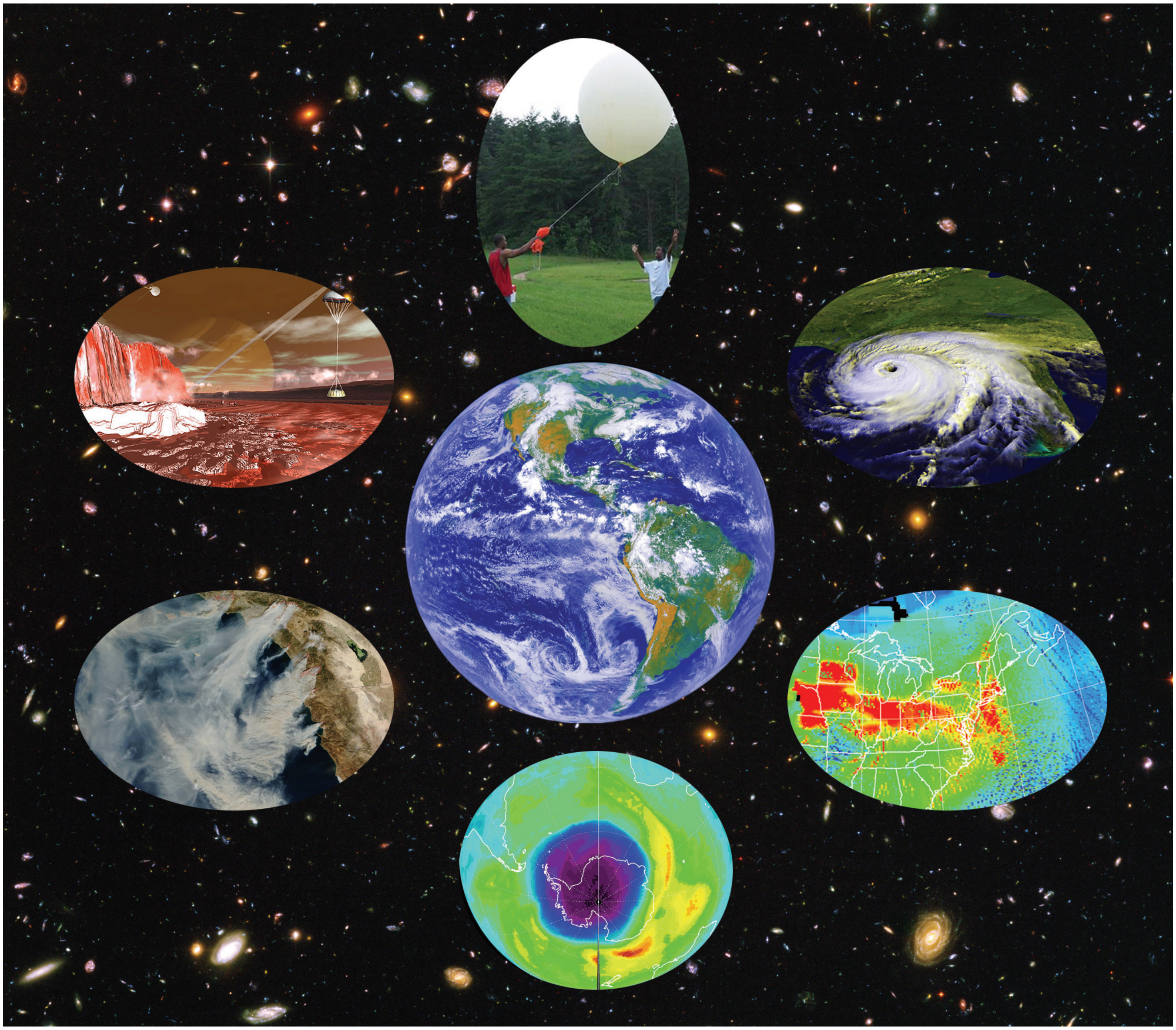
NASA/TM—2005–212782

Laboratory for Atmospheres 2004 Technical Highlights



National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

April 2005

Cover Caption

The seven images on the cover convey the interests and activities of the Laboratory for Atmospheres. The center image of the Earth (from GOES-8) represents the Laboratory's primary, but not exclusive, focus on Earth-related science. Clockwise, from the top, the surrounding images are as follows.

- A balloon launch by Howard University students during a summer program at their Beltsville, Maryland facility. This image represents the substantial involvement of the Laboratory in Education and Outreach activities.
- Hurricane Ivan approaching Florida's Gulf Coast on Sept. 15, 2004 (from GOES-12). This image represents the Mesoscale Atmospheric Processes Branch's interest in understanding the physics and dynamics of atmospheric processes, in part, through the use of satellite-based observations. This Branch focuses its research on all aspects of the hydrologic cycle, its connections to the global energy cycle, and associated weather hazards.
- Observation of the NO_2 burden over the Eastern United States made in November 2004 by the OMI instrument aboard the Aura satellite. The red areas represent relatively polluted areas having burdens of the order of 5×10^{15} molecules/cm^2. Several disciplines of interest to Laboratory scientists are supported by Aura observations.
- The Ozone Hole. This Earth Probe TOMS view of Antarctic ozone depletion (shown in purple) on October 5, 2004, the day of the ozone minimum, represents the Atmospheric Chemistry and Dynamics Branch's interest in understanding and predicting the long-term evolution of the ozone layer and changes in global air quality caused by human activity.
- The massive smoke plume emanating from fires in Southern California is illustrative of the interest of the Climate and Radiation Branch in studying the emissions of gaseous and particulate pollutants. This image was acquired by the MODIS sensor aboard the EOS Terra satellite on October 26, 2003 and was published on-line as the Branch's "Picture of the Week" in February 2004.
- An artist's conception of the landing of the Huygens Probe on Saturn's moon, Titan. Some of the instruments aboard the Cassini Orbiter and the Huygens Probe were developed by the Atmospheric Experiment Branch. This represents the Laboratory's interest in advancing knowledge of the atmospheres of other planets.
- The above images are superposed on a field of stars and galaxies shown by the Hubble Ultra Deep Field. The star field shown here is in the constellation Fornax and contains an estimated 10,000 galaxies. This represents the longer term goal of the Laboratory, of NASA, and of Humanity to explore the universe to the edge of our solar system and beyond.

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Laboratory Chief's Summary

Dear Reader:

Welcome to the Laboratory for Atmospheres' 2004 annual report. I thank you for your interest. We publish this report each year to describe our research and to summarize our accomplishments.

This document is intended for 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 work scope, our people and facilities, our place in NASA's mission, and our accomplishments for calendar year 2004.

The Laboratory's approximately 300 scientists, technologists, and administrative personnel are now part of the Earth-Sun Exploration Division in the Sciences and Exploration Directorate of the NASA Goddard Space Flight Center. This is due to NASA's transformation in response to the President's Exploration Initiative. This transformation has brought Earth Science and Space Science back together under one science umbrella. Our Laboratory will continue our mission of advancing the knowledge and understanding of the atmospheres of Earth and the planets.

The Laboratory had an exciting and productive year organizing and participating in international field campaigns, developing instruments, analyzing data, developing data sets, and improving our models. We saw a successful launch of the Aura spacecraft, and are now actively participating in validation studies and analysis of the data from Aura itself. Aura joins the complement of EOS satellites that will help us better understand our home planet's vital environment, and will increase our knowledge of the complex chemistry of the atmosphere.

We initiated the very successful Distinguished Lecturer Seminar Series, which focused on precipitation, clouds, aerosol and their physical/chemical linkages; details of the series can be found on our Web site, http://atmospheres.gsfc.nasa.gov.

As in previous years, Laboratory scientists garnered many top professional society honors. Anne Thompson was presented the International Achievement Award from Women in Aerospace; Marshall Shepherd was awarded the Presidential Early Career for Scientists and Engineers award in a White House ceremony; Robert Adler, Robert Atlas, Yoram Kaufman, and Joan Rosenfield were elected Fellows of the AMS; and Pawan Bhartia was presented the NASA Outstanding Leadership Medal. Warren Wiscombe was elected President of the Atmospheric Sciences Section of the AGU, and David Starr, the Secretariat of the International Commission on Clouds and Precipitation (ICCP). A complete list of award winners is given in the Web version of this report. I congratulate them for their outstanding achievements.

The year 2004 was also a time to bid farewell to a valuable civil servant member of the Laboratory, Anne Thompson, who retired but will be continuing her chemistry studies in the Meteorology Department at Penn State.

I am pleased to greet two new civil servants in the Laboratory during 2004, Daniel Glavin and Andrew Garcia.

Noteworthy events that took place during 2004 include: Extensive preparations were made for the Saturn–Titan encounter; the Saturn orbit insertion occurred in July 2004; the Probe release to Titan took place on December 25, 2004; and Probe entry into the atmosphere of Titan occurred on January 14, 2005. Goddard Space Flight Center was selected to lead an international team to develop an instrument suite for the Mars Science Laboratory, which will land on Mars in 2010 and operate on the surface for an entire Mars year (about two Earth years). Our Atmospheric Experiment Branch and Paul Mahaffy played a key role in the Mars Science Laboratory and the Sample Analysis at Mars (SAM) suite, which will assess the extent and nature of organic carbon compounds and take an inventory of the chemical building blocks of life. Robert Cahalan is chairing the Observations Working Group of the Climate Change Science Program Office, tasked to evaluate and coordinate multi-agency contributions to the U.S. Government climate observing system. James Gleason was appointed NPP Project Scientist. Proposal winners for developing instruments for UAV applications were Matt McGill for the Cloud Physics Lidar, and Bruce Gentry for a Doppler receiver for measuring Tropospheric winds.

Because of the transformation, the Laboratory lost the Atmospheric Experiment Branch, which moved to the Solar System Exploration Division. We wish Hasso Niemann and all of his Branch members continued success under the new organizational structure.

This report is being published in two forms: an abridged printed version, and a full electronic version on our Laboratory for Atmospheres Web site. Check out our Web site. It continues to be redesigned to be more informative for our scientists, colleagues, and the public. We welcome comments—which may be submitted via the Web site—on this 2004 report and on the Web material.

Sincerely,

William K.-M. Lau,
Chief, Laboratory for Atmospheres, Code 613

April 2005

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PREFACE

This Technical Highlights for 2004 is the product of the efforts of all of the members of the Laboratory for Atmospheres. Their dedication to advancing knowledge of Earth and Space Science has produced many significant results, which can only be briefly highlighted in this report.

The production of the report has been under the guidance of our Laboratory Chief, William K.-M. Lau. Our Associate Chief, Charles E. Cote, checked the report for accuracy, suggested some simplifications, and has spun off an expanded Instrument Report. Laura Rumburg, who was responsible for gathering the material for the Major Activities section, has carefully proofread the report. Richard Stewart designed the cover, contributed to a highlight article, and composed the Education and Outreach section. Jean Howard, who did a superb job on the Laboratory Brochure, organized meetings, and kept watch on the report's timeliness. The administrative staff in the Branch offices and in the Laboratory office, were a great help in gathering material, and cajoling Lab members into responding to our requests. Elaine Firestone performed the final editing and formatting, turning our product into a polished report in a most timely manner. Goran Halusa, our Laboratory Web Master, who has greatly improved our Web site, is responsible for publishing the expanded version of the report on our Laboratory Web site, http://atmospheres.gsfc.nasa.gov.

This is my last year as Editor—it has been a very rewarding experience working with the staff and members of the Laboratory for Atmospheres on these reports.

—Walter R Hoegy

Mission: Advance Knowledge and Understanding of the Atmospheres, of the Earth and Other Planets

1. INTRODUCTION

As a result of the recent transformation, the Laboratory for Atmospheres (Code 613) is now part of the Earth–Sun Exploration Division (Code 610) under the Sciences and Exploration Directorate (Code 600) based at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

In line with NASA's Exploration Initiative, the Laboratory executes a comprehensive research and technology development program dedicated to advancing knowledge and understanding of the atmospheres of the Earth and other planets. The research program is aimed at: understanding the influence of solar variability on the Earth's climate; predicting the weather and climate of the Earth; understanding the structure, dynamics, and radiative properties of precipitation, clouds, and aerosols; understanding atmospheric chemistry, especially the role of natural and anthropogenic trace species on the ozone balance in the stratosphere and the troposphere; and advancing our understanding of physical properties of the atmospheres and ionospheres of the Earth and other planets.

The research program identifies problems and requirements for atmospheric observations via satellite missions. Laboratory scientists conceive, design, develop, and implement ultraviolet, infrared, optical, radar, laser and lidar technology for remote sensing of the terrestrial and planetary atmospheres. Laboratory members conduct field measurements for satellite data calibration and validation, carry out computer-based climate model simulations, observing system simulation studies, cloud resolving scale modeling, develop next-generation Earth system models, and climate process submodels. Interdisciplinary research is carried out in collaboration with other laboratories and research groups within the new Earth–Sun Exploration Division, as well as across the Sciences and Exploration Directorate.

The Laboratory for Atmospheres is a vital participant in NASA's research agenda. Our Laboratory often has relatively large programs, sizable satellite missions, or observational campaigns that require the cooperative and collaborative efforts of many scientists. We 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.

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.

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. The Laboratory makes substantial efforts to attract new scientists to the various areas of atmospheric research. We strongly encourage the establishment of partnerships with federal and state agencies that have operational responsibilities to promote the societal application of our science products.

This report describes our role in NASA's mission, gives a broad description of our research, and summarizes our scientists' major accomplishments during calendar year 2004. The report also contains useful information on human resources, scientific interactions, and outreach activities. This report is published in two versions: a printed version, and an unabridged electronic version on our Laboratory for Atmospheres Web site, http://atmospheres.gsfc.nasa.gov/.

2. STAFF, ORGANIZATION, AND FACILITIES

2.1 Staff

The diverse staff of the Laboratory for Atmospheres is made up of scientists, engineers, technicians, administrative assistants, and resource analysts, with a total staff of about 300.

The civil servant composition of the Laboratory consists of 70 members, plus 14 co-located members (4 resource analysts, 1 scientist, 1 project manager, 4 engineers, and 4 technicians). Of the 70 in-house civil servants, 62 are scientists, 2 are engineers, and 1 a technical manager. Out of the 64 civil servant scientists and engineers, 90% hold doctoral degrees.

An integral part of the Laboratory staff is composed of onsite research associates and contractors. The research associates are primarily members of joint centers between the Earth Sciences Directorate and nearby university associations (JCET[1], GEST[2], and ESSIC[3]), or are employed by universities with which the Laboratory has a collaborative relationship, such as George Mason University, University of Arizona, and Georgia Tech. Out of the 74 research associates, 84% hold Ph.D.'s. The onsite contractors are a very important component of the staffing of the Laboratory. Out of the total of 142 onsite contractors, 22% hold Ph.D.'s. The makeup of our Laboratory, therefore, is 28% are civil servants, 25% are associates, and 47% are contractors.

The refereed publication output of the Laboratory members is shown in Figure 2-1. The difference between the red and blue bars gives the number of papers that our scientists co-authored with outside scientists and is one measure of our extensive collaboration. The reduced numbers in 2004 is due in part to the spin off of the Global Modeling and Assimilation Office (GMAO), which is no longer a part of our Laboratory, and to the implementation of full cost accounting, which necessitates increased time spent on proposal writing.

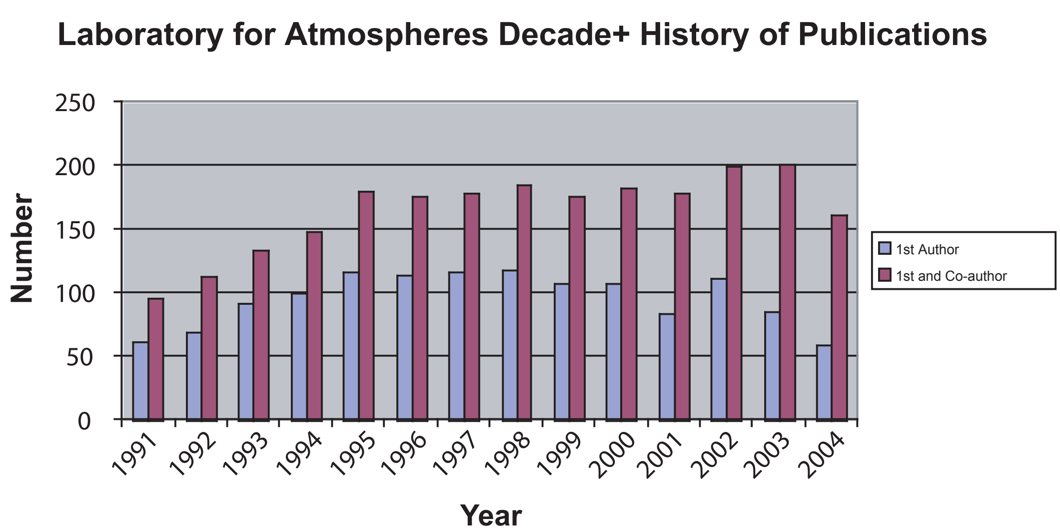


Figure 2-1. Number of refereed publications by Laboratory for Atmospheres members over the years. The red bar is the total number of publications where a Laboratory member is the first author or co-author, and the blue bar is the number of publications where a Laboratory member is first author.

2.2 Organization

The management and branch structure for the Laboratory for Atmospheres during 2004 is shown in Figure 2-2.

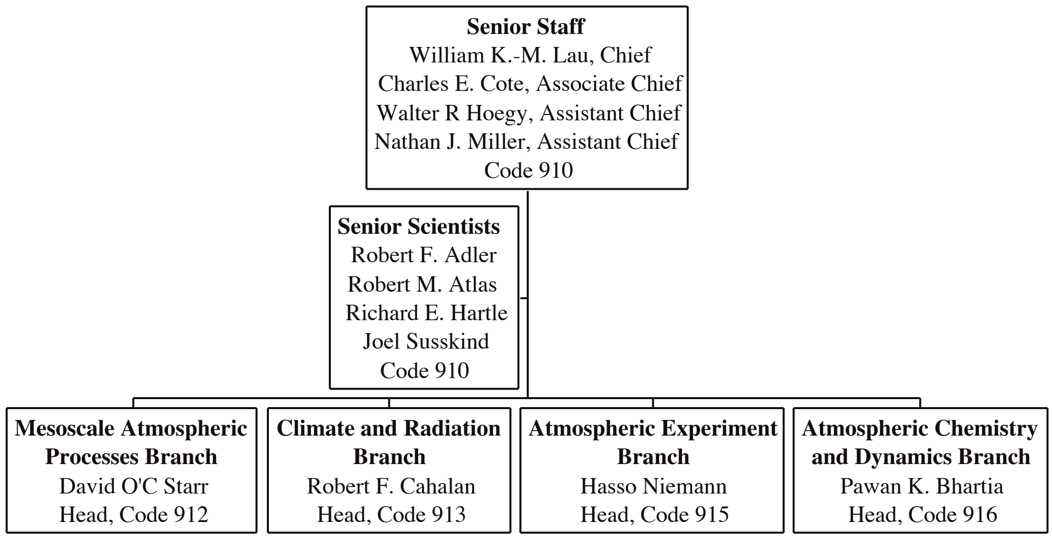


Figure 2-2. Laboratory for Atmospheres organization chart during calendar year 2004.

As a result of the Exploration Initiative and the transformation/reorganization of NASA GSFC, our new organization chart appears in Figure 2-3.

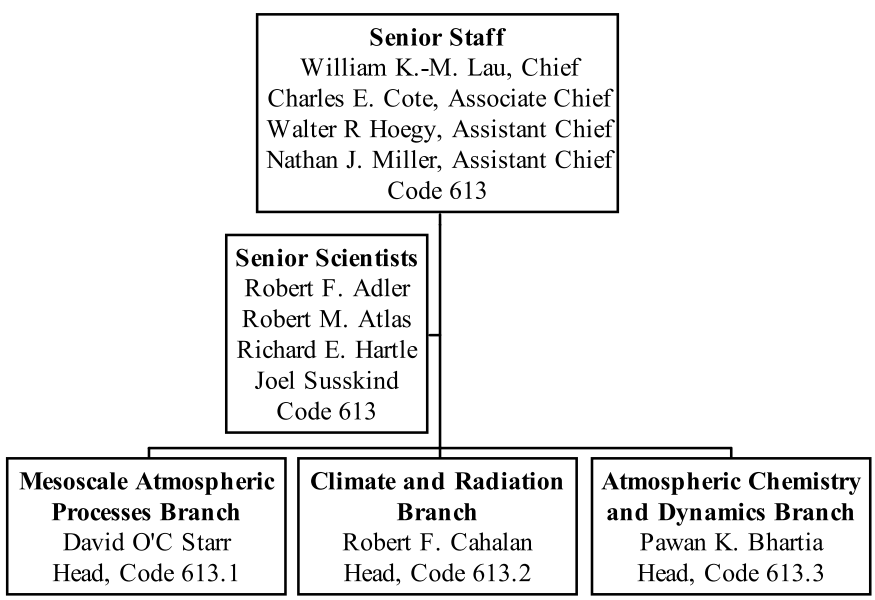


Figure 2-3. Laboratory for Atmospheres organization chart after the transformation, for calendar year 2005.

2.3 Branch Descriptions

The Laboratory has traditionally been organized into branches; however, we work on science projects that are becoming more and more cross-disciplinary. Branch members collaborate with each other within their branch, across branches, and across Divisions within the Directorate. Some of the recent cross-disciplinary research themes of interest in the Laboratory are the Global Water and Energy Cycle, Carbon Cycle, Weather and Short-Term Climate Forecasting, Long-Term Climate Change, Atmospheric Chemistry, Aerosols, and Planetary Studies. The employment composition of the Senior Staff Office (910) and the four Branches is broken down by Civil Servant, Associate, and Contractor are shown in Figure 2-4.

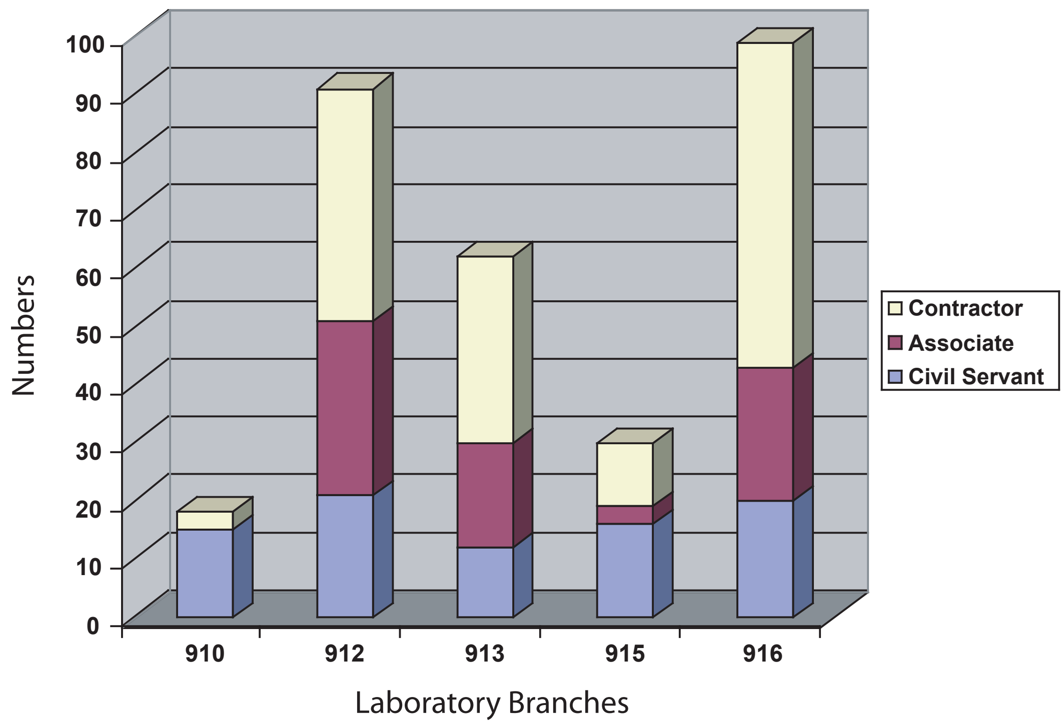


Figure 2-4. Employment composition of the members of the Laboratory for Atmospheres.

A brief description is given for each of the Laboratory's four Branches. Later, in Section 5, the Branch Heads summarize the science goals and achievements of their branches. The Branch summaries are supplemented by a selection of press releases and samples of highlighted journal articles, given in Appendices A1 and A2, respectively.

Mesoscale Atmospheric Processes Branch, Code 912

The mission of this Branch is to understand the physics and dynamics of atmospheric processes through the use of satellite, airborne, and surface-based remote sensing observations and computer-based simulations. Development of advanced remote sensing instrumentation (primarily lidar) and techniques to measure meteorological parameters in the troposphere is an important focus. Key areas of investigation are cloud and precipitation systems and their environments, including aerosols, from the scale of individual clouds and thunderstorms to mesoscale convective systems and cyclonic storms, and their climate impacts at regional and global scales. The processes constituting the interaction of the atmosphere with the land and ocean surface are also of high priority. The Branch, therefore, focuses its research on all aspects of the atmospheric hydrologic cycle, its connections to the global energy cycle, and associated hazards. The Branch also seeks to contribute to the formulation of mission concepts to support planetary exploration, both measurements and modeling concerned with the assessment of meteorological hazards. Further information about Branch activities may be found on the Web (http://rsd.gsfc.nasa.gov/912/code912/).

Climate and Radiation Branch, Code 913

The Climate and Radiation Branch has a threefold mission:

(1) to understand, assess, and predict climate variability and change, including the impact of natural forcings and human activities on climate now and in the future;
(2) to assess the impacts of climate variability and change on society; and
(3) to consider strategies for adapting to, and mitigating, climate variability and change.

To address this mission, a wide-scale range is studied, from the microscale to the Sun–Earth distance in space, and from microsecond to geologic in time. Research focus areas include tropospheric aerosols, cloud processes, rainfall, solar radiation, and surface properties. Key disciplines are radiative transfer, both as a driver for climate change and as a tool for the remote sensing of parameters of the Earth's climate system; climate theory and modeling over the full range of scales; and the development of new methods for the analysis of climate data. Ongoing projects in cooperation with NASA partners address gaps in the current climate observing system, development and deployment of new instruments, and planning for future space-based and *in situ* missions. Further information about Branch activities may be found on the 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 upper atmosphere of the Earth. The Branch developed and is constantly refining neutral gas, ion, and gas chromatograph mass spectrometers to measure atmospheric gas composition using entry probes and orbiting satellites. Further information about Branch activities may be found on the Web (http://webserver.gsfc.nasa.gov/). In early 2005, the Atmospheric Experiment Branch moved out of our Laboratory to reside in the new Solar System Exploration Division as a laboratory. Our former Branch is playing a leading role in the new Exploration Initiative.

Atmospheric Chemistry and Dynamics Branch, Code 916

The Atmospheric Chemistry and Dynamics Branch conducts research on remote sensing of aerosols and atmospheric trace gases from satellite, aircraft, and ground, and develops computer-based models to understand and predict the long-term evolution of the ozone layer and changes in global air quality caused by human activity. Recent focus has been on understanding the interaction between atmospheric chemistry and climate change. The Branch develops and maintains research quality, long-term data sets of ozone, aerosols, and surface UV radiation for assessment of the health of the ozone layer and its environmental impact. It continues its long history of providing science leadership for NASA's atmospheric chemistry satellites, such as TOMS and UARS, and the recently launched EOS Aura. The Aura satellite hosts four advanced atmospheric chemistry instruments designed to study the evolution of stratospheric ozone, climate, and air quality. Analysis of Aura data will be the central focus of the Branch activities in the coming years. Further information on Branch activities may be found on the Web (http://hyperion.gsfc.nasa.gov/).

Branch Web sites may also be found by clicking on the Laboratory home page (http://atmospheres.gsfc.nasa.gov/).

2.4 Facilities

Computing Capabilities

Computing capabilities used by the Laboratory range from high-performance supercomputers to scientific workstations to desktop personal computers. Each Branch maintains its own system of computers, which are a combination of Windows, Linux, and Mac OS X computers. The major portion of scientific data analysis and manipulation, and image viewing is still done on the cluster machines with increasing amounts of data analysis and imaging done on single user personal computers.

Mass Spectrometry

The Atmospheric Experiment Branch's Mass Spectrometry Laboratory is equipped with unique facilities for designing, fabricating, assembling, calibrating, and testing flight-qualified mass spectrometers used for atmospheric sampling. The facility has been used to develop instruments for exploring the atmospheres of Earth, Venus, Saturn, and Mars (on orbiting spacecraft), and of Jupiter and Titan (on probes). The Branch has moved out of our Laboratory and now resides in the Solar System Exploration Division.

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 nm to beyond 1,000 nm are available, as is a range of sensitive photon detectors for use throughout this wavelength region. Details may be found in the Laboratory for Atmospheres Instrument Systems Report (NASA-TP-2005-212783).

Radiometric Calibration and Development Facility

The Radiometric Calibration and Development Facility (RCDF) supports the calibration and development of instruments for ground- and space-based observations for atmospheric composition including gases and aerosols. As part of the Earth Observing System (EOS) calibration program, the RCDF provides calibrations for all national and international ultraviolet and visible (UV/VIS) space-borne solar backscatter instruments, which include the Solar Ultraviolet/Version 2 (SBUV/2) and Total Ozone Mapping Spectrometer (TOMS) instruments, and the European backscatter instruments flying on Envisat and Aura. The RCDF also provides laboratory resources for developing and testing of advanced space-borne instruments being developed in the Laboratory for Atmospheres. In addition, ground-based sky-viewing instruments used for research and validation measurements of chemistry missions, such as Envisat and Aura, are also supported in the RCDF. The facility maintains state-of-the-art instrument radiometric test equipment and has a close relationship with the National Institute of Standards and Technology (NIST) for maintaining radiometric standards. For further information contact Ernest Hilsenrath (ernest.hilsenrath@nasa.gov).

Footnotes:

[1] Joint Center for Earth Systems Technology
[2] Goddard Earth Sciences and Technology Center
[3] Earth System Science Interdisciplinary Center

3. OUR RESEARCH AND ITS PLACE IN NASA'S MISSION

NASA's overall program, outlined in the Agency's strategic plan of 2003, has influenced the direction of our research effort in Earth and Space Science in recent years. The new vision for space exploration has resulted in the transformation of NASA's goals and has produced a reorganization of NASA Headquarters and the NASA Centers during 2004. The former seven strategic enterprises have been transformed into four components or mission offices: Exploration Systems, Space Operations, Science, and Aeronautics Research. Following NASA Headquarters, Goddard Space Flight Center has reorganized and formed one Directorate combining Earth and Space Science into the Sciences and Exploration Directorate. The three Divisions under the new Sciences and Exploration Directorate are Earth–Sun Exploration, Solar System Exploration, and Exploration of the Universe. The Laboratory for Atmospheres is under the Earth–Sun Exploration Division. During 2004, one of our branches—the Atmospheric Experiment Branch, has been our Laboratory's main contributor to Space Science. Effective at the end of 2004, the Atmospheric Experiment Branch will transition into the Solar System Exploration Division. Our remaining three Branches, Mesoscale Atmospheric Processes, Climate and Radiation, and Atmospheric Chemistry and Dynamics will continue their strong programs of research in Earth Sciences and in this way, will make significant contributions to the President's Exploration Initiative. The remainder of this section outlines the connection of our research to NASA's mission and strategic plans.

3.1 Earth Science and Space Science in the Laboratory for Atmospheres

The Laboratory for Atmospheres has a long history (40+ years) in Earth Science and Space Science missions studying atmospheres of Earth and the planets. The wide array of our work reflects this dual history of atmospheric research:

(1) from the early days of the TIROS and Nimbus satellites with emphasis on ozone, Earth radiation, and weather forecasting; and

(2) from the thermosphere and ionosphere satellites, the Orbiting Geophysical Observatory (OGO), the Explorer missions, and Pioneer Venus Orbiter to the recent Galileo mission, and current Cassini mision.

A current focus is on global climate change and one goal is to increase the accuracy and lead-time with which we can predict weather and climate change. The Laboratory for Atmospheres conducts basic and applied research in the cross-disciplinary research areas outlined in Table 1, and Laboratory scientists focus their efforts on satellite mission planning, instrument development, data analysis, and modeling.

Table 1: Science themes and our major research areas.

Science Themes	Major Research Areas
Aerosol Atmospheric Chemistry Carbon Cycle Climate Change Global Water and Energy Cycle Weather and Short-term Climate Forecasting Geodynamics and Solid Earth Planetary Studies	• Aerosol • Atmospheric Chemistry and Ozone • Atmospheric Hydrologic Cycle • Carbon Cycle • Clouds and Radiation • Climate Variability and Prediction • Mesoscale Processes • Precipitation Systems • Planetary Studies • Severe Weather • Chemistry-Climate Modeling • Global and Regional Climate Modeling • Data Assimilation

Our work can be classified into four primary activities or products: measurements, data sets, data analysis, and modeling. Table 2 depicts these activities and some of the topics they address.

Table 2: Laboratory for Atmospheres Science Activities.

Measurements	Data Sets	Data Analysis	Modeling
Aircraft Balloon Field campaigns Ground Space	Assimilated products Global precipitation MODIS cloud and aerosol TOMS aerosol TOMS surface UV TOMS total ozone TOVS Pathfinder TRMM Global precipitation products TRMM validation products	Aerosol cloud climate interaction Aerosol Atmospheric hydrologic cycle Climate variability and climate change Clouds and precipitation Global temperature trends Ozone and trace gases Radiation UV-B measurements Validation studies	Atmospheric chemistry Clouds and mesoscale Coupled climate–ocean Data assimilation Data retrievals General circulation Radiative transfer Transport models Weather and climate

Classification in the four major activity areas: measurements, data sets, data analysis, and modeling, is somewhat artificial, in that the 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, generate data sets, analyze the data, model the data, and ask the next question.

4. MAJOR ACTIVITIES

The previous section outlined the science activities pursued in the Laboratory for Atmospheres. This section presents summary paragraphs of our major activities in measurements, field campaigns, data sets, data analysis, and modeling. In addition, we summarize the Laboratory's support for the National Oceanic and Atmospheric Administration's (NOAA) remote sensing requirements. The section concludes with a listing of project scientists, a description of interactions with other scientific groups, and a statement of our interest in commercialization and technology transfer.

4.1 Measurements

Studies of the atmospheres of Earth and the planets require a comprehensive set of observations, relying on instruments borne on spacecraft, aircraft, balloons, or those that are ground-based. Our instrument systems 1) provide information leading to basic understanding of atmospheric processes, and 2) serve as calibration references for satellite instrument validation.

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. Airborne instruments provide critical *in situ* and remote measurements of atmospheric trace gases, aerosol, ozone, and cloud properties. Airborne instruments also serve as stepping-stones in the development of spaceborne instruments, and serve an important role in validating spacecraft instruments.

Table 3 shows the principal instruments that were 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 3 also indicates each instrument's deployment—in space, on aircraft, balloons, on the ground, or in the laboratory. Instrument details are not presented here, but appear in a separate Laboratory technical publication, the "Instrument Systems Report," NASA-TP-2005-212783.

Table 3: 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 Polychromatic Imaging Camera (EPIC)		Gas Chromatograph Mass Spectrometer (GCMS)– Cassini Huygens Probe Ion and Neutral Mass Spectrometer (INMS)– Cassini Orbiter
Aircraft/Balloon	ER-2 Doppler Radar (EDOP) Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) Air Goddard Lidar Observatory for Winds (Air GLOW)	Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTAL) Raman Airborne Spectroscopic Lidar (RASL)	Cloud Physics Lidar (CPL) cloud THickness from Offbeam Returns (THOR) Lidar Cloud Radar System (CRS) UAV Cloud Physics Lidar (UAV CP Lidar)	
Ground/ Laboratory/ Development	Scanning Raman Lidar (SRL) Goddard Lidar Observatory for Winds (GLOW) Lightweight Rain Radiometer-X band (LRR-X)	Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE) Aerosol and Temperature Lidar (AT Lidar) Brewer UV Spectrometer Kiritimati Island Lidar Trailer (KILT) Lagrange-2 Solar Viewing Interferometer Prototype (L2-SVIP) Instrument Incubator Program (IIP) GeoSpec (IIP)	Micro-Pulse Lidar (MPL) COmpact Visible Infrared Radiometer (COVIR) Surface-Sensing Measurements for Atmospheric Radiative Transfer (SMART)—Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere (COMMIT)	

4.2 Field Campaigns

Field campaigns use the resources of NASA, other agencies, and other countries to carry out scientific experiments, to validate satellite instruments, 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-based systems are also used for soundings, remote sensing, and other radiometric measurements. In 2004, Laboratory personnel supported many such activities as scientific investigators, or as mission participants, in the planning and coordination phases.

Aura Validation Experiment (AVE)

AVE is a measurement campaign designed to acquire correlative data needed for the validation of the Aura satellite instruments. Aura was launched in July 2004 with four instruments: OMI, TES, MLS, and HIRDLS. Aura has three science objectives: 1) analyze the recovery of the ozone layer, 2) assess air quality problems, and 3) determine how the Earth's climate is changing.

The first component of the AVE mission (Pre-AVE) was conducted during January–February 2004. Measurements were made in the western U.S. and the tropics from San Jose, Costa Rica using the NASA WB-57F high altitude aircraft. The objective of Pre-AVE was to test concepts for using high-quality *in situ* and remote data sets for Aura validation. The high altitude NASA WB-57F carried 18 *in situ* instruments and 1 remote sensing instrument. During this campaign, a total of eight flights were conducted (one test, two mid-latitude flights, three equatorial flights, and two transit flights between Houston and San Jose, Costa Rica).

The second component of AVE (AVE-October) was conducted during October–November 2004. Again, measurements were made in the western U.S. and over the Gulf of Mexico in support of Aura. During AVE-October, the payload consisted of 11 instruments (8 *in situ* and 3 remote sensing). A total of eight flights were conducted that were precisely timed to coincide with the Aura overpass. For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov).

Figure 4-1. Picture of the Galapagos Islands taken from the NASA WB-57F from an altitude of 60,000 feet on January 30, 2004. Photo by Brian J. Barnett (NASA JSC).

CPL Activities

During 2004, the Cloud Physics Lidar (CPL) was modified to operate on the NASA WB-57F aircraft. Historically the CPL has operated only on the ER-2 aircraft. Future missions, however, will require use of the WB-57F, so it became imperative to adapt CPL to that aircraft. Mechanical, thermal, and data system modifications were required for operation on the WB-57F.

After modifications were made, the CPL participated in the first Aura Validation Experiment (AVE) conducted from Ellington Field in Houston, TX from October 18 to November 12, 2004. The purpose of this experiment was to validate the instruments onboard the Aura satellite. A total of nine satellite underflights were performed under a variety of atmospheric conditions.

For more information on the CPL instrument, or for access to CPL data, visit http://cpl.gsfc.nasa.gov/, or contact Matthew McGill (matthew.j.mcgill@nasa.gov).

