, O. Dubovik and S.J. Lin, 2001: Sources and distributions of dust aerosols simulated with the GOCART model. *JGR (Atmospheres)*, **106** (D17), 20,255-20,273.

Griffin, D., V.H. Garrison, J.R. Herman, and E.A. Shinn, African dust in the Caribbean atmosphere: Microbiology and public health. *Aerobilogia*, **17**, 203-213, 2001.

Hutterli, M.A., J.R. McConnell, R.W. Stewart, H.W. Jacobi and R.C. Bales, 2001: Impact of temperature-driven cycling of hydrogen peroxide (H2O2) between air and snow on the planetary boundary layer. *JGR (Atmospheres)*, **106** (D14), 15,395-15,404.

Herman, J.R., E. Celarier, and D. Larko, "UV 380 nm Reflectivity of the Earth's Surface, Clouds, and Aerosoles," 2001. *J. Geophys. Res.*, **106**, 5335-5351.

Herman, J.R., D. Larko, and J. Ziemke, "Changes in the Earth's Global UV Reflectivity from Clouds and Aerosoles," 2001. *J. Geophys Res.*, **106**, 5353-5368.

Jackman, C.H., R.D. McPeters, G.J. Labow, E.L. Fleming, C.J. Praderas and J.M. Russell, 2001: Northern Hemisphere atmospheric effects due to the July 2000 solar proton event. *Geophys. Res. Lett.*, **28** (15), 2883-2886.

Jones, D.B.A., A.E. Andrews, H.R. Schneider, and M.B. McElroy, Constraints on meridional transport in the stratosphere imposed by the mean age of air in the lower stratosphere. *J. Geophys. Res*., **106**, D10, 10243-10256, 2001.

Krotkov, N.A., J.R. Herman, P.K. Bhartia, V. Fioletov and Z. Ahmad, 2001: Satellite estimation of spectral surface UV irradiance 2. Effects of homogeneous clouds and snow. *JGR (Atmospheres)*, **106** (D11), 11,743-11,759.

Lambert J.C., M. Van Roozendael, P.C. Simon, J.P. Pommereau, F. Goutail, J.F. Gleason, S.B. Andersen, D.W. Arlander, C.H. Van Nab, J. de la Noe, M. De Maziere, V. Dorokhov, P. Eriksen, A. Green, K.K. Tornkvist, B. Hoiskar E. Kyro, J. Leveau, M.F. Merienne, G. Milinevsky, H.K. Roscoe, A. Sarkissian. J.D. Shanklin, J. Stahelin, C.W. Tellefsen, and G. Vaughan, Combined characterization of GOME and TOMS total ozone measurements from space using ground-based observations from the NDSC. *Adv. Space Res*., **26**, (12), 1931-1940, 2001.

Lazzaratto, M. Frioud, G. Larcheveque, V. Mitev, P. Quaglia, V. Simeonov, A.M. Thompson, H. van den Bergh, and B. Calpini, Ozone and water vapor measurements by Raman lidar in the planetary boundary layer; Error sources and field measurements. *Applied Optics*, ***18***, 2985-2997, 2001.

Mayr, H.G., C.L. Wolff and R.E. Hartle, 2001: Wave driven non-linear flow oscillator for the 22-year solar cycle. *Geophys. Res. Lett.*, **28**, 463-466.

Mayr, H.G., J.G. Mengel, K.L. Chan and H.S. Porter, 2001: Mesosphere dynamics with gravity wave forcing: Part I. Diurnal and semi-diurnal tides. *J. Atmospheric and Solar-Terrestrial Physics*, **63** (17), 1851-1864.

Mayr, H.G., J.G. Mengel, K.L. Chan and H.S. Porter, 2001: Mesosphere dynamics with gravity wave forcing: Part II. Planetary waves. *J. Atmospheric and Solar-Terrestrial Physics*, **63** (17), 1865-1881.

Middleton, E., J.R. Herman, E. Celarier, J.W. Wilkinson, C. Carey, and R.J. Rusin, Evaluating ultraviolet radiation exposures determined from TOMS satellite data at sites of amphibian declines in Central and South America. *Conservation Biology*, **15**, 914-929, 2001.

