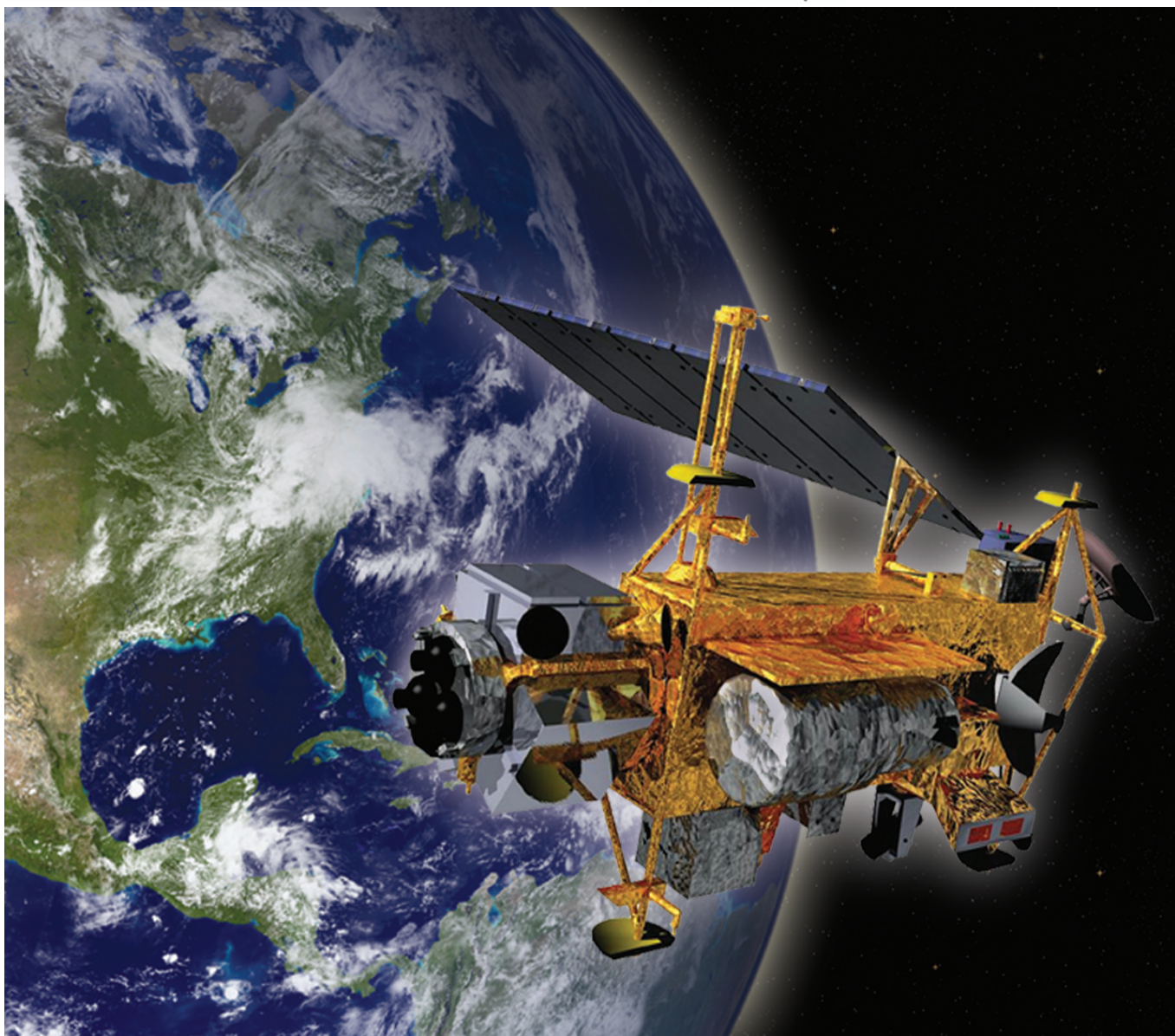
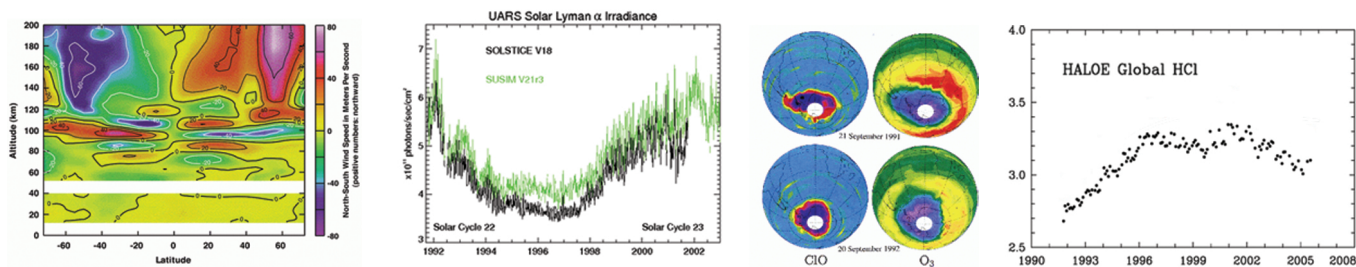


# Laboratory for Atmospheres 2005 Technical Highlights



## Cover Caption

Central figure. Artist's concept of the Upper Atmosphere Research Satellite (UARS) orbiting above Earth. UARS was launched in September 1991 and decommissioned in December 2005, after a 14-year mission.

Graphics at top of cover page (left to right):

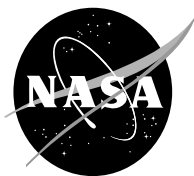
Far left. Composite of measured meridional winds from the UARS High Resolution Doppler Image (HRDI) and Wind Imaging Interferometer (WINDII) instruments for the spring periods of 1993 and 1994 in the altitude range of 10–200 km and from  $-60^\circ$  to  $60^\circ$  latitude for a local time of 12:00. The color bar indicates wind speeds from  $-80$  to  $80$  m/s (positive northward). The prominent oscillations about the equator in the Mesosphere–Lower thermosphere (MLT) region are due to “atmospheric tides” driven by the daily change in solar heating. [Figure courtesy of Mark D. Burrage (deceased).]

Middle left. Variations in solar irradiance of Lyman  $\alpha$  (121.6 nm) over about 11 years (late 1991 through the end of 2002) measured by the UARS (Solar Ultraviolet Spectral Irradiance monitor (SUSIM, in green) and Solar/Stellar Irradiance Comparison Experiment (SOLSTICE, in black) instruments. These ultraviolet flux measurements tracked the general solar irradiance decrease from a peak near the maximum of solar cycle 22 through a minimum in 1996 up to the maximum of solar cycle 23. Changes in solar irradiance at Lyman  $\alpha$  from solar minimum to maximum are over 50%, a very substantial change. (Figure courtesy of Linton E. Floyd.)

Middle right. Chlorine monoxide (ClO) and ozone ( $O_3$ ) in the Southern Hemisphere on 21 September 1991 (upper half of figure) and 20 September 1992 (lower half). The mapped quantities are vertical columns obtained by integrating the profiles retrieved from UARS Microwave Limb Sounder (MLS). High ClO amounts are indicated by the more brilliant red and purple colors. Low  $O_3$  amounts are indicated by the more muted light blue and violet colors. The strong anti-correlation between high ClO and low  $O_3$  indicates that the ClO is responsible for the  $O_3$  destruction. (Figure courtesy of Joseph W. Waters.)

Far right. Time series of UARS Halogen Occultation Experiment (HALOE) global average hydrogen chloride (HCl) mixing ratio measurements (in parts per billion) at 55 km between late 1991 and 2005. The increases in HCl from late 1991 to 1997 were probably caused by increases in human-produced chlorofluorocarbon (CFC) gases. The decreases in HCl after 2001 were likely caused by international regulations limiting the production of CFC gases. Variations between 1997 and 2001 are not well understood at the present time. (Figure courtesy of James M. Russell, III.)

NASA/TM—2006—214138



# Laboratory for Atmospheres 2005 Technical Highlights

National Aeronautics and  
Space Administration

**Goddard Space Flight Center**  
Greenbelt, Maryland 20771

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September 2006

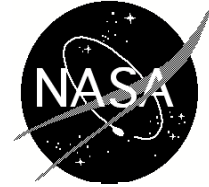
Available from:

NASA Center for AeroSpace Information  
7121 Standard Drive  
Hanover, MD 21076-1320  
Price Code: A17

National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22161  
Price Code: A10

National Aeronautics and  
Space Administration

**Goddard Space Flight Center**  
Greenbelt, Maryland  
20771



## Laboratory Chief's Summary

Dear Reader:

Welcome to the Laboratory for Atmospheres' 2005 Technical Highlights 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 colleagues within NASA, scientists outside the Agency, science graduate students, and members of the general public. Inside are descriptions of our organization and facilities, our major activities and science highlights, and our education and outreach accomplishments for calendar year 2005.

The Laboratory's approximately 230 scientists, technologists, and administrative personnel are part of the Earth-Sun Exploration Division in the Sciences and Exploration Directorate of the NASA Goddard Space Flight Center. The Laboratory for Atmospheres is continuing our mission of advancing knowledge and understanding of the Earth's atmosphere.

Laboratory scientists continued having a productive year organizing and participating in international field campaigns, developing and refining instruments, analyzing data, expanding data sets, and improving models. The Aura spacecraft, launched in July 2004, is an important component of the Lab's science activities through validation campaigns and data analysis and modeling. Aura has joined the complement of EOS satellites that is helping us better understand our home planet's environment, and is increasing our knowledge of the complex chemistry of the atmosphere.

We continued the very successful Distinguished Lecturer Seminar Series, which focused on precipitation, clouds, aerosols, and their physical/chemical linkages; details of the series can be found on our Web site.

As in previous years, Laboratory scientists garnered many top professional honors. The NASA Exceptional Achievement Medal was awarded to two lab members: Dr. Mian Chin for her development of the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model, and Dr. Yogesh Sud for his advances on land-surface parameterization and biospheric-atmospheric processes. Fritz Hasler, now retired from the Mesoscale Atmospheric Processes Branch, was awarded the Barry M. Goldwater award by the AIAA National Capitol Section for his education and outreach activities with the Electronic Theater (E-Theater). The IEEE elevated Chuck Cote to the grade of Senior Member, their highest professional grade. The Department of Energy (DOE) announced the selection of Dr. Warren Wiscombe as Chief Scientist for DOE's Atmospheric Radiation Measurement (ARM) program. In addition, there were several Group Achievement Awards. These were awarded to the Aura Education Outreach Team, the Aura Project Science Team, the SAGE Ozone Loss Validation Experiment (SOLVE)-II DC-8 Science Team, and the MODIS Aerosol Algorithm Team. A list of award winners is given in this report. I congratulate them for their outstanding achievements.

The year 2005 was also a time to bid farewell to several valuable members of the Laboratory. Dean Duffy, Fritz Hasler, Ernie Hilsenrath, Walt Hoegy, Larry Korb, Nathan Miller, Cuddapah Prabhakara, and Peter Wetzel retired. Marshall Shepherd left the Laboratory to become a professor at the University of Georgia and Bob Atlas is now with NOAA as director of The Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami.

I am pleased to greet new civil servants in the Laboratory, Peter Colarco, Christina Hsu, Ken Pickering, and Eric Wilcox.

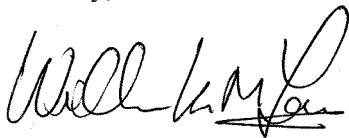
Several noteworthy events took place during 2005. Two components of the Aura Validation Experiment (AVE) were successfully completed. The Polar AVE (PAVE) experiment was completed successfully from Pease Tradeport, New Hampshire on January 24, 2005. The experiment utilized the NASA DC-8, out of Dryden Flight Research Center. AVE Houston took place in June of 2005 from Ellington Field in Houston, Texas. The NASA WB-57 completed 8 successful science flights over the course of 14 days.

Several Laboratory scientists were selected as investigators under the Instrument Incubator Program: Bruce Gentry (613.1), "Tropospheric Wind Lidar Technology Experiment" (TWiLiTE); Gerald Heymsfield (613.1), "High-Altitude Imaging Wind and Rain Airborne Profiler" (HIWRAP); David Whiteman (613.1), "Airborne Water, Aerosol, Cloud, and Carbon Dioxide Lidar"; Omar Torres (613.3/SSAI) Co-Investigator on "A High-Accuracy Spectropolarimetric Camera for Aerosol Remote Sensing from Space"; Warren Wiscombe (613.2), Collaborator with Langley Research Center (LaRC) investigators on "In-Situ Net Flux Within the Atmosphere of the Earth."

The Tropical Rainfall Measuring Mission (TRMM) was extended beyond its June 15 termination date. TRMM is expected to last until at least 2010, when the first of a series of planned follow-on Global Precipitation Measurement Mission (GPM) satellites is due to launch. The Upper Atmosphere Research Satellite (UARS) was retired from service on December 14 after making measurements of the upper atmosphere for more than 14 years. Scott Braun (613.1) was appointed Deputy Project Scientist for TRMM, and Joanne Joiner (613.3) was appointed Deputy Project Scientist for Aura.

This report is being published in two media: a printed version, and an electronic version on our Laboratory for Atmospheres Web site, <http://atmospheres.gsfc.nasa.gov>. Check out our Web site. It continues to be redesigned to be more useful for our scientists, colleagues, and the public. We welcome comments on this 2005 report and on the material displayed on our Web site; your comments may be submitted via the Web site.

Sincerely,

A handwritten signature in black ink, appearing to read "William K.-M. Lau". The signature is fluid and cursive, with a horizontal line underlining the name.

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

## TABLE OF CONTENTS

|                                                                                 |           |
|---------------------------------------------------------------------------------|-----------|
| <b>Preface</b> . . . . .                                                        | <b>v</b>  |
| <b>1. Introduction</b> . . . . .                                                | <b>1</b>  |
| <b>2. Staff, Organization, and Facilities.</b> . . . . .                        | <b>3</b>  |
| 2.1 Staff . . . . .                                                             | 3         |
| 2.2 Organization . . . . .                                                      | 4         |
| 2.3 Branch Descriptions . . . . .                                               | 4         |
| 2.4 Facilities . . . . .                                                        | 6         |
| <b>3. Our Research and Its Place in NASA's Mission.</b> . . . . .               | <b>7</b>  |
| <b>4. Major Activities</b> . . . . .                                            | <b>9</b>  |
| 4.1 Measurements. . . . .                                                       | 9         |
| 4.2 Field Campaigns . . . . .                                                   | 11        |
| 4.3 Data Sets . . . . .                                                         | 14        |
| 4.4 Data Analysis . . . . .                                                     | 20        |
| 4.5 Modeling . . . . .                                                          | 24        |
| 4.6 Support for NOAA Operational Satellites. . . . .                            | 28        |
| 4.7 Project Scientists . . . . .                                                | 32        |
| 4.8 Interactions with Other Scientific Groups. . . . .                          | 33        |
| 4.9 Commercialization and Technology Transfer. . . . .                          | 34        |
| <b>5. Highlights of Laboratory for Atmospheres Activities in 2004</b> . . . . . | <b>35</b> |
| 5.1 Mesoscale Atmospheric Processes Branch, Code 613.1 . . . . .                | 35        |
| 5.2 Climate and Radiation Branch, Code 613.2 . . . . .                          | 37        |
| 5.3 Atmospheric Chemistry and Dynamics Branch, Code 613.3 . . . . .             | 39        |
| 5.4 Laboratory Highlights . . . . .                                             | 43        |
| 5.5 Awards. . . . .                                                             | 48        |
| 5.6 UARS . . . . .                                                              | 50        |
| <b>6. Education and Outreach</b> . . . . .                                      | <b>53</b> |
| 6.1 Introduction . . . . .                                                      | 53        |
| 6.2 Education . . . . .                                                         | 53        |
| 6.3 Open Lecture Series. . . . .                                                | 59        |
| 6.4 Project Outreach . . . . .                                                  | 61        |
| <b>7. Acronyms</b> . . . . .                                                    | <b>65</b> |
| <b>Appendix A1. Press Releases</b> . . . . .                                    | <b>71</b> |
| <b>Appendix A2. Refereed Articles</b> . . . . .                                 | <b>81</b> |
| <b>Appendix A3. Highlighted Articles Published in 2005</b> . . . . .            | <b>93</b> |





## PREFACE

The Technical Highlights for 2005 is the product of the efforts of all the members of the Laboratory for Atmospheres. Their dedication to advancing Earth Science through conducting research, developing and running models, designing instruments, managing projects, running field campaigns, and numerous other activities has produced many significant results. These can only be briefly highlighted in this report.

Production of this report has been guided by William K.–M. Lau, Chief of the Laboratory for Atmospheres who, along with Charles Cote, our Associate Chief, checked the report for accuracy, made suggestions regarding its content, and contributed to several sections. Walt Hoegy, editor for the past five years and now an emeritus member of the Laboratory, continued his association with this report by participating in teleconferences, and making valuable suggestions concerning the organization of this report and its content. Laura Rumburg gathered material for the Major Activities section, carefully proofread the report, and corrected many errors present in the initial drafts. Members of the administrative staff of the Laboratory and its branches: Jean Howard, Caroline Maswanganye, Marquita Harris, Pat Luber, and Cathy Newman were instrumental in gathering material for the report and soliciting the contributions of Lab members. Elaine Firestone performed the final editing and formatting, turning this report into a polished product in a timely manner.