United Arab Emirates Unified Aerosol Experiment (UAE^2)

The Goddard Surface-sensing Measurements for Atmospheric Radiative Transfer (SMART) facility deployed successfully in the United Arab Emirates Unified Aerosol Experiment (UAE^2, http://uae2.gsfc.nasa.gov/index.html) from August–September 2004 near the oasis of Al Ain city, UAE. UAE^2 was conducted by the regional scientists and authorities in concert with researchers from NASA AERONET, U.S. Naval Research Laboratory (NRL) aerosol group, and aircraft research team at the University of the Witwatersrand, South Africa. This experiment used ground-based and airborne instruments in the vicinity of the Persian Gulf to characterize the chemical, microphysical, optical and radiative properties of the regional dust and anthropogenic aerosols, and to aid in the satellite retrievals (http://code916.gsfc.nasa.gov/Missions/UAE/images.html) for assessing the aerosol impact on the regional-to-global climate. SMART (http://smart-commit.gsfc.nasa.gov/) is a mobile, ground-based remote sensing facility (8' × 8' × 20' weather-sealed trailer with thermostatic temperature control), which includes a sun photometer, a rotating shadow-band radiometer, a micropulse lidar, a solar spectrometer, an interferometer, a whole-sky imager, a microwave radiometer, an array of shortwave and longwave flux radiometers, and a system of surface meteorological probes. MPLNET supplied one of the lidars and performed data analysis on the lidars.

During UAE^2, we devoted a great deal of effort to characterize the surface radiative properties of deserts by using in-house, custom-built instruments. The differential warming/cooling effects exerted by atmospheric aerosols constitute one of the most uncertain factors in climate change related research. This is especially true over regions of bright-reflecting surface, such as desert areas. Furthermore, one of the key ingredients for achieving accurate aerosol retrievals from satellite observations is a comprehensive understanding of surface spectral-bidirectional reflectance. Working under daytime dead heat of ~35–45°C and a wide range of relative humidity (~10–80%), we have acquired many first-hand, first-class data sets of surface radiative properties. Currently, the compilation of these spectral-bidirectional reflectances of desert surface is underway for community use. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

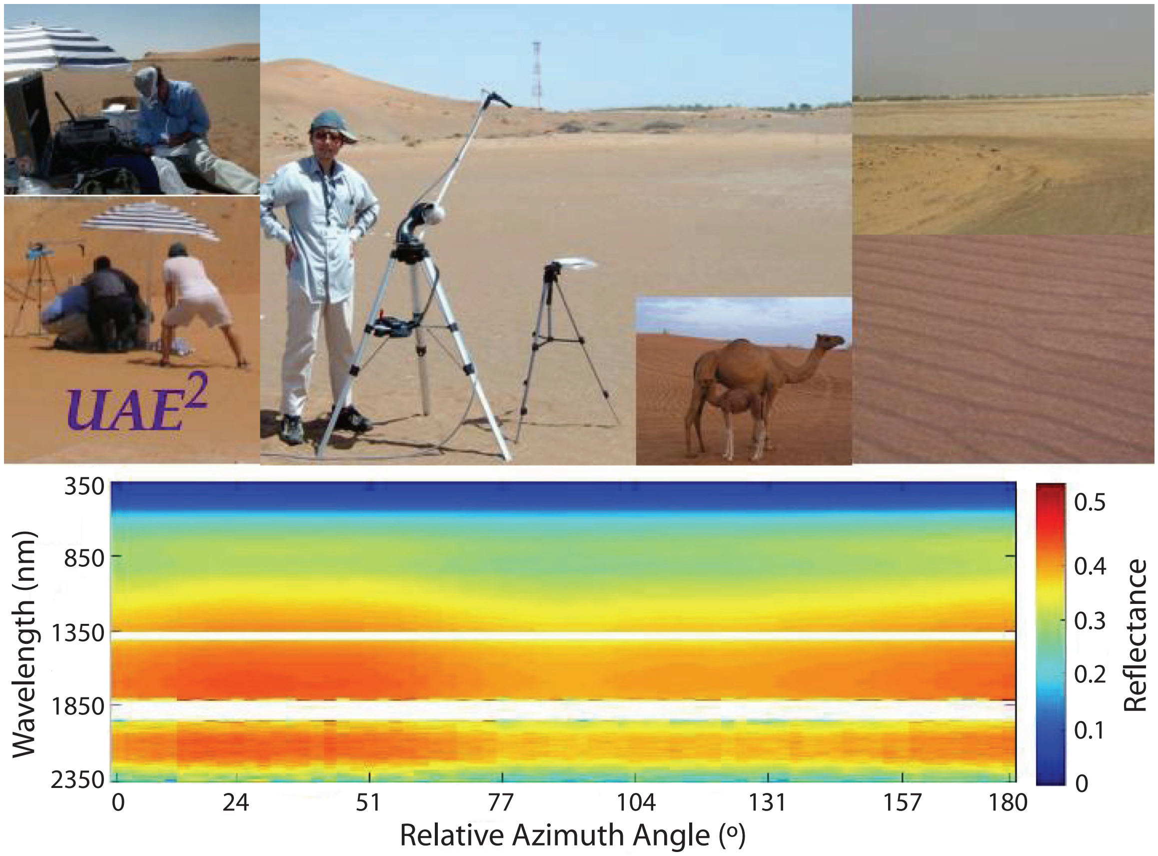


Figure 4-2. "Light through a Camel's Eyes" What is seen in a camel's eyes through reflected sunlight by hazy desert? To assist satellite retrievals of aerosol properties over desert regions, we deployed our "camel robot"—a spectroradiometer mounted on a tripod seen in the center panel. The team of NASA/University researchers are shown in the left panel. The color of the surface ranged from dull white near the coast (the remains of oceanic wash-up) to pinkish-red inland (pictures in the right panel). One of the key ingredients for achieving accurate aerosol retrievals from satellite observations is a comprehensive understanding of surface spectral Bidirectional Reflectance Factors (BRFs), defined as a ratio of radiance measurements reflected from a targeted surface and from a spectral-angular featureless referencing plate (cf. instrument setup in the center panel). Shown in the bottom panel is the spectral (350–2500 nm) characteristics of BRF's acquired at one of the inland sites around 13:20 local time on October 1, 2004.

4.3 Data Sets

In the previous discussion, we examined the array of instruments and some of the field campaigns that produce the atmospheric data used in our research. The raw and processed data from these instruments and campaigns is used directly in scientific studies. Some of this data, plus data from additional sources, is arranged into data sets useful for studying various atmospheric phenomena. The major data sets are described in the following paragraphs.

50-Year Chemical Transport Model (CTM) Output

A 50-year simulation of stratospheric constituent evolution has been completed using the Code 916 three-dimensional chemistry and transport model. Boundary conditions were specified for chlorofluorocarbons, methane, and N_2O appropriate for the period 1973–2023. Sulfate aerosols were also specified, and represent the eruptions of El Chichón and Mt. Pinatubo. Simulations with constant chlorine and without the volcanic aerosols have also been completed to help distinguish chemical effects from effects of interannual variability in meteorological fields. The model output from all simulations is available on the Code 916 science system; software to read the output is also available. Although the CTM itself is run at 2° × 2.5° latitude/longitude horizontal resolution; the output is stored at 4° × 5° latitude/longitude. Higher resolution files are available from UniTree, the Code 930 archive. The model output stored on the science system is for six days each month (1, 5, 10, 15, 20, 25); daily fields are saved on UniTree. Details about this and other CTM simulations are available from the Code 916 Web site at http://code916.gsfc.nasa.gov/Public/Modelling/3D/exp.html. Questions or comments should be addressed to Anne Douglass (Anne.R.Douglass@nasa.gov).

Aerosol Products from TOMS and OMI

Laboratory scientists are generating a unique new data set of atmospheric aerosol by reanalyzing the 17-year data record of Earth's ultraviolet albedo as measured by TOMS. Since 1996, Laboratory staff members have developed techniques for extracting aerosol information from measured UV radiances. TOMS aerosol detection capability is based on the change in spectral contrast of upwelling near-UV radiances at the top of an aerosol-laden atmosphere. The spectral contrast variability is measured in relation to that of a pure molecular atmosphere. The near-UV technique differs from conventional visible methods of aerosol detection in that the UV measurements can separate UV-absorbing aerosol (such as desert dust, smoke from biomass burning, and volcanic ash) from nonabsorbing aerosol (such as sulfates, sea salt, and ground-level fog). In addition, the UV technique can detect aerosol over water and land surfaces, including deserts where traditional visible and near-IR methods do not work. TOMS aerosol data are currently available in the form of a contrast index and as near-UV extinction optical depth.

The aerosol index is a qualitative parameter that provides excellent information about absorbing aerosol sources, transport, and seasonal variation of a variety of aerosol types. The aerosol index is the only known remote-sensing technique capable of detecting desert dust, smoke, and volcanic ash aerosol over snow or ice and clouds. The most recent version of the data, based on Version 8 reprocessing, has been released.

The science value of the TOMS aerosol information has been enhanced by the application of an inversion procedure to the TOMS measured radiances to derive the near-UV extinction optical depth and single-scattering albedo of aerosol. The combination of these two products yields the aerosol absorption optical depth. Figure 4-3 shows the retrieved TOMS extinction optical depth and single scattering albedo of the dense smoke plume formed during the fires in California in October 2003. The third panel shows the resulting aerosol absorption optical depth.

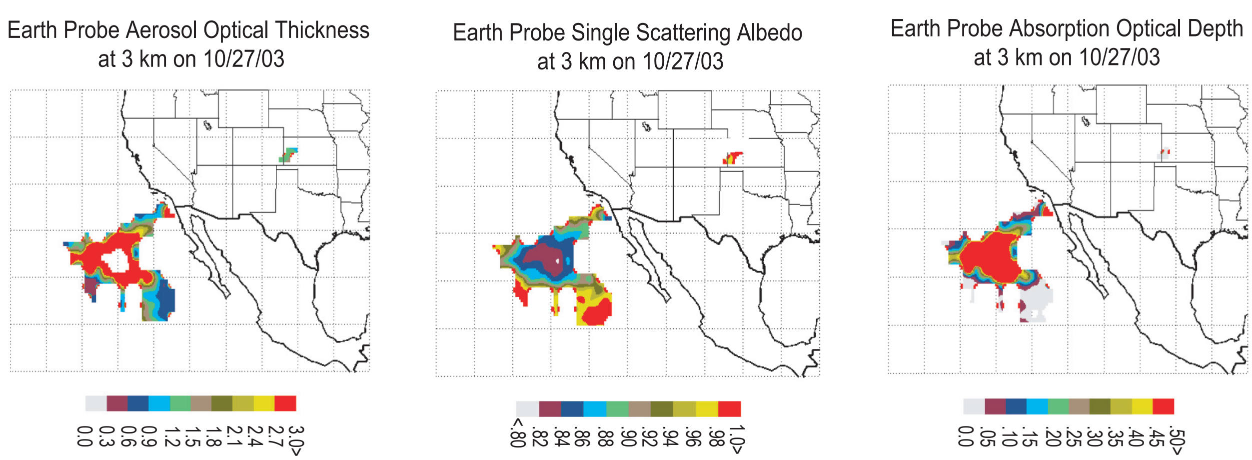


Figure 4-3. TOMS retrievals of aerosol extinction optical depth, single scattering albedo, and absorption optical depth of the aerosol layer produced by fires in Southern California in late October 2003.

The TOMS aerosol algorithm has been applied to the entire TOMS record to produce the longest available data set on aerosol optical depth over the oceans and the continents at a 1° × 1° resolution. The TOMS aerosol optical depth record (available at http://toms.gsfc.nasa.gov/aerosols/aot.html) is a useful data set for the analysis of aerosol trends, especially over land areas, where aerosol sources are located, and no other long-term records are available.

Analysis of the TOMS long-term record on aerosol optical depth has detected the existence of statistically significant trends in the atmospheric aerosol load over China and India, as shown in Figure 4-4. The TOMS aerosol record indicates that an increasing trend of 17% per decade in the winter aerosol load has taken place in the China coastal plain. A similar analysis also shows a 7% per decade trend in aerosol concentration in India. These TOMS observed trends in aerosol optical depth are consistent with observed increases of SO_2 emissions associated with anthropogenic activities in these regions.

For more information on the TOMS aerosol optical depth and single-scattering albedo products, contact Omar Torres (torres@tparty.gsfc.nasa.gov).

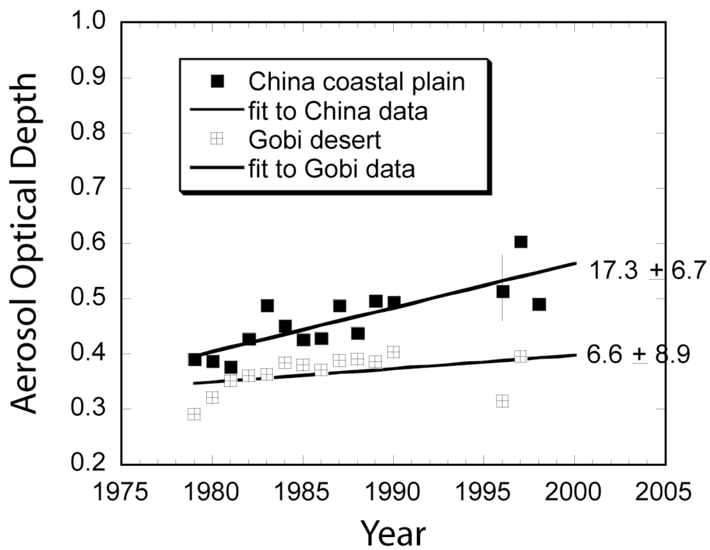


Figure 4-4. Trends in aerosol optical depth in China and India as derived from TOMS observations.

The near-UV record of aerosol properties will be extended into the future making use of observations by the Ozone Monitoring Instrument (OMI) on the Aura spacecraft, launched on July 2004. Figure 4-5 shows preliminary retrieval results of aerosols over Australia derived from OMI observations.

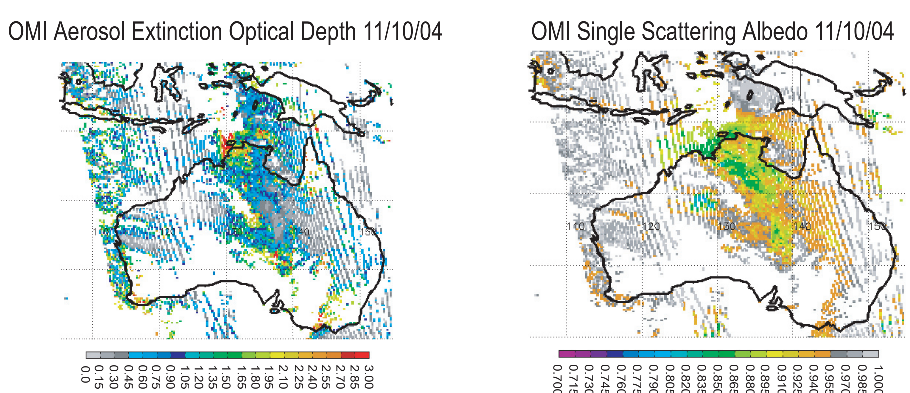


Figure 4-5. OMI retrieved optical depth and single scattering albedo over Australia on November 10, 2004.

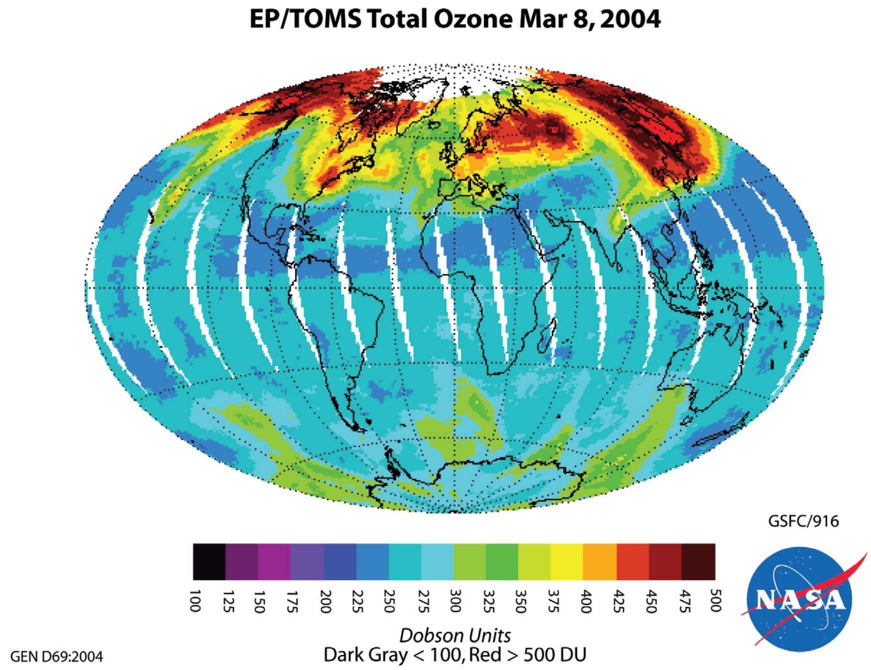


Figure 4-6. Polar image and partial day data set updated for March 8, 2004. The latest daily image and a full-day data set are updated once each day (when we have a full day of data). This near-real time system is automated.

Global Precipitation

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 climatic fluctuations and trends 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 the period, January 1979 to the 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) and at the Goddard Distributed Active Archive Center (DAAC). Evaluation is ongoing for this long-term data set in the context of climatology, El Niño Southern Oscillation (ENSO)-related variations, and regional and global trends. The seven-year TRMM data set is being used in the assessment of the longer GPCP data set.

Development of data sets with finer time resolution (daily and 3 h) is proceeding. A daily, global analysis for the period 1997–present has also been completed for the GPCP and is available from the archives. A quasi-global, 3 h resolution rainfall analysis combining TRMM and other satellite data is being produced in real time, with images and data available through the TRMM Web site. A research version of this 3 h data set will soon be available. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Merged TOMS/SBUV Data Set

We have recently updated our merged satellite total ozone data set to include the Version 8 TOMS and SBUV data. We have transferred the calibration from the original six satellite instruments to the NOAA 16 SBUV/2. This allows us to extend the record despite issues with the calibration of the Earth Probe TOMS (EP-TOMS) for the last few years. The data sets now extend through the end of 2003. We have added a merged profile data set from the SBUV instruments. The data, and information about how they were constructed, can be found at http://code916.gsfc.nasa.gov/Data_services/merged. It is expected that these data will be useful for trend analyses for ozone assessments and for scientific studies in general. During 2005, we will update the data through the end of 2004 and will incorporate the data from the OMI instrument on Aura as soon as it has gone through its calibration checks. For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (smh@code916.gsfc.nasa.gov).

MPLNET Data Sets

The Micro-Pulse Lidar Network (MPLNET) is composed of ground-based lidar systems, co-located with sun–sky photometer sites in the NASA Aerosol Robotic Network (AERONET). The MPLNET project uses the MPL system, which is a compact and eye-safe lidar capable of determining the range of aerosols and clouds continuously in an autonomous fashion. The unique capability of this lidar to operate unattended in remote areas makes it an ideal instrument to use for a network. The primary purpose of MPLNET is to acquire long-term observations of aerosol and cloud vertical structure at key sites around the world. These types of observations are required for several NASA satellite validation programs, and are also a high priority in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The combined lidar and sun photometer measurements are able to produce quantitative aerosol and cloud products, such as optical depth, sky radiance, vertical structure, and extinction profiles. MPLNET results have contributed to studies of dust, biomass, marine, and continental aerosol properties, the effects of soot on cloud formation, aerosol transport processes, and polar clouds and snow. MPLNET data has also been used to validate results from NASA satellite sensors, such as the Multi-Angle Imaging Spectroradiometer (MISR) and TOMS, and to help construct algorithms used to interpret space-based lidar data from GLAS. MPLNET sites will be used as ground calibration/validation sites for NASA's next satellite lidar—CALIPSO. Further information on the MPLNET project, and access to data, is available online at http://mplnet.gsfc.nasa.gov. For questions on the MPLNET project contact Judd Welton (Judd.Welton@nasa.gov).

Multiyear Global Surface Wind Velocity Data Set

The Special Sensor Microwave Imagers (SSM/I) aboard 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 was limited by the lack of directional information. In an effort to extend the applicability of these data, our scientists developed methodology to assign directions to the SSM/I wind speeds and to produce analyses using these data. This methodology has been used since 1987 to generate 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. In addition, a new higher resolution integrated data set in which data from all SSM/I and available scatterometers from 1987 to the present is now being produced. For more information, contact Robert Atlas (Robert.M.Atlas@nasa.gov).

Southern Hemisphere ADditional OZonesondes (SHADOZ) Data Set

Initiated by NASA's Goddard Space Flight Center in 1998, in collaboration with NOAA and meteorological and space agencies from around the world, SHADOZ augments balloonborne ozonesonde launches in the tropics and subtropics. SHADOZ presently includes 13 sites, including 2 that are north of the equator (Suriname and Malaysia). Launches are usually weekly at each station. SHADOZ archives ozone and temperature profile data at a user-friendly, open Web site: http://croc.gsfc.nasa.gov/shadoz. SHADOZ ozone data are used for a number of purposes:

(1) Satellite algorithm retrievals and validation of satellite measurements,
(2) Mechanistic studies of processes affecting ozone distributions in the tropical stratosphere and troposphere, and
(3) Evaluation of photochemical and dynamical models that simulate ozone.

SHADOZ has led to significant scientific advances. For example, satellite retrievals are using longitudinal and seasonal variations in tropical ozone for the first time. By having so many profiles, it has been possible to improve accuracy and precision of the ozonesonde measurement under tropical conditions. All SHADOZ stations fly a radiosonde electrochemical concentration cell (ECC) ozonesonde combination. The World Meteorological Organization (WMO) uses SHADOZ as the paradigm for developing new ozone sounding stations in WMO's Global Atmospheric Watch (GAW) program. In 2004, SHADOZ methods were tested in a field campaign called BESOS: Balloon Experiment on Standards for Ozonesondes. For additional details, contact Anne Thompson (anne@met.psu.edu). The archive URL is located at http://croc.gsfc.nasa.gov/shadoz.

Skyrad Ground-Based Observations

Skyrad, a ground-based measurement program to observe the zenith sky, continues to investigate radiative transfer properties of the atmosphere in the near-UV and visible (300–500 nm). The purpose of these observations is to test the accuracy of the Laboratory's highly regarded radiative transfer models, to improve ozone algorithms (for both ground and space), and to validate orbiting satellite instruments, which also operate in this wavelength range. There are now several U.S. and international instruments in orbit (Aura, TOMS, and Envisat) operating in this wavelength range. The observations are taken from the Laboratory's Radiometric Calibration and Development Facility (RCDF), which houses several ground-based instruments, notably the Shuttle Solar Backscatter Ultraviolet (SSBUV) and a double monochromator Brewer instrument. This location is ideally suited for these studies because several instruments measuring aerosols (AERONET and sun photometers) are located near the RCDF.

Nearly three years of zenith sky data have been taken over a range of sky conditions using SSBUV. In addition, an accurate set of tables of expected zenith sky radiances were calculated for conditions over Goddard including a range of aerosol characteristics and ozone amounts. Comparisons of observations and models resulted in differences of less than 3%. The zenith data are also being used to derive ozone column amounts and aerosol characteristics in the ultraviolet at high solar zenith angles. Accurate ground-based measurements of ozone under these conditions are desperately needed for validation of satellite data. Errors in satellite observation are the largest at high solar zenith angles, a critical region for observing ozone trends. The GSFC Brewer monochromator has been modified and further calibrated to measure, in addition to ozone, nitrogen dioxide, sulfur dioxide, and the absorbing properties of aerosols, which is a new application for this instrument. These measurements are being proposed for local air-quality observations and for validating the Ozone Monitoring Instrument (OMI) flying on Aura as well as similar instruments flying on European satellites. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath@nasa.gov) and Jay Herman (Jay.herman@nasa.gov).

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 TOVS. TOVS is composed 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 1979–2004 and consists of global fields of surface skin and atmospheric temperatures, atmospheric water vapor, cloud amount, and cloud height, Outgoing Longwave Radiation (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 AIRS data on EOS Aqua. We have demonstrated with the 25-year TOVS Pathfinder Path A data set that TOVS data can be used to study interannual variability and trends of surface and atmospheric temperatures and humidity, cloudiness, OLR, and precipitation. The TOVS precipitation data is being incorporated in the monthly and daily GPCP precipitation data sets.

We have also developed the methodology used by the AIRS science team to generate products from AIRS for weather and climate studies, and continue to improve the AIRS science team retrieval algorithm. A new algorithm, Version 4.0, was recently delivered to JPL. The Goddard DAAC has been producing AIRS level-2 soundings since September 2002 using an early version of the AIRS science team retrieval algorithm. The DAAC will begin producing improved AIRS level-2 soundings starting in February 2005 based on the Version 4.0 AIRS Science Team retrieval algorithm. All products obtained in the TOVS Pathfinder data set will also be produced from AIRS, including precipitation estimates. In joint work with Robert Atlas, AIRS temperature profiles derived using this improved retrieval algorithm have been assimilated into the Laboratory forecast analysis system and have shown a significant improvement in weather prediction skill. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

TOMS Data Sets

Since the Atmospheric Chemistry and Dynamics Branch first formed, it has been tasked with making periodic ozone assessments. Through the years the Branch has led the science community in conducting ozone research by making measurements, analyzing data, and modeling the chemistry and transport of trace gases that control the behavior of ozone. This work has resulted in a number of ozone and related data sets based on the TOMS instrument. The first TOMS instrument flew onboard the Nimbus-7 spacecraft and produced data for the period from November 1978 through May 6, 1993 when the instrument failed. Data are also available from the Meteor-3 TOMS instrument (August 1991–December 1994) and from the TOMS that flew on the Earth Probe spacecraft (July 1996–present).

TOMS data are given as daily files of ozone, reflectivity, aerosol index, and erythemal UV flux at the ground. A new Version 8 algorithm was released in 2004, which addresses errors associated with extreme viewing conditions. These data sets are described on the Atmospheric Chemistry and Dynamics Branch Web site, which is linked to the Laboratory Web site, http://atmospheres.gsfc.nasa.gov/. Click on the Code 916 Branch site, and then click on Data Services. The TOMS spacecraft and data sets are then found by clicking on TOMS Total Ozone data. Alternatively, TOMS data can be accessed directly from http://toms.gsfc.nasa.gov.

Tropospheric O_3 Studies

In 2004, our branch members developed a long record (1979–present time) of tropospheric and stratospheric ozone from TOMS satellite measurements, extending from the tropics to the high latitudes in both hemispheres. In a recently submitted paper in the *Journal of Geophysical Research*, this data set was used to determine long-term changes in ozone in both the troposphere and stratosphere. The paper discusses the important issues of stratospheric ozone recovery and the long-term increase in tropospheric ozone related to an increase in industrial pollution. Also in 2004, satellite measurements of tropospheric ozone were used to characterize the ozone pollution in the Northern Hemisphere. This study indicated that ozone values over surface emission-free regions of the Atlantic and Pacific Oceans are relatively high (50–60 DU) and are comparable to industrial regions of North America, Europe, and Asia where surface emissions of NO_x from industrial sources are significantly high. For more information, contact Jerry Ziemke (Jerald.R.Ziemke.1@gsfc.nasa.gov).

4.4 Data Analysis

A considerable effort by our scientists is spent in analyzing the data from a vast array of instruments and field campaigns. This section details some of the major activities in this endeavor.

Aerosol and Water Cycle Dynamics

Aerosol can influence the regional and possibly the global water cycle by changing the surface energy balance, and altering cloud and rainfall patterns via direct and indirect effects. On the other hand, condensation heating from rainfall, and radiative heating from clouds and water vapor associated with fluctuations of the water cycle drive circulation, which determines the residence time, and transport of aerosols, and their interaction with the water cycle. Understanding the mechanisms and dynamics of aerosol-clouds-precipitation, and eventually implementing realistic aerosol-cloud microphysics in climate models are clearly important pathways to improve the reliability of predictions by climate and Earth system models. Laboratory scientists are involved in analyses of the interrelationships among satellite derived quantities such as cloud optical properties, effective cloud radii, aerosol optical thickness (MODIS, TOMS, Cloudsat, and CALIPSO) in conjunction with rainfall, water vapor, cloud liquid water (TRMM, AMSR), with large scale circulation, moisture convergence (ECMWF and NCEP re-analyses) in different climatic regions of the world, including the semi-arid regions of southwest U.S., the Middle East, Northern Africa, and central and western Asia, as well as the extremely wet monsoon regions of South and East Asia, South America and West Africa. The empirical studies will be coordinated with modeling studies, using global and regional climate models, as well cloud resolving models, coupled to land surface and vegetation models, and ocean models. A major goal of this research is to develop a fully interactive climate-aerosol climate system model, including data assimilation, so that atmospheric water cycle dynamics can be studied in a unified modeling and observational framework. This research also calls for the need to organize and coordinate field campaigns for aerosol and water cycle measurements in conjunction with GEWEX, CLIVAR, and other WCRP international programs on aerosols and water cycle studies. For more information, contact William Lau (William.K.Lau@nasa.gov), Mian Chin (Mian.Chin@nasa.gov), Lorraine Remer (Lorraine.A.Remer@nasa.gov), or W.K. Tao (Wei-Kuo.Tao-1@nasa.gov)

Atmospheric Hydrologic Processes and Climate

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 output, and assimilated data. Diagnostic studies are combined with modeling studies to unravel physical processes underpinning climate variability and predictability. The key areas of research include ENSO, monsoon variability, intraseasonal oscillation, air–sea interaction, and water vapor and cloud feedback processes. More recently, the possible impact of anthropogenic aerosol on regional and global atmospheric water cycle is also included. A full array of standard and advanced analytical techniques, including wavelets transform, multivariate empirical orthogonal functions, singular value decomposition, canonical correlation analysis, nonlinear system analysis, and satellite orbit-related sampling calculations are used. Maximizing the use of satellite data for better interpretation, sampling, modeling, and eventually prediction of geophysical and hydroclimate systems 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, and land surface characteristics are obtained from a number of different projects: the EOS Terra and Aqua series; TRMM, Quick Scatterometer Satellite (QuikSCAT) and Topography Experiment (TOPEX)/Poseidon; the Earth Radiation Budget Experiment (ERBE); Clouds and the Earth's Radiant Energy System (CERES); the International Satellite Cloud Climatology Project (ISCCP); Advanced Very High Resolution Radiometer (AVHRR); TOMS; SSM/I; MSU; and TOVS Pathfinder. Diagnostic and modeling studies of diurnal and seasonal cycles of various geophysical parameters will be conducted using satellite data to validate climate model outputs, and to improve physical parameterization in models. For more information, contact William Lau (William.K.Lau@nasa.gov) or Yogesh Sud (Yogesh.C.Sud@nasa.gov).

Atmospheric Ozone Research

The Clean Air Act Amendment of 1977 assigned NASA the 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, with 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, both into the stratosphere from the troposphere, and out of the stratosphere to the troposphere. 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@nasa.gov).

First Measurements of Trace Gases (NO_2, SO_2, HCHO, O_3) Amounts Using a Brewer Double Monochromator

O_3, NO_2, HCHO, and SO_2 column amounts were measured by using a modified double Brewer spectrometer in direct-sun mode. A new "bootstrap" solar irradiance method of solar calibration has enabled the Brewer spectrometer to detect NO_2, HCHO, and SO_2 with a sensitivity of approximately 0.4 DU. The method for obtaining the column amounts uses a modified DOAS (spectral fitting) technique having the advantage that measured direct sun slant-column amounts can be accurately converted into vertical column amounts without needing to know the height distribution or making the unlikely assumption of horizontal homogeneity, especially in urban areas. The method described in this study can be applied to the worldwide Brewer network to obtain global distributions of pollution related trace gas amounts. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

First Simultaneous UV and Visible Wavelength Measurements of Aerosol Scattering and Absorption Properties

Very little is known about aerosol absorption in UV compared to the visible spectral region. Without such information, it is impossible to quantify the causes of the observed discrepancy between modeled and measured UV irradiances and photolysis rates. We have performed an aerosol UV absorption closure experiment using a UV-shadowband radiometer and a well-calibrated CIMEL sun–sky run side-by-side continuously for 17 months at the NASA GSFC site in Greenbelt, Maryland. The new combination of the two instruments has enabled the first determination of consistent aerosol scattering and absorption properties in both the visible and UV wavelength regions. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

Impact of Aerosols on Atmospheric Heating and Rainfall

The impact of smoke aerosols generated from biomass burning activities in Southeast Asia on the total reflected solar and emitted thermal radiation (direct and indirect effects) from clouds was investigated using satellite data. Narrowband radiance measurements were combined with broadband irradiance measurements to quantify how smoke aerosols modulate the cloud radiative forcing. Results show that smoke in Southeast Asia is frequently present over large areas of cloud-covered regions during boreal spring. Depending on the loading of the smoke aerosols, the reflected solar (emitted thermal) radiation from clouds was reduced by as much as 100 Wm^{-2} or enhanced by as much 20 Wm^{-2} during spring conditions.

The effect of smoke aerosols produced by agricultural practice from the Indochina peninsula on the precipitation over Southern China was carried out using long-term (~20 years) measurements of cloud fraction, precipitation, wind circulation, and aerosols from the combined satellite and model reanalysis data sets. We found that there are statistically significant indirect effects from smoke aerosols on clouds and precipitation in Southeast and East Asia region. Results show that the precipitation increased downstream from the peak aerosol concentrations and decreased in regions of high aerosol loading. This is caused by aerosols absorption of short wave radiation increasing air temperature and stabilizing the atmosphere in the area with high aerosol loading. These patterns are consistently observed during March through early May when more aerosols are produced from biomass burning. Mean southwesterly winds transport aerosols from biomass burning regions over dry Indochina to southern China where the mean climate is wetter in the pre-monsoon season spring of each year. Based on current measurements we find that the southern China monsoon now starts a couple weeks earlier than the climatological mean onset date because of precipitation increased by aerosol–cloud interaction. We also found that the increase is not due to a northward shift of tropical cloud systems. These results help us understand the impact of large-scale biomass burning on the fresh water distribution in Southeast Asia and also help in the prediction of the onset of the tropical monsoon system. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

Observing System Simulation Experiments

Observing system simulation experiments (OSSEs) are an important tool for designing spaceborne meteorological sensors, developing optimum methods for using satellite soundings and winds, and assessing the influence of satellite data on weather prediction and climate research. 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 other advanced passive sensors. For more information, contact Robert Atlas (Robert.M.Atlas@nasa.gov).

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:

- 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 for improved estimations.

- An empirical relationship that relates cloud thickness, humidity, and other parameters to rain rates, using TOVS and Aqua–AIRS sounding retrievals.

- An analysis technique that uses TRMM, other 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 quasi-global (50°N, 50°S) 3-h 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@nasa.gov).

Rain Measurement Validation for 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 is being established with accuracies that meet mission requirements. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Unified Onboard Processing and Spectrometry

Increasingly, scientists agree that spectrometers are the wave of the future in passive Earth remote sensing. The difficulty, however, stems from the vast volume of data generated by an imaging spectrometer sampling in the spatial and spectral dimensions. The data volume from an advanced spectrometer could easily require 10 times the present EOS Data Information System (EOSDIS) capacity—something NASA simply cannot afford. A group of scientists and engineers at GSFC, led by Si-Chee Tsay, is funded (3rd year) by ESTO Advanced Component Technologies (ACT), which is a project to unify onboard processing techniques with compact, low-power, low-cost, Earth-viewing spectrometers being developed for eventual space missions. The philosophy is that spectrometry and its onboard processing algorithms must advance in lockstep, and eventually unite in an indistinguishable fashion. 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. In the meantime, we must quickly find ways to losslessly compress (onboard) spectra, using a combination of physics-based removal and proximal differencing, to the maximum extent possible. A system of hyperspectral imager (Quantum Well Infrared Photodetectors) has been integrated and flight-tested in a Navy research aircraft for building a testbed. Currently, we are analyzing an effective flat-fielding algorithm, which will be applied to the Field Programmable Processor Array, also known as Reconfigurable Data Path Processor (FPPA/RDPP) software simulator. In the meantime, we are implementing a cloud-detection algorithm in the FPPA/RDPP software simulator. The final goal is to demonstrate both flat-fielding and cloud-detection in "Real Time." We are also exploring lossy compressions for specific applications in Earth sciences. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

4.5 Modeling

Modeling is an important aspect of our research, and is the path to understanding the physics and chemistry of our environment. Models are intimately connected with the data measured by our instruments: models are used to interpret data, and the data is combined with models in data assimilation. Our modeling activities are highlighted below.

Aerosol Modeling (GOCART)

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. Aerosol is also a key component determining air quality. To understand the various processes that control aerosol properties and to understand the role of aerosol in atmospheric chemistry and climate, we have developed an atmospheric aerosol model, the GOCART model. This model uses the meteorological fields produced by the Goddard Global Modeling and Assimilation Office (GMAO, Code 900.3), and includes major types of aerosols: sulfate, dust, black carbon, organic carbon, and sea salt. Among these, sulfate, and black- and organic carbon originate mainly from human activities—such as fossil fuel combustion and biomass burning—while dust and sea salt are mainly generated by natural processes, for example, uplifting dust from deserts by strong winds.

We have been using the GOCART model to study intercontinental transport, global air quality, aerosol radiative forcing, and aerosol–chemistry–climate interactions. It has also been used to support aircraft and satellite observations and for analyzing satellite and atmospheric measurement data. The output of the model is used by many groups worldwide for studies of air pollution, radiation budget, tropospheric chemistry, hydrological cycles, and climate change. For more information, contact Mian Chin (Mian.Chin@nasa.gov), or go to the Web site http://code916.gsfc.nasa.gov/People/Chin/aot.html.

Cloud and Mesoscale Modeling

The mesoscale model 5 (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, hurricanes, winter storms, cold 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, cloud–aerosol interactions, and stratospheric–tropospheric interaction. Other important applications include long-term integrations of the models that allow for the study of air–sea, cloud–aerosol, cloud–chemistry (transport) and cloud–radiation interactions and their role in cloud–climate feedback mechanisms. Such simulations provide an integrated system-wide assessment of important factors such as surface energy, precipitation efficiency and radiative exchange processes, and diabatic heating and water budgets associated with tropical, subtropical, and mid-latitude weather systems. Data collected during several major field programs, GATE, (1974), PRESTORM (1985), TOGA COARE (1992–1993), ARM (1997, 2000), SCSMEX (1998), TRMM LBA (1999), TRMM KWAJEX (1999), WMO01 (2001), CAMEX4 (2001), CRYSTAL (2002), and IHOP (2002) has been 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 central U.S.

and China). 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, and moist processes represented in large-scale models (i.e., weather forecast model and climate model). Both Open MultiProcessing (OpenMP) and Message Passing Interface (MPI) versions of the GCE model are developed and can be efficiently run on different computing platforms. This allows the GCE model to be used in many applications related to NASA missions.