Nagel, D., U. Leiterer, H. Dier, A. Kats, J. Reichardt, and A. Behrendt, High accuracy humidity measurements using the standardized frequency method with a research upper-air sounding system, *Meteorol. Z.*, *10*, 395-405, 2001.

Newman, P.A., J.C. Wilson, M.N. Ross, C. Brock, P. Sheridan, M.R. Schoeberl, L.R. Lair, T.P. Bui and M. Loewenstein, 2001: Chance encounter with a stratospheric kerosene rocket plume from Russia over California. *Geophys. Res. Lett.*,, **28**, 959-962.

Newman, P.A., E.R. Nash and J.E. Rosenfield, 2001: What controls the temperature of the Arctic stratosphere during the spring? *JGR (Atmospheres)*, **106** (D17), 19,999-20,010.

Nielsen, J.E. and A. Douglass, 2001: A simulation of Bromoform's contribution to stratospheric bromine. *JGR*, **106**, 8089-8100.

Oltmans, S.J., B.J. Johnson, J.M. Harris, H. Vomel, A.M. Thompson, K. Koshy, P. Simon, R.J. Bendura, J.A. Logan, F. Hasebe, M. Shiotani, V.W.J.H. Kirchhoff, M. Maata, G. Sami, A. Samad, J. Tabuadravu, H. Enriquez, M. Agama, J. Cornejo, F. Paredes, Ozone in the Pacific tropical troposphere from ozonesonde observations. *J. Geophys. Res.*, **106**, D23, 32,503-32,526, 2001.

Pierson, J.M., S.R. Kawa, R.J. Salawitch, T.F. Hanisco, E.J. Lanzendorf, K.K. Perkins and R.S. Gao, 2001: Influence of airmass histories on radical species during POLARIS. *JGR*, **105**, 15185-15199.

Pickering, K.E., A.M. Thompson, H.C. Kim, A.J. DeCaria, L. Pfister, M. Avery, D.R. Blake, J.H. Crawford, B.G. Heikes, G.W. Sachse, S.T. Sandholm, R.W. Talbot, Trace gas transport and scavenging in PEM-Tropics-B SPCZ convection. *J. Geophys. Res*., **106**, D23, 32,591-32,605, 2001.

Pickering, K.E., A.M. Thompson, W. Qin, J.R. Herman, and Z. Ahmad, A fast, accurate algorithm to account for non-Lambertian surface effects on TOA radiance. *J. Geophys. Res*., **106**, 22,671-22,684, 2001.

Planet, W.G., A.J. Miller, K. Horvath, R. Nagatani, L.E. Flynn, E. Hilsenrath, S. Kondragunta, R.P. Cebula and M.T. DeLand, 2001: Total ozone determinations from National Oceanic and Atmospheric Administration operational solar backscattered ultraviolet 2 instrument observations: An update. *JGR (Atmospheres)*, **106** (D15), 17,471-17,478.

Popp, P.J., M.J. Northway, J.C. Holecek, R.S. Gao, D.W. Fahey, J.W. Elkins, D.F. Hurst, A. Romashkin, G.C. Toon, B. Sen, S.M. Schauffler, R.J. Salawitch, C.R. Webster, R.L. Herman, H. Jost, T.P. Bui, P.A. Newman and L.R. Lait, 2001: Severe and extensive denitrification in the 1999-2000 Arctic winter stratosphere. *Geophys. Res. Lett.,* **28** (15), 2875-2878.

Qin, W., J.R. Herman, and Z. Ahmad, "A fast, accurate algorithm to account for non-Lambertian surface effects on TOA radiance," 2001. J. Geophys. Res., **106**, 22,671.

Richard, E.C., K.C. Aikin, A.E. Andrews, B.C. Daube, C. Gerbig, S.C. Wofsy, P.A. Romashkin, D.F. Hurst, E.A. Ray, F.L. Moore, J.W. Elkins, T. Deshler, and G.C. Toon, Severe chemical ozone loss inside the arctic polar vortex during winter 1999-2000 inferred from in situ measurements. *Geophys. Res. Lett*., **28**, 2197-2200, 2001.