The cover on this year's report recognizes the valuable contributions to Earth Science made by the Upper Atmosphere Research Satellite (UARS) over its 14 year life in orbit. The cover theme was suggested by Charles Cote. Charles Jackman, UARS project scientist, contributed the graphical components for the cover, the cover caption, and a special summary section on UARS in Section 5.

Finally, Goran Halusa, our Laboratory Web Master, created the final cover design and published this report on our Web site, <http://atmospheres.gsfc.nasa.gov>.

—*Richard W. Stewart*



**Mission: Advance Knowledge and Understanding of the Atmospheres,  
of the Earth and Other Planets****1. INTRODUCTION**

The Laboratory for Atmospheres (Code 613) is 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 Earth’s atmospheres.

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 atmosphere. Laboratory members conduct field measurements for satellite data calibration and validation, and carry out numerous modeling activities. These models include climate model simulations, modeling the chemistry and transport of trace species on regional to global scales, cloud resolving modes, and developing next-generation Earth system models. 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 ensure 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 2005. Please note that any seasonal references refer to those in the Northern Hemisphere. The report also contains useful information on human resources, scientific interactions, and outreach activities. This report is published in a printed version, and an 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 230.

The civil servant composition of the Laboratory consists of 59 members, plus 14 co-located members (4 resource analysts, 1 scientist, 1 project manager, 4 engineers, and 4 technicians). Of the 59 in-house civil servants, 49 are scientists, 2 are engineers, and 1 a technical manager. Of the 51 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 involving the Earth–Sun Exploration Division and nearby university associations (JCET<sup>1</sup>, GEST<sup>2</sup>, and ESSIC<sup>3</sup>), or are employed by universities with which the Laboratory has a collaborative relationship, such as George Mason University, the University of Arizona, and Georgia Tech. Out of the 54 research associates, 91% hold Ph.D.'s. The onsite contractors are a very important component of the staffing of the Laboratory. Out of the total of 115 onsite contractors, 23% hold Ph.D.'s. The makeup of our Laboratory, therefore, is 26% civil servants, 24% associates, and 50% contractors.

The number of refereed publications (from 1991) and proposals (from 1997) written by laboratory members is shown in Figure 2.1. The number in each category is shown above the bars. Percentages in each category may be read from the ordinate. The difference between the yellow and red bars gives the number of papers that our scientists co-authored with outside scientists and is one measure of our extensive collaboration. The blue bars show the number of proposals written in recent years and indicate an increasing percentage as a function of papers written. The reduced number of refereed papers in 2004 and 2005 are due in part to the loss of the Atmospheric Experiment Branch, which is no longer part of our laboratory, to reduction in civil service scientists from attrition, and to the implementation of full cost accounting, which necessitates increased time spent on proposal writing.

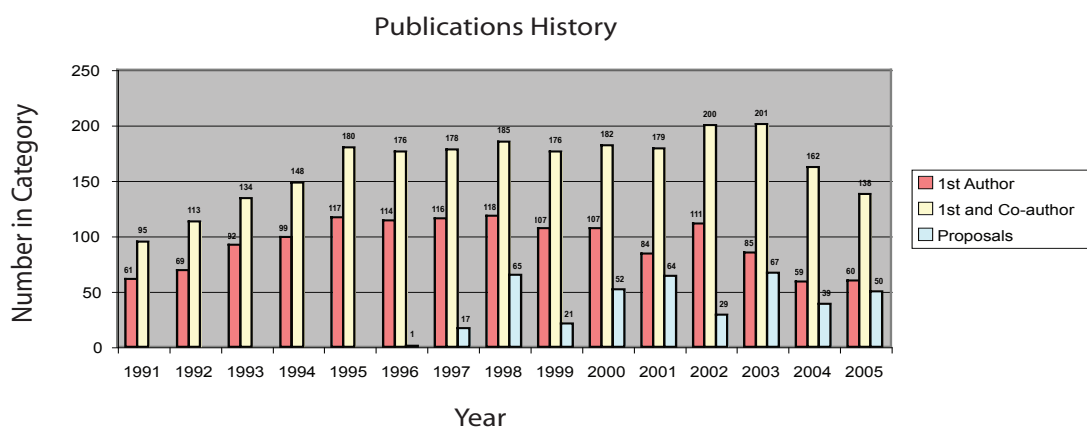


Figure 2-1. Number of proposals and refereed publications by Laboratory for Atmospheres members over the years. The yellow bar is the total number of publications where a Laboratory member is the first author or co-author, and the red bar is the number of publications where a Laboratory member is first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

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

## 2.2 Organization

The management and branch structure for the Laboratory for Atmospheres during 2005 is shown in Figure 2-2.

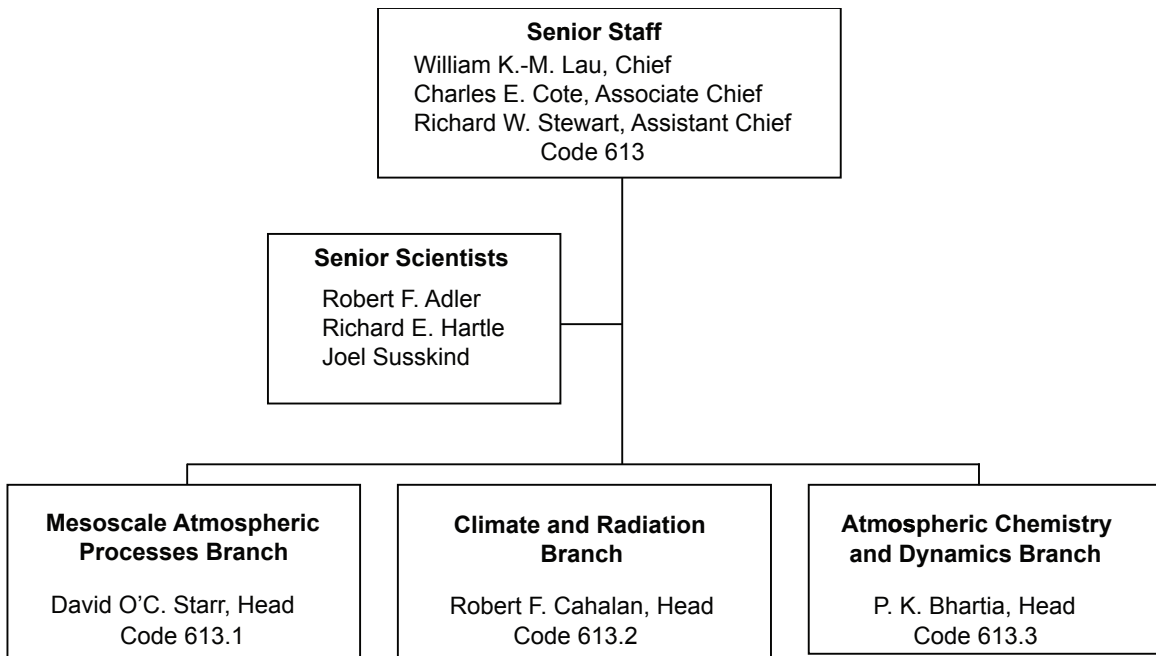


Figure 2-2. Laboratory for Atmospheres organization chart at the end of calendar year 2005.

## 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, and Aerosols. The employment composition of the Senior Staff Office (613) and the three branches is broken down by Civil Servant, Associate, and Contractor as shown in Figure 2.3.

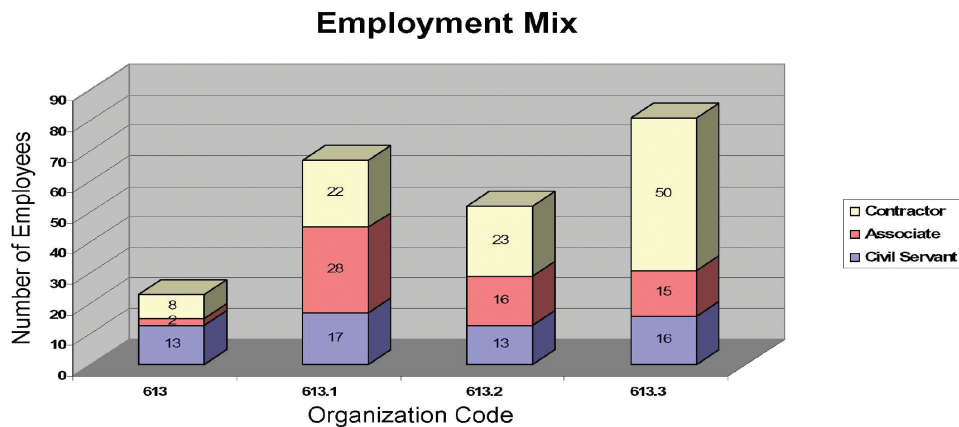


Figure 2-3. Employment composition of the members of the Laboratory for Atmospheres.

A brief description is given for each of the Laboratory's three 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, publication lists, and samples of highlighted journal articles given in Appendices 1 through 3, respectively.

### **Mesoscale Atmospheric Processes Branch, Code 613.1**

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 at <http://atmospheres.gsfc.nasa.gov/meso/>.

### **Climate and Radiation Branch, Code 613.2**

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 Chemistry and Dynamics Branch, Code 613.3**

The Atmospheric Chemistry and Dynamics Branch conducts research on remote sensing of atmospheric trace gases and aerosols 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 ultraviolet (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 the Total Ozone Mapping Spectrometer (TOMS) and Upper Atmosphere Research Satellite (UARS), and the recently launched Earth Observing System (EOS) Aura satellite, and works closely with the National Oceanic and Atmospheric Administration (NOAA) on ozone sensors on the operational weather satellites (NOAA-N, the National Polar

Orbiting Environmental Satellite System [NPOESS], and the NPOESS Preparatory Project [NPP]). 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://atmospheres.gsfc.nasa.gov/acd/>.

Branch Web sites may also be found by clicking on the branch icons at the Laboratory's home page: <http://atmospheres.gsfc.nasa.gov/>.

## **2.4 Facilities**

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### **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.

### **Lidar**

The Laboratory has well-equipped facilities to develop lidar systems for airborne and ground-based measurements of clouds, 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, which is available on the Laboratory home page.

### **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 EOS calibration program, the RCDF provides calibrations for all national and international ultraviolet and visible (UV/VIS) spaceborne solar backscatter instruments, which include the Solar Ultraviolet/Version 2 (SBUV/2) and TOMS instruments, and the European backscatter instruments flying on the Environmental Satellite (EnviSat) and Aura. The RCDF also provides laboratory resources for developing and testing of advanced spaceborne 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 Scott Janz ([Scott.J.Janz@nasa.gov](mailto:Scott.J.Janz@nasa.gov)).



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

The direction of our research effort is influenced by NASA's overall program, outlined in the Agency's strategic plan of 2003, [http://www.nasa.gov/pdf/1968main\\_strategi.pdf](http://www.nasa.gov/pdf/1968main_strategi.pdf). The new vision for space exploration resulted in the transformation of NASA's goals and 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 (ESED). Our 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. In October 2005, the Earth–Sun Exploration Division published a strategic plan for the Division outlining the Division's mission and goals in greater detail than the Agency plan <http://webserv.gsfc.nasa.gov/images/esappdocs/ESEDstratplanv2.pdf>. The Laboratory's research is guided by the goals contained in this plan. The remainder of this section outlines the connection of our research to NASA's mission and strategic plans.

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

- (1) the early days of the Television Infrared Observation Satellite (TIROS) and Nimbus satellites with emphasis on ozone, Earth radiation, and weather forecasting; and
- (2) the thermosphere and ionosphere satellites, the Orbiting Geophysical Observatory (OGO), the Explorer missions, and the Pioneer Venus Orbiter, to the more recent Galileo mission, and the current Cassini mission.

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 3.1, and Laboratory scientists focus their efforts on satellite mission planning, instrument development, data analysis, and modeling.

Table 3.1: Science themes and our major research areas.

| Science Themes                             | Major Research Areas                   |
|--------------------------------------------|----------------------------------------|
| Aerosols                                   | • Aerosols                             |
| Atmospheric Chemistry                      | • Atmospheric Chemistry and Ozone      |
| Carbon Cycle                               | • Atmospheric Hydrologic Cycle         |
| Climate Change                             | • Carbon Cycle                         |
| Global Water and Energy Cycle              | • Clouds and Radiation                 |
| Weather and Short-term Climate Forecasting | • Climate Variability and Prediction   |
|                                            | • Mesoscale Processes                  |
|                                            | • Precipitation Systems                |
|                                            | • 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 3.2 depicts these activities and some of the topics they address.

**Table 3.2: Laboratory for Atmospheres science activities.**

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

- a. Moderate Resolution Imaging Spectroradiometer
- b. TIROS Operational Vertical Sounder
- c. Tropical Rainfall Measuring Mission
- d. Ultraviolet-B

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 variables needed to answer it, conceive the best instrument to measure the variables, 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 NOAA's remote sensing requirements. The section concludes with a listing of project scientists, and a description of interactions with other scientific groups.

### 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 space-flight 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 4.1 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 4.1 also indicates each instrument's deployment—in space, on aircraft, balloons, on the ground, or in the laboratory. In most cases, details are presented in a separate Laboratory technical publication, the *Instrument Systems Report*, NASA/TP-2005-212783, available on the Laboratory Web site. Exceptions are the Unmanned Aerial Vehicle (UAV) Radar (URAD), High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP), and CO<sub>2</sub> lidar for which recent developments are described in Section 5.4.

Table 4.1: Principal instruments supporting scientific disciplines in the Laboratory for Atmospheres.

|       | Atmospheric Structure and Dynamics | Atmospheric Chemistry                     | Clouds and Radiation |
|-------|------------------------------------|-------------------------------------------|----------------------|
| Space |                                    | Total Ozone Mapping Spectrometer (TOMS)   |                      |
|       |                                    | Earth Polychromatic Imaging Camera (EPIC) |                      |

## MAJOR ACTIVITIES

|                                       |                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                           |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Aircraft/Balloon                      | <p>ER-2 Doppler Radar (EDOP)</p> <p>Holographic Airborne</p> <p>Rotating Lidar Instrument Experiment (HARLIE)</p> <p>Air Goddard Lidar Observatory for Winds (Air GLOW )</p> | <p>Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTAL)</p> <p>Raman Airborne Spectroscopic Lidar (RASL)</p> <p>Airborne Compact Atmospheric Mapper (ACAM)</p>                                                                                                                                                                              | <p>Cloud Physics Lidar (CPL)</p> <p>cloud THickness from Offbeam Returns (THOR) Lidar</p> <p>Cloud Radar System (CRS)</p> <p>UAV Cloud Physics Lidar (UAV CP Lidar)</p>                                                                                   |
| Ground/<br>Laboratory/<br>Development | <p>Scanning Raman Lidar (SRL)</p> <p>Goddard Lidar Observatory for Winds (GLOW)</p> <p>Lightweight Rain Radiometer-X band (LRR-X)</p>                                        | <p>Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE)</p> <p>Aerosol and Temperature Lidar (AT Lidar)</p> <p>Brewer UV Spectrometer</p> <p>Kiritimati Island Lidar Trailer (KILT )</p> <p>Lagrange-2 Solar Viewing Interferometer Prototype (L2-SVIP) Instrument Incubator Program (IIP)</p> <p>GeoSpec (IIP)</p> <p>CO<sub>2</sub> Lidar</p> | <p>Micro-Pulse Lidar (MPL)</p> <p>COmpact Visible Infrared Radiometer (COVIR)</p> <p>Surface-Sensing Measurements for Atmospheric Radiative Transfer (SMART)—Chemical, Optical, and Microphysical Measurements of <i>In situ</i> Troposphere (COMMIT)</p> |

## 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, DC-8, and WB-57F 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 2005, 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 the High Resolution Dynamics Limb Sounder (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.

There have been three AVE missions flown since the Aura launch. The first AVE campaign was flown from NASA's Johnson Space Center (JSC) Ellington Field in October–November 2004 on the high altitude NASA WB-57F aircraft. The second AVE (the Polar Aura Validation Experiment, PAVE) campaign was flown from Portsmouth, New Hampshire, in January 2005 on the long range NASA DC-8 aircraft. The third campaign was also flown from Ellington Field in June 2005 on the high altitude NASA WB-57F aircraft. Eight successful science flights were completed over the course of 14 days



Figure 4-1. Instrument locations on the WB-57 for the AVE Houston campaign.

Laboratory members participating in this mission were Paul Newman (613.3, Project Scientist), Scott Janz (613.3, ACAM Principal Investigator [PI]), Kent McCullough (ACAM and Argus Team/SSAI), Rich McPeters

## MAJOR ACTIVITIES

(613.3, Aura/OMI Co-PI), Matt McGill (613.1, CPL PI), Dennis Hlavka (613.1/SSAI, CPL Team), William Hart (613.1/SSAI, CPL Team), and Leslie Lait (613.3/SSAI, Met. Team). For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov). More information may be found at the Aura Web site: <http://aura.gsfc.nasa.gov/> and the Aura Validation Data Center Web site: <http://avdc.gsfc.nasa.gov/Overview/news.html>.

A fourth AVE is scheduled to be flown from San Jose, Costa Rica in January–February 2006 on the high altitude NASA WB-57F aircraft.