Several Goddard Microphysical schemes (2ICE, 3ICE), Goddard radiation (including explicitly calculated cloud optical properties), Goddard Land Information System (LIS, including the CLM and NOAH land surface models), rainfall and bogus vortex assimilation techniques and diagnostics are being implemented into the *Weather Research and Forecast* (WRF). The WRF is the next generation regional-scale model that will replace MM5 and the NOAA NCEP numerical prediction model. In addition, a coupled Goddard fvGCM and GCE model is being developed. The use of the fvGCM will enable global coverage, and the use of a high-resolution GCE model will allow for better and more sophisticated physical parameterization.

The scientific output of the modeling activities was again exceptional in 2004 with 12 new papers published and many more submitted. For more information, contact Wei-Kuo Tao (WeiKuo.Tao.1@gsfc.nasa.gov).

Global Modeling Initiative

The Global Modeling Initiative (GMI) was initiated under the auspices of the Atmospheric Effects of Aircraft Program in 1995. The goal of GMI is to develop and maintain a state-of-the-art modular 3-D chemistry and transport model (CTM) that can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including, but not exclusively, the effect of aircraft. The GMI model also serves as a testbed for model improvements. The goals of the GMI effort are threefold:

(1) Reduce uncertainties in model results and predictions by understanding the processes that contribute most to the variability of model results, and by evaluation of model results against existing observations of atmospheric composition;
(2) Understand the coupling between atmospheric composition and climate through coordination with climate models; and
(3) Contribute to the assessment of the anthropogenic perturbations to the Earth system.

At present, the GMI model exists in separate tropospheric, stratospheric, and aerosol versions. Stratospheric simulations ozone trends have been carried out from 1995 to 2030 using the winds from the NASA Finite Volume General Circulation Model (fvGCM) and the NASA Finite Volume Data Assimilation System (fvDAS). Additional simulations for the years 1973–2025 have been carried out using a "warm" and "cold" realization of fvGCM meteorological fields. Tropospheric simulations have been carried out for 1997 conditions, utilizing winds from GMAO, as well as the Middle Atmosphere Community Climate Model (MACCM version 3), and the Goddard Institute for Space Studies (GISS-II'). The results have been evaluated by comparing them to existing ground-based, aircraft, and remotely-sensed measurements. Sensitivities of a new aerosol model (University of Michigan) to meteorological fields and chemical inputs are also being tested. For more information, contact Jose Rodriguez (jrodriguez@code916.gsfc.nasa.gov).

Physical Parameterization in Atmospheric GCM

The development of submodels of physical processes (physical parameterizations) is an integral part of better preparing the climate models for addressing the remaining outstanding climate change issues. Laboratory scientists are actively involved in developing and improving physical parameterizations of the moist processes affecting land–atmosphere interaction, as well as clouds and cloud-radiation and cloud-aerosol interactions.

The accuracy of such process-interactions is extremely important for eliminating climate-model biases, which is vital 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 with parameterized direct effects of man-made and natural aerosols. The radiation codes allow efficient computation of climate sensitivities to water vapor, cloud microphysics, and optical properties of clouds and aerosols. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

The second key area of climate model development is the cloud physics itself. Almost all of the state-of-the-art models of our times develop large simulation biases, that are often larger than the outstanding climate change issues which need to be assessed by these models; it is primarily due to the biased heating and moistening fields simulated by the model's cloud physics. We are evaluating and eliminating such simulation biases of McRAS, an in-house prognostic cloud-scale dynamics and cloud water substance scheme that includes representation of source and sink terms of cloud-scale condensation, microphysics of precipitation and evaporation, as well as horizontal and vertical advection of cloud water substance. Our cloud scheme incorporates attributes from physically based cloud life cycles, effects of convective updrafts and downdrafts, cloud microphysics within convective towers and anvils, cloud-radiation interactions, cloud-aerosol interactions, and cloud inhomogeneity corrections for radiative transfers. The boundary-layer clouds are based on the physics of boundary-layer convection. We are evaluating coupled radiation and the prognostic water schemes with *in situ* observations from the ARM Cloud and Radiation Test Bed (ARM-CART) and TOGA COARE IOPs, as well as satellite data. Recently, GCM-simulated diurnal cycle of rainfall, that shows significantly different characteristics in different regions of the world, has become an active area of research; TRMM satellite rainfall retrievals provide the essential validation statistics.

For land surface, we are using the Land Information System (LIS) for comparing state-of-the-art algorithms used for representing hydrologic, snow-cover, and evapotranspiration processes for different biomes in each land model. Moreover, the soil moisture prediction in our own model, called HYdrology and Simple Biosphere (HY-SiB) is extended down to 5 m, which often goes through the groundwater table. Two-year long integration with Global Soil Wetness Project (GSWP) forcing data from analysis of observations from 1987 and 1988 have revealed several salient characteristics of each land model that would significantly impact climate change studies. All these improvements have been found to better represent the hydrologic cycle in climate simulation studies. Currently, we are performing objective intercomparisons of different parameterization concepts (applied to models and satellite data retrievals) within the GSFC laboratories. NCAR and GISS scientists are our active collaborators. For more information, contact Yogesh Sud (Yogesh.C.Sud@nasa.gov).

Trace Gas Modeling

The Atmospheric Chemistry and Dynamics Branch has developed two- and three-dimensional (2-D and 3-D, respectively) models to understand the behavior of ozone and other atmospheric constituents. We use the 2-D 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. Three-dimensional stratospheric chemistry and transport models simulate the evolution of ozone and trace gases that affect ozone. The constituent transport is calculated using meteorological fields (winds and temperatures) generated by the GMAO or using meteorological fields that are output from a GCM. 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 multiannual. The model simulations are compared with observations, with the goal of illuminating the complex chemical and dynamical processes that control the ozone layer, thereby improving our predictive capability.

The modeling effort has evolved in the following directions:

1. Lagrangian models are used to calculate the chemical evolution of an air parcel along a trajectory. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations.

2. Two-dimensional 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 CTMs 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 GCM developed jointly by the GMAO and NCAR exhibit many observed features. We have coupled this GCM with the stratospheric photochemistry from the CTM to produce a fully interactive 3-D model that is appropriate for assessment calculations. We are also using output from this GCM in the current CTM for multidecadal simulations. The CTM is being improved by implementation of a chemical mechanism suitable for both the upper troposphere and lower stratosphere. This capability is needed for interpretation of data from EOS Aura, which was launched in July 2004.

The Branch uses trace gas data from sensors on the Upper Atmosphere Research Satellite (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 or 3-D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass@nasa.gov).

4.6 Support for NOAA Operational Satellites

In the preceding pages, we examined the Laboratory for Atmosphere's Research and Development work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA's operational 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 ensure 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 fly on POES. Postdoctoral 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, which will supply a hundredfold increase in real-time data. Laboratory scientists are involved in specifying the requirements for the GOES-R advanced imager, high-resolution sounding suite, solar imaging suite, and *in situ* sensors. They participate in writing each Request for Proposal (RFP), and serve on each Source Evaluation Board (SEB) for the engineering formulation of these instruments. For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

GOES

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

NPOESS

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the Source Evaluation Board as technical advisors. Laboratory personnel were involved in evaluating proposals for the Ozone Mapper and Profiler System (OMPS) and the Crosstrack Infrared Sounder (CrIS), which will accompany the Advanced Technology Microwave Sounder (ATMS), an Advanced Microwave Sounding Unit (AMSU)-like crosstrack microwave sounder. Collaboration with the IPO continues through the Sounder Operational Algorithm Team (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 infrared 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 2 ppm (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@nasa.gov).

CrIS for NPP

CrIS is a high-spectral resolution interferometer infrared sounder with capabilities similar to those of AIRS. AIRS was launched with AMSU-A and the Humidity Sounder for Brazil (HSB) on the EOS Aqua platform on March 5, 2002. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. Current results with AIRS/AMSU/HSB data demonstrate that the temperature sounding goals for AIRS, i.e., root mean squared (RMS) accuracy of 1K in 1 km layers of the troposphere under partial cloud cover, are being met over the ocean. The AIRS soundings will be used in a pseudo-operational mode by NOAA/NESDIS and the NOAA/National Center for Environmental Prediction (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 NPP bridge mission in 2006. Trade studies have also been done for ATMS, which will accompany CrIS on the NPP mission and replace AMSU/HSB. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

Ozone Mapper Profiler Suite (OMPS)

OMPS will become the next U.S. operational ozone sounder to fly on NPOESS. The instrument suite has heritage from TOMS and SBUV for total ozone mapping and ozone profiling. The need for high performance profiles providing better vertical resolution in the lower stratosphere resulted in the addition of a limb scattering profiler to the suite. The limb scattering profiler instrument has heritage from the two SOLSE/LORE shuttle demonstration flights in 1997 and 2002. These missions were developed by our Laboratory with partial support by the IPO. Data from these experimental flights are being used by Laboratory staff personnel to characterize the OMPS instrument and algorithm.

Laboratory scientists continue to support the Integrated Program Office (IPO) through the Ozone Operational Algorithm Team (OOAT) and the NPP mission science team. Laboratory scientists are conducting algorithm research, advising on pre- and postlaunch calibration procedures, and providing recommendations for validation. They participate in reviews for the OMPS instrument contractor and the NPOESS system integrator. The Laboratory staff members are also assessing OMPS data for climate research. An algorithm has been developed to analyze the Stratospheric Aerosol and Gas Experiment (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-1 and SOLSE-2 missions. The advanced ultraviolet and visible radiative transfer models developed in the Laboratory over the last two decades enable this research. The two decades of experience in TOMS and SBUV calibration and validation will also be applied to OMPS. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath@nasa.gov) or Richard McPeters (Richard.D.McPeters@nasa.gov).

Holographic Scanning Lidar Telescope Technology

The Integrated Program Office supports the development of Holographic Scanning Lidar Telescope technology as a risk reduction for lidar applications on NPOESS, including direct detection wind lidar systems. 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 m 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 large aperture scanning receivers by another factor of three. To date, two conical scanning lidar instruments have been developed in this Lab: the Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing (PHASERS) and the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE). PHASERS is located in Manchester, New Hampshire and operated by Saint Anselm College. HARLIE is operated by GSFC and is currently being modified for use at a wavelength of 355 nm and interfaced to a Doppler receiver for atmospheric wind measurements. For more information on this technology, visit the Web site at http://harlie.gsfc.nasa.gov/, or contact Geary Schwemmer (Geary.K.Schwemmer@nasa.gsfc.gov).

Tropospheric Wind Profile Measurements

Measurements of tropospheric wind profiles from ground, air and spaceborne platforms are important for understanding atmospheric dynamics on a variety of time scales. Numerous studies have shown that direct measurement of global winds will greatly improve numerical weather prediction. Because of this importance, the operational weather forecasting communities have identified global tropospheric winds as the number one unmet measurement requirement in the Integrated Operational Requirements Document (IORD-1) for NPOESS, the next generation polar orbiting weather satellite. The Laboratory is using these requirements to develop new Direct Detection Doppler Lidar technologies and systems to measure tropospheric wind profiles, first from the ground and on high altitude aircraft and then from satellites. The ground and airborne Doppler lidar systems provide critical validation of new technologies proposed for eventual spaceborne operation. The NPOESS Integrated Program Office is supporting the effort. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

4.7 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 4 lists project and deputy project scientists for current missions and Table 5 lists the validation and mission scientists for various campaigns.

Table 4: Laboratory for Atmospheres project and deputy project scientists.

Project Scientists		Mission and Deputy Project Scientists	
Name	Project	Name	Project
Robert Adler	TRMM	Anne Douglass	EOS Aura, UARS
Pawan K. Bhartia	TOMS	Ernest Hilsenrath	EOS Aura
Robert Cahalan	EOS SORCE	Hans Mayr	AIM
Dennis Chesters	GOES	Matt McGill	CALIPSO
James Gleason	NPP	Matt McGill	CloudSat
Jay Herman	DSCOVR	Steve Platnick	EOS Aqua
Charles Jackman	UARS	Marshall Shepherd	GPM
Eric Smith	GPM	Si-Chee Tsay	EOS Terra
Joel Susskind	POES		

Table 5: Laboratory for Atmospheres campaigns and mission scientists.

EOS Validation Scientist		Field/Aircraft Campaigns	
Name	Mission	Name	Campaign
David Starr	EOS	Matt McGill	CPL
		Paul Newman	AVE
		Si-Chee Tsay	UAE[2]
		Judd Welton	MPLNET

4.8 Interactions with Other Scientific Groups

Interactions with the Academic Community

The Laboratory relies 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. (See Section 6 for more details on the education and outreach activities of our Laboratory). The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community.

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 published in 2004 (presented in Appendix A2), reflects our many scientific interactions with the outside community—over 85% of the publications involve coauthors from institutions outside the Laboratory.

A prime example of the collaboration between the academic community and the Laboratory is given in this list of collaborative relationships via Memoranda of Understanding or cooperative agreements:

- Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA), with Howard University;
- Cooperative Institute of Meteorological Satellite Studies (CIMSS) with the University of Wisconsin, Madison;
- Earth System Science Interdisciplinary Center (ESSIC), with the University of Maryland, College Park;
- Goddard Earth Sciences and Technology Center (GEST Center), with the University of Maryland, Baltimore County (and involving Howard University);
- Joint Center for Earth Systems Technology (JCET), with the University of Maryland, Baltimore County; and
- Joint Center for Observation System Science (JCOSS) with the Scripps Institution of Oceanography, University of California, San Diego.

These collaborative relationships have been organized to increase scientific interactions between the Earth Sciences Directorate at GSFC, and the faculty and students at the participating universities.

In addition, university and other outside scientists visit the Laboratory for periods ranging from one day to as long as two years. 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 GEST Center. Visiting Scientists are appointed for up to two years and perform research in pre-established areas. Visiting Fellows are appointed for up to one year and are free to carry out research projects of their own design.

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/National Science Foundation (NSF) Joint Center for Satellite Data Assimilation (JCSDA), which is building on 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 TRMM, with the Japanese National Space Development Agency (NASDA); the Huygens Probe GCMS, with the ESA (*Centre Nationale d'Etudes Spatiales* [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. Another example of international collaboration was in the SOLVE II (SAGE III Ozone Loss and Validation Experiment) campaign, which was conducted in close collaboration with the Validation of International Satellites and study of Ozone Loss (VINTERSOL) campaign sponsored by the European Commission. More than 350 scientists from the United States, the European Union, Canada, Iceland, Japan, Norway, Poland, Russia, and Switzerland participated in this joint effort, which took place in January 2003. In 2004, another international collaboration started with the upload of instruments for the Polar Aura Validation Experiment (PAVE). PAVE is an Aura satellite validation involving instruments on the DC-8. Many of the experimenters from SOLVE II are involved in this campaign, which took place in late January and early February of 2005.

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.

4.9 Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government–Industry partnerships, SBIR projects, and technology transfer activities. 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 MPL, holographic optical scanner technology, and Circle to Point Conversion Detector. Industry now uses these innovations for topographic mapping, medical imaging, and for multiplexing in telecommunications. New research proposals involving technology development will have strong commercial partnerships wherever possible.

5. HIGHLIGHTS OF LABORATORY FOR ATMOSPHERES ACTIVITIES IN 2004

This section highlights the Laboratory's accomplishments for 2004 with summaries written by the Branch Heads, which give examples of the research carried out by Branch scientists and engineers. The Branch highlights are supplemented by NASA press releases in Appendix A1, by abstracts of highlighted journal articles in Appendix A2, and by a complete listing of refereed papers that appeared in print in 2004, in Appendix A3. For more details on Branch science activities, the Branch Web sites can be accessed from the Laboratory for Atmospheres home page at http://atmospheres.gsfc.nasa.gov/.

5.1 Mesoscale Atmospheric Processes Branch, Code 912 (now Code 613.1)

The Mesoscale Atmospheric Processes Branch seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. Research is conducted on the physical and dynamical properties, structure and evolution of meteorological phenomena ranging from synoptic scale down to microscales, with a strong focus on the initiation, development, and effects of cloud systems. A major emphasis is placed on understanding energy exchange and conversion mechanisms; especially cloud microphysical development and latent heat release associated with atmospheric motions. The research 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 members participate in satellite missions and develop advanced remote sensing technology with strengths in the active remote sensing of aerosols, water vapor, winds, and convective and cirrus clouds. There are also strong research activities in cloud system modeling, and in the analysis, application, and visualization of a great variety of data.

Branch scientists develop retrieval techniques to estimate precipitation using satellite observations from TRMM and other satellites such as GOES and the AMSR-E sensor on EOS Aqua. There were many notable accomplishments in 2004: provision of 3-hourly near-global rainfall fields in near-real time, studies of African easterly waves, publication of an effective El Niño predictor, and application of TRMM data to study the urban heat island effect, and effects of Amazon deforestation. The TRMM Ground Validation team processes and applies data from rain gauge networks, and ground-based radars. TRMM and other precipitation data are used within the Branch for a wide spectrum of studies on precipitating cloud systems and the global water cycle. Increasingly, these activities integrate global or regional data sets with modeling. Research is conducted on the assimilation of TRMM observations into models to explore the potential benefits to weather forecasting, such as for hurricanes, and to improve understanding of precipitating cloud systems. Branch scientists are also an integral part of the developing Global Precipitation Measurement (GPM) mission, presently in the formulation phase. GPM seeks to establish an international calibrated satellite network for high-resolution (space and time) global precipitation measurements.

Development of lidar technology and application of lidar data for atmospheric measurements are also key areas of research. Systems have been developed to characterize the vertical profile structure of cloud systems (CPL), atmospheric aerosols (MPL), water vapor (SRL), and winds (GLOW) at fine temporal and/or spatial resolution from ground-based or airborne platforms. In addition, the Cloud Radar System (CRS), a millimeter-wavelength radar for profiling cloud systems has been developed and integrated on NASA's high altitude ER-2 research aircraft for use in sensing the microphysical properties of cirrus and other cloud types, and complements the existing ER-2 Doppler (EDOP) radar that has been extensively used to study precipitating cloud systems.

Of particular note in 2004, was the publication of new techniques to derive atmospheric temperature profiles, aerosol size distributions, and cirrus ice water content all from Raman lidar observations. In addition, analysis of Raman lidar observations provided useful guidance for key assumptions made in deriving cirrus optical properties using more conventional elastic cloud lidar measurements, such as used in retrievals from MPL, CPL, GLAS, and CALIPSO observations. Results from a first CloudSat-CALIPSO-Aqua/MODIS (A-Train simulator) analysis based on data obtained during the 2002 CRYSTAL-Florida Area Cirrus Experiment (CPL, CRS, and MAS on NASA ER-2) provided unique insights into the data that will be obtained once CloudSat and CALIPSO are launched in 2005. Studies using MPL measurements of aerosol (pollution) and transport (ACE-Asia and Canadian forest fires) were also published and illustrate the significant intercontinental connections that exist on this planet. Major efforts are underway to expand MPLNET from its present 5 sites to 15 sites around the globe in the next two years. An MPL was deployed to the United Arab Emirates for an aerosol experiment; and CPL, newly integrated on NASA's high-altitude WB-57F aircraft, was flown in the first Aura Validation Experiment over the Gulf of Mexico. Work continues to complete development of compact lightweight CPL and CRS instruments for use in future missions using high-altitude unmanned aerial vehicles (UAVs).

Branch scientists developed atmosphere-sensing capabilities of the Geoscience Laser Altimeter System (GLAS) that was launched on ICESat early in 2003. GLAS is used to profile the vertical distributions of cloud and aerosol layers. Analysis of the data from this exciting new mission is ongoing and many conference presentations of early results were given in 2004. Branch scientists serve as Project Scientists for the CALIPSO (lidar), and CloudSat (millimeter-radar) missions, which are planned for launch in 2005. The Branch also organized and hosted the First International Raman Lidar Techniques Workshop, which attracted more than 90 registrants from 21 countries. This workshop sought to enhance the exchange of ideas, knowledge, and practices within the worldwide Raman lidar science community.

Cloud-resolving (Goddard Cumulus Ensemble, GCE) and mesoscale (MM5 and WRF) models are used in investigations of the dynamic and thermodynamic processes associated with tropical and extratropical cyclones and rainbands, and tropical and midlatitude deep convective systems. The models are also used to research cloud–chemistry interactions, stratospheric–tropospheric interactions, aerosol effects on clouds and precipitation, and the effects of the ocean surface (sea surface temperature) and land surface (vegetation and soil moisture) on atmospheric convection and weather systems. Other important applications include assessment of the potential benefits of assimilating satellite-derived water vapor and precipitation fields on simulations and forecasting of tropical and extra-tropical regional-scale weather systems (i.e., hurricanes and cyclones). Long-term integrations of the models are used to investigate climate feedback mechanisms, such as cloud–radiation interactions. The simulations provide a basis for integrated system-wide assessment of important factors, such as surface energy and radiative exchange processes, and diabatic heating and water budgets associated with tropical and midlatitude weather systems. The models are also used to develop retrieval algorithms. For example, the GCE model provides TRMM investigators with four-dimensional data sets for developing and improving TRMM rainfall and latent heating retrieval algorithms.

A highlight for 2004 was the publication of a unified analysis of GCE simulations of well-observed deep convective cloud systems from various field experiments. The analyses quantify and compare the atmospheric energy budget and precipitation efficiency of these systems. Significant improvements were made to GCE including implementation of message passing interface (MPI) to enable application on massively parallel state-of-the-art large-scale computers with excellent performance. A land surface model and a land information system were also implemented in the 3-D and MPI version of the GCE model; GCE has now been coupled to the Goddard finite volume global circulation model (fvGCM) as a super-parameterization within a Multi-scale Modeling Framework. A land surface model was also configured to represent urban processes and to use, for the first time, a unique tiling capability to properly characterize the heterogeneity of land surfaces when coupled with the most recent MM5 model. This framework provides a mechanism for investigating the impact of land use and land cover change (e.g., deforestation and urbanization) on mesoscale water cycle processes.

Branch scientists actively participated in international model comparison and evaluation activities of the GEWEX Cloud System Study for the purpose of increasing confidence in the cloud-resolving models and facilitating research on the development and testing of cloud parameterizations used in large-scale climate and forecast models (GCMs).

The Branch has developed a world-class visualization lab that is 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. The TRMM Outreach Office, the EOS Project Science Office, Earth Sciences Directorate, and the NASA Earth Science Enterprise (HQ) heavily utilize these capabilities in bringing the value of NASA missions and science accomplishments to the forefront of U.S. Global Change Research.

5.2 Climate and Radiation Branch, Code 913 (now 613.2)

One of the most pressing issues we face, is to understand the Earth's climate system and how it is affected by human activities now and in the future. This has been the driving force behind many of the activities in the Climate and Radiation Branch. We have made major scientific contributions in five key areas: hydrologic processes and climate, aerosol–climate interaction, clouds and radiation, model physics improvement, and technology development. Examples of these contributions may be found in the workshops, seminars, and the list of refereed papers in Appendix 2.

Besides scientific achievements, we have made great strides in many areas of science leadership, as well as science enabling, education, and outreach. Thanks to the organizational efforts of Yoram Kaufman and Lorraine Remer, the AeroCenter seminar series continues to remain focused on challenging unresolved issues affecting climate-aerosol interactions and is very well attended. The biweekly seminars overflow the meeting room and attract aerosol researchers from NOAA and the University of Maryland on a regular basis.

Collaborative papers between AeroCenter members from different disciplines are now commonplace. Previous AeroCenter visitors submitted papers based on the work done during their visits to Goddard. MODIS data have been used for quantitative assessment of the emission, transport, and fate of dust from Africa. The MODIS data shows, in agreement with chemical transport models, that 120 Tg of dust are deposited annually into the oceans. It also resolves an old paradox about the need of Saharan dust as the main fertilizer of the Amazon basin and the amount of dust that was calculated to arrive in the Amazon region. Evidence was found that heavy smoke in the Amazon significantly reduces formation of boundary layer cumulus clouds and can change the smoke forcing from net cooling to net warming for which a paper was published in *Science*.

A strong collaboration has been established with the Environmental Protection Agency (EPA) and with NASA/Langley Research Center for the purpose of air quality monitoring and forecasting. As part of NASA's Applications effort the potential of using the MODIS aerosol products as a Decision Support Tool within the EPA's Air Quality Decision Support System has been demonstrated. The availability of MODIS cloud and aerosol products has opened many new pathways of research in climate modeling and data assimilation in the Laboratory. In recognition of his leadership in aerosol research in 2004, Yoram Kaufman was elected a Fellow of the American Meteorological Society (AMS).

We continue to serve in key leadership positions on international programs, panels, and committees. Si-Chee Tsay leads a group of scientists from NASA and universities in initiating a new project—Biomass-burning Aerosols in SouthEast-Asia: Smoke Impact Assessment (BASE-ASIA), to study the effects of smoke aerosol on tropospheric chemistry, water, and carbon cycles, and their interactions in the Southeast Asia monsoon region, using multiplatform observations from satellites, aircraft, networks of ground-based instruments and dedicated field experiments.

Robert Cahalan serves as project scientist of SOlar Radiation and Climate Experiment (SORCE), launched in December 2002, which is measuring both Total Solar Irradiance (TSI, formerly "solar constant") and Spectral Solar Irradiance (SSI) with unprecedented accuracy and spectral coverage (1–2000 nm for SSI, 1–100,000 nm for TSI) during a 5-year nominal mission lifetime. Cahalan is chairing the Observations Working Group of the Climate Change Science Program Office, tasked to evaluate and coordinate multiagency contributions to the U.S. Government climate observing system. He also chairs the 3-Dimensional Radiative Transfer Working Group of the International Radiation Commission and directs the International Intercomparison of 3-Dimensional Radiation Codes, as described in a paper accepted by the *Bull. Amer. Meteor. Soc*. In recognition of his long-standing leadership in radiative transfer during 2004, Warren J. Wiscombe of the Climate and Radiation Branch was elected President of the Atmospheric Sciences Section of the American Geophysical Union (AGU).

The Climate and Radiation Branch Web site (http://climate.gsfc.nasa.gov/) has a front page that changes almost daily. It provides the latest news in climate research and automatically updates the calendars of users who subscribe. Its "Image of the Week" highlights research by Branch members, and a search page provides easy access to archived news, images, publications, and other climate information and data. The Branch Web site also has an extensive glossary of Earth science acronyms, and a list of links to related sites. The Earth Observatory Web site (http://earthobservatory.nasa.gov/) also continues to provide the science community with direct communication gateways to the latest breaking news on NASA Earth Sciences. It provides the new media and other communications outlets with a "one-stop shopping" resource for publication quality images and data visualizations from NASA Earth Science satellite missions such as Terra, Aqua, and many others. The Earth Observatory Web site now boasts over 27,000 subscribers, with roughly 1 million page views per month worldwide. The contents of the Web site are increasingly syndicated by NASA Headquarters and other public sites.

Alexander Marshak is an editor (together with A. Davis from Los Alamos) of the "Three-Dimensional Radiative Transfer for Cloudy Atmospheres" monograph being published by Springer-Verlag. He also has authored and co-authored three chapters in the book; two additional chapters were authored by R. Cahalan and W. Wiscombe.

A new method to measure aerosol absorption from space has been developed. The method measures aerosol attenuation of sun glint over the ocean to derive aerosol absorption. The method will be best applied to future satellites that can measure the same spot over the ocean at an angle at glint and at an angle off glint.

A method to simultaneously analyze measurements from a two-wavelength lidar and a passive spectroradiometer, such as MODIS, has been introduced. The MODIS data are used to constrain the lidar inversion, thus decreasing the weight of assumptions in retrieving the aerosol profiles. The method was applied to Saharan dust and smoke from Africa in two field experiments.

There has been substantial progress in the area of land model development and its evaluation for more realistic representation of land–atmosphere interactions in general circulation models. Four land models that have been variously used at the Laboratory were put into the Land Information System (LIS) framework for interoperability, testing, evaluation, and intercomparisons using standard model-driving data. Two yearlong integrations with Global Soil Wetness Project (GSWP) forcing data (from analysis of observations from 1987 and 1988), have revealed several salient characteristics of different land models that will have an impact on the climate change studies. We are well on our way to use the outcome for a better land model that draws algorithms from the most realistic features of all the models. This activity is led by Yogesh Sud in collaboration with Randall Koster and his team in the GMAO, and Paul Houser and Christa Peters of the Hydrological Sciences Branch, Code 614.3. In addition, our land model provided simulations for the study of the influence of soil moisture on seasonal precipitation published in *Science*. We also constructed and used a robust methodology for objective evaluation of the benefits of including a new physics package in a GCM—a daunting task with changes giving mixed plus–minus signals. The method helped to show that our cloud scheme named "McRAS" indeed outperforms the cloud scheme of the finite volume GCM, which uses NCAR cloud physics.

The second key area of climate model development is in cloud-physics. Almost all state-of-the-art models develop large simulation biases, which are often larger than the outstanding climate change issues that need to be assessed by these models. This is primarily due to the biased heating and moistening fields simulated by the model's cloud physics. Efforts to curb such model biases continue. Yogesh Sud and Gregory Walker have determined that temperature biases near the surface of land, a feature common to most models evaluated with ARM-CART SCM data sets, are caused, in part, by patchiness of land that leads to non-uniform heating and moistening with deeper mixing of surface fluxes than those provided by uniform small-scale land conditions. Such corrections can mitigate this kind of model bias. Among other innovative modifications, are radiative and cloud-modulation effects of aerosol on cloud condensation nuclei and number of cloud drops. This work involves collaboration with Mian Chin of Code 613.3. In addition, the work also involves parameterization of convection associated with different cloud types, and research on moist processes involving convective triggers and inhibitors, and treatment of smaller than the grid scale cloud processes with horizontal transports. We are also participating in cloud model intercomparison and improvements for the next generation of GMAO and NCAR models. This work is in collaboration with Arthur Hou of the GMAO, and Leo Donner of GFDL. William Lau of the Laboratory is strongly encouraging research on aerosol-cloud-radiation interaction. He is active in assessing the role of aerosol in providing the radiative and cloud and precipitation scale modulations using both model and satellite data. He recently led two studies on the radiative influence of aerosol on tropical circulation; of these, one will be an article in *Nature*.

We are evaluating coupled cloud-radiation and prognostic cloud-water schemes with *in situ* observations available from satellite retrievals, the ARM Cloud and Radiation Test Bed (ARM CART), and TOGA COARE IOPs. Future ARM data will provide badly needed forcing data on aerosol as well. All these data will contribute to cloud model improvements. Together, model evaluations with these testbeds have been found to better represent the hydrologic cycle in climate simulation studies. For more information, contact Yogesh Sud (Yogesh.C.Sud@nasa.gov).

5.3 Atmospheric Experiment Branch, Code 915 (now in Code 690, and renamed Atmospheric Experiments Laboratory, Code 699)

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 through 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.

1) The Branch continued providing postlaunch support for the following key planetary missions:

   a) A Gas Chromatograph Mass Spectrometer on the Cassini/Huygens Probe mission to explore the atmosphere of the Saturn moon, Titan.

   Extensive preparations have been made for the upcoming Saturn–Titan encounter. The Saturn orbit insertion occurred in July 2004. The Probe release to Titan occurred on December 25, 2004, and Probe entry into the atmosphere of Titan occurred on January 14, 2005. Existing instrument calibration facilities were prepared for pre- and post-flight calibration of the Flight Spare instrument, which is available in the Laboratory to simulate flight environments and to assist in the interpretation of the flight data. The effort is substantial because of the high complexity of the instrument and the difficulties involved in conducting *in situ* measurements from a fast-descending probe into an essentially unknown atmosphere.

b) An Ion and Neutral Mass Spectrometer on the Cassini Orbiter to explore the upper atmosphere of Titan and the tenuous atmospheres of Saturn's icy satellites, rings and magnetosphere.

The Ion and Neutral Mass Spectrometer (INMS) was designed, built, and calibrated by the Branch for the Cassini Mission and is currently operated as a facility team instrument. Branch personnel participated as team members in the INMS science and operations planning in 2004. The INMS cover was jettisoned shortly after Saturn orbit insertion on July 1, 2004 and immediately began making measurements. Molecular and atomic oxygen ions, and protons were detected in the vicinity of Saturn's A-ring. A likely explanation for these ions is solar ultraviolet photo ionization of neutral O_2 molecules associated with a tenuous ring atmosphere whose lifetime is longer than that of water products, which are lost because of sticking on the ring particle surfaces.

The first high altitude passes through the atmosphere of Titan occurred on October 26 at 1174 km above the surface and on December 15 at 1198 km. The densities of molecular nitrogen and methane, the main constituents of the atmosphere, were determined and are comparable with earlier Voyager-derived values, which have also been used for lower altitude engineering studies. The homopause altitude, where the eddy diffusion coefficient because of mixing, is equal to the molecular diffusion coefficient, is high, in the 1150–1250 km region, while the exobase, where the mean free path is equal to the scale height, is low, about 1420 km. The exospheric temperature is estimated to be around 149 K, lower than Voyager-derived values.

Wave structures have been observed in the INMS molecular nitrogen data, which may help explain the high altitude extent (1200 km) of the well-mixed atmosphere of Titan. Detection of trace amounts of more complex (C_2, C_3, and C_4) hydrocarbons and nitriles at the spacecraft altitudes support the concept of a high altitude well-mixed atmosphere. Isotopic ratio measurements of carbon and nitrogen suggest a very dense early atmosphere dominated by nitrogen derived from photo dissociation of ammonia, most of which escaped into space, leaving the substantial remnant observed today. In contrast, the methane in today's atmosphere must be continually replaced by degassing, from an unknown source. Photochemistry of these two species produces nitriles and hydrocarbons that contribute to the formation of the aerosol layer which completely hides the surface in visible light. Measurements in this lower altitude region were made by the Cassini/Huygens Probe Gas Chromatograph Mass Spectrometer, which entered Titan's atmosphere on January 14, 2005. The INMS will continue to make *in situ* measurements through the next four years as the Cassini spacecraft tours the Saturn system.

The Branch engineering team is also participating in the flight instrument health assessment and in preparations for pre- and post-encounter laboratory calibration of an identical spare instrument. Considerable effort went into the design and construction of the molecular beam calibration system with which the environmental conditions of a Titan flyby of the Cassini Orbiter can be simulated.

2) Goddard Space Flight Center was selected to lead an international team to develop an instrument suite for the Mars Science Laboratory that will land on Mars in 2010 and operate on the surface for an entire Mars year (about two Earth years). The objective of the Mars Science Laboratory is to explore and quantitatively assess a potential habitat on Mars. The Sample Analysis at Mars (SAM) suite investigation will contribute to an assessment of the biological potential of the target environment by determining the extent and nature of organic carbon compounds and by taking an inventory of the other chemical building blocks of life such as H, N, O, P, and S. A range of isotope measurements is designed to contribute to the understanding of the long term atmosphere evolution processes that may have substantially transformed this planet over time. SAM will be able to measure the abundance and isotopic composition of the Martian atmospheric methane that has recently been discovered by remote sensing.

The SAM suite instruments selected by NASA for the Mars Science Laboratory are a mass spectrometer provided by Goddard Space Flight Center, a gas chromatograph provided by the University of Paris, and a tunable laser spectrometer provided by the Jet Propulsion Laboratory. These instruments work in concert to carry out a range of composition and isotopic analysis of gases with a special focus on a comprehensive analysis of carbon containing compounds. The instruments are supported by a chemical separation and processing laboratory developed at Goddard that releases gas from solid material and also provides gas enrichment and separation capability. Our industrial collaborator, Honeybee Robotics, provides the SAM sample manipulation system that moves small samples of Mars surface materials into their thermal processing stations. All these elements are designed to realize the goal of the SAM suite investigation to explore the potential for life on Mars.

3) Branch members continued to advance development in, and participated in the preparation of, NASA proposals for measurements on future planetary missions. These include (a) a probe of the deep atmosphere of Venus to carry out precision measurements of isotopes designed to resolve questions of the origin and processing of this atmosphere; (b) 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; (c) a comet fly-by mission; and (d) a lander experiment on Mars to sample isotopes and molecules from its atmosphere and below its surface, which can address studies of past climate and the possibility of past life on this planet. A program of analysis of organics in Mars analog materials was initiated to test and validate the analytical approach.

4) The Branch leads one of four themes of the recently selected Goddard node of the NASA Astrobiology Institute. As part of this activity, Branch members participate in a collaborative astrobiology investigation with the Johns Hopkins University Applied Physics Laboratory (JHU/APL) to develop analytical protocols for *in situ* instruments that will aid in the evaluation of prebiotic chemistry on primitive solar system bodies, which might have contributed directly or indirectly to the emergence of life on early Earth. The approach includes analysis with a miniaturized time-of-flight mass spectrometer combined with a gas chromatograph, which will allow both simple and complex organic molecules to be resolved. Direct ionization of solid samples using laser ablation or energetic ions combined with electron ionization of gases thermally released from the same samples will allow a wide range of highly volatile-to-highly refractory components to be analyzed. This powerful technique will also enable *in situ* characterization of organics contained in solid phase material from the Jovian moons, or Mars.

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

5.4 Atmospheric Chemistry and Dynamics Branch, Code 916 (now 613.3)

The Atmospheric Chemistry and Dynamics Branch develops computer models and remote sensing instruments and techniques, as aids in studies of aerosol, ozone, and other trace gases that affect chemistry, climate, and air quality on Earth. The Branch is a world-class center of research in stratospheric chemistry. Using satellite, aircraft, balloon, and ground-based measurements coupled with data analysis and modeling, Branch scientists have played a key role in improving our understanding of how human-made chemicals affect the stratospheric ozone layer.

Branch scientists have been active participants in satellite research projects. In the late 1960s, our scientists pioneered development of the backscattered ultraviolet (BUV) satellite remote sensing technique. Applying this technique to data taken from NASA and NOAA satellites, Branch scientists have produced a unique long-term record of the Earth's ozone shield. The data record now spans more than three decades, and provides to scientists worldwide, valuable information about the complex influences of Sun, climate, and weather on ozone and ultraviolet radiation reaching the ground. Branch scientists expect to maintain this venerable record using data from a series of BUV instruments that are planned for use on U.S. and international satellites in the next two decades. Branch scientists were also instrumental in developing the Upper Atmosphere Research Satellite (UARS) project, which generated data used by researchers to produce a highly detailed view of the chemistry and dynamics of the stratosphere. Currently, Branch scientists are providing scientific leadership for the EOS Aura satellite, which was launched on July 15, 2004. Aura contains four advanced instruments to study the stratospheric ozone layer, chemistry and climate interactions, and global air quality. Branch scientists are also involved in the design of instruments to measure tropospheric air quality and chemical species from spacecraft located at high vantage points (at distances ranging from 20,000–1,500,000 km from Earth), which may be launched in support of NASA's new Exploration Initiative. In addition, they operate a suite of advanced lidar instruments to study the stratosphere from ground and aircraft.

The measurement activities of the Branch are highly coupled with modeling and data analysis activities. The Branch maintains state-of-the-art 2-D and 3-D chemistry models that use meteorological data, produced by the GMAO, to interpret global satellite and aircraft measurements of trace gases. Results of these studies are used to produce congressionally-mandated periodic international assessments of the state of the ozone layer, as well as to provide a strategic plan for guidance in developing the next generation of satellite and aircraft missions. A major new thrust of the Branch is to apply the unique synergy between Branch modeling and measurement groups, which proved very successful for the study of stratospheric chemistry, to study chemically and radiatively active tropospheric species—including aerosol, CO_2, O_3, CO, NO_x, and SO_2—which affect climate, air quality, and human health.