Rosenfield, J.E. and M.R. Schoeberl, On the Origin of Polar Vortex Air. *J. Geophys. Res.,* **106**, 33,485-33,497, 2001.

Sherwood, S.C. and A.E. Dessler, A model for transport across the tropical tropopause. *J. Atmos.Sci.*, **58**, 765-779, 2001

Sparling, L.C. and J.T. Bacmeister, Scale dependence of tracer microstructure: PDFs, intermittency and the dissipation scale. *Geophy. Res. Lett.* **28**, 2823-2826, 2001.

Stolarski, R.S., History of the Study of Stratospheric Ozone. *Ozone Science Engr*., **23**, 421-428, 2001.

Suhasini, R., R. Raghavarao, H. G. Mayr, W.R. Hoegy and L.E. Wharton, 2001: Equatorial temperature anomaly during solar minimum. *JGR (SpacePhysics)*, **106** (A11), 24,777-24,783.

Thompson, A.M., R.D. Hudson, J.C. Witte, J.R. Herman, H. Guo and M. Fujiwara, 2001: Tropical tropospheric ozone and biomass burning. *Science,* **291** (5511), 2128-2132.

Vasilkov, A., N. Krotkov, J. Herman, C. McClain, K. Arrigo and W.T. Robinson, 2001: Global mapping of underwater UV irradiances and DNA-weighted exposures using total ozone mapping spectrometer and sea-viewing wide field-of-view sensor data products. *JGR (Oceans),* **106** (C11), 27,205-27,219.

Voss, P.B., R.M. Stimpfle, R.C. Cohen, T.F. Hanisco, G.P. Bonne, K.K. Perkins, E.J. Lanzendorf, J.G. Anderson, R.J. Salawitch, C.R. Webster, D.C. Scott, R.D. May, P.O. Wennberg, P.A. Newman, L.R. Lait, J.W. Elkins and T.P. Bui, 2001: Inorganic chlorine partitioning in the summer lower stratosphere: Modeled and measured [ClONO2]/[HCl] during POLARIS. *JGR (Atmospheres)*, **106** (D2), 1713-1732.

Weaver, C.J., P. Ginoux, N.C. Hsu, M.-D. Chou and J. Joiner, 2001: Radiative forcing of Saharan dust: GOCART model simulations compared with ERBE data. *J. Atmos. Sci.,* **59**, 736-747.

Weinstock, E.M., E.J. Hintsa, D.B. Kirk-Davidoff, J.G. Anderson, A.E. Andrews, R.L. Herman, R.D. May, C.R. Webster, and T.P. Bui, 2001: Constraints on the seasonal cycle of stratospheric water vapor using in situ measurements from the ER-2 and a CO photochemical clock. *J. Geophys. Res.(Atmos)*, **106**, 22707-22724.

Wu, J., and A.E. Dessler, Comparisons between modeled and measured polar ozone loss. *J. Geophys. Res.*, **106**, 3195-3201, 2001.

Zerefos, C., D. Balis, M. Tzortziou, A. Bais, K. Tourpali, C. Meleti, G. Bernhard and J. Herman, 2001: A note on the interannual variations of UV0B erythemal doses and solar irradiance from ground-based and satellite observations. *Annales Geophysicae,* **19** (1), 115-120.

Ziemke, J.R., S. Chandra and P.K. Bhartia, 2001: “Cloud slicing”: A new technique to derive tropospheric ozone profile information from satellite measurements. *JGR*, **106**, 9853-9867.

APPENDIX 8. 2001 AWARDS/HONORS/ MEMBERSHIPS/ EDITORSHIPS

LABORATORY FOR ATMOSPHERES

Walter R. Hoegy:

LaRC Group Achievement Award.

Minority University Programs Certificate for Support of Minority University Programs and Activities at GSFC.

DATA ASSIMILATION OFFICE

Robert Atlas:

Member of the Ocean Vector Winds Science Team.

NASA Medal for Exceptional Scientific Achievement.

Michael Bosilovich:

NASA Laboratory for Atmospheres Scientific Research Award.

NASA Special Act Award.

Ron Gelaro:

Member, International Scientific Steering Committee for the Hemispheric Observing-system Research and Predictability Experiment (THORpex).