### **Polar Aura Validation Experiment (PAVE)**

The Polar Aura Validation Experiment (PAVE), one of a number of Aura validation experiments, is a NASA international science mission to acquire critical high quality measurements of the polar region in support of the recently launched Aura satellite. PAVE is the third of a series of Aura validation missions designed to provide correlative measurements to help understand the transport of gases and aerosols in the troposphere and their exchange with the lower stratosphere. The PAVE experiment was completed successfully from Pease Tradeport, New Hampshire, in January 2005. The experiment utilized the NASA DC-8, based at Dryden Flight Research Center (DFRC). Included in these flights was AROTAL, which made measurements of O<sub>3</sub>, temperature, and aerosol profiles. The AROTAL team on this mission consisted of Tom McGee (613.3, PI), Walter Hoegy (613, Emeritus), Don Silbert (613.3), Grant Sumnicht (613.3/Science Systems and Application, Inc. [SSAI]), and Larry Twigg (613.3/SSAI). The project scientists are Mark Schoeberl (NASA Goddard Space Flight Center [GSFC]) and Eric Jensen (NASA Ames Research Center [ARC]). For more information contact Tom McGee (Thomas.J.McGee@nasa.gov) or Mark Schoeberl (Mark.R.Schoeberl@nasa.gov). More information may be found at the PAVE Web site: <http://cloud1.arc.nasa.gov/ave-polar/>.

### **CPL Activities**

During 2004, the CPL was modified to operate on the NASA WB-57F aircraft. Historically, the CPL 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 AVE conducted from Ellington Field in Houston, Texas 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 was performed under a variety of atmospheric conditions.

In June 2005, the CPL participated in the second AVE, also conducted from Ellington Field. The NASA WB-57F completed eight successful science flights over the course of 14 days.

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).

### **Airborne Compact Atmospheric Mapper (ACAM)**

A new aircraft based measurement program was started in 2005. ACAM was test flown onboard the NASA WB57F during AVE in June of 2005 flying out of Houston, Texas. This new system, developed in the RCDF, combines high resolution photographic imagery of both nadir and forward looking cloud conditions with nadir UV and VIS spectrographic measurements in order to map trace gas concentrations of nitrogen dioxide, ozone, and aerosols. These measurements will be used to validate similar measurements from the Ozone Monitoring Instrument (OMI) onboard Aura. The test flights were successful and led to instrument improvements that will be implemented for the Costa Rica AVE (CR-AVE) mission in February of 2006.

For more information contact Scott Janz ([Scott.Janz@nasa.gov](mailto:Scott.Janz@nasa.gov)) or Paul Newman ([Paul.A.Newman@nasa.gov](mailto:Paul.A.Newman@nasa.gov)), or visit the Web site at [http://code916.gsfc.nasa.gov/Public/Ground\\_based/acam/acam/html](http://code916.gsfc.nasa.gov/Public/Ground_based/acam/acam/html).

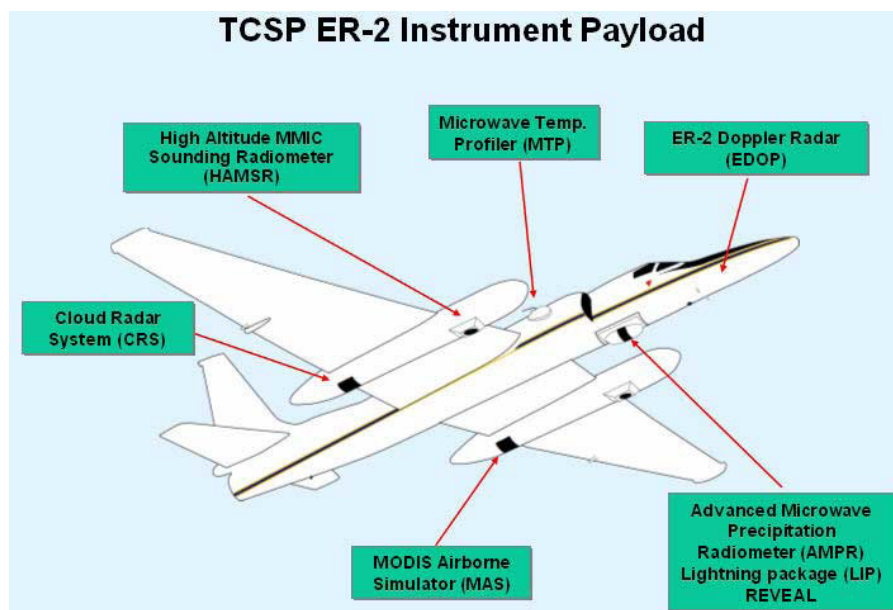
## Tropical Cloud Systems and Processes (TCSP)

The Tropical Cloud Systems and Processes (TCSP) mission is an Earth science field research investigation sponsored by NASA's Science Mission Directorate. The field phase was conducted during the period July 1–27, 2005 out of the Juan Santa Maria Airfield in San Jose, Costa Rica. The TCSP field experiment flew 12 NASA ER-2 science flights, including missions to Hurricanes Dennis and Emily, Tropical Storm Gert, and an eastern Pacific mesoscale complex that may possibly have further developed into Tropical Storm Eugene. The P-3 aircraft from the NOAA Hurricane Research Division (HRD) flew 18 coordinated missions with the NASA research aircraft to investigate developing tropical disturbances. Additionally, the aerosonde Unmanned Aerial Vehicle (UAV) flew eight surveillance missions and the *Instituto Meteorologico Nacional* (IMN) of Costa Rica launched RS-92 balloon sondes daily to gather humidity measurements and provide validation of the water vapor measurements.

TCSP is focused on the study of the dynamics and thermodynamics of precipitating cloud systems and tropical cyclones using NASA-funded aircraft and surface remote sensing instrumentation. Targeted data sets were collected using the NASA ER-2 research aircraft, in synergy with other surface and airborne remote sensing observations provided by NASA and other agencies. These observations will be used to answer key questions pertaining to the origins and life cycle of weather disturbances in the tropics. Analyses of data sets will address a wide variety of atmospheric space and time scales, ranging from the convective through the synoptic. Investigations will also be conducted to improve upon numerical modeling studies of tropical cyclogenesis, including wave-to-depression transition in the western Caribbean, Gulf of Mexico, and eastern Pacific Ocean.

TCSP research addresses the following topical areas: 1) tropical cyclone structure, genesis, intensity change, moisture fields and rainfall; 2) satellite and aircraft remote sensor data assimilation and validation studies pertaining to development of tropical cyclones; and 3) the role of upper tropospheric/lower stratospheric processes governing tropical cyclone outflow, the response of wave disturbances to deep convection, and the evolution of the upper level warm core.

The TCSP experiment builds upon the success of the previous Convection and Moisture Experiment (CAMEX) missions. For further information contact Gerald Heymsfield ([Gerald.M.Heymsfield@nasa.gov](mailto:Gerald.M.Heymsfield@nasa.gov)) or visit the TCSP Web site at <http://camex.msfc.nasa.gov>.



## 4.3 Data Sets

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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 613.3 three-dimensional chemistry and transport model. Boundary conditions were specified for chlorofluorocarbons, methane, and N<sub>2</sub>O 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 (1979 source gases) and low chlorine (1970 levels) and without the volcanic aerosols have also been completed to help distinguish chemical effects from effects of both interannual variability and a trend in the residual circulation in the input meteorological fields. The model output from all simulations is available on the Code 613.3 science system; software to read the output is also available. Although the CTM itself is run at  $2^\circ \times 2.5^\circ$  latitude/longitude horizontal resolution; the output is stored at  $4^\circ \times 5^\circ$  latitude/longitude. Higher resolution files are available from UniTree, the Code 606.2 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 613.3 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](mailto:Anne.R.Douglass@nasa.gov)).

### Near-UV Aerosol Products from TOMS and OMI

The near-UV technique of aerosol characterization differs from conventional visible and near-IR methods 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 (VIS) and near-infrared (IR) methods do not work. TOMS aerosol data are currently available in the form of a contrast index and as near-ultraviolet (UV) extinction optical depth. 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. Satellite-derived single scattering albedo from TOMS observations for biomass burning episodes was evaluated by comparison to the Aerosol Robotic Network (AERONET) ground based retrievals. The evaluation indicates that the TOMS and AERONET single-scattering albedo products are in agreement within 0.03 in most cases.

The record of Aerosol Index and near-UV 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. The figure below shows a 4-day sequence of a Saharan dust outbreak in March 2005 as seen by OMI.

For more information contact Omar Torres ([torres@tparty.gsfc.nasa.gov](mailto:torres@tparty.gsfc.nasa.gov)).



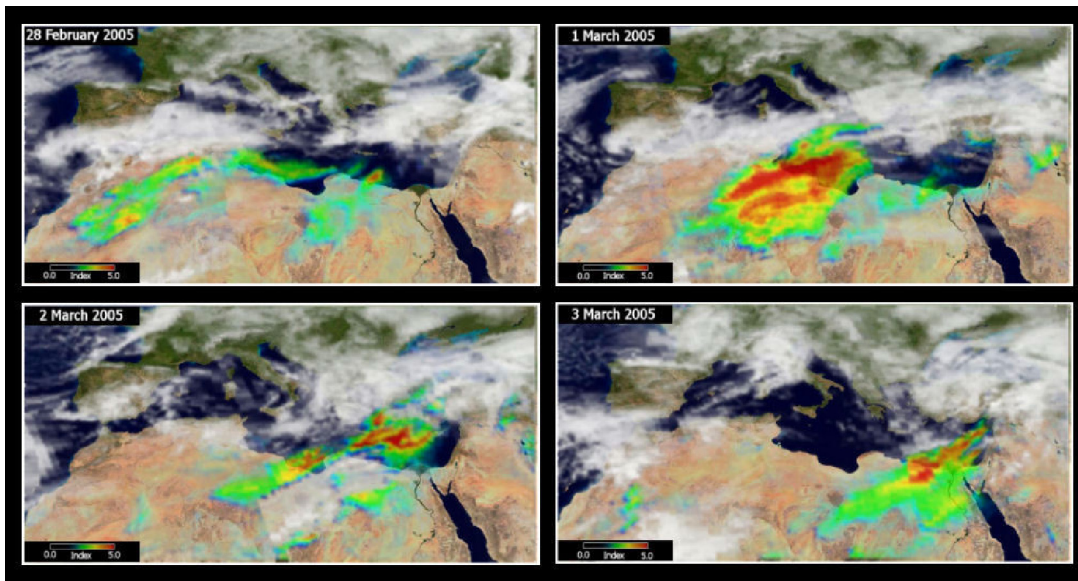


Figure 4-2. Saharan dust aerosols as seen by the Aura-OMI sensor Aerosol Index. The aerosol detection capability in the presence of clouds is a unique advantage of the OMI and TOMS observations.

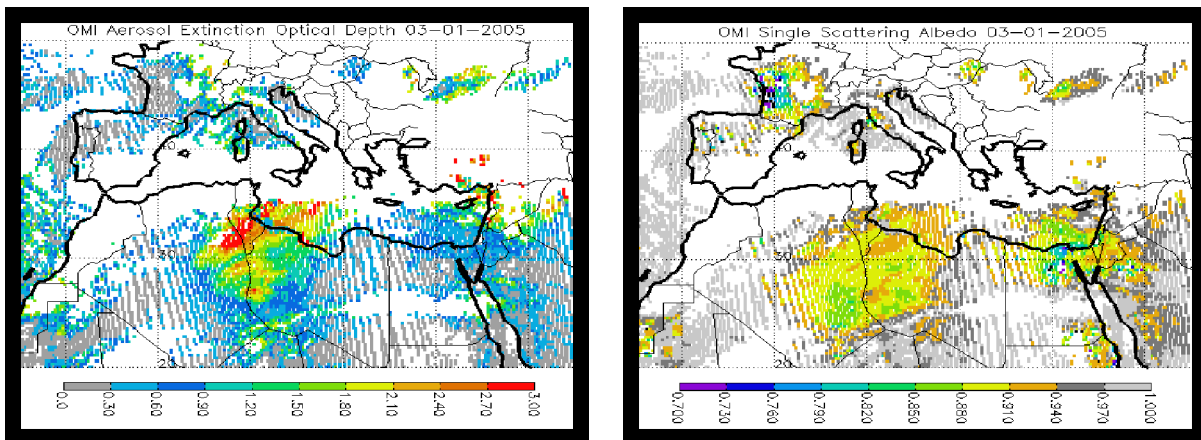


Figure 4-3. OMI retrievals of aerosol extinction optical; depth (left), single scattering albedo (right), during a Saharan dust outbreak on March 1, 2005.

## 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) has established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory are leading the GPCP effort to merge data from both low-Earth orbit satellites and geosynchronous satellites, and ground-based rain gauges, to produce research-quality estimates of global precipitation.

The GPCP 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 NOAA's 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 eight-year TRMM data set is being used in the assessment of the longer GPCP data set. A daily, globally complete analysis of precipitation is also being produced by Laboratory scientists for GPCP for the period 1997 to the present and is available from the archives.

An even finer time resolution, a TRMM-based quasi-global, 3 h resolution rainfall analysis, the TRMM Multi-satellite Precipitation Analysis (TMPA) is available from the Goddard DAAC for the period of January 1998 to the present. This product uses TRMM data to calibrate or adjust rainfall estimates from other satellite data and combines these estimates into rainfall maps at a frequency of every 3 h. A real-time version of this analysis is available through the TRMM Web site. For more information, contact Robert Adler ([Robert.F.Adler@nasa.gov](mailto:Robert.F.Adler@nasa.gov)).

### **Merged TOMS/SBUV Data Set**

We have recently updated our merged satellite total ozone data set through late 2005. We have transferred the calibration from the original six satellite instruments to the current instrument NOAA 16 SBUV/2. We also have 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](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 2006, we will incorporate the data from the OMI instrument on Aura. For further information, contact Richard Stolarski ([Richard.S.Stolarski@nasa.gov](mailto:Richard.S.Stolarski@nasa.gov)) or Stacey Frith ([smh@code916.gsfc.nasa.gov](mailto:smh@code916.gsfc.nasa.gov)). For further information, contact Richard Stolarski ([Richard.S.Stolarski@nasa.gov](mailto:Richard.S.Stolarski@nasa.gov)) or Stacey Frith ([smh@code916.gsfc.nasa.gov](mailto:smh@code916.gsfc.nasa.gov)).

### **Moderate Resolution Imaging Spectroradiometer (MODIS)**

Operational MODIS data includes both level-2 and level-3 products. There are six categories of level-2 (pixel-level or swath data) MODIS Atmosphere products collected from two platforms: Terra and Aqua. There are three level-3 (global gridded) MODIS Atmosphere Products produced from each platform. Each of the level-3 products contains statistics generated from the first four level-2 products noted below.

The level-2 product files are grouped by Aerosol, Water Vapor, Cloud, Atmospheric Profile, and Cloud Mask geophysical retrievals. In addition, the Joint Atmosphere Product contains a spatial sample of the more popular atmospheric retrievals. Level-3 MODIS Atmosphere products provide statistics on a  $1^\circ \times 1^\circ$  global grid and are produced for daily, eight-day, and monthly time periods.

#### *Level-2 Products*

The Aerosol Product provides aerosol optical thickness over the oceans globally and over a portion of the continents. Further, information regarding the aerosol size distribution is derived over the oceans, while the aerosol type is derived over continents. Level-2 aerosol retrievals are at the spatial resolution of a  $10 \times 10$ , 1 km (at nadir) pixel array.

The Precipitable Water Product consists of two-column water vapor retrievals. During the daytime, a near-infrared algorithm is applied over clear land areas, ocean sun glint areas, and above clouds over both land and ocean. An infrared algorithm used in deriving atmospheric profiles is also applied both day and night.

The Cloud Product combines infrared and visible techniques to determine both physical and radiative cloud properties. Cloud optical thickness, effective particle radius, and water path are derived at a 1 km resolution using MODIS visible through mid-wave infrared channel observations. Cloud-top temperature, pressure, and effective emissivity are produced by infrared retrieval methods, both day and night, at a  $5 \times 5$ , 1 km pixel resolution. Cloud thermodynamic phase is derived from a combination of techniques and spectral bands. Finally, the MODIS Cloud Product includes an estimate of cirrus reflectance in the visible at a 1 km pixel resolution; these retrievals are useful for removing cirrus scattering effects from the land-surface reflectance product.

The Atmospheric Profile Product consists of several parameters: total column ozone, atmospheric stability, temperature and moisture profiles, and atmospheric water vapor. All of these parameters are produced day and night at a  $5 \times 5$ , 1 km pixel resolution when a  $5 \times 5$  region is suitably cloud free.

The Cloud Mask Product indicates to what extent a given instrument field of view (FOV) of the Earth's surface is unobstructed by clouds. The cloud mask also provides additional information about the FOV, including the presence of cirrus clouds, ice/snow, and sun glint contamination.

The Joint Atmosphere Product contains a subset of key parameters gleaned from the complete set of operational level-2 products: Aerosol, Water Vapor, Cloud, Atmospheric Profile, and Cloud Mask. The Joint Atmosphere product was designed to be small enough to minimize data transfer and storage requirements, yet robust enough to be useful to a significant number of MODIS data users. Scientific data sets (SDSs) contained within the Joint Atmosphere Product cover a full set of high-interest parameters produced by the MODIS Atmosphere Group, and are stored at 5 km and 10 km (at nadir) spatial resolutions.

### *Level-3 Products*

The Level-3 MODIS *Atmosphere Daily Global Product* contains roughly 600 statistical data sets, which are derived from approximately 80 scientific parameters from four Level-2 MODIS Atmosphere Products: Aerosol, Water Vapor, Cloud, and Atmospheric Profile. Statistics are sorted into  $1^\circ \times 1^\circ$  cells on an equal-angle grid that spans 24 hours (0000 to 2400 UTC). A range of statistical quantities is computed, depending on the parameter being considered. In addition to simple statistics, the level-3 files include a variety of one- and two-dimensional histograms. Similarly, the level-3 *Eight-Day* and *Monthly Global Product* contain roughly 800 statistical data sets that are derived from the level-3 *Daily* and *Eight-Day* products, respectively.