The following provides more detailed descriptions of some of the current Branch activities:

1) 3-D Stratospheric Chemistry Model Studies

Several Branch scientists are analyzing a recently completed 50-year chemical transport model simulation of stratospheric ozone chemistry. They are focusing on its comparison to long-term data records from satellites and ground-based instruments. The goal is to use the model results, combined with data, to draw inferences about long-term ozone trends and about the expectation of a decrease in stratospheric chlorine accompanied by a recovery of ozone while the Montreal Protocol is being implemented. Our Branch has further initiated collaborative work with the GMAO to examine the sensitivity of the finite volume general circulation model dynamics to changes of the ozone climatology in the radiation code of the GCM. This work is being combined with the effort to put the full-chemistry transport model online in the GCM. This is the first step in coupling the chemistry to the dynamics for chemistry–climate studies.

2) Global Modeling Initiative (GMI)

GMI is a project designed to reduce uncertainty in assessment modeling by developing and maintaining state-of-the-art chemistry and transport models that are appropriate for both stratospheric and tropospheric applications. The CTM is modular so that the sensitivity of results to various CTM components can be quantified. A science team with members from government labs, universities, and the private sector contributes to the project. Branch scientists contribute at all levels to this project, including scientific management, experiment design, and evaluation of the GMI simulations. Susan Strahan and Anne Douglass use physically based diagnostics to evaluate the realism of the GMI stratospheric simulations. These simulations are identical except that one uses meteorological fields from the GMAO data assimilation system and the other uses meteorological fields from the general circulation model (GCM) that is used in that assimilation system. The transport produced by the GCM is more realistic, except in the upper stratosphere where horizontal transport is weak leading to lower-than-observed mixing ratios for CH_4. Anne Douglass compared the same simulations with observations of radical and reservoir species with the goal of understanding the differences in simulations for 1995–2030. The ClO in the upper stratosphere is higher than observed in the simulation using GCM winds because the low CH_4 noted above shifts partitioning towards ClO and away from HCl.

3) Tropospheric O_3 Studies

In 2004, our branch members developed a long record (1979–present) of tropospheric and stratospheric ozone from TOMS satellite measurements extending from the tropics to the high latitudes in both hemispheres. In a recently submitted paper to the *Journal of Geophysical Research* (JGR), this data set was used to determine long-term changes in ozone in both the troposphere and stratosphere. This paper discusses the important issues of stratospheric ozone recovery and the long-term increase in tropospheric ozone related to increased industrial pollution. This study indicated that ozone values over surface emission-free regions of the Atlantic and Pacific Oceans are relatively high (50–60 DU) and are comparable to industrial regions of North America, Europe, and Asia.

4) Global Transport of Aerosol

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. To understand the various processes that control the aerosol properties and to understand the role of aerosol in atmospheric chemistry and climate, the Branch scientists have developed the Global Ozone Chemistry Aerosols Radiation and Transport (GOCART) model. In the past few years, the GOCART model has been used to study tropospheric aerosol and its effect on air quality and climate forcing. Major types of aerosol particles are simulated, including sulfate, dust, black carbon, organic carbon, and sea salt. Among these, sulfate, and 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 such as the uplift of dust from deserts by strong winds.

The modeling activities have been strongly connected to the satellite and aircraft observations. Our recent research involves studies of intercontinental transport of dust and pollutants using a combination of models and data. The data is from satellite observations (MODIS and TOMS), ground-based network (AERONET), and *in situ* measurements (ACE-Asia). The aerosol absorption in the atmosphere is based on the GOCART model and AERONET data, and the aerosol radiative forcing is based on assimilated products of the model and MODIS data. In addition, the model results are used by many groups worldwide for studies of air pollution, radiation budget, tropospheric chemistry, hydrological cycles, and climate change.

Analysis of the TOMS long-term record on aerosol optical depth has detected the existence of statistically significant trends in the atmospheric aerosol load over regions of the world that have experienced substantial economic growth over the last 30 years. The TOMS aerosol record indicates that an increasing trend of 17% per decade in the winter aerosol load has taken place in the China coastal plain, while a 7% per decade trend in aerosol concentration has been observed over India. These trends in aerosol optical depth are consistent with observed increases of SO_2 emissions associated with anthropogenic activities in these regions.

5) Aerosols and Their Impact on UV Radiation

Aerosol UV absorption measurements are necessary to quantify the causes of the observed discrepancy between modeled and measured UV irradiances and photolysis rates. Since 2002, scientists from the Branch, the AERONET program, and the USDA UV Monitoring and Research Program (UVMRP) have shared equipment, personnel, and analysis tools to quantify aerosol absorption using ground-based radiation measurements in Greenbelt, Maryland. In 2004, a 17-month monitoring experiment was completed, where the aerosol UV absorption was inferred from the measurements of direct and diffuse atmospheric transmittances by a UV-Multifilter Rotating Shadowband radiometer (UV-MFRSR) combined with ancillary measurements of aerosol particle size distribution and refractive index in the visible wavelengths (by CIMEL sun–sky radiometers), column ozone, surface pressure, and surface albedo. Combining these measurements with a Radiative Transfer model, the seasonal dependence of the aerosol absorption optical thickness, τ_{abs}, was derived for the first time in the UV wavelengths. The τ_{abs} had a pronounced seasonal dependence with maximum values of ~0.1 occurring in summer hazy conditions and <0.02 in the boreal winter–fall seasons, when aerosol loadings are small. The measured τ_{abs} was sufficient to explain both the magnitude and seasonal dependence of the bias in satellite estimates of surface UV irradiance previously seen with ground-based UV measurements.

6) Measurement and Modeling of Atmospheric Carbon Dioxide

Recent Laboratory progress in carbon cycle science has come in the areas of atmospheric transport modeling and instrument construction and testing. The atmospheric chemistry and transport model, used for calculating global CO_2 transport, is incorporating a land biosphere model, high temporal resolution fossil fuel emissions, and satellite data-constrained biomass burning emissions to produce CO_2 fields, which are closely tied to actual meteorology and emission events. These distributions will be compared with real-time CO_2 observations to improve our knowledge of the coupling between carbon cycle processes and climate change.

A Fabry–Perot Interferometer, to measure column CO_2, has been assembled and flight tested in California on the NASA DC-8 aircraft. Results indicate that the instrument has sufficient sensitivity to measure CO_2 at high precision. In addition, integrated horizontal path measurements (400 m) of CO_2 have been made with a lidar at 1.57 µ and tracked the diurnal changes observed by a collocated *in situ* instrument (Licor) over 24 h. A high-speed photon counting system suitable for making range-resolved measurements of CO_2 within the planetary boundary layer (PBL) has been assembled and tested. An EDFA fiber amplifier with 2% duty cycle, 100-ns pulses and 300 mW average power has been fully characterized and is being integrated with the counting system for preliminary testing. Initial efforts are being directed towards integrated CO_2 column measurements using cloud bases for the signal source and nighttime CO_2 profiling within the PBL at very high resolution using boundary layer aerosols. The instrument's range resolution will vary from 15–150 m and the initial measurement precision will be several parts per million by volume (ppmv).

7) Sun–Earth Connection Studies

Branch members were involved in several investigations into the influence of the Sun on the Earth's atmosphere. One current study involves the effect of the very large solar storms in October–November 2003 on the middle atmosphere. These solar storms resulted in solar proton events at the Earth that created HO_x (H, OH, HO_2) and NO_x (N, NO, NO_2), which depleted ozone. The solar proton event of October 28–31, 2003 was the fourth largest of the past 40 years and caused huge NO_x enhancements measured by the HALOE instrument and significant ozone depletions measured by the SBUV/2 instrument in the middle atmosphere.

It has been previously suggested, based on empirical correlations, that solar cycle affects the waves that drive the Quasi-biennial Oscillation (QBO) at low latitudes. The Branch scientists had partially modeled this effect using a 2-D model. Recent results using 3-D models show the solar cycle caused large variations in the QBO of the lower stratosphere in low latitudes, as well as variations in tropospheric temperatures in high latitudes. Further work is necessary to establish the mechanism and robustness of these results.

8) New Instrument Development

Two new instruments are being developed under the Instrument Incubator Program (IIP), the Solar Viewing Interferometer Prototype (SVIP) and the GeoSpec (Geostationary Spectrograph). The SVIP is a 1–2 µ prototype of an instrument that will make measurements at 1–2 µ to determine the amounts of CO_2, H_2O, O_3, N_2O, and CH_4 in the Earth's atmosphere from a position at L2. The SVIP is designed for testing in the laboratory, outside at Goddard, and on a mountaintop. The GeoSpec is a dual spectrograph operating in the UV/VIS and VIS/NIR wavelength regions to measure trace gas concentrations of O_3, NO_2, and SO_2, coastal and ocean pollution events, tidal effects, and aerosol plumes. GeoSpec is intended to support future missions in the combined fields of atmospheres, oceans, and land. GeoSpec is a collaboration of our Laboratory, Pennsylvania State University, Washington State University, and Research Support Instruments. GeoSpec activities during the current year included final optical prescription and mechanical design, detector procurement, and breadboard assembly plans. Initial testing of the prototype instrument is planned for spring 2005 with validation deployment during the summer at Washington State University.

5.5 Science Highlight Articles

This section presents short science highlights representing a snapshot of the Laboratory's activities.

GLAS Sheds New Light on Global Clouds and Aerosol (by James Spinhirne of the Atmospherics Lidar Group)

The Geoscience Laser Altimeter System (GLAS) developed by GSFC was launched in 2003. In 2004, the first data results were presented and made available to the outside science community. GLAS gives the first global profiling from an active laser remote sensing instrument in space, providing fundamentally new measurements for atmospheric research. The GLAS atmospheric group completed and delivered the operational algorithms for data products for the mission. The results show that a very accurate, new measurement of the coverage and height distribution of global cloud cover is being made. GLAS has found that the actual coverage of the globe by clouds is 70%, of which 45% are single layered within the limits of optical attenuation, and a very surprising 76% of clouds are sufficient to block the optical surface return. The results have also shown significant limitations in the passive satellite data on polar cloudiness. Another important new result is the first global measurements and maps of boundary layer aerosol optical depth and the height of the PBL. The PBL measurements are part of the broader frame of the first global measurements of the true height distribution of global aerosol layers. From these and other applications, the GLAS measurements represent an important new tool for Earth science and global change research.

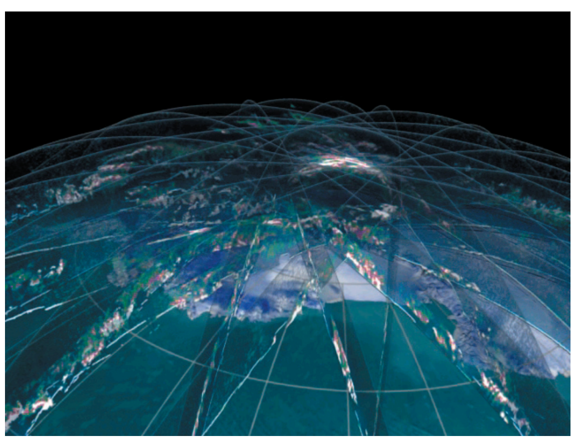


*Figure 5-1. Above is a depiction of one day of GLAS measurements over Antarctica from a movie (*http://www.nasa.gov/centers/goddard/earthandsun/icesat_light.html*) made by NASA Public Affairs. The measurements give a very accurate detection and height profile of all significant clouds and aerosol layers in the atmosphere. Here we see the structure of an Antarctica storm system overlaid by polar stratospheric clouds.*

Totally unique in the GLAS data is the accuracy of the height measurement and the ability to clearly distinguish cloud, aerosol and surface-scattering signals. The GLAS measurements provide the capability to resolve atmosphere-scattering layers from resolutions below 100 m to globally girded data results. Examples of these unique and new measurements are shown in Figures 5-2 and 5-3. The GLAS measurements give atmospheric scientists a new view on the world.

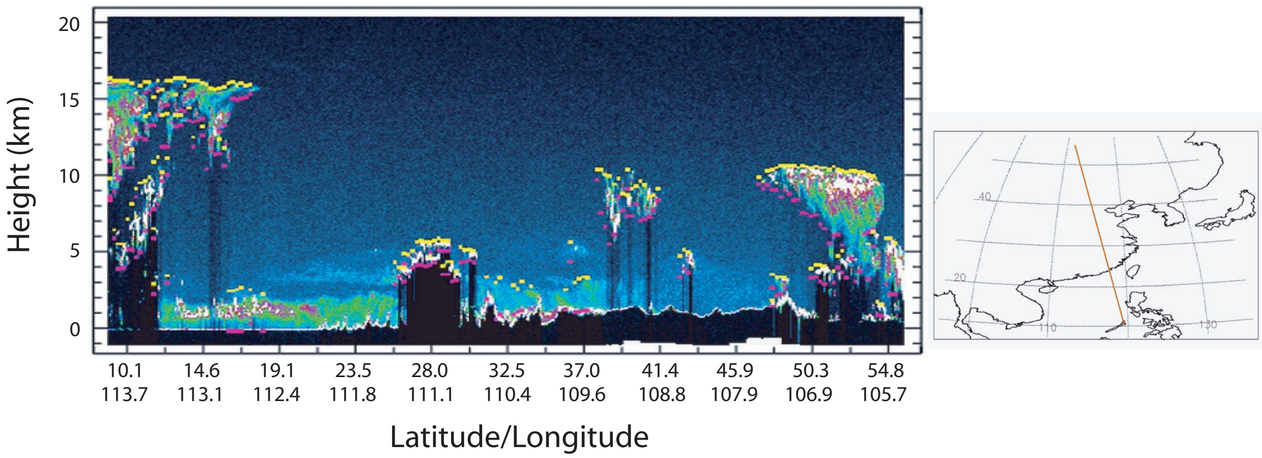


Figure 5-2. GLAS cloud and aerosol signal over China on October 23, 2003. Also shown are the GLAS cloud height data product produced from analysis of the signal. The yellow line is the detected cloud top height, and the purple line is the cloud base height (for optically transmissive clouds). The scattering layers not outlined here are aerosol dust and pollution, segregated in processing from cloud layers. In this case, the aerosol is part of the consistent dense haze (in the Asian region) sometimes termed the "atmospheric brown cloud."

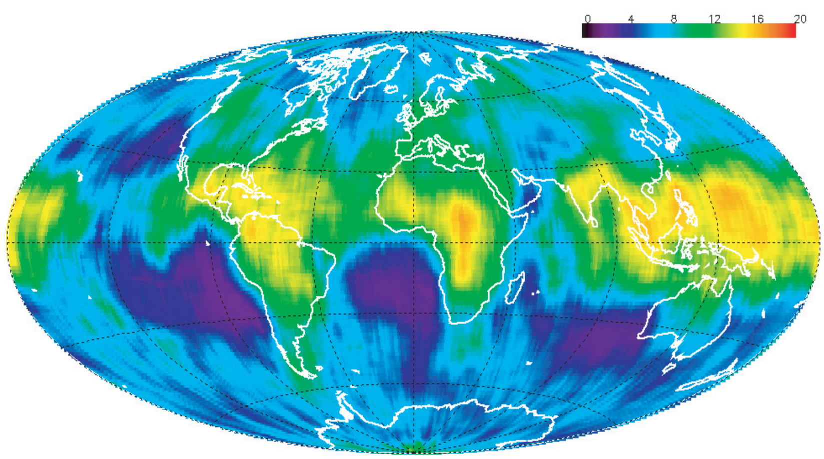


Figure 5-3. Global maximum cloud height derived from GLAS for October 2003. In each 1°×1° grid box the maximum detected cloud top height over the month is shown. These are the first measurements of this parameter. In significant cases, cloud exchange into the stratosphere is observed.

Center for Aerosol Research at the NASA Goddard Space Flight Center (by Lorraine Remer of the AeroCenter)

AeroCenter is one of the five crosscutting themes of the Earth Science Directorate and an interdisciplinary union of GSFC researchers who are interested in many facets of atmospheric aerosols. Yoram Kaufman (613.2) heads AeroCenter with the current steering committee composed of Mian Chin (613.3), Oleg Dubovik (614.4), Charles Ichoku (613.2), Judd Welton (613.1), and Lorraine Remer (613.2). Interests include observations of aerosols from space, aircraft and the ground, aerosol effects on clouds, precipitation, rainfall, climate and the biosphere, aerosols and radiative transfer, the aerosol role in air quality and human health, and the atmospheric correction of aerosol blurring of satellite imagery of the ground.

AeroCenter recognizes that GSFC has a unique role in worldwide aerosol research in terms of the depth and breadth of the work undertaken. Established aerosol research at Goddard includes the AERONET group (614.4), the lidar group (613.1), the MODIS aerosol group (613.2), the TOMS aerosol group (613.3), SeaWiFS atmospheric correction (614.2), MODIS atmospheric correction (614.4), Landsat atmospheric correction (614), the SMART observation system (613.2), Air Quality applications (613.2, 613.3), GMAO aerosol assimilation (610.1, 613.3), chemical transport modeling (613.3), cloud-aerosol interaction modeling (613.1), and climate modeling. In addition, the Goddard DAAC is responsible for the dissemination of a great quantity of EOS data including MODIS aerosol products. This wealth of resources is spread out over many divergent disciplines and organizations. Before AeroCenter, Goddard aerosol researchers were more likely to meet and talk at a conference in another city than in the hallways of their own building. One of the underlying reasons for AeroCenter's genesis was to provide a fast track for newcomers so that they could become aware of the aerosol work happening beyond the walls of their own little cubicle.

The history of AeroCenter began with the EOS era and the launch of the Terra satellite. The new satellite products, soon to become available, would bring unprecedented aerosol information to the world. However, these new products would also swamp the average researcher with information. We searched for a way to make the data more accessible, involve more people in using the products, and increase our overall understanding of the science that involves aerosols. We started with support from NASA Headquarters and some seed money for a three-prong strategy: (a) develop Web tools to make the data more accessible; (b) create a visitors program to bring both senior scientists and student researchers to GSFC for training and collaboration; and (c) enhance collaborative efforts of the research currently in progress at GSFC.

a) The MOVAS Web site (http://lake.nascom.nasa.gov/movas/) developed by the Goddard DAAC in conjunction with AeroCenter allows easy access of a limited set of MODIS aerosol and cloud products using interactive maps and graphics. Researchers can access products, produce regional or temporal subsets, Hovmoller diagrams or time series plots, and download ASCII files. Recent additions to the site in 2004 include parameter comparison capabilities. Soon, global data sets from models will be available on this site as well.

b) The visitor program brought researchers from all over the world to Goddard for a few weeks to several months. Unfortunately, NASA Headquarters has discontinued funding for this program, and thus, we suspended the AeroCenter visiting scientist program in 2004.

c) The most visible success of AeroCenter is the increased collaboration within Goddard's own aerosol community. The biweekly seminar series that continues with enthusiastic response both from speakers who wish to give a seminar and an eager audience that actively engages in discussion. The annual winter poster session is a highlight of the AeroCenter year, as is the annual aerosol update that is organized to keep the Directorate informed on the progress of Goddard's aerosol research. The AeroCenter seminars and annual updates are widely attended, not just by GSFC researchers, but also by local colleagues from the University of Maryland and NOAA. Since AeroCenter began, the number of collaborative papers and proposals written and submitted that involve authors across organizational codes within GSFC, agencies, and universities has increased dramatically. The AeroCenter Web site (http://aerocenter.gsfc.nasa.gov) will soon be updated to become a source of internal information and enhance the feeling of community that AeroCenter members enjoy.

AeroCenter recognizes that GSFC is a Center of Excellence in aerosol research. The combination of expertise in observations, modeling and applications available within AeroCenter, and the type of collaboration that AeroCenter fosters will be necessary to firmly define the role of aerosols in climate change, weather modification, air quality and other applications.

For further information on the AeroCenter, contact Lorraine Remer (Lorraine.A.Remer@nasa.gov).

High Resolution finite volume General Circulation Model (fvGCM) (by Robert Atlas and Oreste Reale)

The finite-volume General Circulation Model (fvGCM), resulting from a development effort of more than ten years, has been brought to the resolution of a quarter of a degree as a part of the ALTIX computing project. The model is based on a finite-volume dynamical core with terrain-following Lagrangian control-volume discretization. The capability of running in real time at such high resolution, which is double the resolution currently adopted by most global models in operational weather centers, has been made possible thanks to a crucial aspect of the fvGCM development: its high computational efficiency, resulting from a careful design aimed to optimize performance on a variety of computational platforms including distributed memory, shared memory and hybrid architectures. Such high global resolution has brought NASA closer to overcoming a fundamental barrier in global atmospheric modeling for both weather and climate, because convection and tropical cyclones can be more realistically represented.

During the 2004 hurricane season, the model was run daily in real-time, and also simulations of the past hurricane seasons 2002 and 2003 have been made. Selected simulations of several Atlantic tropical cyclones, chosen because of varied difficulties presented to numerical weather forecasting, have been analyzed. The fvGCM has produced very good forecasts and simulations of several of these tropical systems, adequately resolving problems like erratic track, abrupt recurvature, intense extra-tropical transition, multiple landfall and reintensification, and interaction among vortices. The most important achievement of the high-resolution fvGCM, however, is probably the increase in intensity and the realism of hurricanes' vertical structure. Figure 5-4 shows the sea level pressure for Hurricane Isidore (2002) from a 60-h fvGCM forecast relative to the National Center for Environmental Prediction (NCEP) analysis for this time. The coarser resolution analysis is not able to represent Isidore's intensity but provides an indication of Isidore's position. In spite of a less-than-satisfactory initialization (due to much lower resolution of the initial conditions), the dynamical core of the fvGCM can produce a minimum of approximately 960 hPa in the 60-h forecast for 1200 UTC 22 September. The observed minimum center pressure is 934 hPa at this time. The observed and simulated change in intensity between 0000 UTC 20 September and 1200 UTC 22 September are both of the order of 40 hPa. Therefore, it can be anticipated that with improved initial conditions the fvGCM could produce an even deeper vortex. In the lower panels of the accompanying figure, the zonal and meridional vertical cross-sections of wind speed, relative vorticity and temperature, are shown, for the 60-h fvGVM forecast for the same time (1200 UTC 22 September). All the prominent features of observed hurricanes can be seen: a vertical column of low speed, a prominent warm-core, an intense gradient of cyclonic vorticity away from the eye, wind and cyclonic vorticity maxima in the lower levels, and a hint of anticyclonic vorticity in the higher levels. Lower resolution GCMs may produce some of these features, but the radius of maximum wind is of the order of 2–300 km (whereas in our runs, it is of less than 100 km) and the vorticity maxima tend to be weaker and located at excessive altitude.

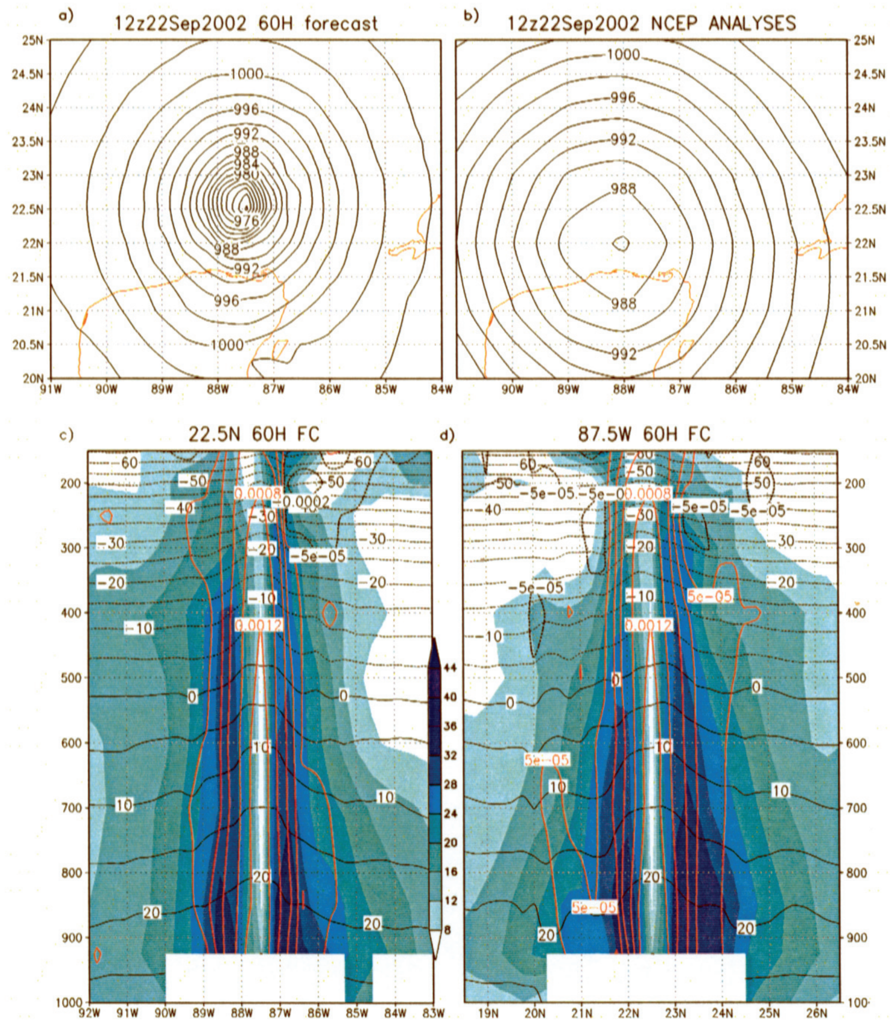


Figure 5-4. Sea level pressure (hPa) relative to 1200 UTC 22 September 2002: 60-h forecast (a), NCEP validating analyses (b). Vertical cross-sections relative to the same 60-h fvGCM forecast (c, d). Plotted are wind speed (ms-1, shaded), relative vorticity (s-1 thick red/blue line), and temperature (C, solid black line). From Atlas et al. (2005)

Atlas, R., O. Reale, B.-W. Shen, S.-J. Lin, J.-D. Chern, W. Putman, T. Lee, K.-S. Yeh, M. Bosilovich, and J. Radakovich, 2005: Hurricane forecasting with the high-resolution NASA finite-volume general circulation model. *Geophys. Res. Lett.,* **32,** L03807, doi:10.1029/2004GL021513.

Lin, S.-J., 2004: A “vertically Lagrangian” finite-volume dynamical core for global models. *Mon. Wea. Rev.,* 132, 2293–2307.

Aura Highlights (by Anne Douglass and Richard Stewart)

The Aura satellite was launched from Vandenberg Air Force Base on July 15, 2004. Aura is designed to study the Earth’s ozone, air quality, and climate and carries a suite of four instruments to accomplish this task. The instruments are the High Resolution Dynamics Limb Sounder (HIRDLS), Microwave Limb Sounder (MLS), Ozone Monitoring Instrument (OMI), and Tropospheric Emission Spectrometer (TES).

Initial results from Aura show that it is fulfilling its promise to provide comprehensive information about the troposphere and lower stratosphere. The following short paragraphs highlight some of the preliminary results from the three working instruments.

Microwave Limb Sounder

The suite of constituents observed by MLS will improve our understanding of the chemistry of the lower stratosphere and upper troposphere. MLS has already provided a comprehensive set of measurements of species related to Arctic ozone loss. The measurements in Figure 5-5 include nitric acid and water, both important for formation of polar stratospheric clouds (PSCs), as well as maps of hydrochloric acid, a reservoir for reactive chlorine, and the radical chlorine monoxide, which is released from the reservoir through reactions involving PSCs. These observations and those made in the Arctic will be used to evaluate the potential for severe loss of Arctic ozone during the next few decades when the abundance of stratospheric chlorine will still be high, and even slight cooling of the stratosphere could exacerbate ozone loss because of chlorine chemistry.

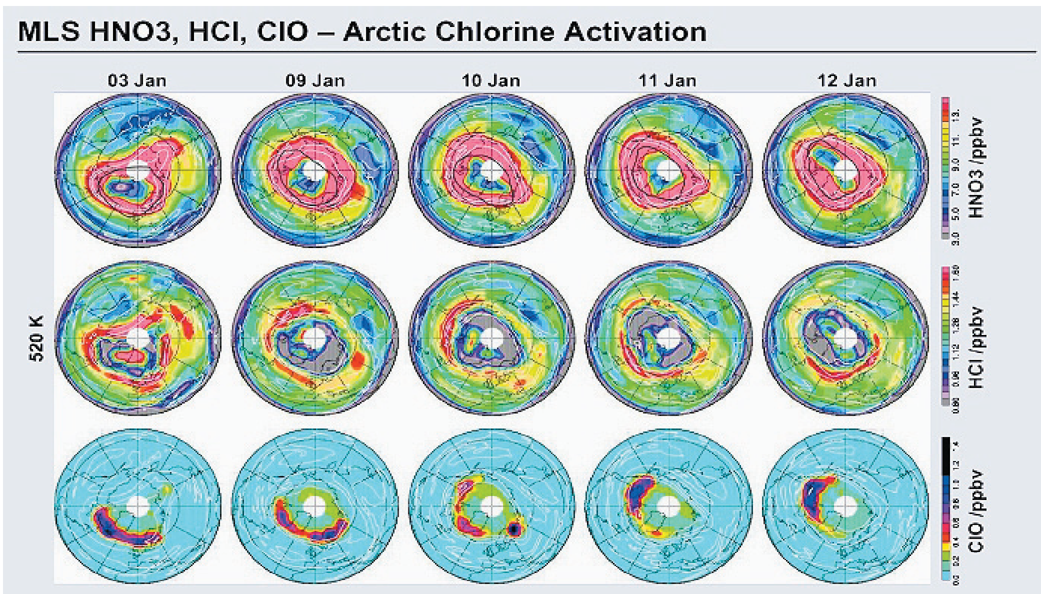


Figure 5-5. MLS observations that show evidence for polar stratospheric cloud (PSC) formation and chlorine activation (Gloria Manney, for Michelle Santee, JPL MLS team). Maps of HNO_3 (top), HCl (center), and ClO (bottom) are shown at 520K (about 20 km). Black contours on the HNO_3 plots are the 195K isotherms, near the existence threshold for PSCs. Depressed HNO_3 inside this contour indicates depletion in gas-phase nitric acid as it is sequestered in PSCs. White contours are potential vorticity with strong gradients indicating the edge of the polar vortex. Low HCl in the vortex indicates chlorine converted from this reservoir form to active forms through reactions on PSCs. In the sunlit portion of the vortex, ClO is enhanced in a manner consistent with HCl depletion.

Ozone Monitoring Instrument

The OMI instrument will continue the Earth Probe Total Ozone Mapping Spectrometer (EP-TOMS) record for total ozone in addition to measuring other atmospheric parameters related to ozone chemistry and climate. OMI has excellent horizontal resolution and gathered four times more data about the 2004 ozone hole (Figure 5-6) than its TOMS predecessor.

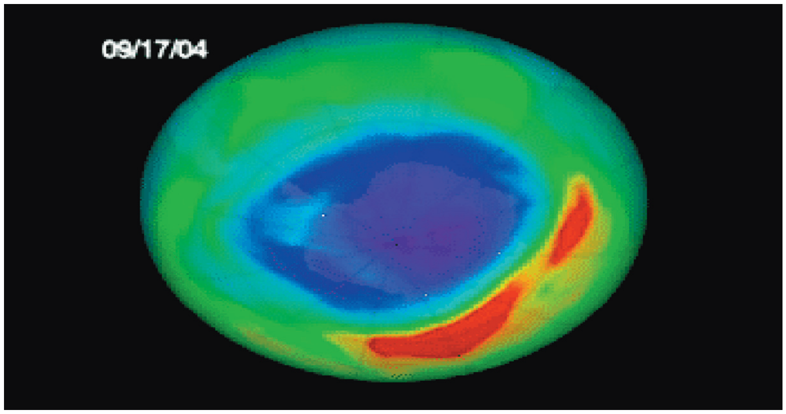


Figure 5-6. OMI measurement of ozone burden over Antarctica on September 17, 2004. High to low ozone values are indicated by red to purple. This shows the earlier stages of the ozone hole that reached a minimum on October 5.

Tropospheric Emission Spectrometer

TES employs both the natural thermal emission of the surface and atmosphere and reflected sunlight, thereby providing day-night coverage anywhere on the globe. Observations from TES will further understanding of long-term variations in the quantity, distribution, and mixing of minor gases in the troposphere, including sources, sinks, troposphere-stratosphere exchange, and the resulting effects on climate and the biosphere.

The TES instrument is providing the first direct measurements of ozone in the troposphere (Figure 5-7). Maps of upper and lower tropospheric ozone shown in the following figure will be used with simulations to evaluate the effects of biomass burning and other continental sources of pollution on our atmosphere and climate. The initial maps already show that ozone pollution spreads beyond continental boundaries and is a global problem.

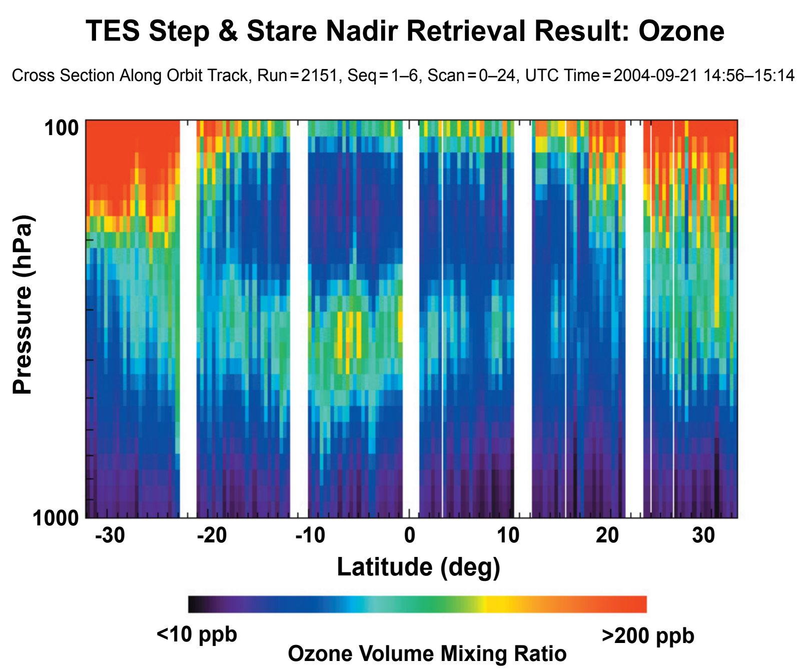


Figure 5-7. TES measurements of tropospheric ozone on September 21, 2004.

6. EDUCATION AND PUBLIC OUTREACH

6.1 Introduction

NASA's founding legislation directs the Agency to expand human knowledge of Earth and space phenomena and to preserve the role of the United States as a leader in aeronautics, space science, and technology. Throughout the 1990s, however, undergraduate and graduate enrollment and the number of doctorates awarded in science and engineering declined by more than 15%. This trend, along with an aging workforce, places an increasing burden on NASA to maintain its level of achievement in science and technology.

In recognition of this problem, NASA established the Education Enterprise in 2003 as one of six Enterprises designed to achieve the Agency's mission. Within the Enterprises, there are seven strategic goals, two of which are the purviews of the Education Enterprise:

> *Strategic Goal 6*: Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics.
>
> *Strategic Goal 7*: Engage the public in shaping and sharing the experience of exploration and discovery.

The Laboratory for Atmospheres is part of the Earth Science Enterprise and is primarily focused on the strategic goals of that enterprise. The Laboratory, however, actively participates in activities that support the goals of the Education Enterprise. Laboratory efforts serve the education community at all levels and provide information to the general public. The Laboratory's educational outreach component enhances educator knowledge and preparation, supplements curricula, forges new education partnerships, and supports 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. Education and public outreach are an important part of our basic science activities and go hand in hand with our work on projects, field campaigns, instrument development, modeling, data analysis, and data set development. This section highlights some of the education and public outreach activities of our Laboratory. More details may be found on our Laboratory Web site and on our Branch and Project Web sites.

6.2 Education

Interaction with Howard University and Other Historically Black Colleges and Universities (HBCUs)

Partnerships with Howard University:

A part of NASA's mission has been to initiate broad-based aerospace research capability by establishing research centers at the Nation's HBCUs. As a part of this initiative, the Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA) was established in 1992 at Howard University (HU) in Washington, D.C. It has been a goal of the Laboratory and the Earth Sciences Directorate to partner with CSTEA to establish a self-supporting facility at HU for the study of terrestrial and extraterrestrial atmospheres, with special emphasis on recruiting and training underrepresented minorities for careers in Earth and space science.

The Laboratory works closely with Howard University faculty in support of 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 who teach courses. A number of Howard students are now on track for earning M.S. and Ph.D. degrees in atmospheric sciences.

The Laboratory has enthusiastically supported the Goddard Howard University Fellowship in Atmospheric Sciences (GoHFAS) program. GoHFAS was established in 1999 by Professor Sonya Smith to broaden and strengthen the research and educational opportunities of underrepresented minorities. The students attended a summer program at Howard University where they engaged in research with mentors at HU, GSFC, or NOAA. They received fellowships at their home institutions during their senior year and were given an opportunity to visit HU during the winter break to continue their research. The GoHFAS program has assisted in the transition from undergraduate-to-graduate school by exposing students to solving open-ended problems, and giving them a head start by exposing them to the workplace of scientific research. Figure 6-1 shows the summer 2004 GoHFAS participants.

Figure 6-1. GoHFAS students participating in the summer 2004 Research Program Colloquium. Left to right the students are: Shawntaye Adams (Clark-Atlanta U.), Coalton Bennett (Howard U), Shyreese Vincent (Clark-Atlanta U), Eleanor Branch (Stanford U), Daniel Bond (Howard U), Alexia Roberson (Clark-Atlanta U), Lydia Edwards (Clark-Atlanta U), Walter Lowe (U. Maryland).

Participation with Howard University on the Beltsville Campus Research Site:

Howard University has for several years been in the process of building a multi-instrument atmospheric research facility at their campus in Beltsville, Maryland. This research facility is part of the NOAA-Howard University Center for Atmospheric Science (NCAS). David Whiteman, Belay Demoz (both Code 912), and others from GSFC are assisting in mentoring students and advising with instrument acquisition for the site. One of the main instruments at the site is a world-class Raman lidar built with heavy involvement from Code 912. The lidar has begun operations and preliminary work on it was reported at the 2005 annual meeting of the AMS in San Diego. David Whiteman and Belay Demoz helped in proposing, designing, building, and operating the lidar.

A workshop was held at the Howard University atmospheric field research facility in Beltsville, Maryland from June 23–27, 2004. Belay Demoz participated in organizing and lecturing at this workshop in which students from Howard University, University of Virginia, University of Texas at El Paso, Jackson State University, University of Maryland (College Park and Baltimore County) participated. The principal goals of this workshop were (1) to introduce students to, and facilitate student-interaction with, leading atmospheric scientists; (2) to develop both horizontal and vertical mentoring strategies with graduate students and participating faculty members; and (3) to employ experiential methods of learning as a means to motivate students to pursue research in atmospheric sciences. The unique features of the workshop included the participation of diverse faculty, the different research interests among participating students and faculty members, and the support received from numerous institutions and agencies.