Joanna Joiner:

Goddard Space Flight Center Special Act Award.

Associate Editor, Quarterly Journal of the Royal Meteorological Society.

Steven Pawson:

Editor, Journal of Geophysical Research-Atmosphere.

Siegfried Schubert:

Editor, Journal of Climate.

NASA GSFC Performance Award.

Man Li C. Wu:

Laboratory for Atmospheres General Recognition Award.

Goddard Space Flight Center Special Act Award.

Eueng-nan Yeh:

NASA Public Service Group Achievement Award.

NASA Group Achievement Award.

SOUNDER RESEARCH TEAM

Joel Susskind:

Member of American Geophysical Union.

Member of American Meteorological Society.

MESOSCALE ATMOSPHERIC PROCESSES BRANCH

Dennis Chesters:

NASA GSFC Time-Off Award for GOES ABI SEB.

Bruce Gentry:

NASA Goddard Outstanding Performance Award.

Gerald Heymsfield:

2001: Outstanding Leadership Award.

2001: Laboratory for Atmospheres Peer Award.

2001: TRMM liaison to Goddard DAAC for field campaigns.

2001: TRMM senior staff & field campaign coordinator.

Andrew Negri:

2001: NASA GSFC Performance Award.

William Olson:

2001: Laboratory for Atmospheres Outstanding Performance in Science Award, GSFC.

V. Stanley Scott:

2001: Silver Snoopy Space Flight Awareness Award NASA.

2001: Laboratory for Atmospheres Outreach Award.

2001: NASA GSFC Group Achievement Award-Outstanding Teamwork Horizon Proposal Development Team.

2001: Special Act Award for superior performance of a special act.

Geary Schwemmer:

2001: Invention Disclosure Award for Methods and Systems for Collecting Data from Multiple Fields of View, from NASA, for patent disclosure.

2001: Tech Brief Award for “Shared Aperture Multiplexed Holographic Scanning Telescopes,” from NASA, for Tech Briefs publication.

Chairman of the AMS Committee on Laser Atmospheric Studies, 3-year term.

2001: Tech Brief Award.

J. Marshall Shepherd:

2001 Laboratory for Atmospheres Award for Outreach-Outstanding outreach on TRMM and Earth Sciences at Goddard.

Presenter and panelist at the City of New York's Graduate Center Symposium on Science and Mathematics. (February 2001).

Group Achievement Award-Outstanding Teamwork Horizon Proposal Development Team. 2001 NASA GSFC.

Served on Congressional Black Caucus Science Braintrust Panel (September 2001).

2001: Special Act Award for superior performance (Outreach Initiatives) NASA GSFC.

2001: Special Act Award for Superior Performance (HORIZON).

James Spinhirne:

2001: NASA Distinguished Service Award.

CLIMATE AND RADIATION BRANCH

Thomas Bell:

Laboratory for Atmospheres Scientific Research Award.

Robert Cahalan:

Elected to International Radiation Commission.

Mentor, 2001 NASA Academy.

David Herring (Earth Observatory Group):

NASA Public Service Group Achievement Award (Earth Observatory).

Lazaros Oreopoulos (JCET):

Climate and Radiation Award for Best Paper.

Steve Platnick (JCET):

Climate and Radiation Best Sr. Author Publication Award.

Max Suarez:

NASA Exceptional Scientific Achievement Medal.

Larry Wharton:

Laboratory for Atmospheres General Recognition Award.

ATMOSPHERIC EXPERIMENT BRANCH

Wayne Kasprzak:

Special Act Award presented by GSFC.

ATMOSPHERIC CHEMISTRY AND DYNAMICS BRANCH

John F. Burris:

Group Achievement Award

NASA Langley Research Center

Work on the SOLVE Mission

Michael K. Heney:

Chairman, Board of Directors, Space Frontier Foundation, January 1999 to Present.

President, Goddard Toastmasters, June 2001 to Present.

Jay Herman:

Special Act Award from GSFC.