For further information, contact Steven Platnick ([Steven.Platnick@nasa.gov](mailto:Steven.Platnick@nasa.gov)) or visit the MODIS Web site at <http://modis-atmos.gsfc.nasa.gov/>. Discussion of the MODIS data processing is contained in Section 5 of this report.

### **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 AERONET. The MPLNET project uses the MPL system, 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 sites served

## MAJOR ACTIVITIES

as ground calibration/validation for NASA's first satellite lidar, the Geoscience Laser Altimeter System (GLAS), and will also provide validation for the next satellite lidar, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). MPLNET data has also been used to validate results from passive NASA satellite sensors such as MODIS, the Multi-Angle Imaging Spectroradiometer (MISR), and TOMS.

The MPLNET project underwent a major expansion in 2005. There are currently 10 active sites in the network: three in the U.S., three in Asia, two in Antarctica, one in the Arctic, and one off the west coast of Africa. Data from several of the sites are already publicly available on our Web site, and the remaining sites will soon be public after the calibrations are completed (data is being acquired offline in the interim). Older data sets from an additional 14 sites remain available as well. Planning is underway for future sites in 2006, including additional sites in the U.S., Asia, the west coast of Africa, and new sites in the Caribbean, South America, and the Middle East.

Further information on the MPLNET project, and access to data, may be obtained online at <http://mplnet.gsfc.nasa.gov>. For questions on the MPLNET project, contact Judd Welton ([Judd.Welton@nasa.gov](mailto:Judd.Welton@nasa.gov)).

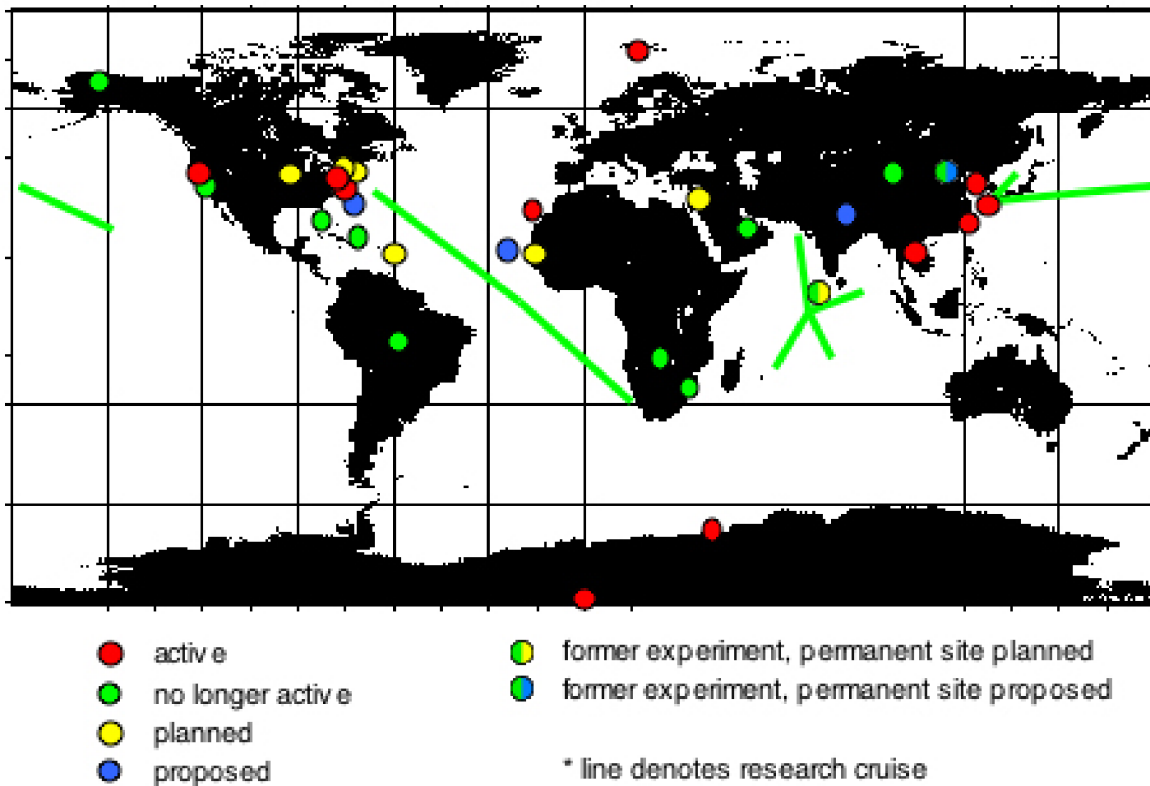


Figure 4.4. MPLNET sites

## 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 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 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 was 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 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 OMI flying on Aura, as well as similar instruments flying on European satellites. For more information, contact Scott Janz ([Scott.Janz@nasa.gov](mailto:Scott.Janz@nasa.gov)) or Jay Herman ([Jay.R.Herman@nasa.gov](mailto:Jay.R.Herman@nasa.gov)).

### **TIROS Operational Vertical Sounder (TOVS) 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 until April 2005, when NOAA 14 stopped transmitting data. We used 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, cloud height, Outgoing Longwave Radiation (OLR), 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 Atmospheric Infrared Sounder (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, trends of surface and atmospheric temperatures, humidity, cloudiness, OLR, and precipitation. The TOVS precipitation data are 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 NASA's Jet Propulsion Laboratory (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 began producing improved AIRS level-2 soundings starting in April 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](mailto:Joel.Susskind-1@nasa.gov)).

### **TOMS and OMI 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 flying on the Earth Probe (EP-TOMS) 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 613.3” 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>.

Very similar data are being produced by the OMI instrument on the recently launched Aura spacecraft and are also available from the TOMS Web site <http://toms.gsfc.nasa.gov>. Because of calibration problems with the aging EP-TOMS instrument, OMI data should be used in preference to TOMS data beginning in 2005.

### **Tropospheric O<sub>3</sub> Studies**

In 2005, new Aura satellite ozone measurements from the OMI and Microwave Limb Sounder (MLS) were used to develop global maps of tropospheric ozone. Day-to-day tropospheric ozone maps from OMI/MLS were processed for more than one year beginning in August 2004. OMI/MLS tropospheric ozone data were validated from ground-based and other satellite-based measurements. Evaluation of OMI/MLS tropospheric ozone shows evidence of a one-to-two month Madden-Julian Oscillation (MJO) in the tropical Pacific. The data also indicate enhancements in tropospheric ozone over Indonesia during November 2004, which coincided with a weak tropical El Niño event. Features in summer months include an accumulation of tropospheric ozone over the broad Mediterranean region as suggested in past modeling studies. General features (e.g., seasonal cycles, spatial patterns) in tropospheric ozone from OMI/MLS compared well with both NCAR’s Model for Ozone and Related Chemical Tracers (MOZART-2) and Goddard’s GMI CTM modeled tropospheric ozone. Daily maps of tropospheric ozone from OMI/MLS have been evaluated and further tested for the application of tracking global pollution events. The new tropospheric ozone maps from OMI/MLS have been shown at many national and international science meetings by both modelers and nonmodelers within Code 613.3 (Atmospheric Chemistry and Dynamics Branch). For more information contact Jerry Ziemke ([Jerald.R.Ziemke.1@gsfc.nasa.gov](mailto:Jerald.R.Ziemke.1@gsfc.nasa.gov)).

## **4.4 Data Analysis**

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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, modifying cloud microphysics, and altering cloud and rainfall patterns. 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) rainfall, water vapor, cloud liquid water (TRMM, Advanced Microwave Sounding Radiometer [AMSR]), in conjunction with large scale circulation, moisture convergence (European Centre for Medium-Range Weather Forecasts [ECMWF] and National Center for Environmental Prediction [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. Observations are being coordinated with modeling studies, using global and regional climate models, as well as 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. Currently, the use of multimodel framework (MMF), including the embedding of cloud resolving models in global general circulation models, is being pursued. This research also calls for the organization and coordination of field campaigns for aerosol and water cycle measurements in conjunction with GEWEX, Climate Variability and Predictability Programme (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), Si-Chee Tsay (Si-Chee.Tsay-1@climate.gsfc.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 cycles 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: MODIS, AMSR, TRMM, the 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, Special Sensor Microwave Imager (SSM/I), MSU, and TOVS Pathfinder. Diagnostic and modeling studies of diurnal and seasonal cycles of various geophysical parameters are being conducted using satellite data to validate climate model output, and to improve physical parameterization in models. For more information, contact William Lau (William.K.Lau@nasa.gov), Tom Bell (Thomas.L.Bell@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<sub>2</sub>, SO<sub>2</sub>, HCHO, O<sub>3</sub>) Amounts Using a Brewer Double Monochromator**

O<sub>3</sub>, NO<sub>2</sub>, HCHO, and SO<sub>2</sub> 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<sub>2</sub>, HCHO, and SO<sub>2</sub> with a sensitivity of approximately 0.4 DU. The method for obtaining the column amounts uses a modified differential Optical Absorption Spectroscopy (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. Comparisons with Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) NO<sub>2</sub> data show good agreement. The results from this investigation have now been accepted for publication. 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. Recently, we have extended these measurements by modifying the design of the shadowband instrument to include a new 440 nm channel that overlaps the Cimel sun photometer’s shortest wavelength almucantar channel. The change should bridge the gap between the two data sets. 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  $100 \text{ Wm}^{-2}$  or enhanced by as much  $20 \text{ Wm}^{-2}$  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 the South East and East Asia regions. 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 premonsoon season spring of each year. Based on current measurements we find that the southern China monsoon now starts a couple of 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 helps in the prediction of the onset of the tropical monsoon system. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov) or Christina Hsu (Nai.C.Hsu@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 AMSR on EOS Aqua (AMSR-E).

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.

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 by the Earth Science Technology Office (ESTO) Advanced Component Technologies (ACT), for 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 (QWIP) has been integrated and flight-tested in a Navy research aircraft for building a testbed. We will perform the final phase of this project by flight testing our QWIP with an onboard simulator in the spring peak-season of biomass burning in a Southeast Asia field deployment. Currently, we are analyzing an effective flat-fielding algorithm, which will be applied to the Field Programmable Processor Array (FPPA), 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**

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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 Global Ozone Chemistry Aerosol Radiation Transport (GOCART) model. This model uses the meteorological fields produced by Goddard’s Global Modeling and Assimilation Office (GMAO, Code 610.1), and includes major types of aerosol: 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.

In 2005, the GOCART model was used as a major tool in the U.S. Climate Change Science Program (CCSP) report on aerosol direct radiative forcing assessment, which has contributed to the most recent report by the Intergovernmental Panel on Climate Change (IPCC). We have also used the model to study intercontinental transport, global air quality, aerosol climate forcing, and aerosol–chemistry–climate interactions. The output of the model is used by many groups worldwide. 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>.

## Chemistry-Climate Modeling

This project brings together the atmospheric chemistry and transport modeling of the Atmospheric Chemistry and Dynamics Branch and the General Circulation Model (GCM) development of the GMAO. The initial goal is to understand the role of climate change in determining the future composition of the atmosphere. We have coupled our stratospheric chemistry and transport into the Goddard Earth Observing System (GEOS) general circulation model and will use this to study the past and future coupling of the stratospheric ozone layer to climate. Our emphasis is on the testing of model processes and model simulations using data from satellites and ground-based measurement platforms.

Co-PIs are Richard Stolarski (Atmospheric Chemistry and Dynamics Branch) and Steven Pawson (GMAO). For further information, contact Richard Stolarski ([Richard.S.Stolarski@nasa.gov](mailto:Richard.S.Stolarski@nasa.gov)), Steven Pawson ([Steven.Pawson-1@nasa.gov](mailto:Steven.Pawson-1@nasa.gov)), or Anne Douglass ([Anne.R.Douglass@nasa.gov](mailto:Anne.R.Douglass@nasa.gov)).

## Cloud and Mesoscale Modeling

Three different coupled modeling systems were developed and improved over the last year. These 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, radiative exchange processes, and diabatic heating and water budgets associated with tropical, subtropical, and mid-latitude weather systems.

In the first modeling system, the NASA Goddard finite volume GCM (fvGCM) is coupled to the Goddard Cumulus Ensemble (GCE) model (a cloud-resolving model). The fvGCM allows for global coverage, and the GCE model allows for explicit simulation of cloud processes and their interactions with radiation and surface processes. This modeling system has been applied and its performance tested for two different climate scenarios, El Niño (1998) and La Niña (1999). The new coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, intraseasonal oscillations, and diurnal variation of precipitation over land, which are very difficult to forecast using even state-of-the-art GCMs.

The second modeling system couples various NASA Goddard physical packages (i.e., microphysics, radiation, and a land surface model) into the next generation weather forecast model known as the Weather Research and Forecasting (WRF) model. This coupled modeling system allows for better forecasts (or simulations) of convective systems in Oklahoma and typhoons in the west Pacific.

The third modeling system is the improved GCE model system, which has been developed and improved at Goddard over the last two decades. The GCE model has recently been improved in its abilities to simulate the impact of atmospheric aerosol concentration on precipitation processes and the impact of land and ocean surfaces on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and precipitation radar model to simulate satellite-observed brightness temperatures at different frequencies. This new coupled model system allows us to better understand cloud processes in the tropics, as well as to improve precipitation retrievals from NASA satellites. The scientific output of the modeling activities was again exceptional in 2005 with 10 new papers published or in press and many more submitted. For more information, contact Wei-Kuo Tao ([WeiKuo.Tao.1@gsfc.nasa.gov](mailto:WeiKuo.Tao.1@gsfc.nasa.gov)).

## Global Modeling Initiative (GMI)

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

- reduce uncertainties in model results and predictions by understanding the processes that contribute most to the variability of model results, and by evaluating model results against existing observations of atmospheric composition;
- understand the coupling between atmospheric composition and climate through coordination with climate models; and
- contribute to the assessment of the anthropogenic perturbations to the Earth system.

The GMI CTM has options for several chemical mechanisms for studying different problems. There are separate tropospheric, stratospheric, and aerosol chemical mechanisms, and recently we have added a combined tropospheric-stratospheric mechanism for investigations of the climatically sensitive upper troposphere/lower stratosphere. We have also added a microphysical aerosol mechanism for the study of aerosol size distributions and their role as cloud condensation nuclei. The chemical mechanisms have been recoded for compliance with the Earth Science Modeling Framework (ESMF). The sensitivity of the aerosol model results to meteorological input was evaluated by GMI team members at the University of Michigan. The GMI tropospheric model participated in an IPCC photochemical intercomparison that investigated model sensitivities to simulation of tropospheric ozone. An important aspect of all GMI studies is the evaluation of the credibility of model results using ground-based, aircraft, and remotely sensed measurements. Comparison to stratospheric observations and to tropospheric observations have been documented for model evaluation. For more information, contact Jose Rodriguez ([jrodriguez@code916.gsfc.nasa.gov](mailto:jrodriguez@code916.gsfc.nasa.gov)).

## Physical Parameterization in Atmospheric GCM

The development of submodels of physical processes (physical parameterizations) is an integral part of preparing our climate models for addressing the remaining outstanding climate change questions. At this time, the scientific community is deeply divided about the feedback influence of clouds and cloud microphysics in a climate change scenario. Laboratory scientists are actively involved in developing and improving physical parameterizations of the moist processes effecting precipitation microphysics, cloud-radiation, and cloud-aerosol interaction, and in validation against *in situ* data and satellite data. The accuracy of such process interactions is extremely important for eliminating climate-model biases, and simulating realistic climate change, both of which are 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 to simulate the direct effects of aerosols. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

With regard to the cloud physics, almost all of the state-of-the-art models of our times develop large simulation biases that are sometimes larger than the outstanding climate change issues to be assessed by these models; it is primarily due to the biased heating and moistening fields simulated by the model's cloud physics and microphysics. We are evaluating and eliminating such simulation biases using the Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme (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, and cloud inhomogeneity corrections for radiative transfers based on algorithms developed by the laboratory scientists. The boundary-layer clouds are based on the physics of boundary-layer convection, which parallels the formulations of moist convection. Recently, we included a version of Nenes and Seinfeld aerosol-cloud interaction scheme for water clouds while a parallel scheme for ice and mixed-phase clouds is an active area of research. These will be evaluated against ARM-2004 data on cloud particle number densities of water and ice clouds.

We have been evaluating coupled radiation and the prognostic cloud-water schemes with *in situ* observations from the ARM Cloud and Radiation Test Bed (ARM CART) and Tropical Ocean Global Atmosphere–Coupled Ocean Atmosphere Response Experiment (TOGA COARE) Integrated Program Offices (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 also provide the essential validation statistics.

We have been using the Land Information System (LIS) for comparing four different sets of algorithms used to represent the hydrologic, snow-cover, and evapotranspiration processes for different biomes in each model. Moreover, the soil moisture prediction of our own model, called HYdrology and Simple Biosphere (HY-SiB) is extended down to the groundwater table. Two-year long integration with Global Soil Wetness Project (GSWP) forcing data from analysis of observations from 1987 and 1988 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. After the formation of the Global Modeling and Assimilation Office (GMAO), however, the project is currently with the Hydrospheric and Biospheric Sciences Laboratory and the GMAO. The National Center for Atmospheric Research (NCAR), GFDL, and Goddard Institute for Space Studies (GISS) scientists are our active collaborators. For more information, contact Yogesh Sud ([Yogesh.C.Sud@nasa.gov](mailto: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 effect 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 multi-annual. 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 multi-decadal 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**

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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.