Summer Programs

Institute on Atmospheric, Hydrospheric, and Terrestrial Sciences

The Laboratory for Atmospheres co-sponsored, with the Laboratory for Hydrospheric Processes, a Summer Institute on Atmospheric, Hydrospheric, and Terrestrial Sciences that extended from June 7 to August 13, 2004. The institute is designed to introduce undergraduate students majoring in physical sciences to research opportunities in Earth sciences. No previous experience in these sciences is needed. The program is directed primarily at students in their Junior year, but all undergraduates are eligible provided they are U.S. citizens or holders of a Green Card.

To complete the program students are required to give an oral presentation and submit a written report on their research effort. Oral reports were given on August 13, 2004. The following summarizes the projects carried out under the supervision of Laboratory for Atmospheres mentors.

Table 6. Students and their Project Titles for the 2004 Summer Institute

Student Name	College/University	Mentor and Code	Project Title
Robert Cooper	Williams College	Andrew Tangborn: Code 910.3	*With Our Powers Combined—Using Data Assimilation to Estimate Chemical Sources*
James B. Miller	Gettysburg College	Geary Schwemmer and David Miller: Code 912	*How to Handle a HOE: Self-Calibration of HARLIE's Backscatter Data*
Jacob Gordon	Harvard University	Sangwoo Lee and Geary Schwemmer: Code 912	*Elucidation of the HARLIE Overlap Function for Calibrating Data from an Aerosol Backscatter LIDAR*
Joel Pommier	Lewis University	David Miller, Geary Schwemmer, and Gerry McIntire: Code 912	*Development of an Automation Toolkit for Web Display of Vaisala Ceilometer Data in Near Real Time*
S. Joseph Munchak	Pennsylvania State University	Ali Tokay: Code 912/ UMBC	*Retrieval of Three-Parameter Drop Size Distribution from Dual-Frequency Radar*
Maura Hahnenberger	University of Utah	Thomas Bell: Code 913	*Does it Rain Less on Weekends? Detecting a Weekly Precipitation Cycle Using the TRMM TMI*

Summer Air Quality Study 2004:

During summer 2004, a team of students from Howard University and the University of Maryland participated in a study to better understand pollution in the Baltimore–Washington corridor. The Director's Discretionary Fund (DDF) was the funding source for this study. The principal investigator (PI) for this program was Anne Thompson (Code 916) and much of the student training was carried out by Jacquie Witte (Code 916/SSAI), Figure 6-2. Balloon launches were carried out several times per week at the Howard University Physics Dept. field site in Beltsville, Maryland. The balloons carried coupled ozone and radiosonde instrumentation to measure profiles of ozone, temperature, and relative humidity. These measurements were part of a larger project funded by NASA titled "IONS" [INTEX (Intercontinental Transport Experiment) Ozonesonde Network Study]. Students presented their first results to undergraduates from a range of HBCUs at Howard's Workshop on Atmospheric Sciences.

Figure 6-2. Training at Howard University Physics Department Beltsville facility, showing students and SSAI's J. Witte pre-conditioning ozonesondes.

University Education

Graduate Student Advising:

Numerous Laboratory members are active in advising graduate students and/or serving on thesis committees. The following table provides a summary.

Table 7. Graduate Student Advising by Laboratory for Atmospheres Members

Member/Code	Student	Degree	Institution	Thesis Topic or Area
John Burris/916	John Outerbridge	Ph.D.	U. Alabama	Measurement of tropospheric ozone with lidar
	Shi Kuang	Ph.D.	U. Alabama	Modeling tropospheric ozone
Belay Demoz and David Whiteman/912	Felicita Russo	Ph.D.	UMBC	Lidar measurement of aerosols and clouds
	Antonia Gambacorta	Ph.D.	UMBC	AIRS water vapor retrievals
	Menghs Mariam	Ph.D.	UMBC	Not defined

Member/Code	Student	Degree	Institution	Thesis Topic or Area
	Segayle Walford	Ph.D.	Howard U.	Lidar boundary layer height characterization
	Rasheen Connel	Ph.D.	Howard U.	Not defined
	Scott Rabenhorst	Ph.D.	UMCP	Mesoscale applications of Raman lidar
David Starr/912	Likun Wang	Ph.D.	U. Alaska	Homogeneity of Midlatitude Cirrus Cloud Structural Properties Analyzed from the Extended FARS data set
	Robert Carver	Ph.D.	Penn. State	Understanding Subtropical Anvil Cirrus: A Coupled-Model Study
Joanna Joiner/916	Paul Poli	Ph.D.	UMBC	Assimilation of global positioning system radio occultation measurements into numerical weather forecast systems
Lorraine Remer/913	Robert Levy	Ph.D.	UMCP	Development of aerosol retrieval algorithm from satellite for specific use in air quality
	Brian Vant-Hunt	Ph.D.	UMCP	Investigation of aerosol–cloud interactions in the boreal and tropical forests using satellite retrievals
Scott Braun/912	Joseph Olson	Ph.D.	SUNY-Stonybrook	Impact of coastal orography on landfalling cold fronts
Mian Chin/916	Hongqing Liu	Ph.D.	UMCP	Not determined
Gerry Heymsfield/912	Haiyan Jiang	Ph.D.	U. Utah	Microwave studies of rainfall
Peter Colarco/ESSIC	Rebecca Matichuk	Ph.D.	U. Colorado	Optical properties of Southern African biomass burning aerosols

Other mentoring activities:

Martha Butler (NASA Graduate Student Research Program); Penn. State
Randy Kawa/916
Fall 2004 to present
Topic: *Modeling atmospheric carbon species*

Laurie Buchner (NASA Academy); USC
Paul Mahaffy/915
Summer 2004
Topic: *Techniques for isotopic analysis of Martian organic carbon*

K-12 Education

Several Laboratory members participated in K-12 education. Lorraine Remer (913) mentored high school senior Jonathan Harris (Eshkol Academy) during the spring semester on the topic of "Deriving aerosol absorption from satellite measurements." Mian Chin (916) gave two seminars to the NASA Summer School for middle school teachers on July 20 and 27. Charlie Jackman (916) presented a talk on Stratospheric Ozone Change to classes at the Air Academy High School in Colorado Springs, Colorado on November 12. Jaime Demick (915/SSAI) gave six talks to second, fifth, and sixth grade students at the Mt. Rainier Elementary School, Mt. Rainier, Maryland on "Careers at NASA." She also lectured on "Careers in Engineering and Science" at the 2nd Annual EduSerc High School Development Conference at the Baltimore Convention Center (Baltimore, Maryland) on November 5.

6.3 Public Outreach

Distinguished Lecturer Seminar Series

One aspect of the Laboratory's public outreach is a Distinguished Lecturer Seminar Series, which is held each year. Most of the lecturers are from outside NASA and this series gives them a chance to visit with our scientists and discuss the latest ideas from experts. The following were the lectures presented in 2004.

January 29, 2004: William K.-M. Lau
NASA's Goddard Space Flight Center, Laboratory for Atmospheres, Greenbelt, Maryland;
"Clouds–Aerosol–Precipitation Interactions: A New Frontier in Climate Change Research"

February 26, 2004: Yoram Kaufman
NASA's Goddard Space Flight Center, Climate and Radiation Branch, Greenbelt, Maryland;
"Aerosol Effect on Climate—The Unique Satellite Vantage Point"

March 18, 2004: Wei-Kuo Tao
NASA's Goddard Space Flight Center, Mesoscale Atmospheric Processes Branch, Greenbelt, Maryland;
"A New Approach to using a Cloud-Resolving Model to Study the Interactions between Clouds, Precipitation, and Aerosols"

April 22, 2004: Dennis L. Hartmann
Department of Atmospheric Sciences, University of Washington, Seattle, Washington;
"Tropical Clouds and Climate Sensitivity: The Fixed Anvil Temperature (FAT) Hypothesis"

May 20, 2004: Akio Arakawa
University of California, Los Angeles (UCLA), Department of Atmospheric and Oceanic Sciences; Los Angeles, California;
"The Cumulus Parameterization Problem: Past Confusions, Current Frustrations, and Future Excitements"

June 17, 2004: Edward Zipser
University of Utah, Salt Lake City, Utah;
"Global Distribution of Intense Convection from TRMM Data"

July 15, 2004: T. N. Krishnamurti
Florida State University, Department of Meteorology, Tallahassee, Florida;
"On the Hurricane Intensity Issue"

September 16, 2004: Richard Somerville
Scripps Institution of Oceanography, University of California, San Diego, California;
"Clouds, Cloud Physics, and Cloud-Radiation Interactions: New Data and Models"

October 7, 2004: Graeme L. Stephens
Colorado State University, Department of Atmospheric Science, Fort Collins, Colorado;
"On the Use of Global Satellite Data in Evaluating Moist Processes in Large-Scale Models"

November 18, 2004: Mark Jacobson
Stanford University, Department of Civil and Environmental Engineering, Stanford, California;
"The Climate Response of Soot, Accounting for its Feedback to Snow and Sea Ice Albedo and Emissivity"

December 02, 2004: Ulrike Lohmann
Swiss Federal Institution of Technology, Institute of Atmospheric and Climate Science, Zurich, Switzerland;
"Aerosol Effects on Water Clouds, Ice Clouds and the Hydrological Cycle"

E-Theater: NASA/NOAA: Earth Science Electronic Theater 2004

The E-Theater uses high definition television (HDTV) display at up to IMAX size to deliver powerful visualizations promoting Earth science. Scientists from the various Earth science disciplines work directly with the Visualization Analysis Laboratory (VAL) team to develop scientifically accurate visualizations. E-Theater visualizations are rendered at HDTV quality, the highest resolution that can be easily distributed. The visualizations are also available in lower resolutions, such as standard definition TV and as QuickTime movies. Multiple resolution versions of each E-Theater visualization are being added to the E-Theater Web page, http://Etheater.gsfc.nasa.gov/, and the Visible Earth Web page: http://visibleearth.nasa.gov/, along with an explanation of the scientific significance and the origin of the data. The E-Theater has been presented at universities, high schools, grade schools, museums, and government laboratories, as well as to scientists and the general public. A summary of presentations on E-Theater during 2004 is given in Table 8.

Table 8. E-Theater presentations during 2004.

Date	Country	City/ State	Size	Event Description
8-Jan	USA	Columbia, MD	50	High Technology Council of Maryland
15-Jan	USA	Greenbelt, MD	50	Frederick County School District Teachers: GSFC, Building 33 Conference Room H114
20-Feb	USA	Salt Lake City, UT	30	US Department of Agriculture: Forest Service Remote Sensing Center
23-Feb	USA	Salt Lake City, UT	100	Public Officials and Legislators Event: Children's Museum of Utah
24-Feb	USA	Provo, UT	50	Two seminars at the Brigham Young University, Electrical Engineering Dept.
28-Feb	USA	Salt Lake City, UT	100	Children's Museum of Utah: Members and General Public Event
1-Mar	USA	Salt Lake City, UT	80	University of Utah Public Lecture: Gould Auditorium of the Marriot Library
2-Mar	USA	Pleasant Grove, UT	40	Mount Mahogany Elementary School
2-Mar	USA	Provo, UT	2	Utah Valley State College
3-Mar	USA	Salt Lake City, UT	80	Children's Museum of Utah: Supports Event
25-Mar	USA	Key West, FL	750	Key West Middle and High Schools
6-Mar	USA	Key West, FL	50	Mel Fisher Maritime Museum E-theater

Date	Country	City/ State	Size	Event Description
8-Apr	USA	Salt Lake City, UT	300	USDA: Remote Sensing 2004—US Forest Service Conference
13-Apr	USA	Greenbelt, MD	50	IRS Tour of Goddard
15-Apr	USA	Atlanta, GA		US FIRST Robotics Competition: Georgia Dome
23-Apr	USA	Asheville, NC	300	Conference on Science Visualization and the Arts UNC
27-Apr	USA	Greenbelt, MD	50	Historian/Librarian Tour of Goddard
6-May	USA	New York City, NY	300	Rodeph Sholom School
7-May	USA	Radnor, PA	150	Armenian Sister's Academy of Philadelphia
28-May	USA	College Park, MD	15	Marshall Space Center Director: Admiral Thomas Donaldson
29-May	USA	College Park, MD		Odyssey of The Mind World Finals: University of Maryland
8-Jun	USA	Greenbelt, MD	20	Howard University Students
9-Jun	USA	Greenbelt, MD	50	Elder Hostel at Goddard Visitor's Center
16-Jun	USA	Greenbelt, MD	20	Summer Interns
29-Jun	USA	Greenbelt, MD	50	AMS Fellows
31-Jul	USA	Greenbelt, MD	500	Goddard Community Day (Presented by Steven Graham)
20-Sep	USA	Anchor-age, AK	300	IGARSS Plenary Session in support of Dr. Asrar
21-Sep	USA	Anchor-age, AK	30	IGARSS Scientific Visualization Session in support of JPL organiz-ers
28-Sep	USA	Logan, UT	50	Agriculture Experimental Station—Space Week: Utah State Univer-sity
29-Sep	USA	Logan, UT	50	Space Dynamics Laboratory—Seminar: Utah State University
1-Oct	USA	Spring-field, MO	200	Drury University
7-Oct	USA	Greenbelt, MD	85	Princeton Alumni: Class of 1947 (Contact: Nina Harris, PAO)
13-Oct	USA	Rosemont, PA	250	Agnes Irwin Lower School
13-Oct	USA	Rosemont, PA	350	Agnes Irwin Middle School
13-Oct	USA	Rosemont, PA	400	Agnes Irwin Upper School

Date	Country	City/ State	Size	Event Description
14-Oct	USA	Haverford, PA	350	Haverford Lower School
14-Oct	USA	Haverford, PA	400	Haverford Middle School
14-Oct	USA	Haverford, PA	500	Haverford Upper School
21-Oct	USA	Greenbelt, MD	30	Earth Sciences Mission Operations, Bldg 32, Contact: Warren Case (warren.case@gsfc.nasa.gov)
2-Nov	Thailand	Bangkok	NA	Asia Institute of Technology (AIT), Contact: Honda Kiyoshi
10-Nov	Thailand	Bangkok	NA	Thammasat University, Rangsit Campus, Contact: Daroonwan Kamthonkiat
12-Nov	Thailand	Bangkok	NA	Mahaidol University, Bangkok, Contact: Suwisa.Mahasandana@ait.ac.th
15-Nov	Russia	Saint Petersburg	NA	International Symposium on Remote Sensing and the Environment (ISRSE) Plenary Presentation
19-Nov	USA	Baltimore, MD	NA	Mount Vernon Elementary School York County, VA, Contact: Mary Beth Wusk, telephone 757–864–3830
27-Nov	USA	Baltimore, MD	NA	Maryland Science Center, Earth Explorer Institute Workshop

Nimbus Meteorological Satellite 40 Year Celebration

August 28, 2004 marked the 40th anniversary of the launch of the Nimbus-1 Earth Observation Satellite. The Nimbus program provided many benefits to the world by increasing our knowledge of the Earth's atmospheric environment, weather, oceanography, and other geophysical properties of the Earth's structure. NASA's Goddard Space Flight Center (GSFC) managed the Nimbus program. Starting in 1964 and for the next 20 years, the Nimbus platform was the country's primary Earth science remote-sensing research and development satellite platform. Seven satellites were launched over a 14-year period and they operated for 30 years. The large, multi-year, multidiscipline Nimbus data sets have been archived and are invaluable for Earth science research. Each Nimbus spacecraft carried instruments that demonstrated new techniques for measuring the Earth's meteorological and environmental behavior and composition. This technology was transferred to the National Oceanic and Atmospheric Administration's (NOAA) new operational satellite instrument designs. The Nimbus research results were applied to NOAA's application systems, resulting in new tools and processes for weather forecasting, environmental monitoring, and Earth resources assessment. NASA satellites use this technology and the heritage of instruments on most Earth-resources satellites launched over the past three decades can be traced to Nimbus instrument technology and/or scientific accomplishments.

On October 26, 2004, the Nimbus program was recognized at a symposium held at the Goddard Visitor Center followed by dinner at the GSFC Recreation Center. Dr. Edward Weiler and Dr. Jack Kaye welcomed invited guests from around the country who returned to Goddard to celebrate the achievements of the program. Attendees included Bill Stroud, the original Project Manager; Bill Houston, a valued member of the Nimbus project team through all seven missions; Ralph Shapiro, Missions Operations Manager; and many other contributors to the Nimbus Project team. A commemorative bronze plaque (Figure 6-3) has been installed in the lobby of Building 3 near the Gott Auditorium to honor the Nimbus Mission Operations Control Center once located there.

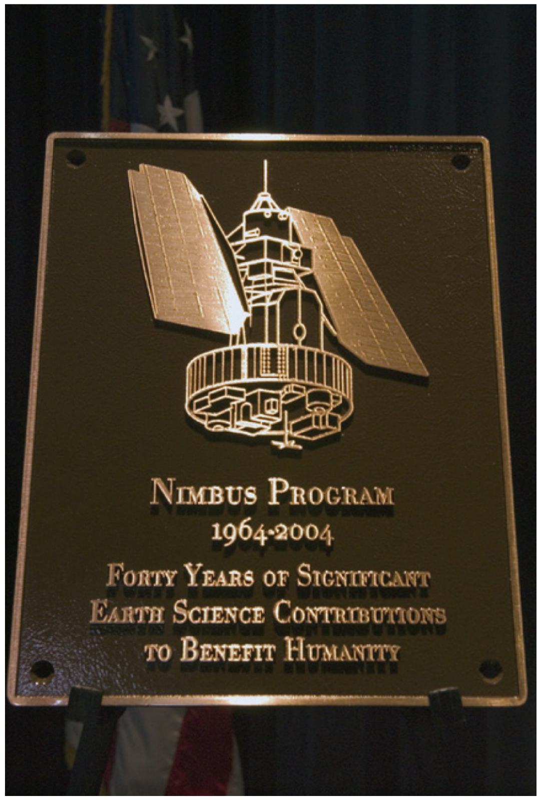
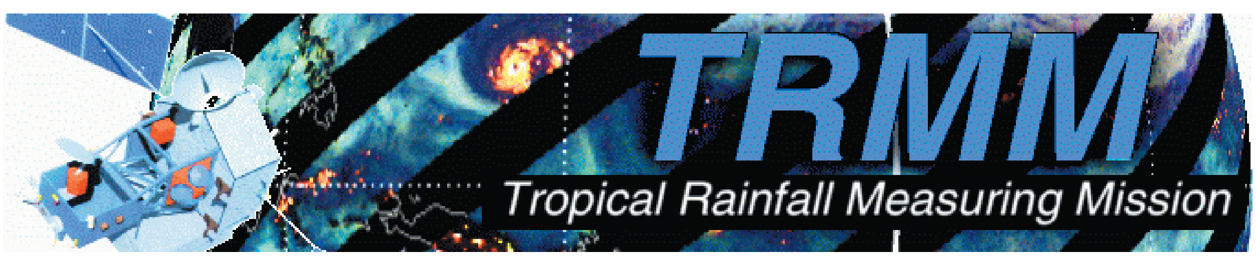


Figure 6-3. The bronze plaque commemorating the 40th anniversary of the Nimbus Program.

6.4 Project Outreach

Funded projects in which Laboratory members participate contain elements of both education and public outreach that are described on the project Web sites. Some of these outreach efforts are summarized in the following sections.

TRMM



The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. TRMM continues its comprehensive Education/Outreach program, in which Laboratory personnel promote TRMM science and technology to the public under the leadership of TRMM Project Scientist Robert Adler (910), and TRMM Education and Outreach Scientist Jeffrey Halverson (912/JCET). TRMM has also included the development of broadcast visuals and educational curriculum in its outreach activities. The Education link on the TRMM home page leads to five problem-based classroom modules in PDF format. These manuals are titled "Investigating the Climate System" and consist of tutorials on clouds, winds, precipitation, weather, and energy. The first four are appropriate for students in grades 5–8, the last is directed at students in grades 9–12. 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.

EOS Aura

The Aura satellite was launched from Vandenberg AFB on July 15, 2004 (Figure 6-4). The Laboratory for Atmospheres has responsibility for conducting the Education and Public Outreach (E&PO) program for the EOS Aura mission. Aura's Education and Public Outreach program has four objectives:

(1) Educate students about the role of atmospheric chemistry in geophysics and the biosphere;
(2) Enlighten the public about atmospheric chemistry and its relevance to the environment and their lives;
(3) Inform geophysics investigators of Aura science, and thus, enable interdisciplinary research; and
(4) 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.

Figure 6-4. Aura launch, July 15, 2004 photo taken by Boeing/Thom Baur.

To accomplish these objectives, the Laboratory has partnered with several institutions that have established infrastructures that reach large audiences through formal and informal education.

The Globe Program (Global Learning and Observations to Benefit the Environment), supported via a grant to Drexel University (Philadelphia, Pennsylvania), is a worldwide network of students, teachers (10,000 schools in over 95 countries), and scientists working together to study and understand the global environment. Aura's E&PO program will also be present at science and environmental fairs, and science and technology conferences to demonstrate how Aura fits into NASA's program to study the Earth's environment.

The American Chemical Society (ACS) will produce four special issues of the publication *ChemMatters* over the next three years. These issues will focus on the chemistry of the atmosphere and various aspects of the EOS Aura mission. The special editions of *ChemMatters* will reach approximately 30,000 U.S. high school chemistry teachers and their students.

The Smithsonian's National Museum of Natural History (NMNH), working with Aura scientists, will design and create an interactive exhibit on atmospheric chemistry as part of its Forces of Change program. NMNH will convey the role that atmospheric chemistry plays in people's lives through the use of remote sensing visualizations and museum objects.

For further information, see the Aura Web site at http://aura.gsfc.nasa.gov/.

EOS Terra

The EOS Terra outreach effort—under the direction of Yoram Kaufman (Code 913), Jon Ranson (Code 920), and David Herring (Code 913)—is a coordinated effort to foster greater cooperation and synergy among the various outreach groups within the EOS community. The Terra mission is designed to improve understanding of the movements of carbon and energy throughout Earth's climate system.

The "About Terra" link on the TERRA home page (http://terra.nasa.gov) contains links to five tutorials designed to inform the public about the importance of the physical parameters observed by the instruments aboard the Terra spacecraft. These tutorials deal with the properties of aerosols, changes in cloud cover and land surface, the Earth's energy balance, and the role of the oceans in climate change.

TOMS

The Atmospheric Chemistry and Dynamics Branch is committed to quality scientific education for students of all ages and levels. The TOMS Web site contains resource materials for science educators at http://toms.gsfc.nasa.gov/teacher/teacher.html. Three lessons that make use of TOM's data and that study the uses of Earth-orbiting satellites are presented at this site. One of these is directed at students in grades 5–8, the others at grades 9–12. There is also a link to five projects for independent research that allow advanced students to learn more about atmospheric chemistry and dynamics.

There is also an online textbook at http://toms.gsfc.nasa.gov/ozone/ozone_v8.html, written by branch scientists and designed as an educational resource for the general public, as well as for students and educators. This book contains 12 chapters covering all aspects of the science of stratospheric ozone. Each chapter has numerous low- and high-resolution figures, and ends with a set of review questions.

7. ACRONYMS

3S	Sun-Sky-Surface photometer
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
AFWEX	ARM-FIRE Water Vapor Experiment
AGCM	Atmospheric Global Circulation Model
AI	Aerosol Index
AIM	Aeronomy of Ice in the Mesosphere
AirGLOW	Air Goddard Lidar Observatory for Winds
AIRS	Atmospheric Infrared Sounder
AL	Aerosol Lidar
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	AMSR Earth Observing System (EOS)
AMSU	Advanced Microwave Sounding Unit
ARM	Atmospheric Radiation Measurement (Program)
ARM CART	ARM Cloud and Radiation Test Bed
AROTAL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ARREX	Aerosol Recirculation and Rainfall Experiment
AT Lidar	Aerosol and Temperature Lidar
ATMS	Advanced Technology Microwave Sounder
ATOVS	Advanced TOVS
AVE	Aura Validation Experiment
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AWEX-G	AIRS Water Vapor Experiment–Ground
BASE-ASIA	Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment
Brewer UV	Brewer Ultraviolet 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
CHINA-TEA	Climate and Health Impacts in North/east Asia–Tropospheric Experiment on Aerosols
CHyMERA	Compact Hyperspectral Mapper for Environmental Remote Sensing Applications
CIFAR	Cooperative Institute for Atmospheric Research

CIMSS	Cooperative Institute of Meteorological Satellite Studies
CLAMS	Chesapeake Lighthouse and Aircraft Measurements for Satellites
CLIVAR	Climate Variability and Predictability Programme
CMDL	Climate Monitoring and Diagnostics Laboratory
CNES	*Centre Nationale d'Etude Spatiales*
Co-I	Co-Investigator
COMMIT	Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere
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
DOI	Digital Object Identifiers
DSCOVR	Deep Space Climate Observatory Project (formerly Triana)
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
EO3	Earth Observing 3 mission called GIFTS
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EPA	Enviromental Protection Agency
EPIC	Earth Polychromatic Imaging Camera
EP-TOMS	Earth Probe TOMS
ERBE	Earth Radiation Budget Experiment
ERBE TOA	Earth Radiation Budget Experiment Top-Of-Atmosphere
ERBS	Earth Radiation Budget Satellite
ESA	European Space Agency
ESE	Earth Science Enterprise
ESPI	ENSO Precipitation Index
ESSIC	Earth System Science Interdisciplinary Center

ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
ESTO/ACT	Earth Science Technology Office/Advanced Component Technologies
E-Theater	Electronic Theater
FFPA	Filter/Focal Plane Array
FvDAS	Finite volume Data Assimilation System
FvGCM	Finite volume GCM
GADS	Global Aircraft Data Set
GATE	GARP Atlantic Tropical Experiment
GCE	Goddard Cumulus Ensemble model
GCM	General Circulation Model
GCMS	Gas Chromatograph Mass Spectrometer
GEOS	Goddard Earth Observing System
GeoSpec	Geostationary Spectrograph
GEST	Goddard Earth Sciences and Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GIFTS	Geosynchronous Imaging Fourier Transform Spectrometer
GIS	Geographical Information Systems
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
GMAO	Global Modeling and Assimilation Office
GMI	Global Modeling Initiative
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 Measurement
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
GWEC	Global Water and Energy Cycle
HARGLO-2	Intercomparison of Wind Profile Systems experiment involving the HARLIE and GLOW instruments
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
I3RC	Intercomparison of 3D Radiation Codes
IAMAS	International Association of Meteorology and Atmospheric Sciences
ICESat	Ice, Cloud, and Land Elevation Satellite
IGS	Internal Government Studies
IHOP	International H_2O Project
IIP	Instrument Incubator Program
INDOEX	Indian Ocean Experiment
INMS	Ion and Neutral Mass Spectrometer
INPE	*Instituto Nacional de Pesquisas Espaciais* (Institute for Space Research)
INSAT	India's Geosynchronous Satellite
IORD	Integrated Operational Requirements Document
IPCC	International Panel on Climatic Change
IPO	Integrated Program Office
IR	Infrared
IRAD	Independent Research and Development
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
JAXA	Japan Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology
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
KILT	Kiritimati Island Lidar Trailer
KNMI	Royal Netherlands Meteorological Institute
L2-SVIP	Lagrange-2 Solar Viewing Interferometer Prototype
LaRC	Langley Research Center
LAS	Leonardo Airborne Simulator
LASAL	Large Aperture Scanning Airborne Lidar
LORE	Limb Ozone Retrieval Experiment
LRR	Lightweight Rainfall Radiometer
MBA	Microbolometer Array
MBL	Marine Boundary Layer
MEIDEX	Mediterranean Israeli Dust Experiment
MEMS	Micro-Electro Mechanical Systems
Metop	future European POES satellites

MISR	Multi-Angle Imaging Spectroradiometer
MIT	Massachusetts Institute of Technology
MLS	Microwave Limb Sounder
MM5	Mesoscale Model 5
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Troposphere
MPI	Message Passing Interface
MPL	Micro-Pulse Lidar
MPLNET	Micro-Pulse Lidar Network
MSU	Microwave Sounding Unit
MTR	Management Technical Review
NAS	NASA Advanced Supercomputing Division
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 Institute of Standards and Technology
NMNH	National Museum of Natural History
NMS	Neutral Mass Spectrometer
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar Orbiting Environmental Satellite System
NPOL	NASA Polarimetric Radar
NPP	NPOESS Preparatory Project
NRC	National Research Council
NRL	Naval Research Laboratory
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
OGO	Orbiting Geophysical Observatory
OLR	Outgoing Longwave Radiation
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapper and Profiler System
OSE	Observing System Experiment
OSIRIS	Odin Spectrometer and IR Imager System
OSSE	Observing System Simulation Experiment

PACJET	Pacific Landfalling Jets Experiment
PAVE	Polar Aura Validation Experiment
PBL	Planetary Boundary Layer
PI	Principal Investigator
PICASSO-CENA	Pathfinder Instruments for Cloud and Aerosol SpaceborneObservations—*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
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
SACZ	South Atlantic Convergence Zone
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
SERDP	Strategic Environmental Research and Development Program
SHADOZ	Southern Hemisphere ADditional OZonesondes
SHARP	Summer High School Apprenticeship Research Program
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies
SLAM	Small Lidar Advanced Measurement
SLP	Sea Level Pressure
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMiR	Scannig Microwave Radiometer
SO	Southern Oscillation
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
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 Enterprise
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
SVIP	Solar Viewing Interferometer Prototype
SVS	Scientific Visualization Studio
TCO	Tropospheric Column Ozone
TES	Tropospheric Emission Spectrometer
THOR	cloud THickness from Offbeam Returns
THORPEX	THe Observing-system Research and Predictability EXperiment
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
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 KWAJEX	TRMM Kwajalein Experiment
TRMM LBA	TRMM Large Scale Biosphere–Atmosphere Experiment in Amazonia
TSI	Total Solar Irradiance
TSVO	TRMM Satellite Validation Office
UAE	United Arab Emirates Unified Aerosol Experiment
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
UNEP	United Nations Environment Programme
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
VINTERSOL	Validation of International Satellites and study of Ozone Loss
VSEP	Visiting Student Enrichment Program
WCRP	World Climate Research Programme
WHO	World Health Organization
WMO	World Meteorological Organization
WMO/UNEP	WMO/United Nations Environment Programme
WVTs	Water Vapor Tracers

APPENDIX A1. PRESS RELEASES

February 10, 2004—RELEASE: 04-058
NASA PREDICTS MORE TROPICAL RAIN IN A WARMER WORLD

As the tropical oceans continue to heat up, following a 20-year trend, warm rains in the tropics are likely to become more frequent, according to NASA scientists.

In a study by **William Lau** and **Huey-Tzu Jenny Wu**, of NASA‘s Goddard Space Flight Center, Greenbelt, Md., the authors offer early proof of a long-held theory that patterns of evaporation and precipitation, known as the water cycle, may accelerate in some areas due to warming temperatures. The research appears in the current issue of Geophysical Research Letters.

The study cites satellite observations showing the rate that warm rain depletes clouds of water is substantially higher than computer models predicted. This research may help increase the accuracy of models that forecast rainfall and climate. The rate water mass in a cloud rains out is the precipitation efficiency. According to the study, when it comes to light warm rains, as sea surface temperature increases, the precipitation efficiency substantially increases.

Computer climate models that predict rainfall have underestimated the efficiency of warm rain. Compared to actual observations from NASA's Tropical Rainfall Measuring Mission (TRMM) satellite, computer models substantially underestimate the precipitation efficiency of light rain. The findings from this study will provide a range of possibilities for warm rain efficiency that will greatly increase a model's accuracy.

"We believe there is a scenario where in a warmer climate there will be more warm rain. And more warm rain will be associated with a more vigorous water cycle and extreme weather patterns," Lau said.

The process that creates warm rain begins when water droplets condense around airborne particles and clouds are created. The droplets collide, combine and grow to form raindrops. The raindrops grow large and heavy enough to fall out as warm rain. The study claims, for each degree rise in sea surface temperature, the rate a cloud loses its water to moderate-to-light warm rainfall over the tropical oceans increases by eight to 10 percent.

Cold rains are generally associated with heavy downpour. They are generated when strong updrafts carry bigger drops higher up into the atmosphere, where they freeze and grow. These drops are very large by the time they fall. Once updrafts take these large drops high enough, and freezing takes place, the process of rainfall is more dependent on the velocity of the updraft and less on sea surface temperatures. Since the process of condensation releases heat, warm rains heat the lower atmosphere. More warm rains are likely to make the air lighter and rise faster, creating updrafts producing more cold rain.

The study found warm rains account for approximately 31 percent of the total global rain amount and 72 percent of the total rain area over tropical oceans, implying warm rains play a crucial role in the overall water cycle. Light warm rains appear to occur much more frequently, and cover more area, than cold rains, even though they drop less water per shower. The total precipitation from all types of warm rains accounts for a substantial portion of the total rainfall.

In a warmer climate, it is possible there will be more warm rain and fewer clouds. If the amount of water entering into clouds stays constant and rainfall efficiency increases, then there will be less water in the clouds and more warm rains.

More study is needed to better understand the relationship between increased warm-rain precipitation efficiency and a rise in sea surface temperatures, and to determine how cold rain might be affected by an increase in warm rain and a decrease in cloud water amounts.

NASA's Earth Science Enterprise is dedicated to understanding the Earth as an integrated system and applying Earth System Science to improve prediction of climate, weather and natural hazards using the unique vantage point of space.

For more information and images related to the study on the Internet, visit: http://www.gsfc.nasa.gov/topstory/2003/1224rainfall.html. For information about NASA on the Internet, visit: http://www.nasa.gov.

March 15, 2004—RELEASE: N04-090
SATELLITE FINDS WARMING 'RELATIVE' TO HUMIDITY

A NASA-funded study found some climate models might be overestimating the amount of water vapor entering the atmosphere as the Earth warms. Since water vapor is the most important heat-trapping greenhouse gas in our atmosphere, some climate forecasts may be overestimating future temperature increases.

In response to human emissions of greenhouse gases, like carbon dioxide, the Earth warms, more water evaporates from the ocean, and the amount of water vapor in the atmosphere increases. Since water vapor is also a greenhouse gas, this leads to a further increase in the surface temperature. This effect is known as "positive water vapor feedback." Its existence and size have been contentiously argued for several years.

Ken Minschwaner, a physicist at the New Mexico Institute of Mining and Technology, Socorro, N.M., and **Andrew Dessler**, a researcher with the University of Maryland, College Park, and NASA's Goddard Space Flight Center, Greenbelt, Md, did the study. It is in the March 15 issue of the American Meteorological Society's Journal of Climate. The researchers used data on water vapor in the upper troposphere (10-14 km or 6-9 miles altitude) from NASA's Upper Atmosphere Research Satellite (UARS).

Their work verified water vapor is increasing in the atmosphere as the surface warms. They found the increases in water vapor were not as high as many climate-forecasting computer models have assumed. "Our study confirms the existence of a positive water vapor feedback in the atmosphere, but it may be weaker than we expected," Minschwaner said.

"One of the responsibilities of science is making good predictions of the future climate, because that's what policy makers use to make their decisions," Dessler said. "This study is another incremental step toward improving those climate predictions," he added.

According to Dessler, the size of the positive water vapor feedback is a key debate within climate science circles. Some climate scientists have claimed atmospheric water vapor will not increase in response to global warming, and may even decrease. General circulation models, the primary tool scientists use to predict the future of our climate, forecast the atmosphere will experience a significant increase in water vapor.

NASA's UARS satellite was used to measure water vapor on a global scale and with unprecedented accuracy in the upper troposphere. Humidity levels in this part of the atmosphere, especially in the tropics, are important for global climate, because this is where the water vapor has the strongest impact as a greenhouse gas.

UARS recorded both specific and relative humidity in the upper troposphere. Specific humidity refers to the actual amount of water vapor in the air. Relative humidity relates to the saturation point, the amount of water vapor in the air divided by the maximum amount of water the air is capable of holding at a given temperature. As air temperatures rise, warm air can hold more water, and the saturation point of the air also increases.

In most computer models relative humidity tends to remain fixed at current levels. Models that include water vapor feedback with constant relative humidity predict the Earth's surface will warm nearly twice as much over the next 100 years as models that contain no water vapor feedback.

Using the UARS data to actually quantify both specific humidity and relative humidity, the researchers found, while water vapor does increase with temperature in the upper troposphere, the feedback effect is not as strong as models have predicted. "The increases in water vapor with warmer temperatures are not large enough to maintain a constant relative humidity," Minschwaner said. These new findings will be useful for testing and improving global climate models.

NASA's Earth Science Enterprise is dedicated to understanding the Earth as an integrated system and applying Earth system science to improve prediction of climate, weather and natural hazards using the unique vantage point of space. NASA plans to launch the Aura satellite in June 2004. Along with the Terra and Aqua satellites already in operation, Aura will monitor changes in Earth's atmosphere.

For information about NASA and agency programs on the Internet, visit:

http://www.nasa.gov

For more information about the research and images on the Internet, visit:

http://www.gsfc.nasa.gov/topstory/2004/0315humidity.html

April 20, 2004—RELEASE: 04-121
SATELLITES ACT AS THERMOMETERS IN SPACE

Like thermometers in space satellites are taking the temperature of the Earth's surface or skin. According to scientists, the satellite data confirms the Earth has had an increasing "fever" for decades.

For the first time, satellites have been used to develop an 18-year record (1981-1998) of global land surface temperatures. The record provides additional proof Earth's snow-free land surfaces have, on average, warmed during this time period, according to a NASA study appearing in the March issue of the Bulletin of the American Meteorological Society. The satellite record is more detailed and comprehensive than previously available ground measurements. The satellite data will be necessary to improve climate analyses and computer modeling.

Menglin Jin, the lead author, is a visiting scientist at NASA's Goddard Space Flight Center, Greenbelt, Md., and a researcher with the University of Maryland, College Park, Md. Jin commented until now global land surface temperatures used in climate change studies were derived from thousands of on-the-ground World Meteorological Organization (WMO) stations located around the world, a relatively sparse set of readings given Earth's size. These stations actually measure surface air temperature at two to three meters above land, instead of skin temperatures. The satellite skin temperature dataset is a good complement to the traditional ways of measuring temperatures.

A long-term skin temperature data set will be essential to illustrate global as well as regional climate variations. Together with other satellite measurements, such as land cover, cloud, precipitation, and sea surface temperature measurements, researchers can further study the mechanisms responsible for land surface warming.

Furthermore, satellite skin temperatures have global coverage at high resolutions, and are not limited by political boundaries. The study uses Advanced Very High Resolution Radiometer Land Pathfinder data, jointly created by NASA and the National Oceanic and Atmospheric Administration (NOAA) through NASA's Earth Observing System Program Office. It also uses recently available NASA Moderate Resolution Imaging Spectroradiometer skin temperature measurements, as well as NOAA TIROS Operational Vertical Sounder (TOVS) data for validation purposes. All these data are archived at NASA's Distributed Active Archive Center.