Thomas J. McGee:

Group Achievement Award

NASA Langley Research Center

Work on the SOLVE Mission

Grant K. Sumnicht:

Group Achievement Award

NASA Langley Research Center

Work on the SOLVE Mission

Laurence W. Twigg:

Group Achievement Award

NASA Langley Research Center

Work on the SOLVE Mission

APPENDIX 9. 2001 ACRONYMS

ACE–Asia	Aerosol Characterization Experiment-Asia
ACMAP	Atmospheric Chemistry Modeling and Analysis Program
ACS	American Chemical Society
ADEOS	Advanced Earth Observation Satellite
AERONET	Aerosol Robotic Network
AETD	Applied Engineering and Technology Directorate
AGCM	Atmospheric Global Circulation Model
AIRS	Atmospheric Infrared Sounder
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
ARM	Atmospheric Radiation Measurement
ARM CART	ARM Cloud and Radiation Test Bed
AROTEL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
AT Lidar	Aerosol and Temperature Lidar
ATMS	Advanced Technology Microwave Sounder
ATOVS	Advanced TOVS
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BUV	backscatter ultraviolet
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	Convection And Moisture EXperiment
CCAST	Cooperative Center for Atmospheric Science and Technology
CCD	Convective Cloud Differential
CDC	Centers for Disease Control and Prevention
CEAS	Center for Earth-Atmosphere Studies
CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions
CERES	Clouds and the Earth's Radiant Energy System
CFCs	Chlorofluorocarbons
CHyMERA	Compact Hyperspectral Mapper for Environmental Remote Sensing Applications
CIFAR	Cooperative Institute for Atmospheric Research
CIMMS	Cooperative Institute of Meteorological Satellite Studies
CLAMS	Chesapeake Lighthouse and Aircraft Measurements for Satellites
CLIVAR	Climate Variability and Predictability Programme
CNES	Center Nationale d'Etude Spatiales
Co-I	Co-Investigator
CONTOUR	Comet Nucleus Tour
COVIR	Compact Visible and Infrared Radiometer
CPL	Cloud Physics Lidar
CrIS	Crosstrack Infrared Sounder
CRS	Cloud Radar System
CRYSTAL/FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers/Florida Area Cirrus Experiment
CSIRO	Commonwealth Scientific Industrial Research Organization
CSTEA	Center for the Study of Terrestrial and Extraterrestrial Atmospheres

CTM	Chemical Transport Model
DAAC	Distributed Active Archive Center
DAO	Data Assimilation Office
DAS	Data Assimilation System
DDF	Director's Discretionary Fund
DIAL	DIfferential Absorption Lidar
DISS	Distributed Image Spreadsheet
DMSP	Defense Meteorological Satellite Program
DWP	Doppler Wind Lidar
ECS	EOSDIS Core System
ECSO	Executive Committee for Science Outreach
EDOP	ER-2 Doppler Radar
EDR	Environmental Data Record
EMC	NCEP’s Environmental Modeling Center
ENSO	El Niño Southern Oscillation
ENVISAT	Environmental Satellite
EOS	Earth Observing System
EO3	Earth Observing 3 mission called GIFTS
EP-TOMS	Earth Probe TOMS
EPA	Environmental Protection Agency
EPIC	Earth Polychromatic Imaging Camera
ERBE	Earth Radiation Budget Experiment
ERBE TOA	Earth Radiation Budget Experiment Top-Of-Atmosphere
ESA	European Space Agency
ESE	Earth Science Enterprise
ESSIC	Earth System Science Interdisciplinary Center
ESSP	Earth System Science Pathfinder
E-Theater	Electronic Theater
FFPA	filter/focal plane array
FvDAS	Finite volume data assimilation system
GATE	GARP Atlantic Tropical Experiment
GCE	Goddard Cumulus Ensemble model
GCM	General Circulation Model
GCMS	Gas Chromatograph Mass Spectrometer
GEOS	Goddard Earth Observing System
GEST Center	Goddard Earth Sciences and Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GIFTS	Geosynchronous Imaging Fourier Transform Spectrometer
GISS	Goddard Institute for Space Studies
GLAS	Geoscience Laser Altimeter System
GLOBE	Global Learning and Observations to Benefit the Environment
GLOW	Goddard Lidar Observatory for Winds
GMS	Geostationary Meteorological Satellite
GOCART	Global Ozone Chemistry Aerosol Radiation Transport
GOES	Geostationary Operational Environmental Satellite
GoHFAS	Goddard Howard University Fellowship in Atmospheric Sciences
GOME	Global Ozone Monitoring Experiment
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Mission