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 for monitoring atmospheric processes, such as moisture, winds, clouds, and surface conditions, in real time. 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](mailto:Dennis.Chesters@nasa.gov)).

## NPOESS

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the SEB 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), and 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) that 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<sub>2</sub>, CO, and CH<sub>4</sub>. These studies indicate that total CO<sub>2</sub> can be obtained to 2 ppm (0.5%) from AIRS under clear conditions, total CH<sub>4</sub> 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](mailto: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 May 4, 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 performance of AIRS/AMSU/HSB with that expected 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](mailto: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 Shuttle Ozone Limb Sounding Experiment (SOLSE)/Limb Ozone Retrieval Experiment (LORE) shuttle demonstration flights in 1997 (STS-87) and 2003 (STS-107). 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 IPO through the 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 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 Richard McPeters (Richard.D.McPeters@nasa.gov).

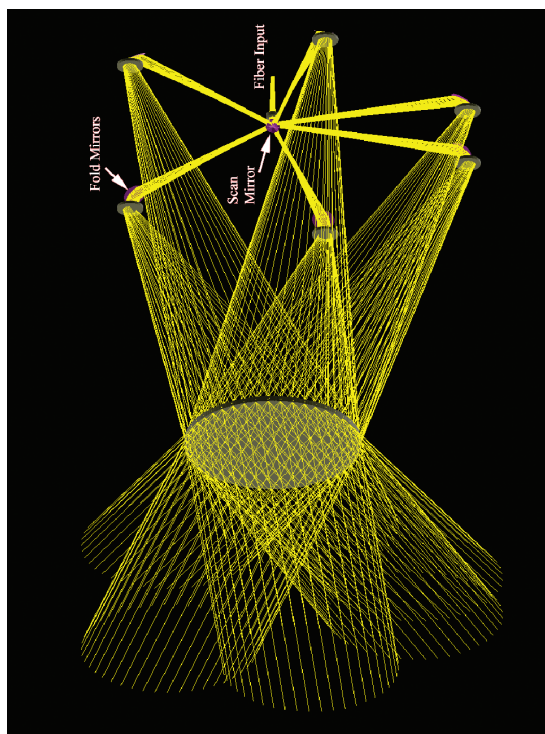
## Holographic Scanning Lidar Telescope Technology

Some lidar remote sensing applications require scanning a large aperture telescope over widely separated fields of view in rapid succession. Conical scanning telescopes that use a Holographic Optical Element (HOE) for their primary optic are being developed to reduce the size, weight, angular momentum, and costs associated with this type of scanning using conventional optical telescopes. Building on our prior successes in developing ground-based and airborne lidar systems using large rotating HOEs in the visible and 1  $\mu\text{m}$  wavelength regions, we are now pushing this technology into the ultraviolet and 2  $\mu\text{m}$  wavelength regions.

The first two lidars using HOE technology are the Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing (PHASERS) and HARLIE. PHASERS is a ground-based lidar using a 532 nm laser, and is now operated by Dr. David Guerra of the Physics Dept. at Saint Anselm College in Manchester, NH. HARLIE is a 1  $\mu\text{m}$  wavelength backscatter lidar operated by GSFC. It is currently being modified for use at a wavelength of 355 nm and interfaced to a Doppler receiver for the first ground-based demonstration of atmospheric Doppler wind measurements using HOE technology. PHASERS and HARLIE have proven the utility of using HOEs as lidar receivers and demonstrated a factor of 3 reduction in the weight of the telescope/scanner assembly compared to conventional technology.

As part of their Instrument Incubator Program (IIP), ESTO is funding the development of a high-altitude airborne Doppler wind lidar that will use a 40 cm diameter rotating HOE telescope operating with a 355 nm laser transmitter called the Tropospheric Wind Lidar Instrument Technology Experiment (TWiLiTE), described previously in this report.

*Figure 4.5. Illustration of how a ShADOE is used to multiplex six narrow fields of view into a single receiver system. Mechanical structures have been omitted for clarity; only the optical components and the ray paths are shown. The ShADOE is the large circular optic near the bottom, focusing light from each field of view to secondary optics located in a circle above. These direct the light to a centrally located small rotating scanner that feeds each beam in sequence into a common fiber optic.*





ESTO also began funding for the development of a Shared Aperture Diffractive Optical Element (ShADOE) telescope, under their Advanced Component Technology program. The ShADOE telescope will eliminate most or all mechanical moving components by sequentially “addressing” several holograms multiplexed into a single optic in order to scan over the multiple fields of view. This last development should reduce the weight of large aperture scanning receivers by another factor of three. The objectives of the ShADOE project follow:

- Enable atmospheric Doppler (e.g., wind profiling) and surface mapping lidar applications from space;
- Develop diffraction-limited holographic, or diffractive optical, elements for use with 2054 nm wavelength lasers and near-diffraction limited ShADOEs for use at 355 nm;
- Demonstrate an angle-multiplexed, multi-wavelength ShADOE telescope suitable for use with single and dual-wavelength lidars; and
- Advance the ShADOE technical readiness level (TRL) from 2 to 4.

Starting from a Director’s Discretionary Fund (DDF) program in the early 1990s, this program is leveraged by prior and current investments by the NASA Small Business Innovation Research Program (SBIR) program, the Cross-Cutting Technology Program, and the GSFC Independent Research and Development (IRAD) and Core Competency programs. The IPO also supports the development of this technology as a risk reduction for lidar applications on NPOESS, including direct detection wind lidar systems. For more information on this technology, visit the Web site at <http://harlie.gsfc.nasa.gov/>, or contact Bruce Gentry (Bruce.M.Gentry@nasa.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. Ground-based (see GLOW) and airborne (see TWiLiTE) Doppler lidar systems provide critical validation of new technologies proposed for eventual spaceborne operation. ESTO and the NPOESS IPO are supporting the effort. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

### **Tropospheric Wind Lidar Technology Experiment (TWiLiTE)**

Global measurement of tropospheric winds is a key measurement for understanding atmospheric dynamics and improving numerical weather prediction. Global wind profiles remain a high priority for the operational weather community and also for a variety of research applications including studies of the global hydrologic cycle and transport studies of aerosols and trace species. In addition to space-based winds, a high altitude airborne system flown on UAV or other advanced platforms would be of great interest for studying mesoscale dynamics and hurricanes. The TWiLiTE project was selected in 2005 by ESTO as part of the IIP. TWiLiTE will leverage significant research and development investments in key technologies made in the past several years. The primary focus will be on integrating these subsystems into a complete molecular direct detection Doppler wind lidar system designed for autonomous operation on a high-altitude aircraft, such as the NASA WB-57, so that the nadir-viewing lidar will be able to profile winds through the full troposphere.

TWiLiTE is a collaboration involving scientists and technologists from NASA Goddard, the NOAA Earth System Research Laboratory (ESRL), Utah State University Space Dynamics Lab, and industry partners Michigan Aerospace Corporation and Sigma Space Corporation. NASA Goddard and its partners have been at the forefront in

the development of key lidar technologies (lasers, telescopes, scanning systems, detectors, and receivers) required to enable spaceborne global wind lidar measurement. The TWiLiTE integrated airborne Doppler lidar instrument will be the first demonstration of an airborne scanning direct detection Doppler lidar and will serve as a critical milestone on the path to a future spaceborne tropospheric wind system. 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 4.2 lists the project- and deputy project scientists for current missions; Table 4.3 lists the validation and mission scientists for various campaigns.

Table 4.2: 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 | Gerald Heymsfield                     | TCSP                 |
| Dennis Chesters    | GOES      | Hans Mayr                             | AIM                  |
| James Gleason      | NPP       | Matt McGill                           | CALIPSO              |
| Jay Herman         | DSCOVR    | Matt McGill                           | CloudSat             |
| Charles Jackman    | UARS      | Steve Platnick                        | EOS Aqua             |
| Eric Smith         | GPM       | Marshall Shepherd                     | GPM                  |
| Joel Susskind      | POES      | Si-Chee Tsay                          | EOS Terra            |
|                    |           | Warren Wiscombe                       | ARM, Chief Scientist |

Table 4.3: Laboratory for Atmospheres campaigns and mission scientists.

| EOS Validation Scientist |         | Field/Aircraft Campaigns |                  |
|--------------------------|---------|--------------------------|------------------|
| Name                     | Mission | Name                     | Campaign         |
| David Starr              | EOS     | Paul Newman              | AVE              |
|                          |         | Si-Chee Tsay             | UAE <sup>2</sup> |
|                          |         | Si-Chee Tsay             | BASE-ASIA        |
|                          |         | Judd Welton              | MPLNET           |

## 4.8 Interactions with Other Scientific Groups

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### 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, presented in Appendix 2, 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:

- Cooperative Institute of Meteorological Satellite Studies (CIMSS) with the University of Wisconsin, Madison;
- ESSIC, with the University of Maryland, College Park;
- GEST Center, with the University of Maryland, Baltimore County (and involving Howard University);
- JCET, with the University of Maryland, Baltimore County; and
- Joint Center for Observation System Science (JCOS) with the Scripps Institution of Oceanography, University of California, San Diego.
- Cooperative agreement with Colorado State University, Fort Collins, CO.

These collaborative relationships have been organized to increase scientific interactions between the Laboratory for Atmospheres 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 the Tropical Rainfall Measuring Mission (TRMM), with the Japanese National Space Development Agency (NASDA); the TOMS Program, with NASDA and the Russian Scientific Research Institute of Electromechanics (NIEM); 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**

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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. New research proposals involving technology development will have strong commercial partnerships wherever possible.

## 5. HIGHLIGHTS OF LABORATORY ACTIVITIES IN 2005

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 613.1

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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 and on the 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. The major accomplishments this year were in the areas of TRMM algorithm improvement and achieving continued operation of the TRMM satellite. In particular, there were significant publications on the latent heating data product. The accuracy of the TRMM algorithms continues to improve. The TRMM Ground Validation team supports this achievement through processing and analysis of data from rain gauge networks and ground-based radars. Six years of high quality data are now available through the Goddard DAAC. 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. Significant progress has been achieved in formulating this mission including incorporation of high-frequency channels for the GPM Microwave Imager (GMI) to improve light rain and snowfall measurement capabilities. Various NASA and international workshops and meetings were held to advance the formulation of the mission and validation program.

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 (MPLNET), water vapor (SRL and RASL), and winds (GLOW) at fine temporal and/or spatial resolution from ground-based or airborne platforms. In addition, CPL and the CRS, a millimeter-wavelength radar for profiling cloud systems, have been integrated on NASA's high altitude WB-57 research aircraft for use in sensing the microphysical properties of cirrus and other cloud types. These systems will participate in field campaigns to validate NASA's Aura satellite, and CloudSat and CALIPSO.

A major accomplishment in 2005 was the success of three IIP proposals. These were: TWiLiTE, an airborne direct detection Doppler lidar to measure wind profiles through the troposphere (0–17 km) using the laser sig-

nal backscattered from molecules; HIWRAP, a conical scanning Doppler radar to provide horizontal winds within precipitation and clouds, and ocean surface winds in addition to more traditional 3-D radar reflectivity and hydrometeor characteristics; and the Airborne Water, Aerosol, Cloud, and Carbon Dioxide Lidar—an Airborne Raman Lidar to simultaneously profile water vapor mixing ratio, aerosol backscattering, extinction and depolarization, and cirrus cloud properties, as well as cloud liquid water and carbon dioxide concentration. Development of these exciting new capabilities presents a major challenge.

Initial papers on results from GLAS were published in a special issue of GRL and elsewhere on topics ranging from applications to global circulation models, to ocean surface signals. Improvements in data processing algorithms continued. In addition, an improved technique for infrared (IR) stereo cloud retrievals including multiple layer analysis was demonstrated with data from the STS-85 shuttle mission of the Infrared Spectral Imaging Radiometer (ISIR) Uncooled Microbolometer Array Detector (UMAD) instrument. Final testing of the COVIR IIP instrument is ongoing.

The MPLNET project underwent a major expansion in 2005. There are currently 10 active sites in the network: 3 in the U.S., 3 in Asia, 2 in Antarctica, 1 in the Arctic, and 1 off the west coast of Africa. Data from several of the sites are publicly available on our Web site, and the remaining sites will soon be public after calibrations are completed. Older data sets from an additional 14 sites remain available. Planning is underway for future sites in 2006–2007, including additional sites in the U.S., Asia, and the west coast of Africa, and new sites in the Caribbean, South America, and the Middle East. MPLNET is preparing for validation of CALIPSO after launch (spring 2006) and will participate in the African Monsoon Multidisciplinary Analysis (AMMA) campaign later in 2006. MPLNET results were compared against competing techniques and were found to have one of the lowest bias errors of all the methods available. Profiles of aerosol extinction are a primary MPLNET data product and an important data product to validate CALIPSO. The paucity of aerosol profile data is a major source of uncertainty in assessing global and regional climate models.

The Raman Lidar group is engaged in a broad range of research involving development and use of technologies for studying atmospheric processes including 1) Aqua and AURA satellite measurement validation; 2) development of an airborne Raman Lidar with the ability to profile water vapor, aerosols, clouds and other quantities during both day and night; and 3) development of the capability to remotely quantify aerosol physical properties using multi-wavelength Raman lidar. Two University of Maryland Baltimore County (UMBC) Ph.D. graduate students and one Ph.D. graduate student from University of Maryland College Park (UMCP) are supported and two visiting scientists from Brazil are currently working with the group. There is also substantial interaction with Howard University (HU) graduate students at the HU Beltsville Research Campus.

The branch is active in the development and application of atmospheric modeling systems. Three major development efforts were achieved in the past year. The NASA fvGCM and GCE model, a cloud-resolving model, were coupled in a multiscale modeling approach. The use of the fvGCM allows global coverage, and the GCE model provides explicit simulation of cloud processes and their interactions with radiation and surface processes, in contrast with conventional parametric approaches. This modeling system has been applied and tested for two different climate regimes, El Niño (1998) and La Niña (1999). The new coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems and intraseasonal oscillations, which are very difficult to forecast using conventional GCMs. A second major effort involved coupling various NASA Goddard physical packages (microphysics, radiation, and land surface models) into a next generation weather forecast model (called weather and research forecast model, or WRF). The new coupled modeling system allows better forecasting (or simulation) of convective systems and tropical typhoons. Lastly, an improved GCE modeling system has been developed at Goddard over the last two decades. The GCE model has been recently improved to simulate the impact of atmospheric aerosol concentration on precipitation processes, and the impact of land and ocean surface on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and precipitation radar model to simulate

the satellite observed brightness temperature at various frequencies. This new coupled model system allows us to investigate tropical cloud processes and improves the precipitation data retrieved from NASA satellites.

Branch scientists conducted research in the areas of hurricane formation, structure, and precipitation processes with an emphasis on storms that occurred during special NASA field programs such as CAMEX-4 and the TCSP experiment. Numerical forecast models, such as Mesoscale Model 5 (MM5) and WRF, were applied to simulate observed storms at very high grid resolution. The results were compared to field program and satellite (e.g., TRMM) measurements. Analysis of the results led to improved understanding of precipitation organization, storm structure, and their relationship to intensity change. Numerical models and TRMM satellite data are also used to study the organization of precipitation in winter storms, the mechanisms responsible for that organization, as well as climatological aspects of winter precipitation at lower mid-latitudes (approximately 24–35°N).

The impact of urbanization on precipitation variability was also explored. The impact of future urbanization on regional climate was investigated using a combination of an urban growth model (UrbanSim), MM5, and land surface model NOAH<sup>1</sup>. Major finds indicate that Houston urban land use in the year 2025 will significantly impact regional cloud and precipitation variability. Results suggest that runoff and potential urban flooding impacts will be elevated because of urban-enhanced convective events. TRMM-based and ground-based rainfall products were used to identify urban rainfall anomalies around Tokyo, Phoenix, Indianapolis, and other urban centers.

## 5.2 Climate and Radiation Branch, Code 613.2

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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 list of refereed papers in Appendix 2 and in the material on the Code 613.2 Branch Web site, <http://climate.gsfc.nasa.gov>.

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 run well 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 submit 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 (Code YO) 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

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1. NOAH is a nested acronym defined as the National Centers for Environmental Prediction (NCEP), Oregon State University (Dept. of Atmospheric Sciences), Air Force (both AFWA and AFRL—formerly AFGL, PL), Hydrologic Research Lab of the NWS (now Office of Hydrologic Development)

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 South East-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 January 25, 2003. SORCE 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 also 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. 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. 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 news 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.

In 2005, several key new findings have arisen from branch research. MODIS aerosol products now enable forecasting air quality, based on a NASA-EPA partnership. MODIS global annual direct aerosol radiative forcing over clear sky oceans is estimated to be  $-5.3 \pm 0.6 \text{ W m}^{-2}$ . For the NE Pacific, aerosols enhance radiative cooling by  $-7 \text{ W m}^{-2}$  for overcast conditions. Evolution of aerosol over land and water surfaces is being tracked using combined Terra-Aqua data. Smoke from African fires increases cloud coverage by  $\sim 0.1$  while reducing cloud droplet size.

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.

The new MODIS “collection 5” level-2 operational cloud algorithm includes pixel-level uncertainties and multilayer cloud detection for thin upper-layer clouds. 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 coauthored three chapters in the book. Two additional chapters were



authored by R. Cahalan and W. Wiscombe. The 3rd Intercomparison of 3D Radiation Codes (I3RC) workshop took place on a boat on the Baltic Sea, with branch members R. Cahalan and A. Marshak leading this international coordination of 3-dimensional radiative transfer activities.