Inter-annually, the 18-year Pathfinder data in this study showed global average temperature increases of 0.43 Celsius (C) (0.77 Fahrenheit (F)) per decade. By comparison, ground station data (2 meter surface air temperatures) showed a rise of 0.34 C (0.61 F) per decade, and a National Center for Environmental Prediction reanalysis of land surface skin temperature showed a similar trend of increasing temperatures, in this case 0.28 C (0.5 F) per decade. Skin temperatures from TOVS also prove an increasing trend in global land surfaces. Regional trends show more variations.

"Although an increasing trend has been observed from the global average, the regional changes can be very different," Jin said. "While many regions were warming, central continental regions in North America and Asia were actually cooling."

One issue with the dataset is that it cannot detect surface temperatures over snow. In winter, most of the land areas in the mid to upper latitudes of the Northern Hemisphere are covered by snow. Of Earth's land area, 90 percent of it is snow free in July, compared to only 65 percent in January. For this reason, the study only focused on snow free areas. Still, in mountainous areas that are hard to monitor, like Tibet, satellites can detect the extent of snow coverage and its variations.

The satellite dataset allows researchers to also look at daily trends on global and regional scales. The largest daily variation was above 35.0 C (63 F) at tropical and sub-tropical desert areas for a July 1988 sample, with decreasing daily ranges towards the poles, in general. Daily changes were also closely related to vegetation cover. The daily skin temperature range showed a decreasing global mean trend over the 18-year period, resulting from greater temperature increases at night compared to daytime.

Things like clouds, volcanic eruptions, and other factors gave false readings of land temperatures, but scientists factored those out to make the skin temperature data more accurate. Scientists are considering extending this 18-year satellite-derived skin temperature record up to 2003. The mission of NASA's Earth Science Enterprise is to develop a scientific understanding of the Earth system and its response to natural or human-induced changes to enable improved prediction capability for climate, weather, and natural hazards. NASA funded the study.

For more information and images about the research, visit:

http://www.gsfc.nasa.gov/topstory/2004/0315skintemp.html

April 28, 2004—RELEASE: 04-110

NEW NASA TECHNOLOGY HELPS FORECASTERS IN SEVERE WEATHER SEASON

NASA is providing new technology and satellite data to help forecasters at the National Oceanic and Atmospheric Administration (NOAA) create the best possible forecasts of severe springtime weather.

New NASA data gathered from satellites, a lightning ground-tracking network and unmanned vehicles that fly into storms are some of the many tools used by NOAA, the federal agency charged with issuing weather forecasts. This data will help make the severe weather season safer for everyone.

"It's an evolutionary process and partnership between NOAA and NASA," said Bill Patzert, oceanographer at NASA's Jet Propulsion Laboratory, Pasadena, Calif. "NOAA is the ultimate operational meteorological agency in the world, and NASA is developing state-of-the-art operational and fundamental research to make it better than ever. Together we're looking to the future to provide better and better service to the American public," he said.

NOAA's National Weather Service (NWS) is responsible for monitoring and forecasting severe weather events. They issue watches and warnings for tornadoes, flash floods, non-precipitation events (such as high wind warnings), severe thunderstorms, and flooding, as well as daily weather forecasts. They reach the public with these warnings mainly through NOAA weather radio and the Internet.

NASA uses data from its Earth-observing satellites and models to characterize and understand the way atmosphere, oceans and land interact. "Adding NASA satellite data and model output to NOAA forecasts could lead to more confident seven-day severe local storm forecasts, better prediction of thunderstorm occurrence by three hours, and an increase in tornado warning lead times by 18 minutes," said **Dr. Marshall Shepherd**, research meteorologist at NASA's Goddard Space Flight Center, Greenbelt, Md.

NASA satellite data that enhances NOAA's weather model forecasts include surface wind data from QuikScat and rainfall data from the Tropical Rainfall Measuring Mission satellite. Launching in June 2004, NASA's Aura satellite will provide temperature and moisture information. That data will provide a clearer atmospheric picture, and it will improve forecast model prediction capabilities.

Better understanding of jet steam locations, temperature, humidity fields and other atmospheric states are critical in assessing the potential for severe weather. Balloon observations taken twice daily at approximately 180 locations in the United States are the main source of this type of information. New NASA satellite observations can fill in the missing data spaces around the United States and surrounding oceans. The NASA-NOAA Joint Center for Satellite Data Assimilation was formed in 2002 to accelerate the use of satellite data within global-scale weather forecast models operated by NOAA.

NASA's Short-term Prediction Research and Transition (SPoRT) Center at NASA's Marshall Space Flight Center, Ala., is working closely with NWS forecasters in the southern United States to improve severe weather forecasting. NASA scientists are using data obtained from the ground-based Lightning Mapping Array in northern Alabama to better understand the relationship between lightning flash rates and tornado-producing thunderstorms.

The SPoRT Center provides lightning data to surrounding NWS forecast offices in real time for use in severe weather warning decision-making. "There has been one event where the NASA lightning data prompted NWS forecasters in the Huntsville, Alabama office to issue a tornado warning on a strong convective cell earlier than they would have otherwise," said Dr. William Lapenta, SPoRT Center research meteorologist. A weak tornado occurred after the warning was issued. Research is also underway to improve flooding forecasts by incorporating new satellite data from the NASA Atmospheric InfraRed Sounder instrument into NWS weather forecast models on a regional scale.

In February, NASA's Langley Research Center, Hampton, Va., flight-tested the Global Positioning System Reflectometer on an unmanned aerial vehicle to collect data in severe weather situations. In 2002, NASA, universities and industries conducted the Altus Cumulus Electrification Study in Florida, the first time a remotely piloted aircraft was used to conduct lightning research.

NASA's Earth Science Enterprise is dedicated to understanding the Earth as an integrated system and applying Earth System Science to improve prediction of climate, weather, and natural hazards using the unique vantage point of space. For more information about severe weather on the Internet, visit:

http://space.mit.edu/HETE/http://www.gsfc.nasa.gov/topstory/2004/0316severeweather.html

May 3, 2004—RELEASE: 04-147
NASA SATELLITES AND BALLOONS SPOT AIRBORNE POLLUTION "TRAIN"

NASA scientists discovered pollution could catch an airborne "express train," or wind current, from Asia all the way to the southern Atlantic Ocean.

Scientists believe during certain seasons, as much as half of the ozone pollution above the Atlantic Ocean may be speeding down a "train" track of air from the Indian Ocean. As it rolls along, it picks up more smog from air peppered with thunderstorms that bring it up from the Earth's surface.

Bob Chatfield, a scientist at NASA's Ames Research Center, Moffett Field, Calif. said, "Man-made pollution from Asia can flow southward, get caught up into clouds, and then move steadily and rapidly westward across Africa and the Atlantic, reaching as far as Brazil."

Chatfield and **Anne Thompson**, a scientist at NASA's Goddard Spaceflight Center, Greenbelt, Md., used data from two satellites and a series of balloon-borne sensors to spot situations when near-surface smog could "catch the train" westward several times annually from January to April.

During those periods of exceptionally high ozone in the South Atlantic, especially during late winter, researchers noticed Indian Ocean pollution follows a similar westward route, wafted by winds in the upper air. They found the pollution eventually piles up in the South Atlantic. "We've always had some difficulty explaining all that ozone," Thompson admitted.

"Seasonal episodes of unusually high ozone levels over the South Atlantic seem to begin with pollution sources thousands of miles away in southern Asia," Chatfield said. Winds are known to transport ozone and pollutants thousands of miles away from their original sources.

Clearly defined individual layers of ozone in the tropical South Atlantic were traced to lightning sources over nearby continents. In addition to ozone peaks associated with lightning, high levels of ozone pollution came from those spots in the Sahel area of North Africa where vegetation burned. However, even outside these areas, there was extra ozone pollution brought by the Asian "express train."

The scientists pinpointed these using the joint NASA-Japan Tropical Rainfall Measuring Mission satellite to see fires and lightning strikes, both of which promote ozone in the lower atmosphere. Researchers also identified large areas of ozone smog moving high over Africa using the Total Ozone Mapping Spectrometer satellite instrument.

The scientists confirmed the movement of the smog by using sensors on balloons in the Southern Hemisphere Additional Ozonesondes (SHADOZ) network. A computer model helped track the ozone train seen along the way by the SHADOZ balloon and satellite sensors. The scientists recreated the movement of the ozone from the Indian Ocean region to the Southern Atlantic Ocean.

Their research results appear in an article in a recent issue of the American Geophysical Union's Geophysical Research Letters.

The mission of NASA's Earth Science Enterprise is to develop a scientific understanding of the Earth system and its response to natural or human-induced changes to enable improved prediction capability for climate, weather, and natural hazards.

For images and information about this research on the Internet, visit:

http://www.gsfc.nasa.gov/topstory/2004/0426pollutiontrain.html

For information about NASA on the Internet, visit: http://www.nasa.gov/home/index.html

May 4, 2004—RELEASE: 04-148
NASA SCIENTISTS AND ENGINEERS RECEIVE PRESIDENTIAL AWARDS

Four NASA-funded researchers received Presidential Early Career for Scientists and Engineers (PECASE) awards today at the White House.

These National Science and Technology Council (NSTC) awards represent the highest honor bestowed by the U.S. government on scientists and engineers beginning their independent careers. The awards recognize recipients' exceptional potential for leadership at the frontiers of scientific knowledge. The NSTC bestows the PECASE award only once during an individual's career.

"We are thrilled to honor these promising researchers, and we certainly will look to them to lead the way for NASA's future scientific and engineering endeavors," said NASA Administrator Sean O'Keefe. "Encouraging young achievers is increasingly important, as we work to advance America's technology and science initiatives," Administrator O'Keefe said.

NASA recipients and their research proposals:

Dr. J. Marshall Shepherd, research meteorologist and deputy project scientist for the Global Precipitation Measurement mission, NASA's Goddard Space Flight Center, Greenbelt, Md. Investigation of Urban-Induced Precipitation Using Satellite-Based Remote Sensing and Numerical Modeling: Linking Land Use and Change to Variations in the Water Cycle.

Dr. Mark Simons, associate professor of geophysics, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, Calif. Constraining Modes of Crustal Deformation Using Interferometric Synthetic Aperture Radar.

Dr. Eric R. Weeks, assistant professor, Department of Physics, Emory University, Atlanta. Confocal Microscopy of Colloidal Glass Transition.

Dr. Thomas H. Zurbuchen, associate professor, Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, Mich. Solar Wind Structure in the Inner Heliosphere: Rationale for the Location of the Sentinel Missions.

The PECASE awards were created to foster innovative and far-reaching developments in science and technology. The awards increase awareness of careers in science and engineering; give recognition to the scientific missions of participating agencies; enhance connections between fundamental research and national goals; and highlight the importance of science and technology for the nation's future. The recipients will each receive funding for their award-winning research projects.

For information about the PECASE awards on the Internet, visit: http://www.ostp.gov/html/pecase2002.html

Images of NASA PECASE award recipients will be available on the Internet at:

ftp://ftp.hq.nasa.gov/pub/pao/images/paoimages/misc/20040503_pecase/

For information about NASA and agency programs on the Internet, visit: http://www.nasa.gov/home/index.html

May 26, 2004—RELEASE: 04-168
NASA'S WEATHERMAN ENCOURAGES YOUNG PEOPLE

An allergic reaction to a childhood bee sting kept **Dr. J. Marshall Shepherd** from becoming an entomologist. It did not keep him from pursuing his dreams of being a scientist and joining NASA.

In elementary school, he became interested in the weather; even creating a science project entitled, "Can a 6th Grader Predict the Weather?" Since then Shepherd has been committed to figuring out why weather behaves as it does and to improving overall understanding of Earth. True to his aspirations, Shepherd, a research meteorologist, has sought to integrate new scientific knowledge from NASA missions into real-life applications and decision-making processes.

Shepherd is the deputy project scientist for NASA's Global Precipitation Measurement mission. The project strives to improve predictions of climate change, the accuracy of weather forecasts, and provides frequent, complete samplings of the Earth's precipitation. He is on the NASA precipitation science team, a member of numerous technical and science committees.

In addition, Shepherd serves the larger scientific and educational communities through membership in the American Meteorological Society, National Technical Association, American Geophysical Union and International Association of Urban Climatology. He recently co-authored a children's book about conducting weather-related science projects and understanding basic weather information.

Shepherd received his B.S., M.S. and Ph.D. in physical meteorology from Florida State University (FSU), Tallahassee, Fla. He is the first African-American to receive a doctorate from the FSU Department of Meteorology, one of the nation's oldest and most respected programs.

He has published numerous papers and made many public appearances as a NASA expert about weather, climate and remote sensing. Shepherd has presented his research to the Office of Management and Budget, the Office of Science and Technology Policy, the Department of Defense and officials from foreign countries.

Shepherd encourages young people to pursue studies in Earth science and meteorology, and strives to improve minority access to these critical fields. "I am motivated to mentor and speak to youngsters who 'look like me' as often as I can," Shepherd said.

Shepherd's valuable scientific contributions and leadership have not gone unnoticed. He is one of NASA's four recipients of the most recent Presidential Early Career for Scientists and Engineers (PECASE) award, the highest federal government award given to young scientists and engineers. Shepherd was chosen based on his research in mesoscale and satellite meteorology.

"This award anchors my motivation to make significant contributions in my science community and beyond. I am particularly interested in moving science from strictly research areas to being more accessible to societal communities that can benefit from it," Shepherd said. He feels like a "kid in a candy store," with his access to world-class NASA technologies and colleagues.

Although Shepherd prides himself on being a good and thorough scientist, most people would agree he is a fairly "normal" guy. He's an avid sports fan, has more than 2000 Compact discs and lifts weights. He is active in his alumni fraternity Alpha Phi Alpha, and the Florida State Alumni Association. Other than trying out fancy electronics, his favorite things to do involve spending time with his wife and new baby daughter.

Media interested in interviewing Shepherd should contact Gretchen Cook-Anderson, NASA Public Affairs, at: 202/358-0836.

June 9, 2004—RELEASE: 04-183

NASA DATA SHOWS DEFORESTATION AFFECTS CLIMATE IN THE AMAZON

NASA satellite data are giving scientists insight into how large-scale deforestation in the Amazon Basin in South America is affecting regional climate. Researchers found during the Amazon dry season last August, there was a distinct pattern of higher rainfall and warmer temperatures over deforested regions.

Researchers analyzed multiple years of data from NASA's Tropical Rainfall Measuring Mission (TRMM). They also used data from the Department of Defense Special Sensor Microwave Imager and the National Oceanic and Atmospheric Administration's Geostationary Operational Environmental Satellites.

The study is in a recent American Meteorological Society Journal of Climate. Lead authors, **Andrew Negri** and **Robert Adler**, are research meteorologists at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Md. Other authors include Liming Xu, formerly with the University of Arizona, Tucson, and Jason Surratt, North Carolina State University, Raleigh.

"In deforested areas, the land heats up faster and reaches a higher temperature, leading to localized upward motions that enhance the formation of clouds and ultimately produce more rainfall," Negri said.

The researchers caution the rainfall increases were most pronounced in August, during the transition from dry to wet seasons. In this transition period, the effects of land cover, such as evaporation, are not overwhelmed by large-scale weather disturbances that are common during the rest of the year. While the study, based on satellite data analysis, focused on climate changes in the deforested areas, large increases in cloud cover and rainfall were also observed in the naturally un-forested savanna region and surrounding the urban area of Port Velho, Brazil, particularly in August and September.

Recent studies by **Dr. Marshall Shepherd** cited similar findings, including an average rain-rate increase of 28 percent downwind of urban areas and associated changes in the daily timing of cloud formation and precipitation. He is also a research meteorologist at GSFC.

This research confirmed the Amazon savanna region experienced a shift in the onset of cloudiness and rainfall toward the morning hours. The shift was likely initiated by the contrast in surface heating across the deforested and savanna region.

The varied heights of plants and trees in the region change the aerodynamics of the atmosphere, creating more circulation and rising air. When the rising air reaches the dew point in the cooler, upper atmosphere, it condenses into water droplets and forms clouds.

Negri acknowledged other factors are involved. The savanna in this study is approximately 100 kilometers (62 miles) wide, the perfect size to influence precipitation, such as rain showers and thunderstorms. Earlier studies hypothesized certain land surfaces, such as bands of vegetation 50 to 100 kilometers (31-62 miles) wide in semiarid regions, could result in enhanced precipitation.

This research is in agreement with the recent and sophisticated computer models developed by the Massachusetts Institute of Technology. The models concluded small-scale circulations, including the mixing and rising of air induced by local land surfaces, could enhance cloudiness and rainfall. Many earlier studies that relied on models developed in the 1990s or earlier concluded widespread deforestation of the Amazon Basin would lead to decreased rainfall.

"The effects here are rather subtle and appear to be limited to the dry season. The overall effect of this deforestation on annual and daily rainfall cycles is probably small and requires more study," Negri said. Future research will use numerical models for investigating the linkage between deforested land surface and the cloud-precipitation components of the water cycle.

NASA's Earth Science Enterprise is dedicated to understanding the Earth as an integrated system and applying Earth System Science to improve prediction of climate, weather, and natural hazards using the unique vantage point of space.

For more information and images about this research on the Internet, visit:

http://www.gsfc.nasa.gov/topstory/2004/0603amazondry.html

For information about NASA and agency programs on the Internet, visit: http://www.nasa.gov

June 10, 2004—RELEASE: 04-187
RESEARCHERS SEEING DOUBLE ON AFRICAN MONSOONS

NASA and University of Maryland scientists have found the African monsoon consists of two distinct seasons.

The first season is in the late spring and early summer. The rain is concentrated on the West African Coast near the Gulf of Guinea, five degrees north of the equator. This season appears strongly influenced by sea surface temperatures off the coast of West Africa.

The second season arrives later in summer in July at around 10 degrees north of the equator. Atmospheric waves moving westward over the Atlantic Ocean appear to play a major role in this summer season monsoon rainfall, according to the research using NASA's Tropical Rainfall Measuring Mission (TRMM) satellite. These waves, called African Easterly Waves, are evident in the rain patterns.

The research results appeared in a recent issue of Journal of Geophysical Research and in a paper in the Journal of Climate. Additional research will explore connections between African Easterly Waves and hurricane activity.

"Most people agree the later season is determined by the atmosphere, but we found the early spring monsoon is determined by being close to the ocean," said **Guojun Gu,** lead author of the study. Gu is a researcher at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Md., and the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County. "Also, if the spring rain is weak, then the summer monsoon is strong, and vice versa," Gu said.

A study from 1998 to 2002 of daily rainfall from the TRMM satellite, combined with information from other satellites, defined the evolution of the African monsoon. This very high-quality dataset of rainfall rates helped determine the distinct northward "jump" in the monsoon from the early summer season to the later summer episode.

In the May to June season, large differences in sea surface temperatures between coastal waters and water further out to sea lead to increased rainfall. When coastal waters are warm and equatorial waters are colder, rainfall is stronger along the coastline. The July monsoon is related to the easterly waves. These waves carry a great deal of moisture and provide the seasonal monsoon rain before moving off the west coast of Africa.

Previous research suggests the African Easterly Waves may kick off small circulations that develop into hurricanes over the North Atlantic Ocean. Up to 80 percent of the major hurricanes that impact the eastern United States may originate with these waves. "You can track a hurricane backward in time to waves coming off the African coast and all the way to the mainland of Africa," said Robert Adler, a co-author and researcher at GSFC.

The African Easterly Waves occur only during summer months, from May through October. While the waves vary greatly in strength from year to year, their numbers stay consistently at about 60 to 70 per year. These waves consist of low-pressure systems that pass every three to four days, with a wavelength of about 2000 to 2500 kilometers. More study is needed to better understand how variations in the waves impact hurricanes.

The researchers also found the nature of these waves shifts at about the 15-degree north line. The waves that pass south of this line carry moisture and create convection that lead to rain clouds. These southern waves play a role in both the later summer monsoons and the genesis of hurricanes. But waves that pass north of the 15-degree line carry hot dry air from the Sahara. These waves may carry tons of dust as they move west with trade winds. In about a week they can carry dust all the way to the Gulf of Mexico and Florida.

The mission of NASA's Earth Science Enterprise is to develop a scientific understanding of the Earth System and its response to natural or human-induced changes to enable improved prediction capability for climate, weather, and natural hazards.

For more information about this research on the Internet, visit:

http://www.gsfc.nasa.gov/topstory/2004/0510africanwaves.html

For more information about TRMM on the Internet, visit: http://trmm.gsfc.nasa.gov/.

July 15, 2004—RELEASE: 04-217

AURA LAUNCHED, TO BETTER UNDERSTAND THE AIR WE BREATHE

Aura, a mission dedicated to the health of the Earth's atmosphere, successfully launched today at 6:01:59 a.m. EDT (3:01:59 a.m. PDT) from Vandenberg Air Force Base, Calif., aboard a Boeing Delta II rocket. Spacecraft separation occurred at 7:06 a.m. EDT (4:06 a.m. PDT), inserting Aura into a 438-mile (705-kilometer) orbit.

NASA's latest Earth-observing satellite, Aura will help us understand and protect the air we breathe.

"This moment marks a tremendous achievement for the NASA family and our international partners. We look forward to the Aura satellite offering us historic insight into the tough issues of global air quality, ozone recovery and climate change," said NASA Associate Administrator for Earth Science Dr. Ghassem Asrar. "This mission advances NASA's exploration of Earth and will also better our understanding of our neighbors in the planetary system. Aura joins its siblings, Terra, Aqua and 10 more research satellites developed and launched by NASA during the past decade, to study our home planet," he added.

Aura will help answer three key scientific questions: Is the Earth's protective ozone layer recovering? What are the processes controlling air quality? How is the Earth's climate changing? NASA expects early scientific data from Aura within 30-90 days.

Aura also will help scientists understand how the composition of the atmosphere affects and responds to Earth's changing climate. The results from this mission will help scientists better understand the processes that connect local and global air quality.

Each of Aura's four instruments is designed to survey different aspects of Earth's atmosphere. Aura will survey the atmosphere from the troposphere, where mankind lives, through the stratosphere, where the ozone layer resides and protects life on Earth.

With the launch of Aura, the first series of NASA's Earth Observing System satellites is complete. The other satellites are Terra, which monitors land, and Aqua, which observes Earth's water cycle.

Aura's four instruments are: the High Resolution Dynamics Limb Sounder (HIRDLS); the Microwave Limb Sounder (MLS); the Ozone Monitoring Instrument (OMI); and the Tropospheric Emission Spectrometer (TES).

HIRDLS was built by the United Kingdom and the United States. OMI was built by the Netherlands and Finland in collaboration with NASA. NASA's Jet Propulsion Laboratory in Pasadena, Calif., constructed TES and MLS. NASA's Goddard Space Flight Center, Greenbelt, Md., manages the Aura mission.

"Many people have worked very hard to reach this point and the entire team is very excited," said Aura Project Manager Rick Pickering of Goddard.

NASA's Earth Science Enterprise is dedicated to understanding the Earth as an integrated system and applying Earth System Science to improve prediction of climate, weather and natural hazards using the unique vantage point of space.

For Aura information and images on the Internet, visit: http://www.gsfc.nasa.gov/topstory/2004/0517aura.html and http://www.nasa.gov/aura

July 22, 2004—RELEASE: 04-235

NASA GOES TO THE "SORCE" OF EARTH SUN-BLOCKERS

Scientists using measurements from NASA's Solar Radiation and Climate Experiment (SORCE) satellite have discovered that Venus and sunspots have something in common: they both block some of the sun's energy going to Earth.

Using data from NASA's SORCE satellite, scientists noticed that, when Venus came between the Earth and the sun on June 8, the other planet reduced the amount of sunlight reaching Earth by 0.1 percent. This Venus transit occurs when, from an earthly perspective, Venus crosses in front of the sun. When it happens, once every 122 years, there are two transits eight years apart. The next crossing happens in 2012 and will be visible to people on the U.S. West Coast.

"Because of its distance from Earth, Venus appeared to be about the size of a sunspot," said Gary Rottman, SORCE Principal Investigator and a scientist at the Laboratory for Atmospheric and Space Physics (LASP), at the University of Colorado at Boulder. The SORCE team had seen similar reductions in the sun's energy coming Earthward during the October 2003 sunspot activity.

In October 2003 the Earth-bound sunlight dimmed 0.3 percent for about four days, due to three very large sunspot groups moving across the face of the sun.

"This is an unprecedented large decrease in the amount of sunlight, and it is comparable to the decrease that scientists estimate occurred in the seventeenth century," Rottman said. That decrease lasted almost 50 years, and was likely associated with the exceptionally cold temperatures throughout Europe at that time, a period from the 1400s to the 1700s known as the "little ice age."

Solar conditions during the little ice age were quite different, as there were essentially no sunspots. Astronomers of the time, like Galileo, kept a good record of sunspot activity before and during the period, encountering only about 50 sunspots in 30 years.

Rottman said, "Something very different was happening during the seventeenth century, and it produced a much more permanent change in the sun's energy output at that time." Today, the large sunspots are surrounded by bright areas called "faculae." Faculae more than compensate for the decrease in sunlight from sunspots, and provide a net increase in sunlight when averaged over a few weeks.

The large number of sunspots occurring in October/November 2003 indicated a very active sun, and indeed many very large solar flares occurred at that time. SORCE observed the massive record-setting solar flares in x-rays. The flares were accompanied by large sunspots, which produced a 0.3 percent decrease in the sun's energy output. SORCE simultaneously collected the energy from all wavelengths, something that had never been done before.

"The SORCE satellite instruments provide measurements of unprecedented accuracy, so the sun's energy output is known with great precision, and precise knowledge of variations in the sun's energy input to Earth is a necessary prerequisite to understanding Earth's changing climate," said **Robert F. Cahalan**, SORCE Project Scientist and Head of the Climate and Radiation Branch at NASA's Goddard Space Flight Center, Greenbelt, Md.

The SORCE measurements provide today's atmospheric and climate scientists with essential information on the sun's energy input to the Earth. These measurements also will be valuable to future scientists, who will be relating their view of the world back to conditions existing today. Likewise Galileo's findings about the sun almost 400 years ago have increased in value as understanding of the sun and its importance for Earth has advanced.

For more SORCE information and images on the Internet, visit: http://www.gsfc.nasa.gov/topstory/2004/0730sunblockers.html and http://lasp.colorado.edu/sorce/

September 2, 2004—NOTE TO EDITORS: N04-135
NASA CONTRIBUTIONS TO HURRICANE SCIENCE

Weather experts will explain how NASA satellite data contributes to our understanding of hurricanes during a telephone media opportunity Tuesday at 1:30 p.m. EDT.

Research meteorologists, **Dr. J. Marshall Shepherd** (NASA) and **Dr. Jeffrey Halverson** (University of Maryland), will discuss the latest in hurricane science. NASA's research aids hurricane forecasting and tracking around the globe during storm seasons.

Sept. 20, 2004—RELEASE: 04-305

THREE NASA WOMEN HONORED FOR AEROSPACE ACCOMPLISHMENTS

Women in Aerospace (WIA) will honor three NASA women for their professional aerospace accomplishments during the organization's 19th annual awards program tomorrow in Washington.

Estelle Condon, Associate Center Director for Astrobiology and Space Programs at NASA's Ames Research Center, Moffett Field, Calif., will receive the Lifetime Achievement Award.

Dr. Ann Thompson, a research scientist in atmospheric chemistry at NASA's Goddard Space Flight Center, Greenbelt, Md., will receive the International Achievement Award.

Dr. Rebecca A. MacKay, Science Advisor to the Materials Division Chief at NASA's Glenn Research Center, Cleveland, will receive the Outstanding Achievement Award.

"Congratulations to these extraordinary women, who embody the very qualities NASA needs to achieve the Vision for Space Exploration," said NASA Administrator Sean O'Keefe. "In addition to their own significant accomplishments, they have consistently worked as role models and mentors to enhance the transfer of knowledge to the next generation of explorers. I salute them for their accomplishments and applaud WIA for recognizing them."

WIA will present the awards during a public reception at the Rayburn House Office Building Foyer from 6 to 8 p.m. WIA will present three other awards at the reception, the Outstanding Leadership Award, the Aerospace Awareness Award, and the Aerospace Educator Award, to women who work in the private sector. WIA is a non-profit organization dedicated to expanding women's opportunities for leadership and increasing their visibility in the aerospace community.

Nov. 8, 2004—RELEASE: 04-369

TRMM SATELLITE PROVES EL NIÑO HOLDS THE REINS ON GLOBAL RAINS

NASA scientists recently found the El Niño Southern Oscillation (ENSO) is the main driver of the change in rain patterns all around the world.

The NASA and Japan Aerospace Exploration Agency (JAXA) Tropical Rainfall Measuring Mission (TRMM) satellite has enabled scientists to look around the globe and determine where the year-to-year changes in rainfall are greatest. The TRMM is a joint mission between NASA and JAXA designed to monitor and study tropical rainfall.

Researchers Ziad Haddad and Jonathan Meagher of NASA's Jet Propulsion Laboratory, Pasadena, Calif., **Robert Adler** and **Eric Smith** of NASA's Goddard Space Flight Center, Greenbelt, Md., used TRMM data to identify areas where the year-to-year change in rainfall between 1998 and 2003 was greatest.

By studying the rain patterns in these areas over the past 50 years, with rain gauge data prior to 1998, they established the main component of this change in global rainfall is directly correlated with the El Niño Southern Oscillation. The study appeared in a recent issue of the Journal of Geophysical Research-Atmospheres.

Haddad and his colleagues compared local changes in worldwide rainfall. For years, scientists have known El Niño drastically modifies rainfall patterns in many regions. For example, Indonesia and the Northeastern Amazon basin consistently suffer droughts during El Niño and excessive rains during La Niña. The Southeastern United States and California are typically wetter than usual during El Niño and drier than usual during La Niña.

Scientists also have known several regions with abundant rain are not influenced by the El-Niño/La-Niña changes, including the Bay of Bengal and the vast expanse of the Western Pacific Ocean between the Marshall Islands, Micronesia and the Marianas.

Until the launch of TRMM in 1997, it was impossible to accurately measure change in tropical rainfall patterns, because no instruments were available to record global rainfall. TRMM uses microwave technology to probe through clouds and estimate how much rainfall they are producing. The TRMM data are invaluable over areas where there are no rain gauges, such as the open ocean.

Using TRMM's measurements, the researchers were able to condense the year-to-year change in rainfall patterns into a single rain-change index. The index is a color-coded map that shows areas of rainfall around the world that are influenced somewhat to greatly, during an ENSO event.

Rainfall data from land and island stations were used to extend this index back in time and to compare it with the ENSO sea-surface temperature and atmospheric pressure. The results showed a strong relationship between the rainfall patterns and ENSO. "The fact that the rain-change index, which comes directly from global measurements, tracks the ENSO indices from the 1950s to the present confirms that El Niño is the principal driver of global year-to-year rainfall change," Haddad said.

NASA plans the Global Precipitation Measurement mission (GPM), a future multi-national multi-satellite mission to expand the scope of TRMM. GPM will focus on producing three-dimensional maps of rain around the world every three hours.

TRMM is the first space-based rain gauge that uses microwaves to see how much precipitation falls from clouds around the tropics. The TRMM satellite's precipitation radar acts like a highly sensitive microwave camera. It is capable of probing clouds to reveal their vertical structure and precipitation they produce. It has enabled scientists to measure rainfall over the oceans and landmasses with unprecedented accuracy.

December 14, 2004—RELEASE: 04-391

NASA'S AURA SATELLITE SHEDS NEW LIGHT ON AIR QUALITY AND OZONE HOLE

NASA scientists announced the agency's Aura spacecraft is providing the first daily, direct global measurements of low-level ozone and many other pollutants affecting air quality.

For the first time, Aura will help scientists monitor global pollution production and transport with unprecedented spatial resolution. Aura's measurements offer new insights into how climate changes influence the recovery of the Earth's protective stratospheric ozone layer.

"Data from NASA missions like Aura are a valuable national asset," said Aura Program Scientist Phil DeCola of NASA Headquarters, Washington. "Clean air is a vital need, and air quality is not merely a local issue. Pollutants do not respect state or national boundaries. They can degrade air quality far from their sources. Aura's view from space enables us to understand the long-range transport of pollutants," he added.

"Aura's early results are nothing short of astounding; measurements like these will help us better understand how the ozone hole will react to future stratospheric cooling, which is expected as carbon dioxide levels continue to rise," said Aura Project Scientist Mark Schoeberl of NASA's Goddard Space Flight Center, Greenbelt, Md.

Aura's instruments study tropospheric chemistry and will provide daily, global monitoring of air pollution. The complexity of pollution transport makes it difficult to quantify how much industry and cars contribute to poor local air quality. Also, the presence of stratospheric ozone sandwiched between the satellite and the troposphere makes seeing tropospheric ozone very difficult. Aura's Tropospheric Emission Spectrometer (TES) uses new technology to see through the stratospheric ozone layer, to measure tropospheric ozone.

Aura also provides new insights into the physical and chemical processes that influence the health of the stratospheric ozone layer and climate. It's producing the most complete suite of chemical measurements ever available to understand the ozone layer and its recovery.

Data will include the first measurements of chemically reactive hydrogen-containing species involved in ozone destruction. The satellite also will provide the first simultaneous measurements of key forms of chlorine and bromine, also important for ozone destruction. Aura measures the upper-tropospheric water-vapor abundance, a key component in the radiation budget, needed to understand climate change.

Launched July 15, 2004, Aura is the third and final major Earth Observing System satellite. Aura's view of the atmosphere and its chemistry will complement the global data already being collected by NASA's other Earth Observing System satellites. These projects are Terra, primarily focused on land, and Aqua, which comprehensively observes Earth's water cycle. Collectively, these satellites allow scientists to study the complexities of how land, water and our atmosphere work as a system.

Aura carries four instruments: Ozone Monitoring Instrument (OMI), Microwave Limb Sounder (MLS), High Resolution Dynamics Limb Sounder (HIRDLS) and the Tropospheric Emission Spectrometer (TES). OMI was built by the Netherlands and Finland in collaboration with NASA. HIRDLS was built by the United Kingdom and the United States.

Dec. 14, 2004—RELEASE: 04-398

NASA SELECTS INVESTIGATIONS FOR THE MARS SCIENCE LABORATORY

NASA has selected eight proposals to provide instrumentation and associated science investigations for the mobile Mars Science Laboratory (MSL) rover, scheduled for launch in 2009. Proposals selected today were submitted to NASA in response to an Announcement of Opportunity (AO) released in April.

The MSL mission, part of NASA's Mars Exploration Program, will deliver a mobile laboratory to the surface of Mars to explore a local region as a potential habitat for past or present life. MSL will operate under its own power. It is expected to remain active for one Mars year, equal to two Earth years, after landing.

In addition to the instrumentation selected, MSL will carry a pulsed neutron source and detector for measuring hydrogen (including water), provided by the Russian Federal Space Agency. The project also will include a meteorological package and an ultraviolet sensor provided by the Spanish Ministry of Education and Science.

"This mission represents a tremendous leap forward in the exploration of Mars," said NASA's Deputy Associate Administrator for the Science Mission Directorate, Dr. Ghassem Asrar. "MSL is the next logical step beyond the twin Spirit and Opportunity rovers. It will use a unique set of analytical tools to study the red planet for over a year and unveil the past and present conditions for habitability of Mars," Asrar said.

"The Mars Science Laboratory is an extremely capable system, and the selected instruments will bring an analytical laboratory to the martian surface for the first time since the Viking Landers over 25 years ago," said Douglas McCuistion, Mars Exploration Program director at NASA Headquarters.

The selected proposals will conduct preliminary design studies to focus on how the instruments can be accommodated on the mobile platform, completed and delivered consistent with the mission schedule. NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif., manages the MSL Project for the Science Mission Directorate.

Selected investigations and principal investigators:

— "Mars Science Laboratory Mast Camera," Michael Malin, Malin Space Science Systems (MSSS), San Diego, Calif. Mast Camera will perform multi-spectral, stereo imaging at lengths ranging from kilometers to centimeters, and can acquire compressed high-definition video at 10 frames per second without the use of the rover computer.

— "ChemCam: Laser Induced Remote Sensing for Chemistry and Micro-Imaging," Roger Wiens, Los Alamos National Laboratory, Los Alamos, N.M. ChemCam will ablate surface coatings from materials at standoff distances of up to 10 meters and measure elemental composition of underlying rocks and soils.

— "MAHLI: MArs HandLens Imager for the Mars Science Laboratory," Kenneth Edgett, MSSS. MAHLI will image rocks, soil, frost and ice at resolutions 2.4 times better, and with a wider field of view, than the Microscopic Imager on the Mars Exploration Rovers.

— "The Alpha-Particle-X-ray-Spectrometer for Mars Science Laboratory (APXS)," Ralf Gellert, Max-Planck-Institute for Chemistry, Mainz, Germany. APXS will determine elemental abundance of rocks and soil. APXS will be provided by the Canadian Space Agency.

— "CheMin: An X-ray Diffraction/X-ray Fluorescence (XRD/XRF) instrument for definitive mineralogical analysis in the Analytical Laboratory of MSL," David Blake, NASA's Ames Research Center, Moffett Field, Calif. CheMin, will identify and quantify all minerals in complex natural samples such as basalts, evaporites and soils, one of the principle objectives of Mars Science Laboratory.

— "Radiation Assessment Detector (RAD)," Donald Hassler, Southwest Research Institute, Boulder, Colo. RAD will characterize the broad spectrum of radiation at the surface of Mars, an essential precursor to human exploration of the planet. RAD will be funded by the Exploration Systems Mission Directorate at NASA Headquarters.

— "Mars Descent Imager," Michael Malin, MSSS. The Mars Descent Imager will produce high-resolution color-video imagery of the MSL descent and landing phase, providing geological context information, as well as allowing for precise landing-site determination.

— "Sample Analysis at Mars with an integrated suite consisting of a gas chromatograph mass spectrometer, and a tunable laser spectrometer (SAM)," **Paul Mahaffy**, NASA's Goddard Space Flight Center, Greenbelt, Md. SAM will perform mineral and atmospheric analyses, detect a wide range of organic compounds and perform stable isotope analyses of organics and noble gases.

APPENDIX A2. REFEREED ARTICLES

This appendix lists all of the refereed articles published in 2004 by Laboratory for Atmosphere members, whose names appear in bold type. The references marked with an asterisk (✴) are those that are highlighted in Appendix A3, with a copy of the first page showing their abstracts.

910 Senior Staff and Senior Scientists

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912 Mesoscale Atmospheric Processes Branch

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APPENDIX A3. HIGHLIGHTED ARTICLES PUBLISHED IN 2004

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The North Pacific as a Regulator of Summertime Climate over Eurasia and North America

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ABSTRACT

The role of the North Pacific as a regulator of boreal summer climate over Eurasia and North America is investigated using observational data. Two summertime interannual climate modes associated with sea surface temperature (SST) variability in the North Pacific are identified. The first mode shows an elongated zone of warm (cold) SST anomalies in the central North Pacific along 40°N, with temporal variability significantly correlated with El Niño during the preceding spring, but its subsequent evolution is quite different from El Niño. The second mode exhibits a seesaw SST variation between the northern and southern North Pacific and is independent of El Niño. Both modes are linked to coherent SST anomalies over the North Atlantic, suggesting the presence of an "atmospheric bridge" linking the two extratropical oceans.