GPS	Global Positioning Satellite
GSFC	Goddard Space Flight Center
GSRP	Graduate Student Researchers Program
GSWP	Global Soil Wetness Project
GTE	Global Tropospheric Experiment
GTWS	Global Tropospheric Wind Sounder
GV	Ground Validation
GVP	Ground Validation Program
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
HBCUs	Historically Black Colleges and Universities
HDTV	High Definition TV
HIRDLS	High Resolution Dynamics Limb Sounder
HIRS	High Resolution Infrared Sounder
HOTS	Holographic Optical Telescope and Scanner
HSB	Humidity Sounder Brazil
HU	Howard University
HUPAS	Howard University Program in Atmospheric Sciences
IAMAS	International Association of Meteorology and Atmospheric Sciences
ICESat	Ice, Cloud, and Land Elevation Satellite
IGS	Internal Government Studies
IHOP	International H20 Project
IIP	Instrument Incubator Program
INDOEX	Indian Ocean Experiment
INMS	Ion and Neutral Mass Spectrometer
IORD	Integrated Operational Requirements Document
IPCC	International Panel on Climatic Change
IPO	Integrated Program Office
IR	infrared
ISAS	Institute of Space and Aeronautical Science
ISCCP	International Satellite Cloud Climatology Project
ISIR	Infrared Spectral Imaging Radiometer
ITCZ	Intertropical Convergence Zone
JARG	Joint Agency Requirements Group
JCET	Joint Center for Earth Systems Technology
JCG	Joint Center for Geoscience
JCOSS	Joint Center for Observation System Science
JCSDA	Joint Center for Satellite Data Assimilation
JHU/APL	Johns Hopkins University Applied Physics Laboratory
JIESIC	Joint Interdisciplinary Earth Science Information Center (with George Mason University)
JPL	Jet Propulsion Laboratory
KAMP	Keys Area Microphysics Project
KWAJEX	Kwajalein Experiment
LaRC	Langley Research Center
LAS	Leonardo Airborne Simulator
LASAL	Large Aperture Scanning Airborne Lidar
LRR	Lightweight Rainfall Radiometer
MBA	microbolometer array
MEIDEX	Mediterranean Israeli Dust Experiment

MISR	Multi-Angle Imaging Spectroradiometer
MIT	Massachusetts Institute of Technology
MM5	Mesoscale Model 5
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Troposphere
MPL	Micro Pulse Lidar
MPL-Net	Micro Pulse Lidar Network
MSU	Microwave Sounding Unit
MTR	Management Technical Review
NAS	Numerical Aerospace Simulation
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency
NCAR	National Center for Atmospheric Research
NCCS	NASA Center for Computational Sciences
NCEP	National Center for Environmental Prediction
NDSC	Network for the Detection of Stratospheric Change
NESDIS	National Environmental Satellite Data and Information Service
NGI	Next Generation Internet
NGIMS	Neutral Gas and Ion Mass Spectrometer
NIEHS	National Institute of Environmental Health Sciences
NIIEM	Russian Scientific Research Institute of Electromechanics
NIST	National Institutes of Standards and Technology
NIWA	National Institute of Water and Atmospheric Research
NMNH	National Museum of Natural History
NMS	Neutral Mass Spectrometer
NOAA	National Oceanic Atmospheric Administration
NOAA CMDL	NOAA Climate Monitoring and Diagnostics Laboratory
NPOESS	National Polar Orbiting Environmental Satellite System
NPP	NPOESS Preparatory Project
NRC	National Research Council
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NSIPP	NASA Seasonal-to-Interannual Prediction Project
NTSC	National Television Standards Committee
NWP	Numerical Weather Prediction
NWS	National Weather Service
OAT	Operation Algorithm Team
ODIN	a Swedish small satellite project for astronomical and atmospheric research
OLR	Outgoing Longwave Radiation
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapper and Profiler System
OSIRIS	ODIN Spectrometer and IR Imager System
OSSE	Observing System Simulation Experiment
PI	Principal Investigator
PICASSO- CENA	Pathfinder Instruments for Cloude and Aerosol Spaceborne Observations-Climatologie Etendue des Nuages et des Aerosols
PLACE	Parameterization for Land Atmosphere Cloud Exchange
POAM	Polar Ozone and Aerosol Measurement
POES	Polar Orbiting Environmental Satellite