Major Field Operations led by the branch include BASE-ASIA and the United Arab Emirates Unified Aerosol Experiment (UAE<sup>2</sup>), deployments of SMART-COMMIT. Warren Wiscombe became Chief Scientist of the DOE/ARM Program. An ARM “thermometer” was developed to measure for cloud liquid water. At the Williamsburg Aerosol Strategy Meeting, the CLAIM-3D concept was recommended to become a NASA HQ directed mission. New 3-D radiative transfer results have demonstrated CLAIM-3D’s potential for retrieving cloud droplet vertical profiles. IUGG-2007 Joint Symposium on 3DRT (3-D Radiative Transfer), co-sponsored by IAMAS<sup>1</sup>, IAHS<sup>2</sup>, and ICCS<sup>3</sup>, to be convened by R. Cahalan, with co-convenor B. Mayer of DLR<sup>4</sup>. The THOR Lidar System has validated precise measurements of the thickness of 1 km thick clouds, to a precision of 50 m. THOR is now being modified for measurement of ice and snow thicknesses.

Six years of TRMM data show a weekly cycle: over the continental U.S. in summer, rain intensity and area increase midweek when pollution is at its maximum; with opposite behavior over nearby waters. This finding provides new potential for determining the influence of human activities on rainfall.

A new activity that is now being co-hosted by the Climate and Radiation Branch and the Goddard Solar Physics Branch is the Goddard Sun–Climate Center. The Sun–Climate Center, like the AeroCenter, is a crosscutting activity within Goddard’s Sun–Earth Exploration Directorate. The Center sponsors research on solar system climate, and investigates new opportunities for advancing the understanding of the Sun’s forcing of Earth’s climate. Visiting scientists from Germany and Japan have recently joined this effort, and the Center receives advice from an international panel of experts. The Center will sponsor a seminar series, and will encourage new collaborations between scientists studying Earth, the Sun, and Earth’s Moon. See <http://sunclimate.gsfc.nasa.gov>

### 5.3 Atmospheric Chemistry and Dynamics Branch, Code 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. 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 scientists worldwide with 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-like 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 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,

1. International Association of Meteorology and Atmospheric Sciences
2. International Association of Hydrological Sciences
3. International Conference on Conceptual Structures
4. *Deutsches Zentrum für Luft und Raumfahrt* (German Aerospace Center)

algorithms, and data systems for the new generation of ozone sensors on the operational weather satellites (NPP and NPOESS) and are developing state-of-the-art instruments to monitor air quality and tropospheric chemical species from spacecraft located at high vantage points (at distances ranging from 20,000–1,500,000 km from Earth). In addition, they operate a suite of advanced active and passive remote sensing instruments to study the chemical composition of the Earth's atmosphere from ground and aircraft. The branch has recently developed an advanced instrument and algorithm capability for ground-based validation of OMI satellite aerosol, NO<sub>2</sub>, SO<sub>2</sub>, and O<sub>3</sub> data.

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<sub>2</sub>, O<sub>3</sub>, CO, NO<sub>x</sub>, and SO<sub>2</sub>, which effect climate, air quality, and human health.

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

### **3-D Stratospheric Chemistry Model Studies**

Branch scientists are analyzing a series of chemical transport model simulations of stratospheric ozone chemistry. These results are being compared with long-term data records from satellites and ground-based instruments. The goal is to use the model results to draw inferences about long-term ozone trends due to decrease in stratospheric chlorine and anticipated changes in the global climate.

The Branch is working collaboratively with the GMAO to couple chemistry to the dynamics in their general circulation models for chemistry–climate studies. The stratospheric chemistry used in the chemistry-transport studies has been coupled to the GEOS 4 GCM. The resulting chemistry-climate model has been integrated for 55 years simulating the period from 1950 through 2004. Time-slice simulations with repeating conditions for 1980, 2000, and 2020 have been run for 25 years each. These simulations are directed at understanding the role of ozone in climate change over the coming decades and the role of climate change in modifying the response of ozone to CFCs.

### **Global Modeling Initiative (GMI)**

The goal of GMI is to develop and maintain a state-of-the-art modular 3-D CTM that can be used for assessing the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including the effects of aircraft. The GMI model also serves as a testbed for model improvements.

The GMI CTM has options for several chemical mechanisms for studying different problems. Recently, we have added a combined tropospheric-stratospheric mechanism for investigations of the climatically sensitive upper troposphere/lower stratosphere, and a microphysical aerosol mechanism for the study of aerosol size distributions and their role as cloud condensation nuclei. The chemical mechanisms have been recoded for compliance with the ESMF. The sensitivity of the aerosol model results to meteorological input was evaluated by GMI team members at the University of Michigan. The GMI tropospheric model participated in an IPCC photochemical intercomparison which investigated model sensitivities to simulation of tropospheric ozone. An important aspect of all GMI studies is the evaluation of the credibility of model results using ground-based, aircraft, and remotely sensed measurements. Several papers comparing GMI results with observations are currently in preparation.

## OMI Data Analysis

The OMI, built by Dutch/Finnish collaboration, was launched on NASA's EOS Aura satellite in July 2005. The primary objective of OMI is to continue the long-term record, created by the Branch scientists, of total ozone, tropospheric ozone, UVB, aerosols (primarily smoke and desert dust), and volcanic SO<sub>2</sub> using data from NASA's TOMS instrument series. OMI is also designed to measure several other trace gases important for air quality studies, including NO<sub>2</sub>, anthropogenic SO<sub>2</sub>, and BrO, with improved spatial and temporal resolution compared to data from previous instruments (the Global Ozone Monitoring Experiment [GOME] and SCIAMACHY) on European satellites. Several Branch scientists are members of a NASA-funded U.S. science team, which is led by Dr. Pawan K. Bhartia, the Branch Head. In 2005, the Branch scientists developed and released several TOMS-like data products from OMI. Preliminary analysis shows that these data are of better quality and have significantly greater accuracy and precision than that from TOMS, particularly for SO<sub>2</sub>. Several new products, not previously available from TOMS, have also been produced and are currently being validated. Several scientific papers describing this work will appear in the journals in 2006.

## Global Aerosol Studies

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 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, MISR, and TOMS), ground-based network (AERONET), and *in situ* measurements (Aerosol Characterization Experiment-Asia [ACE-Asia], surface measurements from EPA and Interagency Monitoring of Protected Visual Environments [IMPROVE] networks). 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. The model has participated in the recent international project of Global Aerosol Model Intercomparison (AEROCOM) and played a major role in the new Climate Change Science Program (CCSP) reports on aerosol direct climate forcing.

## 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<sub>2</sub> transport, has incorporated a land biosphere emissions model and satellite data-constrained biomass burning emissions to produce CO<sub>2</sub> fields that are closely tied to actual meteorology and emission events. The modeling group is actively participating in an international model intercomparison exercise, TransCom-C, which is aimed at improving models' ability to utilize upcoming space-based CO<sub>2</sub> observations, such as the Orbiting Carbon Observatory. We are also collaborating with the GMAO in a new effort to develop a carbon cycle data assimilation system. We are in a collaborative effort with the Hydrospheric and Biospheric Sciences Laboratory to develop an airborne CO<sub>2</sub> laser sounder under the IIP. The modeling effort will help to optimize the sounder

measurement characteristics through observing system simulation experiments. A partner instrument, the ground-based laser CO<sub>2</sub> profiler, is also being developed in the Laboratory for Atmospheres. The laser profiler has recently achieved CO<sub>2</sub> detection in reflection from clouds and has made range-resolved measurements of aerosols at both the online and offline wavelengths. This is the final step in making range-resolved measurements of CO<sub>2</sub> within the planetary boundary layer. The real-time CO<sub>2</sub> observations will be compared with modeled distributions to improve our knowledge of the coupling between carbon cycle processes and climate change.

## **Sun–Earth Connection Studies**

Branch members were involved in several investigations into the influence of the Sun on the Earth's atmosphere. One study published in 2005 involved the effect of the very large solar storms in October–November 2003 on the middle atmosphere. The solar proton event of October 28–31, 2003 was the fourth largest of the past 40 years and caused huge NO<sub>x</sub> (N, NO, NO<sub>2</sub>) enhancements measured by the HALOE instrument and significant ozone depletions measured by the SBUV/2 instrument in the middle atmosphere. Another published study focused on the impact of all solar proton events in the years 2000–2003 on the middle atmosphere. This work showed polar total ozone depletions >1% lasting for several months past three of the event periods because of the large NO<sub>x</sub> increases due to the intense flux of solar protons.

## **New Instrument Development**

Two new instruments are nearing completion under the IIP, the Solar Viewing Interferometer Prototype (SVIP) and the GeoSpec (Geostationary Spectrograph). The SVIP is a 1.3 m prototype of an 8 m instrument that will make measurements between 1–4 μ to determine the amounts of CO<sub>2</sub>, H<sub>2</sub>O, O<sub>3</sub>, N<sub>2</sub>O, and CH<sub>4</sub> 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/Near-Infrared (NIR) wavelength regions to measure trace gas concentrations of O<sub>3</sub>, NO<sub>2</sub>, and SO<sub>2</sub>, 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, The 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 2006 with validation deployment during the summer at Washington State University.

A commercial Brewer double-grating spectrometer has been modified for nearly continuous measurement of column aerosols, NO<sub>2</sub>, and SO<sub>2</sub>, by the direct-Sun technique. This instrument has traditionally been used for measurements of total ozone and UV irradiance. Polarization and multiangle measurement capabilities have been added to test the possibility of deriving ozone profiles, as well as particle size and refractive indices of aerosols in the UV. The technology is being transferred to other Brewers around the world to form a network for satellite data validation.

An imaging polarimeter-spectrometer instrument is being developed using internal research and development funds to measure aerosol plume height from space using a passive remote sensing technique developed by the Branch scientists.

A new aircraft-based measurement program was started in 2005. ACAM was test flown onboard the NASA WB-57 during the AVE in June of 2005 flying out of Houston, Texas. This system combines high resolution photographic imagery of both nadir and forward-looking cloud conditions with nadir UV and VIS spectrophotometric measurements in order to map trace gas concentrations of NO<sub>2</sub>, O<sub>3</sub>, and aerosols. These measurements will be used to validate similar measurements from the OMI onboard Aura. The tests flights were successful and led to instrument improvements that have been implemented for the CR-AVE mission in February of 2006.

## 5.4 Laboratory Highlights

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### **Biomass-Burning Aerosols in South East Asia: Smoke Impact Assessment (BASE-ASIA)**

Recent studies reveal that large scale biomass burning appears to have an impact on regional climate. Aerosols produced by biomass burning play an important role in determining cloud lifetime and precipitation, hence, altering the regional to global scale radiation and water budgets. The climatology of Southeast Asia is very different from that of Africa and South America. Large scale biomass burning in Southeast Asia causes smoke to interact extensively with clouds during March and April when fires are normally set. Smoke plumes generated from these fires can stretch hundreds of kilometers downwind of the fires. NASA scientists in the Laboratory for Atmospheres (led by Dr. Si-Chee Tsay) are interested in conducting in-depth observations to evaluate the effects of biomass-burning aerosols on aerosol-cloud interactions. Accurately assessing the impact of smoke aerosols requires continuous observations from satellites and networks of ground-based instruments as well as dedicated field experiments utilizing aircraft and ground-based instruments. NASA and the Chulalongkorn University (CU), Thailand, share an interest in strengthening research and education in Earth Sciences by utilizing spaceborne, airborne, and ground-based observations. The Letter of Agreement between NASA and CU has been signed to jointly conduct the BASE-ASIA research project and educational activities from 2006 to 2009.

The objectives of BASE-ASIA are: (1) to characterize and assess the impact of biomass-burning aerosols on Southeast Asian monsoon onset and precipitation (or fresh water distribution) patterns, (2) to understand the effects of biomass-burning aerosols on remote sensing observations, and (3) to provide educational opportunities for regional scientists and graduate students who desire additional training and research experience. Air and ground observations from Thailand during the studied period will be coordinated with data received during the same time periods from NASA's Terra, and A-Train satellites and other satellite data sets of Southeast Asia. The study areas are the Kingdom of Thailand and possibly the vicinity of the Association of South East Asian Nations (ASEAN), members of which include Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

### **Developments in 3D Radiative Transfer**

The Third I3RC workshop was held October 11–14, 2005 at the Leibniz-Institute of Marine Sciences at the University of Kiel (Germany) and partly onboard the vessel *Color Fantasy*. Climate and Radiation Branch members (Robert Cahalan, Alexander Marshak, Lazaros Oreopoulos, and T.Varnai) were among the main organizers of the workshop. This was the third I3RC workshop; the first two workshops were both held in Tucson, Arizona in 1999 and 2000. The I3RC is an international project that compares the performance of 3D radiative transfer codes used in a variety of scientific applications in the atmospheric sciences. I3RC participants come from more than 30 research groups based in several countries. The project is sponsored by the GEWEX Radiation Panel and the International Radiation Commission, and has been jointly funded by the DOE Atmospheric Radiation Measurements Program and by the NASA Radiation Sciences Program.

Goddard's Climate and Radiation Branch delegated six scientists to give presentations at the workshop: Robert Cahalan, Alexander Marshak, Vanderlei Martins, Lazaros Oreopoulos, Tamas Varnai, and Guoyong Wen. L. Oreopoulos and T. Varnai chaired two sessions and A. Marshak also led the final discussion. T. Varnai and G. Wen presented two new I3RC cases, which are based on a broken cloud field observed by several instruments on the Terra satellite, and 3D spread of lidar pulses in optically thick clouds. In addition to the I3RC cases, publicly available 3D radiative transfer codes, approximation methods, cloud stochastic models, and 3D radiative transfer science, in general, were widely discussed. Forty-six people from 10 countries attended the

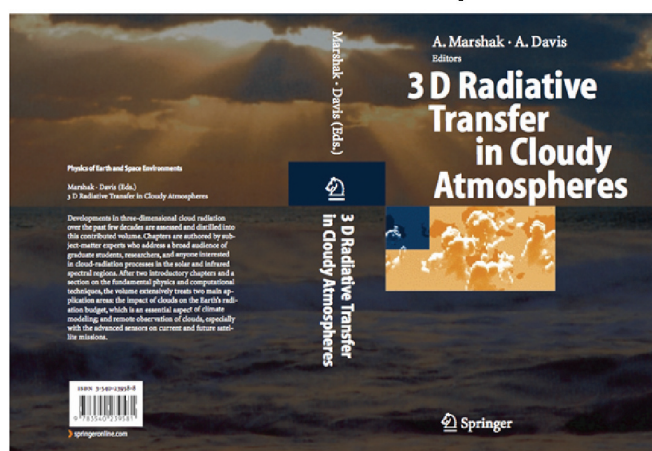
workshop. The results of the workshop were summarized in the paper “New Directions in the Radiative Transfer of Cloudy Atmospheres” recently published in EOS. For further information contact Alexander Marshak (Alexander.Marshak@nasa.gov).

## New Book on 3D Radiative Transfer Published

In August, a new book titled “3D Radiative Transfer in Cloudy Atmospheres” was published. Authored by leading 3D radiation scientists from around the world, this 700-page volume contains expert information on many aspects of this highly complex subject. Laboratory radiative transfer experts R. Cahalan, A. Marshak, and W. Wiscombe are among the authors of the book chapters.

For almost a century, scientists relied on simple one-dimensional models to approximate radiant energy exchange in climate simulations; solar and thermal radiation were only allowed to move vertically. This somewhat crude representation of the atmosphere’s radiant energy balance was the best approach science had to offer at the time. In this new publication, developments in 3D cloud radiation during the past few decades are assessed and distilled into a textbook-like tutorial, paving the way for a change in the “business as usual” attitude toward 1D approaches.

“It is time to think of 3D theory as the gold standard in atmospheric radiative transfer, rather than as a perturbation of standard 1D theory,” wrote authors A. Marshak (Code 613.2) and A. Davis in the preface of the book, for which they also served as editors.



*Figure 5.1. Developments in 3-D cloud radiation over the past few decades are assessed and distilled into this volume.*

After two introductory chapters and a section on the fundamental physics and computational techniques, the book extensively treats two main application areas: the impact of clouds on the Earth’s radiation budget, which is an essential aspect of climate modeling; and remote observation of clouds, especially with advanced sensors on current and future satellite missions. The book, funded in large part by the ARM Program, is written to satisfy a broad audience of graduate students, researchers, and others interested in cloud-radiation processes in the solar and infrared spectral regions. Published by Springer-Verlag (ISBN#3-540-23958-8). For further information contact Alexander Marshak (Alexander.Marshak@nasa.gov).

To see the first nine pages of this book, use the following URL to access the Web version of this report and click on the link given at the end of that section. <http://atmospheres.gsfc.nasa.gov/reportsdocs/html/2005/06.php#3D>

## MODIS Data Processing

The MODIS Atmosphere Team is responsible for generating cloud, aerosol, and clear sky level-2 (pixel-level) and level-2 (gridded) products from the MODIS Terra and Aqua instruments. As a part of the latest MODIS Atmosphere Team reprocessing effort (referred to as “collection 5”), the GSFC level-2 cloud optical and microphysical properties algorithm (thermodynamic phase, optical thickness, effective size, water path) has been largely rewritten. In addition to a number of improvements, the updated algorithm includes new components that have never been incorporated into operational retrievals of this type, including: (1) Pixel-level uncertainties for optical thickness, effective particle size, and water path retrievals, along with estimates of the uncertainty in level-3 gridded means; (2) development of a set of spatially-complete surface spectral albedo maps derived from the MODIS land albedo product and used in modeling above-cloud spectral reflectances; (3) retrievals derived from novel spectral band combinations; and (4) a research-level multilayer cloud detection product. All level-2 retrievals from this algorithm are contained in the MOD06 and MYD06 product files (for MODIS Terra and Aqua, respectively). The algorithm is the responsibility of M.D. King (610) and S. Platnick (613.2), as are the entire set of MODIS Atmosphere Team level-3 (daily, eight-day, and monthly) algorithms.