Using the principal component of the most dominant mode as the North Pacific index (NPI), composite analyses show that the positive (negative) phase of NPI features a warm (cold) North Pacific associated with the formation of contemporaneous low-level stationary anticyclones (cyclones) over the North Pacific and North Atlantic, respectively. The anticyclones (cyclones) are linked by quasi-zonally symmetric circulation anomalies in the middle to upper troposphere spanning Eurasia and North America, accompanied by a poleward (equatorward) shift of the subtropical jet and storm tracks. Associated with the positive (negative) phase of NPI, are hot/dry (cool/wet) summers over Japan, Korea, and eastern-central China, which are linked to hot/dry (cool/wet) conditions in the Pacific Northwest, western Canada, the U.S. northern Great Plains, and the Midwest. Cumulative probability computed from pentad temperature and rainfall data show that the odds of occurrence of extreme events are impacted consistently with the mean climate shift during opposite phases of the NPI. The possible roles of air–sea interaction and transient-mean flow interaction in exciting and sustaining the climate modes are discussed.

1. Introduction

In the past several years, the influence of the North Pacific on the climate variability of the United States has received much attention, mainly due to the identification of the so-called Pacific decadal oscillation (PDO) and its possible long-term modulation of El Niño impacts on the climate of the nation (Trenberth and Hurrell 1994; Kawamura 1994; Deser and Blackmon 1995; Zhang et al. 1997; Gershunov and Barnett 1998; Mantua et al. 1997, and others). However, it is worth noting that the importance of the North Pacific in regulating extratropical climate on a wide range of time scales had been known for a long time. In numerous papers dating back to the 1960–70s, Namias and collaborators (e.g., Namias 1959, 1976, and others) observed that SST and atmospheric circulations over the North Pacific had a strong influence on weather and climate over North America. Yet, atmospheric general circulation model studies of the impact of the North Pacific on extratropical climate were generally incon-

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GRAND CHALLENGES IN EARTH SYSTEM MODELING

GLOBAL WEATHER PREDICTION AND HIGH-END COMPUTING AT NASA

The authors demonstrate the current capabilities of NASA's finite-volume General Circulation Model in high-resolution global weather prediction and discuss its development path in the foreseeable future. This model is a prototype of a future NASA Earth-modeling system intended to unify development activities across various disciplines within NASA's Earth Science Enterprise.

NASA's goal for an Earth-modeling system is to unify the model development activities that cut across various disciplines in the Earth Science Enterprise, which is a NASA organization for all NASA's activities related to Earth science. Earth-modeling system applications include, but are not limited to, weather and chemistry climate-change predictions and atmospheric and oceanic data assimilation. High-resolution global weather prediction, among these applications, requires the highest temporal and spatial resolution, and, hence, demands the most capability from a high-end computing system.

In the continuing quest to improve and perhaps push the limit of weather prediction (see the "Weather Predictability" sidebar), we are adopting more physically-based algorithms with much higher resolution than that of earlier models, which is crucial to improving forecast skill. We also are including additional physical and chemical components such as a chemical transport model previously not coupled to modeling systems.

Because a comprehensive high-resolution Earth-modeling system requires enormous computing power, we must design all component models efficiently for parallel computers with distributed-memory platforms. To this end, we started developing the finite-volume General Circulation Model (fvGCM) of the atmosphere, which is based on the work of Shian-Jiann Lin and Richard Rood[1–4] and their collaboration with the National Center for Atmospheric Research (NCAR). Some of the fvGCM's more technical aspects and climate characteristics appear elsewhere.[5]

In this article, we will first demonstrate the model's current capabilities in high-resolution global weather forecasting by predicting real weather events in terms of both accuracy and efficiency, and then outline the model's development-evolution path and its computer requirements in the foreseeable future.

The Current High-End Modeling System for Weather Prediction

The fvGCM features a unique finite-volume dynamics system with local conservation and monotonicity to ensure a global consistency of simulated or predicted atmospheric dynamical processes. It describes the Earth's surface with the traditional latitude–longitude grid system consisting of a set of grid boxes defined along the latitude circles and along the meridians. We assume that the model atmosphere is in hydrostatic equilibrium—that is, the

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The Atmospheric Energy Budget and Large-Scale Precipitation Efficiency of Convective Systems during TOGA COARE, GATE, SCSMEX, and ARM: Cloud-Resolving Model Simulations

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ABSTRACT

A two-dimensional version of the Goddard Cumulus Ensemble (GCE) model is used to simulate convective systems that developed in various geographic locations (east Atlantic, west Pacific, South China Sea, and Great Plains in the United States). Observed large-scale advective tendencies for potential temperature, water vapor mixing ratio, and horizontal momentum derived from field campaigns are used as the main forcing. The atmospheric temperature and water vapor budgets from the model results show that the two largest terms are net condensation (heating/drying) and imposed large-scale forcing (cooling/moistening) for tropical oceanic cases though not for midlatitude continental cases. These two terms are opposite in sign, however, and are not the dominant terms in the moist static energy budget.

The balance between net radiation, surface latent heat flux, and net condensational heating vary in these tropical cases, however. For cloud systems that developed over the South China Sea and eastern Atlantic, net radiation (cooling) is not negligible in the temperature budget; it is as large as 20% of the net condensation. However, shortwave heating and longwave cooling are in balance with each other for cloud systems over the west Pacific region such that the net radiation is very small. This is due to the thick anvil clouds simulated in the cloud systems over the Pacific region. The large-scale advection of moist static energy is negative, as a result of a larger absolute value of large-scale advection of sensible heat (cooling) compared to large-scale latent heat (moistening) advection in the Pacific and Atlantic cases. For three cloud systems that developed over a midlatitude continent, the net radiation and sensible and latent heat fluxes play a much more important role. This means that the accurate measurement of surface fluxes and radiation is crucial for simulating these midlatitude cases.

The results showed that large-scale mean (multiday) precipitation efficiency (PE) varies from 24% to 31% (or 32% to 45% using a different definition of PE) between cloud systems from different geographic locations. The model results showed that there is no clear relationship between the PE and rainfall, the positive cloud condensation (condensation plus deposition), or the large-scale forcing. But, the model results suggest that cases with large, positive net condensation terms in the moist static energy budget tend to have a large PE.

The PE and its relationship with relative humidity and the vertical shear of the horizontal wind are also examined using 6-hourly model data. The model results suggest that there is no clear relationship between the individual PE and total mass-weighted relative humidity or the middle- and upper-tropospheric moisture for each case. The model results suggest that for the west Pacific and east Atlantic cases, PE slightly decreases with increasing middle-tropospheric wind shear in low to moderate shear regimes. The correlation (based on the best polynomial fit) is quite weak however. No strong relationship between PE and wind shear was found for the South China Sea and cases over the United States.

1. Introduction

Cloud-resolving (or cumulus ensemble) models (CRMs) are one of the most important tools used to establish quantitative relationships between diabatic heating and rainfall. This is because latent heating is dominated by phase changes between water vapor and small, cloud-sized particles, which cannot be directly detected. CRMs have sophisticated (though still parameterized) microphysical processes that can simulate the conversion of cloud (liquid and solid) condensate into

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Westerly wind events and precipitation in the eastern Indian Ocean as predictors for El Niño: Climatology and case study for the 2002–2003 El Niño

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[1] This study expands on recent work linking intraseasonal-to-seasonal variability in observed precipitation and wind from September to March in the eastern Indian Ocean with the initiation of El Niño events during the last 25 years. First, westerly wind burst (WWB) events are defined as days when westerly wind speeds averaged over 5°–15°S and 70°–100°E were greater than 1.5 standard deviations from the mean. The number of WWB days from September to March was high before the onset of the 1982–1983, 1991–1992, 1997–1998, and 2002–2003 El Niño events, but not the 1986–1987 El Niño. This study suggests that for the 1979–2002 period, variations in precipitation in the eastern Indian Ocean is a more robust predictor of El Niño onset than analyzed winds. On the basis of the work of *Curtis et al.* [2002], a real-time precipitation-based El Niño Onset Index is presented, which during the austral summer of 2001–2002 successfully predicted the 2002–2003 El Niño. The index focuses on the magnitude of 30–60 day oscillations and mean conditions in the precipitation field. Case studies of high-resolution satellite-based data sets of precipitation, wind, and sea surface temperature (SST) for the 2001–2002 season are examined to better understand how events in the Indian Ocean are linked to Pacific Ocean wind disturbances and SST changes. Twice during this season maxima in precipitation and zonal winds propagated eastward, the first near the equator and the second to the south. For the southern case, warm waters preceded heavy precipitation in the eastern Indian Ocean, which preceded strong westerly winds. A cooling of the sea surface followed the wind-rain system. This sequence of events moved through the ocean passage between Indonesia and Australia, suggesting a coupling of convection, wind, and sea surface temperatures on the timescale of days. These case studies provide a basis for how the east Indian Ocean variations are linked to subsequent events in the Pacific Ocean, including the initiation of El Niño events. *INDEX TERMS:* 3360 Meteorology and Atmospheric Dynamics: Remote sensing; 3359 Meteorology and Atmospheric Dynamics: Radiative processes; 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854); 4522 Oceanography: Physical: El Nino; *KEYWORDS:* precipitation, El Niño, onset

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1. Introduction

[2] There is an ongoing debate as to the usefulness of wind observations in predicting the development of El Niño events. Recent papers have argued whether or not the Madden-Julian Oscillation (MJO) [*Madden and Julian*, 1994] and/or westerly wind burst events act as a stochastic forcing for El Niño [e.g., *Kessler and Kleeman*, 2000; *Vecchi and Harrison*, 2000; *Zhang and Gottschalck*, 2002; *Fedorov*, 2002; *Fedorov et al.*, 2003; *Belamari et al.*, 2003]. Many of these studies have concentrated on the western Pacific. However, recently intraseasonal convective anomalies associated with the MJO have been tracked from the Indian Ocean to the western Pacific [*Jones et al.*, 2004]. Using a coarse 5° × 5°-resolution outgoing longwave radiation (OLR) data set as a proxy for convection, these authors did not find a significant relation between the MJO and the phases of El Niño/Southern Oscillation, although there was an enhancement of western Pacific wind speeds. However, *Krishnamurti et al.* [2000] suggest important teleconnections between the phase and amplitude of zonal winds over the near-equatorial southern Indian Ocean and the subsequent onset of El Niño events.

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African easterly waves and their association with precipitation

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[1] Summer tropical synoptic-scale waves over West Africa are quantified by the 850 mb meridional wind component from the National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis project. Their relationships with surface precipitation patterns are explored by applying the data from the Tropical Rainfall Measuring Mission satellite in combination with other satellite observations during 1998–2002. Evident wavelet spectral power peaks are seen within a period of 2.5–6 days in both meridional wind and precipitation. The most intense wave signals in meridional wind are concentrated along 15°N–25°N. Wave signals in precipitation and corresponding wavelet cross-spectral signals between these two variables, however, are primarily located at 5°N–15°N, the latitudes of major summer rain events. Southerly wind perturbations tend to lag (lead) precipitation signals south (north) of 15°N. In some cases either an in-phase or out-of-phase relationship can even be found, suggesting two distinct relationships between the waves and convection. Moreover, the lagging relationship (and/or the out-of-phase tendency) is only observed south of 15°N during July–September, indicating a strong seasonal preference. This phase relationship is generally consistent with the horizontal wave structures from a composite analysis. *INDEX TERMS:* 3314 Meteorology and Atmospheric Dynamics: Convective processes; 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854); 3374 Meteorology and Atmospheric Dynamics: Tropical meteorology; *KEYWORDS:* African easterly waves, tropical convection

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1. Introduction

[2] Westward propagating synoptic-scale waves over West Africa, commonly called African easterly waves (AEWs), are important weather phenomena during the boreal summer. They can organize and effectively modulate precipitation over the western African continent, and occasionally evolve into tropical cyclones under certain favorable circumstances when they move into the Atlantic Ocean [e.g., *Carlson*, 1969a, 1969b; *Burpee*, 1972, 1974, 1975; *Reed et al.*, 1977].

[3] Various surface and upper air data, particularly the data from the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE), and satellite InfraRed (IR) observations have been widely applied to extract synoptic-scale wave signals and to characterize their spatial structures through spectral and composite analyses, respectively [e.g., *Burpee*, 1974; *Reed et al.*, 1977; *Duvel*, 1990]. Generally encompassing a period of 3–8 days, these synoptic-scale waves propagate westward at a speed of 5–10 m s^{-1}, yielding a wavelength on the order of 1000–5000 km. Maximum wave amplitude is in the meridional wind component and located in the 850–650 mb layer [e.g., *Burpee*, 1972; *Reed et al.*, 1977]. These waves are fed mostly by the African Easterly Jet (AEJ) through combined barotropic and baroclinic energy conversions [e.g., *Burpee*, 1972]. Their structures and particularly their relations with cloudiness and/or precipitation are emphasized [e.g., *Carlson*, 1969a, 1969b; *Burpee*, 1974; *Reed et al.*, 1977; *Chen and Ogura*, 1982; *Duvel*, 1990; *Diedhiou et al.*, 2001]. It is generally found that two perturbation centers are actually associated with these waves. (1) One is south of about 10°N and always accompanied by moist convection. Maximum northerly and southerly wind components in the lower layer occur before and after the wave trough, respectively. Most intense upward motions occur within, and somewhat ahead of the wave trough (corresponding to the intense convergence near the surface), where maximum precipitation is generally observed. Weakest precipitation is found in and ahead of the wave ridge. (2) The second center of wind perturbation is located between 10°N–20°N, not necessarily with precipitation or even cloud. Most precipitation events occur in the

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The Impact of Amazonian Deforestation on Dry Season Rainfall

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ABSTRACT

Many modeling studies have concluded that widespread deforestation of Amazonia would lead to decreased rainfall. Geosynchronous visible and infrared satellite data over southwest Brazil are analyzed with respect to percent cloudiness, and rain estimates are analyzed from both the Tropical Rainfall Measuring Mission and Special Sensor Microwave Imager. The studies conclude that in the dry season, when the effects of the surface are not overwhelmed by synoptic-scale weather disturbances, shallow cumulus cloudiness, deep convective cloudiness, and rainfall occurrence all are larger over the deforested and nonforested (savanna) regions than over areas of dense forest. This paper speculates that this difference is in response to a local circulation initiated by the differential heating of the region's varying forestation. Analysis of the diurnal cycle of cloudiness reveals a shift in the onset of convection toward afternoon hours in the deforested and toward the morning hours in the savanna regions when compared to the neighboring forested regions. Analysis of 14 years of monthly estimates from the Special Sensor Microwave Imager data revealed that in August there was a pattern of higher monthly rainfall amounts over the deforested region. Analysis of available rain gauge data showed an increase in regional rainfall since deforestation began around 1978.

1. Introduction

Initial modeling efforts assessing the impact of Amazonian deforestation assumed widespread deforestation. Nobre et al. (1991) ran simulations using a global spectral model and found that large-scale conversion of forest to pasture decreased the precipitation by 25%. Using the Goddard Global Circulation Model (GCM), Walker et al. (1995) ran a 5-day simulation and showed a decrease in precipitation of 8% in the wettest month of the year. The National Center for Atmospheric Research (NCAR) community climate model results (Hahmann and Dickinson 1997) noted an eastward shift in wet season precipitation with deforestation rather than an overall decrease over the deforested area. More recent modeling work utilized a mesoscale model with realistic forcing using a "fishbone" pattern (Wang et al. 2000). This revealed that mesoscale circulations enhanced cloudiness and localized rainfall as well as dry season enhancement of shallow clouds under weak synoptic forcing. Observations and modeling of landscape heterogeneity resulting from differential land use indicated a direct thermal circulation over areas of the Midwest (Weaver and Avissar 2001).

Observations have not borne out the initial modeling studies. Analysis of outgoing longwave radiation (OLR) from 1974 to 1990 and monthly rainfall at Belem and Manaus both showed upward trends in cloudiness and precipitation, despite deforestation in that period (Chu et al. 1994). Using the Global Historical Climatological Network (GHCN) (Easterling et al. 1996) OLR, and National Centers for Environmental Prediction (NCEP) reanalysis, Chen et al. (2001) noted an increasing trend of precipitation over the Amazon Basin. They found clear evidence in the observed global-scale water vapor convergence patterns that more moisture is moving into the Amazon Basin than in the past. They conclude that this inter-

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Combined lidar-radar remote sensing: Initial results from CRYSTAL-FACE

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[1] In the near future, NASA plans to fly satellites carrying a two-wavelength polarization lidar and a 94-GHz cloud profiling radar in formation to provide complete global profiling of cloud and aerosol properties. The Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE) field campaign, conducted during July 2002, provided the first high-altitude collocated measurements from lidar and cloud profiling radar to simulate these spaceborne sensors. The lidar and radar provide complementary measurements with varying degrees of vertical measurement overlap within cloud layers. This paper presents initial results of the combined airborne lidar-radar measurements during CRSYTAL-FACE. A comparison of instrument sensitivity is presented within the context of particular CRYSTAL-FACE observations. It was determined that optically thin cirrus clouds are frequently missed by the radar but are easily profiled with the lidar. In contrast, optically thick clouds and convective cores quickly extinguish the lidar signal but are easily probed with the radar. Results are presented to quantify the portion of atmospheric features sensed independently by each instrument and the portion sensed simultaneously by the two instruments. To capture some element of varying atmospheric characteristics, two cases are analyzed, one with convective systems and one having synoptic cirrus and considerable clear air. The two cases show quite different results, primarily due to differences in cloud microphysics. *INDEX TERMS:* 0320 Atmospheric Composition and Structure: Cloud physics and chemistry; 0394 Atmospheric Composition and Structure: Instruments and techniques; 3360 Meteorology and Atmospheric Dynamics: Remote sensing; 3394 Meteorology and Atmospheric Dynamics: Instruments and techniques; *KEYWORDS:* lidar, radar, remote sensing, cirrus anvil

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1. Introduction

[2] When complete, NASA's "A-train" constellation will consist of a group of five remote sensing satellites flying in formation. The instruments aboard these satellites will provide a wealth of cotemporal and collocated data products whose synergies should provide a greatly enhanced understanding of Earth's atmosphere. The A-train takes its name from the Aqua satellite [*Parkinson*, 2003], which leads the string of satellites. Following Aqua are, in order, the CloudSat [*Stephens et al.*, 2002], CALIPSO [*Winker et al.*, 2002], PARASOL [*Deschamps et al.*, 1994], and Aura [*Schoeberl et al.*, 2001] satellites. These satellites will fly in a 705-km sun-synchronous orbit with an equatorial crossing time of 1:30 pm. This satellite formation is designed to acquire complementary data products to provide improved global remote sensing of the atmosphere.

[3] The Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE) field campaign during July 2002 [*Jensen et al.*, 2004] deployed a comprehensive suite of instruments on six aircraft and at two ground sites to study tropical cirrus cloud properties and formation processes. Sensors onboard one of the aircraft, the NASA ER-2, provided high-altitude downlooking measurements from instruments that can be considered close proxies for A-train instruments. The new Cloud Radar System (CRS) [*Li et al.*, 2003; *Racette et al.*, 2003] is a 94 GHz pulsed polarimetric Doppler radar and provides measurements similar to those of the CloudSat cloud profiling radar (although CloudSat will not have Doppler capability). The Cloud Physics Lidar (CPL) [*McGill et al.*, 2002, 2003] provides measurements similar to the polarization-sensitive lidar on CALIPSO, which operates at 532 nm and 1064 nm. Detailed instrument

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Inversion of multiwavelength Raman lidar data for retrieval of bimodal aerosol size distribution

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We report on the feasibility of deriving microphysical parameters of bimodal particle size distributions from Mie–Raman lidar based on a triple Nd:YAG laser. Such an instrument provides backscatter coefficients at 355, 532, and 1064 nm and extinction coefficients at 355 and 532 nm. The inversion method employed is Tikhonov's inversion with regularization. Special attention has been paid to extend the particle size range for which this inversion scheme works to ~10 μm, which makes this algorithm applicable to large particles, e.g., investigations concerning the hygroscopic growth of aerosols. Simulations showed that surface area, volume concentration, and effective radius are derived to an accuracy of ~50% for a variety of bimodal particle size distributions. For particle size distributions with an effective radius of <1 μm the real part of the complex refractive index was retrieved to an accuracy of ±0.05, the imaginary part was retrieved to 50% uncertainty. Simulations dealing with a mode-dependent complex refractive index showed that an average complex refractive index is derived that lies between the values for the two individual modes. Thus it becomes possible to investigate external mixtures of particle size distributions, which, for example, might be present along continental rims along which anthropogenic pollution mixes with marine aerosols. Measurement cases obtained from the Institute for Tropospheric Research six-wavelength aerosol lidar observations during the Indian Ocean Experiment were used to test the capabilities of the algorithm for experimental data sets. A benchmark test was attempted for the case representing anthropogenic aerosols between a broken cloud deck. A strong contribution of particle volume in the coarse mode of the particle size distribution was found.

OCIS codes: 010.1100, 010.3640, 290.1090, 290.5860.

1. Introduction

Aerosols are one of the key atmospheric constituents that influence the Earth's radiation budget and require a detailed characterization of optical and physical properties to reduce uncertainties in the modeling of the planet's radiative forcing.[1] Because of the highly variable lifetime of tropospheric aerosols of the order of days to weeks,[2] their inhomogeneous spatial distribution over the globe, as well as different source and transport paths, continuous monitoring is demanded. Satellite-based aerosol remote sensing provides for global coverage. Ground-based aerosol remote sensing is best suited for reliable and continuous monitoring of aerosol properties in key locations. Aerosol sounding with multiwavelength lidar in recent years has emerged as a powerful tool that is capable of providing comprehensive, quantitative information of aerosol properties on a vertically resolved scale.[3,4]

Techniques for the retrieval of microphysical particle parameters from multiwavelength lidar, developed since the early 1980s,[5–7] have made major progress in the past 5 years.[8–12] In that respect the most successful technique has been developed at the Institute for Tropospheric Research (ITR), Leipzig, Germany. It was developed initially for the retrieval of aerosol size distribution parameters and complex refractive indices from a multiwavelength Mie–Raman lidar that provides backscatter coefficients at six wavelengths and extinction coefficients at two wavelengths.[13] In recent years this tech-

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A new way to measure cirrus cloud ice water content by using ice Raman scatter with Raman lidar

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[1] To improve our understanding of cirrus cloud radiative impact on the current and future climate, improved knowledge of cirrus cloud microphysical properties is needed. However, long-term studies of the problem indicate that accurate cirrus cloud measurements are challenging. This is true for both, remote sensing as well as in situ sampling. This study presents a new method to remotely sense cirrus microphysical properties utilizing the Raman scattered intensities from ice crystals using a Raman lidar. Since the intensity of Raman scattering is fundamentally proportional to the number of molecules involved, this method provides a more direct way of measuring the ice water content compared with other schemes. Case studies presented here show that this method has the potential to provide simultaneous measurements of many of the essential information of cirrus microphysical properties. *INDEX TERMS:* 0320 Atmospheric Composition and Structure: Cloud physics and chemistry; 0394 Atmospheric Composition and Structure: Instruments and techniques; 3360 Meteorology and Atmospheric Dynamics: Remote sensing. **Citation:** Wang, Z., D. N. Whiteman, B. B. Demoz, and I. Veselovskii (2004), A new way to measure cirrus cloud ice water content by using ice Raman scatter with Raman lidar, *Geophys. Res. Lett.*, *31*, L15101, doi:10.1029/2004GL020004.

1. Introduction

[2] Cirrus clouds affect the surface and top-of-atmosphere energy budgets and can produce large local variations in atmospheric heating. The degree and extent of the so-called greenhouse-versus-albedo effects involving cirrus clouds will lead to significant atmospheric differential cooling and heating in the vertical as well as on horizontal scales [*Liou*, 1986] and is dependent on cirrus microphysical properties and their vertical distribution [*Stephens et al.*, 1990]. However, it is a challenging task to measure cirrus Ice Water Content (IWC) and particle size by remote sensing or in situ sampling. IWC estimated from in situ particle size probes has large uncertainties associated with different ice crystal shapes and densities [*Heymsfield et al.*, 2002]. There have been significant advances in ground-based remote sensing of cirrus clouds using the Department of Energy Atmospheric Radiation Measurement (ARM) program Cloud and Radiation Testbed (CART) site measurements [*Mace et al.*, 1998; *Wang and Sassen*, 2002]. Nevertheless, uncertainty in the retrieved IWC by using lidar, radar, and radiometer measurements might be very large under some situations because one has to make several critical assumptions about cirrus clouds such as the size distribution and density of ice crystals, which vary a lot in cirrus clouds. A remote sensing method that possesses a signal that is directly related to IWC would be very attractive for IWC measurements and would also be of great value in studying other techniques for obtaining IWC. Here, we report on a new method to remotely measure IWC using Raman scattering from ice in cirrus clouds. First, we briefly describe our Raman lidar system. Then we present the method and measurements. Results from a lidar-radar algorithm are used to calibrate the ice Raman scatter based retrieval algorithm.

2. The GSFC Scanning Raman Lidar (SRL)

[3] The GSFC/NASA SRL uses a tripled Nd:YAG laser (355 nm) combined with two telescopes using different fields of view to measure high altitude and low altitude signals. Light backscattered by molecules and aerosols at the laser wavelength as well as Raman scattered light from water vapor (3657 cm^{-1}), liquid/solid water (3200 cm^{-1} to 3600 cm^{-1}), and nitrogen (2329 cm^{-1}) molecules is collected by a 0.76 m, f/5.2, variable field-of-view Dall-Kirkham telescope mounted horizontally on a 3.7 m optical table. This telescope is typically operated using 0.25-milliradian field of view and acquires the high altitude signals. A smaller 0.25 m telescope is mounted inside of the larger telescope and operates at ~1.0 milliradian field of view. Figure 1 presents the transmission of solid/liquid water and water vapor filters used in SRL along with the water and ice Raman scatter spectrum at the laser wavelength of 355 nm

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Subtropical cirrus cloud extinction to backscatter ratios measured by Raman Lidar during CAMEX-3

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[1] The NASA/GSFC Scanning Raman Lidar was stationed on Andros Island, Bahamas for the third Convection and Moisture Experiment (CAMEX 3) held in August–September, 1998 and acquired an extensive set of cirrus cloud measurements [*Whiteman et al.*, 2001]. Distinct differences in the optical properties of the clouds are found when the cirrus are hurricane-induced versus non-hurricane-induced. Hurricane-induced cirrus clouds are found to generally possess lower values of extinction-to-backscatter ratio (S) than non-hurricane-induced clouds. Comparison of the S measurements made here with those of other studies reveal at times large differences. Given that S is often a required parameter for space-based retrievals of cloud optical depth using backscatter lidar, these large differences in S measurements imply difficulties in developing a parameterization of S for use in space-based lidar retrievals.

INDEX TERMS: 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0360 Atmospheric Composition and Structure: Transmission and scattering of radiation; 3360 Meteorology and Atmospheric Dynamics: Remote sensing. **Citation:** Whiteman, D. N., B. Demoz, and Z. Wang (2004), Subtropical cirrus cloud extinction to backscatter ratios measured by Raman Lidar during CAMEX-3, *Geophys. Res. Lett.*, *31*, L12105, doi:10.1029/2004GL020003.

1. Introduction

[2] Cirrus clouds affect the earth's radiation budget strongly by influencing both the greenhouse effect and planetary albedo [*Liou*, 1986] and can create errors in satellite retrievals. The study of *McFarquher et al.* [2000] showed that tropopause tropical cirrus clouds with optical depths of 0.01 have corresponding heating rates and cloud radiative forcing of 1.66 K day^{-1} and 1.6 W m^{-2}, respectively. Cloud climatology studies based on SAGE II observations [*Wang et al.*, 1996] have indicated frequencies of sub-visual cirrus (optical depths below ~0.03) near the tropical tropopause of up to 70% indicating that the radiative effects of cirrus clouds are very large in tropical locations.

[3] Space-based lidar offers great potential for acquiring accurate global statistics on cloud heights and optical depths. However, due to the presence of multiple scattering and tropospheric aerosols, the retrieval of cirrus cloud optical depth from space-based lidar will under many circumstances require an accurate parameterization of the extinction-to-backscatter ratio for cirrus clouds. This parameterization may be a function of geographic location and/or cirrus type. Therefore, studies of the cirrus extinction-to-backscatter ratio are needed in differing geographic locations. Mid-latitude cirrus cloud properties have been extensively studied using lidar, cloud radar and radiometers [*Platt et al.*, 1987; *Mace et al.*, 2001; *Sassen and Comstock*, 2001; *Wang and Sassen*, 2002; *Sakai et al.*, 2003] but corresponding measurements in tropical or sub-tropical areas, where cirrus occurrences frequencies are high, are more limited [*Sassen et al.*, 2000; *Platt et al.*, 1998; *Comstock et al.*, 2002; *Immler and Schrems*, 2002] and none of those studies has made use of Raman scattering measurements.

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2. Raman Lidar Measurements of Cirrus Clouds

[4] Raman Lidar systems have proven very useful at quantifying cirrus cloud optical depth and extinction-to-backscatter ratio [*Ansmann et al.*, 1992; *Reichardt et al.*, 2002; *Whiteman et al.*, 2001; *Sakai et al.*, 2003] even in the presence of multiple scattering [*Eloranta*, 1998; *Reichardt et al.*, 2000; *Whiteman et al.*, 2001]. The unique advantage of a lidar system that measures pure molecular scattering such as a Raman or High Spectral Resolution Lidar [*Eloranta*, 2000] is that the cirrus cloud extinction-to-backscatter ratio (S in units of sr) can be determined directly without the use of inversion [*Klett*, 1981]. To our knowledge the current work is the only study of cirrus cloud properties made in a sub-tropical or tropical location using either a Raman or High Spectral Resolution Lidar (HSRL).

3. The NASA/GSFC Scanning Raman Lidar (SRL) in CAMEX-3

[5] During July–September, 1998 the NASA/GSFC Scanning Raman Lidar (SRL) was stationed on Andros Island (24.7N, −77.75W) in the Bahamas as a part of the third Convection and Moisture Experiment (CAMEX-3). Though the main goal of the SRL participation in CAMEX-3 was to acquire detailed water vapor measurements during hurricane season, the system also provided high quality measurements of cirrus clouds. The cirrus cloud extinction-to-backscatter ratio derived from approximately 220 hours of SRL cloud measurements are studied here.

[6] The SRL is a mobile lidar system designed to detect light backscattered at the laser wavelength by molecules and aerosols as well as Raman-backscattered light from water vapor, nitrogen, and oxygen molecules. The measurements

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The effect of surface heterogeneity on cloud absorption estimates

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[1] This study presents a systematic and quantitative analysis of the effect of inhomogeneous surface albedo on shortwave cloud absorption estimates. We used 3D radiative transfer modeling over a checkerboard surface albedo to calculate cloud absorption. We have found that accounting for surface heterogeneity enhances cloud absorption. However, the enhancement is not sufficient to explain the reported difference between measured and modeled cloud absorption. *INDEX TERMS:* 0320 Atmospheric Composition and Structure: Cloud physics and chemistry; 1640 Global Change: Remote sensing; 3322 Meteorology and Atmospheric Dynamics: Land/atmosphere interactions; 3359 Meteorology and Atmospheric Dynamics: Radiative processes; 3360 Meteorology and Atmospheric Dynamics: Remote sensing. **Citation:** Chiu, J.-Y. C., A. Marshak, and W. J. Wiscombe (2004), The effect of surface heterogeneity on cloud absorption estimates, *Geophys. Res. Lett.*, *31*, L15105, doi:10.1029/2004GL020104.

1. Introduction

[2] Anomalous shortwave cloud absorption is defined as the difference between measured and model-calculated absorption. Regardless of the recent debates about the size of the effect [*Ackerman et al.*, 2003; *O'Hirok and Gautier*, 2003; *Valero et al.*, 2003], there is no doubt that some discrepancies exist between observed and calculated cloud absorption, which tend to be a bias rather than a random error [*Valero et al.*, 2003]. This excess absorption is on the order of 10 W/m^2 [*O'Hirok and Gautier*, 2003; *Valero et al.*, 2003]. Any such bias is of concern since radiative transfer models are tacitly assumed to be unbiased in climate modeling and remote sensing applications.

[3] Numerous efforts have been made to identify potential sources of this shortwave cloud absorption bias, including sampling issues in the observations, measurement uncertainties, cloud inhomogeneity, microphysics optical properties, and aerosol loadings [*Barker*, 1992; *Marshak et al.*, 1997; *Valero et al.*, 1997; *Cess et al.*, 1999; *Knyazikhin et al.*, 2002; *Ackerman et al.*, 2003; *O'Hirok and Gautier*, 2003; *Oreopoulos et al.*, 2003]. Based on high-resolution spectral albedo data, along with a state-of-the-art radiative transfer model [*Li et al.*, 2002], [*Li et al.*, 2003] stated that accounting for the heterogeneity of surface albedo could eliminate the systematic difference between measured and modeled cloud absorption. However, the influence of inhomogeneous surface albedo has been ignored in most radiative transfer models. As a result, up to now, there have been no systematic and quantitative analyses of the effects of surface heterogeneity on cloud absorption estimates. This study aims both to understand how more realistic treatments of surface heterogeneity affect cloud absorption and to examine whether the bias between observed and modeled cloud absorption could be explained by inhomogeneous surface albedo.

2. Approach

[4] We used the Discrete-Ordinate-method (DISORT) [*Stamnes et al.*, 1988], a Monte Carlo method [*Marchuk et al.*, 1980], and the Spherical Harmonics Discrete Ordinate Method (SHDOM) [*Evans*, 1998] radiative transfer models to calculate cloud absorption. Models were set up with clouds over a surface with a checkerboard albedo α (shown in Figure 1), where the complexity of clouds increased from homogeneous to broken. The checkerboard surface was changed from the extreme case of black ($\alpha = 0$) and white ($\alpha = 1$), having the largest contrast, to a black and gray ($\alpha = 0.5$) pattern, which is closer to measured albedos for the Atmospheric Radiation Measurement (ARM) program Southern Great Plains (SGP) central facility. Cloud properties are defined via cloud optical depth τ and single scattering albedo ϖ_0, and cosine of the solar zenith angle (SZA) is denoted as μ_0. For simplicity, molecular scattering, aerosols and gaseous absorption are not taken into account.

[5] Based on energy conservation, cloud absorptance A can be computed from reflectance R and transmittance T as

$$A(\alpha) = 1 - R(\alpha) - (1 - \alpha)T(\alpha), \qquad (1)$$

where A, R, and T are all functions of Lambertian surface albedo α, and $(1 - \alpha)T$ presents total surface absorption. Note that A, R, and T are also functions of τ, ϖ_0 and μ_0. For plane-parallel clouds,

$$R(\alpha) = R_0 + \frac{T_0^2\alpha}{1 - \alpha R^*} \qquad (2)$$

and

$$T(\alpha) = \frac{T_0}{1 - \alpha R^*}, \qquad (3)$$

where R_0 and T_0 are cloud reflectance and transmittance, respectively, in the case of black surface and R^* is the reflectance of clouds when illuminated from below by

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Global aerosol remote sensing from MODIS

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Abstract

Global aerosol concentration and size parameters derived from MODIS sensors onboard the Terra and Aqua satellites are continuously being evaluated with ground-based measurements and used for various aerosol studies. These parameters have enabled a two-year assessment of aerosol loading and seasonal trends over several important regions on land and ocean, based on 5 × 5° monthly averages. Similar studies were conducted at higher spatial (50 × 50-km) and temporal (daily) resolutions over selected sites representative of pollution, smoke, dust, and sea-salt aerosol types. Also, a two parameter clustering technique has been employed successfully for categorizing the predominant aerosol types and events affecting selected locations over the Atlantic and Pacific Oceans. In addition, results of regional aerosol radiative forcing calculations over a few regions are reported.

Keywords: Aerosol remote sensing; MODIS; Aerosol concentration and size parameters; Regional aerosol radiative forcing

1. Introduction

The study of atmospheric aerosols is a very important element to understanding the earth's solar radiation budget, water cycle balance, and climate change dynamics. Aerosol particles in the atmosphere scatter and/or absorb earth-bound solar radiation as well as emitted and reflected radiation from the earth, to different degrees, depending on their chemical and physical properties. Also, certain aerosol types interact with cloud droplets, modifying their microphysical properties, thereby influencing their radiative properties and precipitation processes.

As a crucial step toward the understanding of the complex effects of aerosols in the atmosphere, aerosol properties and distribution should first be quantified accurately. Aerosol parameters can be measured in situ or by remote sensing from the ground, aircraft, or satellite. All these methods are important and complementary. However, this study employs satellite remote sensing, which offers the advantage of providing the most extensive coverage in the shortest time interval, thereby allowing for better tracking of regional and global distribution of aerosols, which are extremely dynamic in nature. Since the last several years, many attempts have been made to retrieve certain aerosol properties from satellite data, with some limitations (see Kaufman et al., 1997a for detailed review). Recently, Kaufman et al. (2002) published a treatise on the important role of satellite sensors in providing the much needed aerosol information for global climate studies.

The physical characteristics, composition, abundance, spatial and temporal distribution, as well as the dynamics of global aerosols are still not well known, and new data from satellite sensors can be used to improve current understanding and to give a boost to the effort in future climate predictions. The derivation of aerosol parameters from the MODerate resolution Imaging Spectro-radiometer (MODIS) sensors onboard the Earth Observing System (EOS) Terra and Aqua polar-orbiting satellites ushers in a new era in aerosol remote sensing from space. Terra and Aqua were launched on December 18, 1999 and May 4, 2002, respectively, with

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ANALYSIS OF LAND SKIN TEMPERATURE USING AVHRR OBSERVATIONS

BY MENGLIN JIN

This newly developed 18-yr AVHRR-based dataset can show the diurnal, seasonal, and interannual variations of land surface skin temperatures.

Satellite-based surface temperature is referred to as skin temperature (Dickinson 1994). The National Research Council (NRC; 2000) and the Intergovernmental Panel on Climate Change (IPCC; Houghton et al. 2001) pointed out the urgent need for long-term remote sensing–based land surface skin temperature (LST) data in global warming studies to improve the limits of conventional 2-m World Meteorological Organization (WMO) surface air temperature observations (T_a). Currently, the long-term surface skin temperature dataset is only available over the ocean [i.e., sea surface temperature (SST), Bates and Diaz 1991]. Over land, developing such a dataset has proved more difficult due to the land's high surface heterogeneities.

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Beside being an indicator of climate change, skin temperature (in particular, its diurnal cycle) is needed in calculating sensible and latent heat fluxes. Specifically, sensible heat flux is determined by the instantaneous difference between LST and near-surface T_a. In the conventional bulk equation, the use of daily averaged LST instead of hourly LST can result in errors up to 100 W m^{-2}.