PR	Precipitation Radar
PRESTORM	Oklahoma-Kansas Preliminary Regional Experiment for STORM-Central
PRiDE	Puerto Rico Dust Experiment
PSAS	Physical-space Statistical Analysis System
PSC	Polar stratospheric clouds
QEM	Quality Education for Minorities
QuikSCAT	(NASA's) Quick Scatterometer satellite
QuikTOMS	spacecraft rapidly developed by Orbital Sciences Corp. to carry TOMS-5
RASL	Raman Airborne Spectroscopic Lidar
RCDF	Radiometric Calibration and Development Facility
RDAS	Retrospective data assimilation system
RTOP	Research and Technology Objectives and Plans
RTOVS	Revised TIROS-N Operational Vertical Sounder
SAFARI	Southern Africa Fire-Atmosphere Research Initiative
SAGE	Stratospheric Aerosol and Gas Experiment
SBIR	Small Business Innovative Research
SBUV	Solar Backscatter Ultraviolet
SBUV/2	Solar Backscatter Ultraviolet/version 2
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SCO	stratospheric column ozone
SCSMEX	South China Sea Monsoon Experiment
SeaWiFS	Sea-viewing Wide Field-of-View Sensor
SHADOZ	Southern Hemisphere ADditional OZonesondes
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies
SLP	Sea Level Pressure
SMART	Surface Measurements for Atmospheric Radiative Transfer
SMiR	Scanning Microwave Radiometer
SOARS	Significant Opportunities in Atmospheric Research and Science
SOAT	Sounder Operation Algorithm Teams
SOLAS	Surface Ocean Lower Atmosphere Studies
SOLSE/LORE	Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment
SOLVE	SAGE III Ozone Loss and Validation Experiment
SORCE	SOlar Radiation and Climate Experiment
SPANDAR	Space Range Radar, Wallops Island, VA
SPCZ	South Pacific Convergence Zone
SPIE	Society of Photo-Optical Instrumentation Engineers
SPRL	Space Physics Research Laboratory
SRL	Scanning Raman Lidar
SRT	Sounder Research Team
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSE	Space Science Enteprise
SSM/I	Special Sensor Microwave Imager
SST	sea surface temperature
SSU	Spectral Sensor Unit
STAAC	Systems, Technology, and Advanced Concepts Directorate

STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
STS	Space Transportation System
TCO	tropospheric column ozone
THOR	cloud THickness from Offbeam Returns
3S	Sun-Sky-Surface photometer
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TIROS	Television Infrared Observation Satellite
TMI	TRMM Microwave Imager
TOGA-COARE	Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment
TOMS	Total Ozone Mapping Spectrometer
TOMS3-F	Total Ozone Measurements by Satellites, Sondes, and Spectrometers at Fairbanks
TOPEX	Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TPW	total precipitable water
TRACE-P	TRAnsport and Chemical Evolution over the Pacific
TRMM	Tropical Rainfall Measuring Mission
TRMM LBA	Large Scale Biosphere-Atmosphere Experiment in Amazonia
TSVO	TRMM Satellite Validation Office
UARS	Upper Atmosphere Research Satellite
UAV	Unmanned Aerial Vehicle
UCAR	University Corporation for Atmospheric Research
UCLA	University of California - Los Angeles
UHI	Urban Heat Island
UMBC	University of Maryland Baltimore County
UMCP	University of Maryland College Park
URF	University Research Foundation
USRA	Universities Space Research Association
USWRP	U.S. Weather Research Program
UV	ultraviolet
UV-B	ultraviolet-B radiation
VAL	Visualization Analysis Laboratory
VSEP	Visiting Student Enrichment Program
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WMO/UNEP	WMO/United Nations Environment Programme
WVTs	Water vapor tracers