Collection 5 reprocessing began production in December 2005 with Terra data; MODIS Aqua collection 5 reprocessing is expected to begin in late spring or early summer 2006. The team has developed an extensive Web site (<http://modis-atmos.gsfc.nasa.gov/>) that provides product documentation, browse imagery, and tools. In particular, documents are provided detailing individual Atmosphere Team collection 5 algorithm modifications, improvements, and impacts. All Atmosphere Team collection 5 products are being processed at GSFC by the MODIS Operations Data Processing System (MODAPS), and will be distributed through the associated MODIS Atmosphere Archive and Distribution System (AADS). The cloud optical and microphysical properties algorithm has also been made available to the University of Wisconsin International MODIS/AIRS Processing Package (IMAPP) team for use with direct broadcast data. For further information contact Steven Platnick ([Steven.Platnick@nasa.gov](mailto:Steven.Platnick@nasa.gov)).

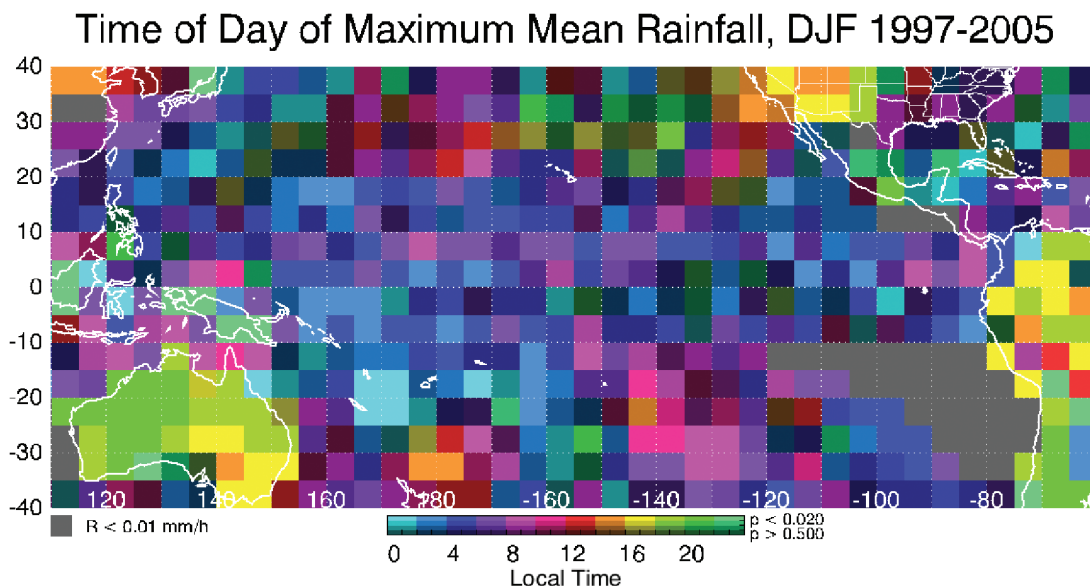
## CO<sub>2</sub> Lidar

Making range-resolved measurements of CO<sub>2</sub> within the lowest 3 km of the atmosphere can significantly enhance our understanding of what is happening to anthropogenically generated CO<sub>2</sub>, an important greenhouse gas. These measurements enable the direction and magnitude of CO<sub>2</sub> fluxes to be determined, which help identify sources and sinks for the gas. In order to be scientifically useful, the measurement precision must be approximately 1 part in 380. Ground-based lidar observations are capable of providing continuous profiles of CO<sub>2</sub> through the planetary boundary layer and into the free troposphere. We have developed a prototype lidar based on components developed in the telecommunications industry. Our Differential Absorption Lidar (DIAL) approach measures absorption by CO<sub>2</sub> of pulsed laser light at 1.58  $\mu\text{m}$  backscattered from atmospheric aerosols. Aerosol concentrations in the planetary boundary layer are relatively high and will be able to provide adequate signal returns for the desired resolution. Performance simulations indicate that an optimized lidar will be capable of providing continuous 10 min averaged profiles with 150 m vertical resolution and better than 1 ppmv precision at 1 km. Precision increases (decreases) at lower (higher) altitudes and is directly proportional to altitude resolution and acquisition time; thus, precision can be improved if temporal or vertical resolution is sacrificed. The long-term goal of the project is to develop a rugged, autonomous system using only commercially available components that can be replicated inexpensively for deployment in a monitoring network. For further information contact John Burris ([John.F.Burris@nasa.gov](mailto:John.F.Burris@nasa.gov)).

## Advances in TRMM Data Analysis

Methods of extracting the dependence of mean rainfall on the time of day have been developed for use with the TRMM data, now available from December 1997 to the present. The method provides not only estimates of the

size of the day/night change, but also statistical confidence limits for the changes. The map shown in Figure 5.2 is an example of the information that can be provided for 5° grid boxes, with brightest colors (colors along the top of the color bar) indicating highest confidence in the daily changes. Note how over the oceans maximum rainfall tends to occur in the morning hours, whereas over land it occurs mostly in the afternoon hours. (Grid boxes with average rain rate below 0.01 mm/h have been masked.) For further information contact Tom Bell (Thomas.L.Bell@nasa.gov).



*Figure 5.2. Nine year record of time from 1997–2005, of maximum rainfall during December, January, and February.*

## Radar-Based Wind Measurements from UAVs

While lidar-based tropospheric wind measurements are ideally suited for clear regions, the signal is strongly attenuated by clouds and precipitation. On the other hand, radar-based winds perform well in these regions and are, therefore, very complementary to the lidar measurements. Two separate efforts are being pursued for radar-based winds measurements in precipitation and cloud regions from UAV. The first effort, called UAV Radar (URAD), was started under Goddard IR&D funding. This radar is a conventional X-band radar that performs conical scan from a high-altitude UAV (HUAV). The conical scan provides a means to estimate the atmospheric horizontal winds and radar reflectivity structure in a three-dimensional grid point below the UAV. It also enables estimation of ocean surface winds in rain-free to light-rain regions through well-known scatterometry techniques. The second effort is funded under the NASA IIP and is called HIWRAP. This system also provides similar measurements to URAD, but it is dual-wavelength (Ku and Ka band) and dual incidence angle to provide higher accuracy in the wind measurements. In addition, HIWRAP uses more advanced technology with solid state rather than tube transmitter technology, pulse compression using digital receiver and Field Programmable Gate-Array (FPGA)-based processing. The technology being pursued under this effort also has application to space-based wind measurement. For further information contact Gerry Heymsfield (Gerald.M.Heymsfield@nasa.gov).

## Effect of Smoke from African Fires on Shallow Cloud Cover

Clouds developing in a polluted environment tend to have more numerous, but smaller, droplets. This property may lead to suppression of precipitation and longer cloud lifetime. Absorption of solar radiation by aerosols,



however, can reduce the cloud cover. The net aerosol effect on clouds is currently the largest uncertainty in evaluating climate forcing. Using large statistics of MODIS satellite data, we indicate, in Figure 5.3, the aerosol effect on shallow water clouds, separately in four regions of the Atlantic Ocean, for June through August 2002: marine aerosol ( $30^{\circ}\text{S}$ – $20^{\circ}\text{S}$ ), smoke ( $20^{\circ}\text{S}$ – $5^{\circ}\text{N}$ ), mineral dust ( $5^{\circ}\text{N}$ – $25^{\circ}\text{N}$ ), and pollution aerosols ( $30^{\circ}\text{N}$ – $60^{\circ}\text{N}$ ). All four aerosol types effect the cloud droplet size. We also find that the coverage of shallow clouds increases in all of the cases by 0.2–0.4 from clean to polluted, smoky, or dusty conditions. Covariability analysis with meteorological parameters associates most of this change to aerosol, for each of the four regions and 3 months studied. In our opinion, there is low probability that the net aerosol effect can be explained by coincidental, unresolved, changes in meteorological conditions that also accumulate aerosol, or errors in the data. For further information contact Steven Platnick (Steven.E.Platnick@nasa.gov).

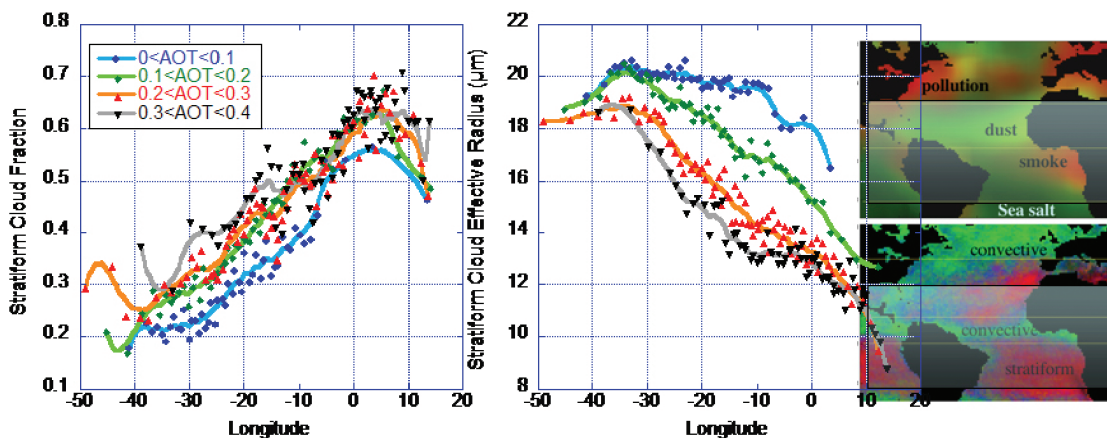


Figure 5.3. Smoke from fires in Africa increases cloud coverage by  $\sim 0.1$  (left panel) while reducing the cloud droplet size (center panel). The effect is linked to smoke inhibition of precipitation and enhancement of the strength of the inversion. The right panel shows the distribution of aerosol and clouds over the Atlantic Ocean for June–August 2002. The upper panel indicates optical thickness, given by the image brightness, and type, given by color. The lower panel shows the distribution of shallow (red), deep convective (green), and mixed (blue) cloud cover. AOT is aerosol optical thickness.

## Cloud-Aerosol Interaction Mission, CLAIM-3D

The effects of aerosols in clouds go all the way from changing Earth's radiative balance, to significant effects on changing precipitation patterns and the intensity of thunderstorms. CLAIM-3D is a proposed satellite mission designed to advance our understanding of cloud and precipitation development by measuring *vertically resolved* cloud microphysical parameters in combination with state-of-the-art aerosol measurements. The CLAIM-3D mission concept uses well-established space technology in a set of innovative measurements that allows simultaneous aerosol and cloud microphysics measurements. The proposed mission has a very unique combination of extended wavelength range (380–12,000 nm), polarization, and multiangle 3D observing geometry, combining properties of several previous satellite missions, as well as adding many new features never flown or even proposed before. It is designed to measure the vertical profile of cloud microphysical properties, and also to combine the best features from previous satellite projects (like the Polarization Detecting Environmental Radiometer [POLDER], MISR, MODIS, and OMI) to characterize aerosols and cloud microphysics with greater synergy than any previous mission. The mission will have flexibility in terms of pointing capability in order to focus on cloud types and regions of particular interest, and also to maximize proper illumination geometry for accurate retrievals of cloud microphysical parameters. The multiangle capabilities of CLAIM-3D (along and

cross track) allow us optimized geometry to focus on very specific cloud structures and regions. The combination between polarization and high resolution multiangle capability also allows CLAIM-3D to measure “cloud droplet rainbows” or cloud bows, which are just like the rainbows that we see out of rain droplets (of millimeters to a fraction of millimeters in diameter), but now formed by much smaller cloud droplets (of a few micrometers in size). The cloud bow measurements will allow us to accurately measure the size of cloud droplets. This is very important for the understanding of cloud microphysical properties and the evolution towards precipitation. For further information contact Jose Martins (Jose.Martins.1@gsfc.nasa.gov),

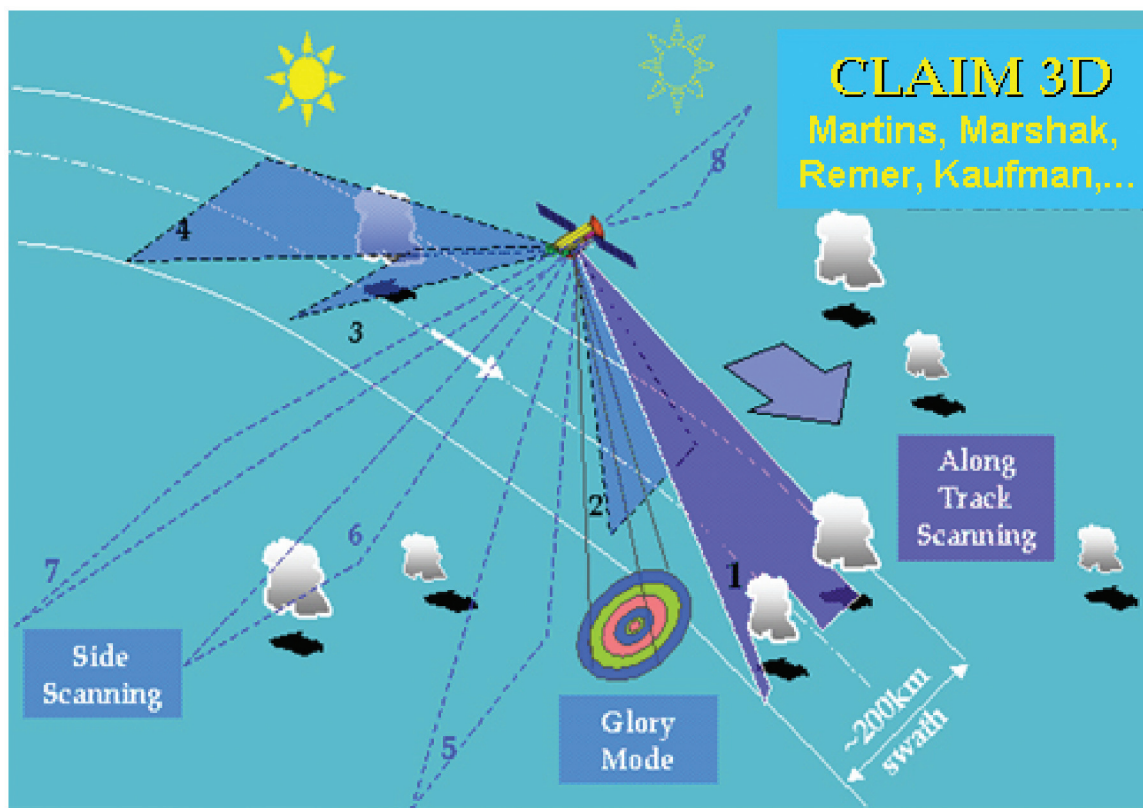


Figure 5.4. Schematic of CLAIM-3D observation modes.

## 5.5 Awards

### 5.5.1 Individual Awards

#### NASA Exceptional Achievement Medal

*Dr. Mian Chin (613.3)*

In recognition of the development of the GOCART model to study atmospheric aerosols and gas species and their impact on air quality and climate.

*Dr. Yogesh Sud (613.2)*

For truly pioneering scientific advances on land-surface parameterization and biospheric-atmospheric processes and their influence on the general circulation.

### **Barry M. Goldwater Award**

On Thursday, June 9, Fritz Hasler, who recently retired from 613.1, was awarded the “Barry M. Goldwater Award” by the American Institute of Aeronautics and Astronautics, Inc. (AIAA) National Capitol Section, which includes about half of all AIAA members. This is a prestigious award that was started at Barry Goldwater’s instigation. He was an avid space enthusiast and supporter. The award was presented by Dr. Mike Griffin, NASA Administrator, and past recipient of the same award.

### **IEEE Senior Member**

The Institute of Electrical and Electronics Engineers (IEEE) elevated Chuck Cote to the grade of Senior Member, their highest professional grade.

#### *Dr. Robert Cahalan (613.2)*

Dr. Cahalan received an award for “Outstanding Leadership and Service” in recognition of his work as Chair of the Observations Working Group of the United States Climate Change Science Program. The award was presented by James Mahoney, Assistant Secretary of Commerce for Oceans and Atmospheres.

## **5.5.2 Group Achievement Awards**

### *Aura Education Outreach Team*

For implementation of an outstanding education and outreach effort to inspire the next generation of explorers.

### *Aura Project Science Team*

For outstanding and innovative efforts in leading the Earth Observing System Aura Science Team, developing the Aura validation plan, and production of outreach materials.

### *SAGE Ozone Loss Validation Experiment (SOLVE)-II DC-8 Science Team*

In recognition of exceptional scientific achievement during the highly successful SOLVE-II polar mission during the winter of 2002–2003.

### **Outstanding Teamwork Award**

*MODIS Aerosol Algorithm Team/Code 613*—Lorraine Remer accepting for team.

Members of the team include: Allen Chu, Richard Hucek, Charles Ichoku, Richard Kleidman, Robert Levy, Rong-Rong Li, Vanderlei Martins, Shana Mattoo, and Bill Ridgway.