The National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites have unique advantages for the LST dataset development because of a long observation period, global coverage, easy data access, an abundance of excellent research, and operational efforts to promote a retrieval process of the highest quality possible. NOAA's Advanced Very High Resolution Radiometer (AVHRR) uses thermal infrared channels to measure the radiative emission of the surface. LST can be derived from AVHRR radiances after removing atmospheric and surface emissivity effects (Ulivieri et al. 1994; Wan and Dozier 1996; Becker and Li 1995; Prata et al. 1995; Kerr 1997). However, AVHRR radiance is measured only twice per day for most areas. How to interpolate these twice-per-day observations into diurnal cycles has been studied for years and is still an ongoing research topic (Jin and Dickinson 1999, 2000;

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Remote Sensing of Liquid Water and Ice Cloud Optical Thickness and Effective Radius in the Arctic: Application of Airborne Multispectral MAS Data

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ABSTRACT

A multispectral scanning spectrometer was used to obtain measurements of the bidirectional reflectance and brightness temperature of clouds, sea ice, snow, and tundra surfaces at 50 discrete wavelengths between 0.47 and 14.0 μm. These observations were obtained from the NASA ER-2 aircraft as part of the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment (FIRE) Arctic Clouds Experiment, conducted over a 1600 km × 500 km region of the north slope of Alaska and surrounding Beaufort and Chukchi Seas between 18 May and 6 June 1998. Multispectral images in eight distinct bands of the Moderate Resolution Imaging Spectroradiometer (MODIS) Airborne Simulator (MAS) were used to derive a confidence in clear sky (or alternatively the probability of cloud) over five different ecosystems. Based on the results of individual tests run as part of this cloud mask, an algorithm was developed to estimate the phase of the clouds (liquid water, ice, or undetermined phase). Finally, the cloud optical thickness and effective radius were derived for both water and ice clouds that were detected during one flight line on 4 June.

This analysis shows that the cloud mask developed for operational use on MODIS, and tested using MAS data in Alaska, is quite capable of distinguishing clouds from bright sea ice surfaces during daytime conditions in the high Arctic. Results of individual tests, however, make it difficult to distinguish ice clouds over snow and sea ice surfaces, so additional tests were added to enhance the confidence in the thermodynamic phase of clouds over the Chukchi Sea. The cloud optical thickness and effective radius retrievals used three distinct bands of the MAS, with a recently developed 1.62- and 2.13-μm-band algorithm being used quite successfully over snow and sea ice surfaces. These results are contrasted with a MODIS-based algorithm that relies on spectral reflectance at 0.87 and 2.13 μm.

1. Introduction

A knowledge of cloud radiative properties and their variation in space and time is especially crucial to the understanding of the radiative forcing of climate. High quality multispectral imagery acquired from high-altitude aircraft or satellite platforms is the most efficient and reliable means of fulfilling these observational requirements. Between 18 May and 6 June 1998, the National Aeronautics and Space Administration (NASA) ER-2 high-altitude research aircraft conducted 11 research flights over the north slope of Alaska and the surrounding Beaufort and Chukchi Seas as part of the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment—Arctic Clouds Experiment (FIRE ACE). The NASA ER-2 aircraft was equipped with seven sensors, among which the Moderate Resolution Imaging Spectroradiometer (MODIS) Airborne Simulator (MAS; King et al. 1996) was designed to obtain measurements that simulate those obtained from MODIS, a 36-band spectroradiometer launched aboard the Earth Observing System (EOS) *Terra* (King and Herring 2000) and *Aqua* (Parkinson 2003) spacecraft.

The strategy for FIRE ACE included spaceborne remote sensing (polar-orbiting satellites), high-altitude remote sensing (NASA ER-2 at ~20 km), lower-altitude remote sensing and in situ measurements [University of Washington CV-580, National Center for Atmospheric Research (NCAR) C-130Q, and Canada's National Research Council Convair 580 (NRC CV-580) aircraft], ground-based measurements (radiation, clouds, meteo-

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Materials and Methods
Figs. S1 to S10
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REPORTS

Measurement of the Effect of Amazon Smoke on Inhibition of Cloud Formation

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Urban air pollution and smoke from fires have been modeled to reduce cloud formation by absorbing sunlight, thereby cooling the surface and heating the atmosphere. Satellite data over the Amazon region during the biomass burning season showed that scattered cumulus cloud cover was reduced from 38% in clean conditions to 0% for heavy smoke (optical depth of 1.3). This response to the smoke radiative effect reverses the regional smoke instantaneous forcing of climate from −28 watts per square meter in cloud-free conditions to +8 watts per square meter once the reduction of cloud cover is accounted for.

The net effect of aerosols on the atmospheric radiation budget and climate constitutes the greatest uncertainty in attempts to model and predict climate (*1*). Aerosols can counteract regional greenhouse warming by reflecting solar radiation to space or by enhancing cloud reflectance (*2*) or lifetime (*3*, *4*). However, aerosol absorption of sunlight is hypothesized to slow down the hydrological cycle and influence climate in ways not matched by the greenhouse effects (*5*, *6*). During periods of heavy aerosol concentration over the Indian Ocean (*7*) and Amazon basin (*8*), for example, measurements have revealed that absorbing aerosols warmed the lowest 2 to 4 km of the atmosphere while reducing by 15% the amount of sunlight reaching the surface.

Less irradiation of the surface means less evaporation from vegetation and water bodies, and (unless the smoke is concentrated near the surface only) a more stable and drier atmosphere, and consequently less cloud formation. This effect was defined theoretically as a positive feedback to aerosol absorption of sunlight (*9*) and was termed the semi-direct effect. A similar process, defined as cloud burning by soot, in which solar heating by the aerosol reaches its maximum near the top of the boundary layer, thereby stabilizing the boundary layer and suppressing convection, has been described (*10*). These cloud simulations were based on aerosol observations of INDOEX (Indian Ocean Experiment) (*11*) and focused mainly on the amplification of daytime clearing due to aerosol heating. Reduction of evaporation from the Mediterranean Sea by pollution from northern and eastern Europe was modeled to reduce cloud formation and precipitation over the Mediterranean region (*12*), in general agreement with measurements (*13*). However, warming of the atmosphere by similar widespread pollution aerosol over southeastern China was modeled to cause uplift of the polluted air mass over an area of 10 million km^2, which then was replaced by cooler moist air from the nearby Pacific Ocean, causing an increase in precipitation and flooding that fits observations from this region in recent years (*14*).

Here, using data from the MODIS-Aqua space instrument, we report measurements of the effect of smoke on cloud formation over the Amazon basin during the dry season (August–September) of 2002—namely, the reduction of the fraction of scattered cumulus clouds with the increase in smoke column concentration.

The area is under the influence of a regional high-pressure zone above a surface boundary layer and is associated with lower precipitation, land clearing, and biomass burning. The moisture source for the cloud formation and precipitation in the region is water vapor evaporated locally through plant evapotranspiration and moisture transported from the Atlantic Ocean (*15*), each responsible for half of the moisture that falls as precipitation. Easterly winds carry the moisture from the Atlantic Ocean throughout the Amazon basin until they reach the barrier of the Andes, where they decrease in velocity and veer either north or south (*16*) (Fig. 1).

The scattered cumulus clouds (also called boundary layer clouds) emerge regularly in the morning over the eastern shore. By local

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Effects of Neglecting Polarization on the MODIS Aerosol Retrieval Over Land

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***Abstract*—Reflectance measurements in the visible and infrared wavelengths, from the Moderate Resolution Imaging Spectroradiometer (MODIS), are used to derive aerosol optical thicknesses (AOTs) and aerosol properties over ocean and land surfaces, separately. Both algorithms employ radiative transfer (RT) code to create lookup tables, simulating the top-of-atmosphere (TOA) reflectance measured by the satellite. Whereas the algorithm over ocean uses a vector RT code that includes the effects of atmospheric polarization, the algorithm over land assumes scalar RT, thus neglecting polarization effects. In the red (0.66 μm) and infrared (2.12 μm) MODIS channels, scattering by molecules (Rayleigh scattering) is minimal. In these bands, the use of a scalar RT code is of sufficient accuracy to model TOA reflectance. However, in the blue (0.47 μm), the presence of larger Rayleigh scattering (optical thickness approaching 0.2) results in nonnegligible polarization. The absolute difference between vector- and scalar-calculated TOA reflectance, even in the presence of depolarizing aerosols, is large enough to lead to substantial errors in retrieved AOT. Using RT code that allows for both vector and scalar calculations, we examine the reflectance differences at the TOA, assuming discrete loadings of continental-type aerosol. We find that the differences in blue channel TOA reflectance (vector–scalar) may be greater than 0.01 such that errors in derived AOT may be greater than 0.1. Errors may be positive or negative, depending on the specific geometry, and tend to cancel out when averages over a large enough sample of satellite geometry. Thus, the neglect of polarization introduces little error into global and long-term averages, yet can produce very large errors on smaller scales and individual retrievals. As a result of this study, a future version of aerosol retrieval from MODIS over land will include polarization within the atmosphere.**

***Index Terms*—Aerosol, land, Moderate Imaging Spectroradiometer (MODIS), polarization, radiative transfer.**

I. INTRODUCTION

ATMOSPHERIC aerosols are intimately linked to earth's climate system [1], hydrological cycle [2], and to the well being of earth's inhabitants [3]. However, aerosols are difficult to study on a global scale because they are inhomogeneous on all temporal, horizontal, and vertical scales. Satellite measurements are increasingly important to the study of aerosols in earth's system [4], [5], because they can view large parts of the globe within a short time span. Passive sensors, such as the Moderate Imaging Spectroradiometer (MODIS) [6], flying aboard Terra [7] and Aqua [8], measure reflected radiation at the top of the atmosphere (TOA) and do not disturb the ambient aerosol composition. As compared to previous satellite sensors used for (but not designed for) aerosol retrieval (such as the Advanced Very High Resolution Radiometer (AVHRR; e.g., [9]), MODIS has a much wider spectral range (0.412–15 μm), finer spatial resolution (250–1000 m), and is calibrated to a much higher accuracy [10]. Thus, MODIS is a premier instrument for estimating the spectral aerosol optical thickness (AOT), leading to estimates of aerosol size parameters.

MODIS retrieves clear sky (noncloudy) aerosol optical thickness (AOT) over ocean and land, using two separate algorithms [11]–[14]. The ocean algorithm retrieves AOT in seven wavelength bands, centered near 0.47, 0.55, 0.66, 0.87, 1.24, 1.64, and 2.12 μm, by inverting reflectance in six of the seven bands (0.47 μm is contaminated by variable ocean surface reflectance and is not used in the retrieval). The land algorithm derives AOT in two bands (0.47 and 0.66 μm), by using reflectance in three bands (0.47, 0.66, and 2.12 μm), and then interpolates to find AOT at 0.55 μm. Therefore, both algorithms report the AOT at 0.55 μm and an estimate of the spectral dependence of the AOT. Both algorithms make use of lookup tables (LUTs), wherein TOA spectral reflectance (in percent) is simulated by radiative transfer (RT) calculations. Included within the RT are assumptions about the surface reflectance, molecular scattering, and aerosol scattering/absorption (functions of assumed aerosol chemical and size parameters). For each cloud-screened MODIS pixel of suitable quality [14], the retrieval algorithm attempts to mimic the observed spectral reflectance with values from the LUT. Minimum total differences between the two spectral quantities lead to solutions of spectral AOT. Over ocean, the minimization is applied to the six wavelengths simultaneously, whereas over land, the minimization is applied to the 0.47- and 0.66-μm channels independently.

Ocean and land AOTs each have theoretical expected error bars [11], [12], which have been subsequently "validated" [14]–[17] by comparing to ground based sunphotometers, such as those of the AERosol Robotic NETwork (AERONET) [18]. Over nondusty ocean sites, global MODIS/AERONET AOT regression lines have slopes near one, offsets near zero, and correlation coefficients of 0.9 and above. Over land sites, the global MODIS/AERONET regression has an offset about 0.1, slope about 0.8, and correlation coefficients of about 0.6.

Why is the MODIS/AERONET comparison so much poorer over land surfaces? The fundamental strategy for each algorithm

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The "RED versus NIR" Plane to Retrieve Broken-Cloud Optical Depth from Ground-Based Measurements

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ABSTRACT

A new method for retrieving cloud optical depth from ground-based measurements of zenith radiance in the red (RED) and near-infrared (NIR) spectral regions is introduced. Because zenith radiance does not have a one-to-one relationship with optical depth, it is absolutely impossible to use a monochromatic retrieval. On the other side, algebraic combinations of spectral radiances, such as normalized difference cloud index (NDCI), while largely removing nonuniqueness and the radiative effects of cloud inhomogeneity, can result in poor retrievals due to its insensitivity to cloud fraction. Instead, both RED and NIR radiances as points on the "RED versus NIR" plane are proposed to be used for retrieval. The proposed retrieval method is applied to Cimel measurements at the Atmospheric Radiation Measurements (ARM) site in Oklahoma. Cimel, a multichannel sun photometer, is a part of the Aerosol Robotic Network (AERONET)—a ground-based network for monitoring aerosol optical properties. The results of retrieval are compared with the ones from microwave radiometer (MWR) and multifilter rotating shadowband radiometer (MFRSR) located next to Cimel at the ARM site. In addition, the performance of the retrieval method is assessed using a fractal model of cloud inhomogeneity and broken cloudiness. The preliminary results look very promising both theoretically and from measurements.

1. Introduction

The most common approach for retrieving cloud optical depth from ground-based observations uses downwelling fluxes measured by pyranometers in the 0.3- to 3.0-μm region of the solar spectrum (Leontieva and Stamnes 1994; Boers 1997). They are relatively cheap and included as standard equipment at many meteorological stations. In addition to broadband pyranometers, there are multifilter rotating shadowband radiometers (MFRSRs) that infer the optical properties of clouds using downwelling fluxes measured at one or at several wavelengths in the visible and/or near-infrared spectral regions (Min and Harrison 1996; Leontieva and Stamnes 1996). The key element in both retrieval techniques is the one-to-one mapping of the "observed" fluxes into cloud optical depth through (the use of) plane-parallel radiative transfer. Both methods are expected to work well only for completely overcast clouds (Ricchiazzi et al. 1995; Dong et al. 1997), giving an *effective* optical depth for the whole sky since, for inhomogeneous clouds, each sky element contributes to the downwelling flux differently (Boers et al. 2000). To infer cloud optical depth locally, one can assume to use a narrow-field-of-view radiometer that measures radiances instead of fluxes (Pavloski and Ackerman 1999). However, lack of one-to-one relationships between radiance and cloud optical depth (e.g., see Fig. 1 in Barker and Marshak 2001 for zenith radiances) prevents the direct use of radiances also.

Recently, Marshak et al. (2000) and Knyazikhin and Marshak (2000) proposed to exploit the sharp spectral contrast in vegetated surface reflectance across 0.7-μm wavelength to retrieve cloud properties from ground-

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Performance of Goddard earth observing system GCM column radiation models under heterogeneous cloud conditions

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Abstract

We test the performance of the shortwave (SW) and longwave (LW) Column Radiation Models (CORAMs) of Chou and collaborators with heterogeneous cloud fields from a single-day global dataset produced by NCAR's Community Atmospheric Model (CAM) with a 2-D Cloud Resolving Model (CRM) installed in each column. The original SW version of the CORAM performs quite well compared to reference Independent Column Approximation (ICA) calculations for boundary fluxes (global error ~ 4 W m^{-2} for reflected flux), largely due to the success of a combined overlap and cloud scaling parameterization scheme. The absolute magnitude of errors relative to ICA are even smaller (global error ~ 2 W m^{-2} for outgoing flux) for the LW CORAM which applies similar overlap. The vertical distribution of heating and cooling within the atmosphere is also simulated quite well with daily averaged zonal errors always less than 0.3 K/day for SW and 0.6 K/day for LW heating (cooling) rates. The SW CORAM's performance improves by introducing a scheme that accounts for cloud inhomogeneity based on the Gamma Weighted Two Stream Approximation (GWTSA).

These results suggest that previous studies demonstrating the inaccuracy of plane-parallel models may have unfairly focused on worst case scenarios, and that current radiative transfer algorithms in General Circulation Models (GCMs) may be more capable than previously thought in estimating realistic spatial and temporal averages of radiative fluxes, as long as they are provided with correct mean cloud profiles. However, even if the errors of our particular CORAMs are small,

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Did life exist on Mars? Search for organic and inorganic signatures, one of the goals for "SAM" (sample analysis at Mars)

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Abstract

Observation of Mars shows signs of a past Earth-like climate, and, in that case, there is no objection to the possible development of life, in the underground or at the surface, as in the terrestrial primitive biosphere. Sample analysis at Mars (SAM) is an experiment which may be proposed for atmospheric, ground and underground in situ measurements. One of its goals is to bring direct or indirect information on the possibility for life to have developed on Mars, and to detect traces of past or present biological activity. With this aim, it focuses on the detection of organic molecules: volatile organics are extracted from the sample by simple heating, whereas refractory molecules are made analyzable (i.e. volatile), using derivatization technique or fragmentation by pyrolysis. Gaseous mixtures thus obtained are analyzed by gas chromatography associated to mass spectrometry. Beyond organics, carbonates and other salts are associated to the dense and moist atmosphere necessary to the development of life, and might have formed and accumulated in some places on Mars. They represent another target for SAM. Heating of the samples allows the analysis of structural gases of these minerals (CO_2 from carbonates, etc.), enabling to identify them. We also show, in this paper, that it may be possible to discriminate between abiotic minerals, and minerals (shells, etc.) created by living organisms.

Keywords: Mars; Astrobiology; Organic matter; Derivatisation; Pyrolysis; Gas chromatography

1. Introduction

In 2009, NASA will probably send a lander/rover to Mars (Mars Science Laboratory, MSL); the aim of the scientific payload of this mission will be, in particular, to search for the presence of extinct or extant traces of life, or prebiotic chemistry that could have existed. It will use a drilling system able to attain depths of some decimeters to meters, and, consequently, will be able to sample zones where inorganic material may be a witness of epochs where Mars atmosphere was able to ensure the development of life, and where organic remnants might have been preserved from destruction (McKay et al., 1992; Brack et al., 1999). The SAM project that we foresee to present as a part of the scientific payload uses the knowledge that we have acquired in developing analog experiments on other space missions (to Titan, to Jupiter, to comets).

Carbonates, as observed in the SNC-Martian meteorites (Gooding, 1992), have not been fully confirmed at the surface of Mars, nevertheless some observations (Pollack et al., 1990; Lellouch et al., 2000) show that one can hope to find them in the underground (Fonti et al., 2001), even if they may have been destroyed at the

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Re-examination of amino acids in Antarctic micrometeorites

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Abstract

The delivery of amino acids by micrometeorites to the early Earth during the period of heavy bombardment (4.5–3.5 Ga) could have been a significant source of the Earth's prebiotic organic inventory. Antarctic micrometeorites (AMMs) in the 100–200 μm size range represent the dominant mass fraction of extraterrestrial material accreted by the Earth today. However, one problem is that these 'large' micrometeorite grains can be heated to very high temperatures (1000 to 1500 °C) during atmospheric deceleration, causing the amino acids to decompose. In this study, we have analyzed the acid-hydrolyzed, hot water extracts from 455 AMMs for the presence of amino acids using high performance liquid chromatography. For comparison, a 5 mg sample of the CM meteorite Murchison was also investigated. In the Murchison sample we found high levels (~3–4 parts-per-million, ppm) of α-aminoisobutyric acid (AIB) and isovaline, two non-protein amino acids that are extremely rare on Earth and are characteristic of amino acids of apparent extraterrestrial origin. In contrast, we were unable to detect any AIB above the 0.1 ppm level in the AMM samples studied. Only in one AMM sample from a previous study has AIB been detected (~300 ppm). To date, more than 600 AMMs have been analyzed for extraterrestrial amino acids. Although our results indicate that less than 5% of all AMMs contain detectable levels of AIB, we cannot rule out the possibility that AIB can be delivered to the Earth intact by a small percentage of AMMs that escaped extensive heating during atmospheric entry.

Keywords: Amino acids; Micrometeorites; Prebiotic organic inventory

1. Introduction

Large micrometeorites ranging in size from 50 to 500 μm have been recovered from the Antarctic blue ice fields during the 1991 and 1994 field seasons. These meteorite grains represent the main source of extraterrestrial material that is accreted by the Earth each year (Chyba and Sagan, 1992; Love and Brownlee, 1993a). It has previously been shown that, Antarctic micrometeorites (AMMs) in the 100–200 μm size range correspond to the peak in the mass distribution of the micrometeorite flux (Kyte and Wasson, 1986; Maurette et al., 1991), estimated to be about 40 000 tons per year (Love and Brownlee, 1993a). In fact, the flux of 50–500 μm sized micrometeorites is 100 times more than objects found outside of this size range, including much larger meteorites and the smaller interplanetary dust particles (IDPs) collected in the stratosphere. AMMs have been found to be similar both petrologically and chemically to the CM type carbonaceous chondrites (Kurat et al., 1994). CM chondrites such as Murchison and Murray as well as several Antarctic meteorites are known to be rich in organic compounds, including amino acids (Kvenvolden et al., 1970; Kvenvolden et al., 1971; Cronin and Moore, 1971; Shimoyama et al., 1979, 1985). Over 70 different amino acids have now been identified in Murchison, most of them completely nonexistent in the terrestrial biosphere (Cronin and Chang, 1993). The α-dialkyl amino acids, α-aminoisobutyric acid (AIB) and isovaline, which are extremely rare amino acids on the

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Updated Galileo probe mass spectrometer measurements of carbon, oxygen, nitrogen, and sulfur on Jupiter

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Abstract

The in situ measurements of the Galileo Probe Mass Spectrometer (GPMS) were expected to constrain the abundances of the cloud-forming condensible volatile gases: H_2O, H_2S, and NH_3. However, since the probe entry site (PES) was an unusually dry meteorological system—a 5-µm hotspot—the measured condensible volatile abundances did not follow the canonical condensation-limited vertical profiles of equilibrium cloud condensation models (ECCMs) such as Weidenschilling and Lewis (1973, Icarus 20, 465–476). Instead, the mixing ratios of H_2S and NH_3 increased with depth, finally reaching well-mixed equilibration levels at pressures far greater than the lifting condensation levels, whereas the mixing ratio of H_2O in the deep well-mixed atmosphere could not be measured. The deep NH_3 mixing ratio (with respect to H_2) of $(6.64 \pm 2.54) \times 10^{-4}$ from 8.9–11.7 bar GPMS data is consistent with the NH_3 profile from probe-to-orbiter signal attenuation (Folkner et al., 1998, J. Geophys. Res. 103, 22847–22856), which had an equilibration level of about 8 bar. The GPMS deep atmosphere H_2S mixing ratio of $(8.9 \pm 2.1) \times 10^{-5}$ is the only measurement of Jupiter's sulfur abundance, with a PES equilibration level somewhere between 12 and 15.5 bar. The deepest water mixing ratio measurement is $(4.9 \pm 1.6) \times 10^{-4}$ (corresponding to only about 30% of the solar abundance) at 17.6–20.9 bar, a value that is probably much smaller than Jupiter's bulk water abundance. The $^{15}N/^{14}N$ ratio in jovian NH_3 was measured at $(2.3 \pm 0.3) \times 10^{-3}$ and may provide the best estimate of the protosolar nitrogen isotopic ratio. The GPMS methane mixing ratio is $(2.37 \pm 0.57) \times 10^{-3}$; although methane does not condense on Jupiter, we include its updated analysis in this report because like the condensible volatiles, it was presumably brought to Jupiter in icy planetesimals. Our detailed discussion of calibration and error analysis supplements previously reported GPMS measurements of condensible volatile mixing ratios (Niemann et al., 1998, J. Geophys. Res. 103, 22831–22846; Atreya et al., 1999, Planet. Space Sci. 47, 1243–1262; Atreya et al., 2003, Planet. Space Sci. 51, 105–112) and the nitrogen isotopic ratio (Owen et al., 2001b, Astrophys. J. Lett. 553, L77–L79). The approximately three times solar abundance of NH_3 (along with CH_4 and H_2S) is consistent with enrichment of Jupiter's atmosphere by icy planetesimals formed at temperatures < 40 K (Owen et al., 1999, Nature 402 (6759), 269–270), but would imply that H_2O should be at least $3 \times$ solar as well. An alternate model, using clathrate hydrates to deliver the nitrogen component to Jupiter, predicts $O/H \geqslant 9 \times$ solar (Gautier et al., 2001, Astrophys. J. 550 (2), L227–L230). Finally we show that the measured condensible volatile vertical profiles in the PES are consistent with column-stretching or entraining downdraft scenarios *only* if the basic state (the pre-stretched column or the entrainment source region) is described by condensible volatile vertical profiles that are drier than those in the equilibrium cloud condensation models. This dryness is supported by numerous remote sensing results but seems to disagree with observations of widespread clouds on Jupiter at pressure levels predicted by equilibrium cloud condensation models for ammonia and H_2S.

Keywords: Jupiter, atmosphere; Atmospheres, composition; Galileo probe

1. Introduction

The Galileo probe's in situ measurements provided a unique opportunity to sample Jupiter's atmosphere below

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Elevated ozone in the troposphere over the Atlantic and Pacific oceans in the Northern Hemisphere

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[1] Tropospheric column ozone (TCO) is derived from differential measurements of total column ozone from Total Ozone Mapping Spectrometer (TOMS), and stratospheric column ozone (SCO) from the Microwave Limb Sounder (MLS) instrument on the Upper Atmosphere Research Satellite (UARS). It is shown that TCO during late spring and summer months over the Atlantic and Pacific oceans at northern mid-latitudes is about 50–60 Dobson Units (DU) which is about the same as over the continents of North America, Europe and Asia (except high altitude mountain regions), where surface emissions of NO_x from industrial sources, biomass and biofuel burning, and biogenic emissions are significantly larger. The zonal characteristics of TCO derived from satellite measurements are generally simulated by a global chemical transport model called MOZART-2, but some discrepancies are also shown. The model results are analyzed to delineate the relative importance of surface NO_x emission, lightning NO_x and stratospheric flux. *INDEX TERMS:* 0322 Atmospheric Composition and Structure: Constituent sources and sinks; 0365 Atmospheric Composition and Structure: Troposphere—composition and chemistry; 0368 Atmospheric Composition and Structure: Troposphere—constituent transport and chemistry; 3362 Meteorology and Atmospheric Dynamics: Stratosphere/troposphere interactions; 3367 Meteorology and Atmospheric Dynamics: Theoretical modeling. **Citation:** Chandra, S., J. R. Ziemke, X. Tie, and G. Brasseur (2004), Elevated ozone in the troposphere over the Atlantic and Pacific oceans in the Northern Hemisphere, *Geophys. Res. Lett.*, *31*, L23102, doi:10.1029/2004GL020821.

1. Introduction

[2] Ozone is a precursor molecule of the hydroxyl (OH) radical which is the main oxidizing agent of several pollutants in the troposphere. In the troposphere ozone is produced primarily by photochemical oxidation of hydrocarbons in the presence of NO_x ($NO + NO_2$) with additional contribution from the stratosphere through stratosphere–troposphere exchange (STE). It is generally believed that tropospheric ozone has been increasing since pre-industrial times as a result of increased concentration of ozone-producing pollutants in Europe and North America [e.g., *Lelieveld and Dentener*, 2000; *Hauglustaine and Brasseur*, 2001; *Lelieveld et al.*, 2002]. There is concern that with industrialization of Asian countries tropospheric ozone may be increasing in the Northern Hemisphere (NH) through long-range transport. Global models of chemistry and transport have been used to assess the contribution of Asian pollution over regions of Asia, North America, and Europe [e.g., *Berntsen et al.*, 1999; *Li et al.*, 2001; *Liu et al.*, 2002; *Phadnis et al.*, 2002]. Model results are usually compared with ozonesonde measurements which are few and far between. At NH mid-latitudes, column ozone derived from ozonesonde measurements tends to peak during summer months when anthropogenic emissions resulting from fossil fuel combustion and biomass burning are high [*Logan*, 1999]. It is difficult to assess the global implications of these results particularly over the vast regions of the Atlantic and Pacific oceans where ozone measurements are sparse. Comparisons of satellite measurements of TCO with global models have been limited mostly to tropical regions because of lack of satellite measurements of TCO outside the tropics.

[3] The purpose of this paper is to use TCO data from TOMS/MLS [*Chandra et al.*, 2003] to characterize the zonal properties of TCO at NH mid-latitudes and to study the implications of various processes affecting TCO by using a global 3-D chemical transport model called MOZART version 2 [*Horowitz et al.*, 2003]. The zonal and seasonal characteristics of TOMS/MLS TCO between ±30° was analyzed in detail by *Chandra et al.* [2003] and compared with a global 3-D model of tropospheric chemistry (GEOS-CHEM) for 1996–1997. In this paper a similar comparison of TOMS/MLS TCO is made with the MOZART-2 model to delineate the relative importance of STE, lightning, and anthropogenic NO_x emission. As *Chandra et al.* [2003] showed, TCO is derived using version 7 TOMS measurements with reflectivity <0.2. In addition, the calibration of MLS is adjusted to TOMS by normalizing MLS SCO to TOMS SCO derived from the convective cloud differential method.

2. TCO From TOMS/MLS

[4] TOMS/MLS measurements overlap for about 20 months (September 1991–April 1993) during the Nimbus-7 TOMS lifetime and for about 2 years (August 1996 to mid-1998) during the Earth Probe (EP) TOMS period. The frequency of MLS measurements also changes from almost daily measurements during the Nimbus-7 period to only a few days per month (5–10 days) during the EP TOMS period. The MLS measurements outside ±34° are available around every alternate month on average because of a 57° inclination of the UARS orbit and planned rotation of the satellite through yaw about every 36 days. Because the MLS instrument does not measure ozone below 100 hPa, zonal maps of TCO are most reliable between ±30°

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Aerosol distribution in the Northern Hemisphere during ACE-Asia: Results from global model, satellite observations, and Sun photometer measurements

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[1] We analyze the aerosol distribution and composition in the Northern Hemisphere during the Asian Pacific Regional Aerosol Characterization Experiment (ACE-Asia) field experiment in spring 2001. We use the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model in this study, in conjunction with satellite retrieval from the Moderate-Resolution Imaging Spectroradiometer (MODIS) on EOS-Terra satellite and Sun photometer measurements from the worldwide Aerosol Robotic Network (AERONET). Statistical analysis methods including histograms, mean bias, root-mean-square error, correlation coefficients, and skill scores are applied to quantify the differences between the MODIS 1° × 1° gridded data, the daytime average AERONET data, and the daily mean 2° × 2.5° resolution model results. Both MODIS and the model show relatively high aerosol optical thickness (τ) near the source regions of Asia, Europe, and northern Africa, and they agree on major features of the long-range transport of aerosols from their source regions to the neighboring oceans. The τ values from MODIS and from the model have similar probability distributions in the extratropical oceans and in Europe, but MODIS is approximately 2–3 times as high as the model in North/Central America and nearly twice as high in Asia and over the tropical/subtropical oceans. Comparisons with the AERONET measurements in the Northern Hemisphere demonstrate that in general the model and the AERONET data have comparable values and similar probability distributions of τ, whereas MODIS tends to report higher values of τ over land, particularly North/Central America. The MODIS high bias is primarily attributed to the difficulties in land algorithm dealing with surface reflectance over inhomogeneous and bright land surfaces, including mountaintops, arid areas, and areas of snow/ice melting and with land/water mixed pixels. The model estimates that on average, sulfate, carbon, dust, and sea salt comprise 30%, 25%, 32%, and 13%, respectively, of the 550-nm τ in April 2001 in the Northern Hemisphere, with ~46% of the total τ from anthropogenic activities and 66% from fine mode aerosols. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0368 Atmospheric Composition and Structure: Troposphere—constituent transport and chemistry; 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); *KEYWORDS:* aerosols, distributions, ACE-Asia

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[2] The Asian Pacific Regional Aerosol Characterization Experiment (ACE-Asia), which studied the characteristics of aerosols from Asia and their radiative effects, took place in spring 2001 in the western Pacific region near the east coast of Asia. In the spring, dust emission in northern Asia is strong, biomass burning in Southeast Asia is at its peak, photochemical production of pollution aerosols is active, and the continental outflow from Asia to the western Pacific is at its strongest. In other words, the timing of ACE-Asia was optimal for studying the impact of maximum Asian aerosol concentrations on

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Transport of smoke from Canadian forest fires to the surface near Washington, D.C.: Injection height, entrainment, and optical properties

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[1] Smoke and pollutants from Canadian forest fires are sometimes transported over the United States at low altitudes behind advancing cold fronts. An unusual event occurred in July 2002 in which smoke from fires in Quebec was observed by satellite, lidar, and aircraft to arrive over the Washington, D.C., area at high altitudes. This elevated smoke plume subsequently mixed to the surface as it was entrained into the turbulent planetary boundary layer and had adverse effects on the surface air quality over the region. Trajectory and three-dimensional model calculations confirmed the origin of the smoke, its transport at high altitudes, and the mechanism for bringing the pollutants to the surface. Additionally, the modeled smoke optical properties agreed well with aircraft and remote sensing observations provided the smoke particles were allowed to age by coagulation in the model. These results have important implications for the long-range transport of pollutants and their subsequent entrainment to the surface, as well as the evolving optical properties of smoke from boreal forest fires. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); 0360 Atmospheric Composition and Structure: Transmission and scattering of radiation; 0365 Atmospheric Composition and Structure: Troposphere—composition and chemistry; *KEYWORDS:* smoke aerosols, optical properties, entrainment

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1. Introduction

[2] Ozone (O_3) and aerosols transported over long distances can affect air quality at local, regional, and even intercontinental scales. For example, the air over the Mediterranean contains a complicated mix of pollutants transported from Asia, North America, and Europe [*Lelieveld et al.*, 2002]. Saharan dust transported to the United States in the summertime occasionally contributes enough to surface level aerosol concentrations to put portions of Florida out of compliance with U.S. Environmental Protection Agency (EPA) standards for fine particulate matter [*Prospero et al.*, 2001]. Of particular interest in this paper is the transport of pollutants associated with emissions from boreal forest fires. Extensive areas in the boreal forests burn every year with significant interannual variability [*Lavoué et al.*, 2000]. These fires produce large amounts of aerosol and trace gas species, including carbon monoxide (CO) and nitrogen oxides (NO_x), important precursors to the photochemical production of tropospheric ozone [*Goode et al.*, 2000]. For example, enhanced surface level concentrations of CO observed during summer 1995 in the eastern and southeastern United States were attributed to pollutants produced and transported in the plumes from large Canadian forest fires [*Wotawa and Trainer*, 2000]. Transatlantic transport of boreal fire emissions can also be important, with several studies focusing on aspects of an event in August 1998 in which pollutants from fires burning in the Canadian Northwest Territories were transported over the Atlantic and into western Europe. *Forster et al.* [2001] attributed observations of enhanced surface level concentrations of CO at Mace Head, Ireland, and aerosol layers between 3 and 6 km altitude over Germany to this fire event. *Spichtinger et al.* [2001] used satellite imagery to track the transport of a NO_x plume associated with the same burning event. *Fiebig et al.* [2002, 2003] discuss the evolution of the smoke aerosol optical and microphysical properties for the plume observed in this event.

[3] Here we discuss a case of smoke from Canadian forest fires transported in an initially midtropospheric altitude plume that was observed at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC, 39.02°N, 76.86°W, near

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Global CO_2 transport simulations using meteorological data from the NASA data assimilation system

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[1] We present a first analysis of atmospheric CO_2 transport using meteorological data from the NASA finite volume data assimilation system (FVDAS). The analyzed meteorological fields are used along with climatological surface sources and sinks in an off-line, forward transport simulation for 1998–2000. Analysis of model diagnostics and comparisons to previous results indicates that the model performance is consistent with that of most previous global transport models. The model interhemispheric gradients along with the timing and magnitude of the CO_2 seasonal cycle are discussed, providing inferences regarding the northern biosphere, tropical land, and southern ocean fluxes. Global distributions of column-integrated CO_2 are presented to provide a basis for measurement requirements for the design of satellite-based instruments for atmospheric CO_2 column. On the synoptic scale we find a significant benefit in using the FVDAS analyzed winds for comparisons to data. At near-equatorial observation sites, the model correctly simulates the observed atmospheric composition transition associated with the latitudinal movement of the ITCZ. Comparison to daily data from continuous analyzer sites shows the model captures a substantial amount of the observed synoptic variability due to transport changes. These results show the potential to use high temporal and spatial resolution remote sensing data to constrain CO_2 surface fluxes, and they form the starting point for developing an operational CO_2 assimilation system to produce high-resolution distributions of atmospheric CO_2 and quantitative estimates of the global carbon budget. *INDEX TERMS:* 0315 Atmospheric Composition and Structure: Biosphere/atmosphere interactions; 0322 Atmospheric Composition and Structure: Constituent sources and sinks; 0368 Atmospheric Composition and Structure: Troposphere—constituent transport and chemistry; 3337 Meteorology and Atmospheric Dynamics: Numerical modeling and data assimilation; *KEYWORDS:* carbon dioxide, data assimilation

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1. Introduction

[2] CO_2 emissions, primarily from fossil fuel burning, are the largest anthropogenic climate driver and will be for the coming decades to centuries [*Intergovernmental Panel on Climate Change* (*IPCC*), 2001]. In order to make accurate projections of future atmospheric CO_2, we need to understand what controls the highly variable atmospheric CO_2 concentrations, the role of various surface sources and sinks in the global carbon cycle, and the mechanisms through which CO_2 sources and sinks interact with changing climate. Currently, significant uncertainties are attached to our understanding of these processes [*IPCC*, 2001; *Schimel et al.*, 2001]. Resolving these issues is critical to reliable predictions of future climate forcing and effective remedial/preventative actions.

[3] The global distribution of CO_2 surface fluxes is commonly inferred from transport models and atmospheric concentration measurements (inverse modeling) [*Enting and Mansbridge*, 1991; *Fan et al.*, 1998; *Bousquet et al.*, 1999]. This approach is limited by the accuracy of the numerical transport model, the circulation/wind inputs that drive the transport, and the observational CO_2 data. Transport model differences have been a major source of variation in the inference of CO_2 sources and sinks [*Law et al.*, 1996; *Denning et al.*, 1999; *Gurney et al.*, 2002; *Peylin et al.*, 2002]. The TransCom project [*Gurney et al.*, 2002, and references therein] is an international effort to quantify the errors introduced into our understanding of the carbon cycle by differences/errors in the circulations and transport computed by models. The work reported here uses the transport core and meteorological analyses from a state of the art data assimilation system to produce 3-D atmospheric CO_2 distributions based on TransCom emission scenarios.

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14. ABSTRACT

This report describes our role in NASA's mission, gives a broad description of our research, and summarizes our scientists' major accomplishments in 2004. The report also contains useful information on human resources, scientific interactions, outreach activities, and the transformation our Laboratory has undergone. This report is published in two versions: (1) an abbreviated print version, and (2) an unabridged electronic version at our Laboratory for Atmospheres Web site, http://atmospheres.gsfc.nasa.gov/.

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