### **Excellence in Outreach Award**

*Earth Observatory Team/Code 613*—Rob Simmon accepting for team.

## **5.5.3 Instrument Incubator Program (IIP)**

The IIP supports NASA’s Science Mission Directorate. The main purpose of the program is to identify, develop, and, where appropriate, demonstrate new measurement technologies to reduce the risk, cost, size, and development time of Earth observing instruments, and/or enable new observation measurements. Five Laboratory scientists were selected as PIs, co-investigators (Co-Is), or collaborators on awards made during 2005 under this program.

*Bruce M. Gentry, Code 613.1*

TWiLiTE:Tropospheric Wind Lidar Technology Experiment

*Gerald M. Heymsfield, Code 613.1*

High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

*David N. Whiteman, Code 613.1*

Airborne Water, Aerosol Cloud and Carbon Dioxide Lidar

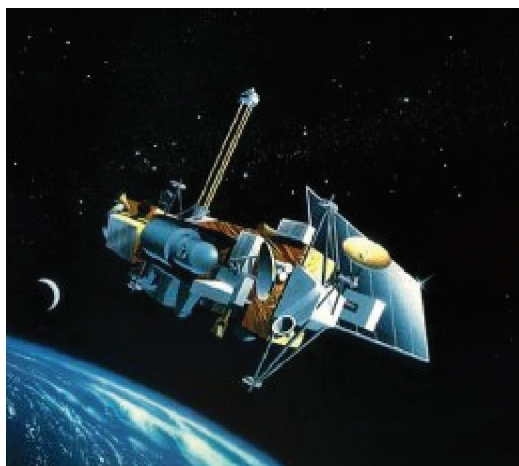
*Omar Torres, Code 613.3, is a Co-I with PI David J. Diner, Jet Propulsion Laboratory for *A High-Accuracy Spectropolarimetric Camera for Aerosol Remote Sensing from Space**

*Warren Wiscombe, Code 613.2, is a Collaborator with PI Martin G. Mlynczak, Langley Research Center, on *In-situ Net Flux Within the Atmosphere of the Earth**

## **5.6 UARS**

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UARS was launched by the Space Shuttle *Discovery* (STS-48) on September 12, 1991.



*Figure 5.5. Artist's conception of UARS in orbit.*

Although launched with a designed mission life of 18 months, UARS made comprehensive measurements of the upper atmosphere for more than 14 years. During this time, UARS provided many scientific accomplishments. Four examples of these follow:

- 1) Quantification of the relation between chlorine-containing constituents and ozone on a global scale in the stratosphere;
- 2) Quantification of the solar ultraviolet irradiance and total solar irradiance over more than a solar cycle (~14 years);
- 3) Quantification of the transport in the stratosphere, mesosphere, and lower thermosphere, including the first satellite measurements of winds in these regions;
- 4) Long-term (~14 years) measurement of several key constituents (ozone, HCl, HF, H<sub>2</sub>O, CH<sub>4</sub>, NO, and NO<sub>2</sub>) in the stratosphere and mesosphere.

There have been over 1,000 papers published in refereed journals that use UARS observations. The study of these valuable measurements has resulted in a rewrite of our understanding of the physical processes acting within and upon the stratosphere, mesosphere, and lower thermosphere.



*Figure 5.6. Cake presented at the UARS retirement party.*

UARS was retired from service on December 14, 2005.



## 6. EDUCATION AND OUTREACH

### 6.1 Introduction

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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.

The Laboratory's parent organization, The Earth–Sun Exploration Division (ESED—Code 610), has established a Committee for Education and Public Outreach, which is charged with coordinating these activities across the Division. This is a work in progress and no attempt will presently be made to place the Laboratory's activities in the context of an overarching theme; however, several Laboratory members are also on the ESED committee. Scott Braun, Goran Halusa, Paul Newman, and Lorraine Remer, are all working with David Herring, Program Manager for Education and Outreach, to achieve the Committee's objectives. More information may be found at <http://esdepo.gsfc.nasa.gov/index.php>.

### 6.2 Education

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#### **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. The Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEa) was established in 1992 at Howard University (HU) in Washington, D.C., as a part of this initiative. It has been a goal of the Laboratory and the Earth–Sun Exploration Division to partner with CSTEa to establish at Howard University (HU) a self-supporting facility 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 HU 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 HU. Scientists from our Laboratory contribute to the HUPAS program as lecturers, advisors to students, and adjunct professors who teach courses. A number of HU students have earned M.S. degrees and are about to earn Ph.D. degrees in atmospheric sciences.

##### *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 613.1), 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 613.1. 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 the proposing, designing, building, and operating the lidar.

## Summer Programs

The Summer Institute in Atmospheric, Hydrospheric, and Terrestrial Sciences was held from June 6–August 12, 2005. The institute is organized by Per Gloersen (614.1) and is hosted by the Earth–Sun Exploration Division (Code 610). It is designed to introduce undergraduate students majoring in all areas of the physical sciences to research opportunities in these areas. After a one-week series of introductory lectures, the students select from a list of research topics and are mentored by a Goddard scientist for a period of nine weeks. At the conclusion of this period, the students give a presentation of their results. Laboratory scientists participating in the institute, students, and research topics are shown in Table 6.1.

Table 6.1 Laboratory Scientists Mentoring Students in the 2005 Summer Institute

| Mentor/Code            | Student         | Topic                                                                                                                                                     |
|------------------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Geary Schwemmer, 613.1 | Ian Brown       | Testing Holographic Optical Elements and Instrument Control.                                                                                              |
| Belay Demoz, 613.1     | Theresa Inman   | Observations of Moisture and Temperature Variability in a Non-convective Dryline.                                                                         |
| Charles Ichoku, 613.2  | Luke Ellison    | Visualization and Analysis of Fire Radiative Energy Measurements from MODIS.                                                                              |
| Yoram Kaufman, 613.2   | Kristen Mihalka | Assessing the Transport of Aerosols Around the World.                                                                                                     |
| Yogesh Sud, 613.2      | Andrea May      | Intercomparison of Satellite Observations and GOCART Model Aerosol Data with the Aim of Preparing a Realistic Aerosol Data Set for Use in Climate Models. |
| Santiago Gasso, 613.2  | Edward Liske    | Characterization of Dust Events in Patagonia Using 15 Years of Weather Observations.                                                                      |
| Rob Levy, 613.2        | Ed Nowottnick   | Correlations of MODIS and PM 2.5 Measurements in the Mid-Atlantic Region.                                                                                 |
| Yaping Zhou, 613.3     | Ahmed Tawfik    | An Analysis of Tropical Cyclone Precipitation Using Satellite Observations.                                                                               |



Figure 6.1. Participants in the 2005 Summer Institute. Per Gloersen is at the left.



*AMS Fellowship Winners' Visit:*

On June 29, 2005 the Earth–Sun Exploration Division hosted a visit to GSFC by a group of AMS Fellowship Winners. The visit was organized by the Laboratory for Atmospheres and consisted of a morning seminar and an afternoon tour of the HU Beltsville site. The AMS Fellowship Program, established in 1991, has awarded over 200 fellowships to students entering their first year of graduate study in the atmospheric or related oceanic or hydrologic sciences, with the total dollars awarded reaching nearly \$3.5 million. The program is designed to attract promising young scientists to the AMS-related sciences and provide adequate funding for their first year, allowing the recipients to focus solely on their studies. The AMS is joined by industry leaders and Federal agencies in sponsoring the fellowships, which carry a \$22,000 stipend. NASA sponsors four of these fellowships. The students, their areas of interest, undergraduate and graduate universities are listed in Table 6.2.

Table 6.2. 2005 AMS Fellowship Winners Visiting GSFC

| Name               | B. S. Degree                                    | Undergraduate                           | Graduate                                      |
|--------------------|-------------------------------------------------|-----------------------------------------|-----------------------------------------------|
| Brian Tang         | Atmospheric Science<br>and Applied Mathematics  | Univ. of California, Los Angeles (UCLA) | Massachusetts Institute of Technology (MIT)   |
| Ashton Robinson*   | Meteorology                                     | Jackson State                           | Univ. Oklahoma                                |
| Andrew Metcalf     | Meteorology                                     | Penn State Univ.                        | Penn State Univ.                              |
| Allen Clark Evens  | Meteorology                                     | Florida State Univ.                     | Florida State Univ.                           |
| Corey Potvin       | Meteorology                                     | Lyndon State Univ.                      | Univ. Oklahoma                                |
| Matthew Greenstein | Meteorology                                     | Penn State Univ.                        | State Univ. of New York, Albany (SUNY-Albany) |
| Heather Coleman    | Atmospheric, Oceanic, and Environmental Science | UCLA                                    | Univ. California-Santa Barbara                |
| Timothy Whitcomb*  | Atmospheric Science                             | Univ. of Washington                     | MIT                                           |
| Nathan Snook       | Meteorology                                     | Iowa State Univ..                       | Univ. Oklahoma                                |

\* Indicates NASA sponsored fellowship

During the morning seminar, presentations were given by scientists from the Laboratory for Atmospheres (Code 613), the Hydrospheric and Biospheric Sciences Laboratory (Code 614), and the Global Modeling and Assimilation Office (GMAO, Code 610.1)). The agenda consisted of the following:

**Welcome and opening remarks**

Dr. Marshall Shepherd: Mesoscale Atmospheric Processes Branch (Code 613.1)

**“On the Cause of the 1930s Dust Bowl”**

Dr. Siegfried Schubert: Global Modeling and Assimilation Office (Code 610.1)

**“Hydrospheric Research at Goddard”**

Dr. Robert Bindshadler: Hydrospheric and Biospheric Sciences Laboratory (Code 614)

**“Two Perspectives on Rainfall: Urban-Induced on Earth, and Methane on Titan”**

Dr. Marshall Shepherd: Mesoscale Atmospheric Processes Branch (Code 613.1)

**“The Aura Project”**

Dr. Anne Douglass: Atmospheric Chemistry and Dynamics Branch (Code 613.3)

“Ozonesonde Networks for Study of Atmospheric Processes, Satellite Validation and Trends”

Ms. Jacquie Witte: SSAI



*Figure 6.2. Dr. Marshall Shepherd (back to camera) in discussion with some of the AMS Fellowship winners during a lunch break.*

During the afternoon, a tour of the Howard University Beltsville facility was lead by Prof. Demetrius Venable, Chairman of the Howard University Physics Department and Prof. Everett Joseph of the same department. The tour agenda was:

- 1:00–1:15 PM Conference Room  
Introduction to Howard University Beltsville Site (Venable, Joseph)
- 1:15–1:30 PM Tour of O<sub>3</sub> Lab and Doppler Radar Facility (O<sub>3</sub> Team)
- 1:30–1:40 PM Walk to Telescope/Tower Site
- 1:40–2:00 PM Radiation and Sounding Sites (Nzeffè, Robjhon, Walford)
- 2:00–2:15 PM Lidar and Telescope (Venable, Connell, Walford)
- 2:15–2:30 PM 31 m Tower, Flux Site (Robjhon, Davis)
- 2:30–2:45 PM MDE Air Quality Monitoring Site (Venable, Joseph)
- 2:45–3:00 PM Return to main building, departure



Figure 6.3. Profs. Venable (cap) and Joseph (back to camera), and Howard University graduate students discuss the Doppler Radar installation with AMS Fellowship students at the Beltsville site. The base of the radar tower is visible in the upper right corner of the photograph.

## University Education

Laboratory members are active in supporting university education through teaching courses and advising graduate students.

Table 6.3. Courses Taught in 2005

| University              | Course                                  | Instructor      |
|-------------------------|-----------------------------------------|-----------------|
| UMBC                    | Physics 622, Atmospheric Physics II     | Steven Platnick |
| Howard University       | Atmospheric Chemistry II                | Richard Stewart |
| George Mason University | Thermodynamics                          | Yogesh Sud      |
| UMCP                    | ESSIC 234, Cycles in the Earth System   | Warren Wiscombe |
| UMCP                    | METO 401, Global Environmental Problems | Warren Wiscombe |

Table 6.4. Graduate Student Advising by Laboratory for Atmospheres Members

| Member/Code                            | Student            | Degree | Institution       | Thesis Topic or Area                                                                                             |
|----------------------------------------|--------------------|--------|-------------------|------------------------------------------------------------------------------------------------------------------|
| John Burris, 613.3                     | John Outerbridge   | Ph.D.  | Univ. Alabama     | Measurement of tropospheric ozone with lidar                                                                     |
|                                        | Shi Kuang          | Ph.D.  | Univ. Alabama     | Modeling tropospheric ozone                                                                                      |
| Belay Demoz and David White-man, 613.1 | Felicita Russo     | Ph.D.  | UMBC              | Lidar measurement of aerosols and clouds                                                                         |
|                                        | Antonia Gambacorta | Ph.D.  | UMBC              | AIRS water vapor retrievals                                                                                      |
|                                        | Menghs G. Mariam   | Ph.D.  | UMBC              | Not defined                                                                                                      |
|                                        | Segayle Walford    | Ph.D.  | Howard Univ.      | Lidar boundary layer height characterization                                                                     |
|                                        | Rasheen Connel     | Ph.D.  | Howard Univ.      | Not defined                                                                                                      |
|                                        | Scott Rabenhorst   | Ph.D.  | UMCP              | Mesoscale applications of Raman lidar                                                                            |
| David Starr, 613.1                     | Likun Wang         | Ph.D.  | Univ. Alaska      | Homogeneity of Midlatitude Cirrus Cloud Structural Properties Analyzed from the Extended FARS data set           |
|                                        | Robert Carver      | Ph.D.  | Penn. State Univ. | Understanding Subtropical Anvil Cirrus: A Coupled-Model Study                                                    |
| Joanna Joanna Joiner, 613.3            | Paul Poli          | Ph.D.  | UMBC              | Assimilation of global positioning system radio occultation measurements into numerical weather forecast systems |
| Lorraine Remer, 613.2                  | 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, 613.1                     | Joseph Olson       | Ph.D.  | SUNY-Stonybrook   | Impact of coastal orography on landfalling cold fronts                                                           |
| Mian Chin/613.3                        | Hongqing Liu       | Ph.D.  | UMCP              | Not determined                                                                                                   |
| Gerry Heymsfield/613.2                 | Haiyan Jiang       | Ph.D.  | Univ. Utah        | Microwave studies of rainfall                                                                                    |

|                         |                   |       |                |                                                                 |
|-------------------------|-------------------|-------|----------------|-----------------------------------------------------------------|
| Peter Colarco/<br>ESSIC | Rebecca Matichuk  | Ph.D. | Univ. Colorado | Optical properties of Southern African biomass burning aerosols |
| William Lau,<br>613     | Massimo Bollasina | Ph.D. | UMCP           | Aerosol-monsoon water cycle interactions                        |
|                         | Stephen Chen      | Ph.D. | UMCP           | Mechanism for forcing of the Pacific High                       |
|                         | Wen Mi            | Ph.D. | UMCP           | Characteristics of aerosol forcings in East Asia                |

Laboratory members participate with faculty at several joint centers identifying students whose research interests are shared by a faculty member and a Laboratory scientist. Students are encouraged to visit Goddard and it is anticipated that the Laboratory member will serve on the student’s thesis committee. The following table lists students currently supported.

Table 6.5. Graduate Students Supported at the Joint Centers

| Student            | University | Topic                                                                                                 | Advisor/Sponsor                                              |
|--------------------|------------|-------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| Kevin Mallen       | CSU        | Radar analyses and studies of precipitation systems                                                   | Michael Montgomery (CSU)/ Scott Braun (GSFC)                 |
| Maike Ahlgrimm     | CSU        | GLAS-derived cloud climatologies                                                                      | Dave Randall (CSU)/ Jim Spinhirne/ Steve Palm (GSFC)         |
| Chris Danforth     | UMCP       | Chaos processes in general circulation models/GCMs                                                    | David Levermore/Eugenia Kalnay (UMCP), Robert Cahalan (GSFC) |
| Stephen Penny      | UMCP       | Innovative numerical methods in geophysical problems                                                  | Charles D. Levermore (UMCP), Warren Wiscombe (GSFC)          |
| Felicita Russo     | UMBC       | Micropulse lidar extinction measurements using Raman lidar                                            | Ray Hoff (UMBC), David Whiteman (GSFC)                       |
| Antonia Gambacorta | UMBC       | Raman lidar studies of water vapor, cirrus cloud, optical depth, particle size, and ice water content | Ray Hoff (UMBC), David Whiteman (GSFC)                       |

CSU: Colorado State University

UMBC: University of Maryland, Baltimore County

### 6.3 Open Lecture 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 27: Warren Wiscombe**

NASA’s Goddard Space Flight Center, Laboratory for Atmospheres, Greenbelt, MD;

“The Brouhaha over Enhanced Absorption of Sunlight by Clouds: What Went Wrong”

**February 10: David Starr**

NASA's Goddard Space Flight Center, Laboratory for Atmospheres, Greenbelt, MD;  
"Current Issues in Cirrus Cloud Microphysics"

**February 24: Tom Ackerman**

DOE Atmospheric Radiation Measurement (ARM) Program, Pacific Northwest National Laboratory,  
Richland, WA;

"Ground-based Measurements of the Atmosphere: The ARM Experience"

**March 24: Ralph Kahn**

NASA's Jet Propulsion Laboratory / Caltech;

"What MISR Multi-Angle Imaging Contributes to Our Picture of Atmospheric Aerosols"

**May 19: Donald Blake**

Department of Chemistry, University of California, Irvine;

"Chinese Urban VOCs, Enhanced Alkanes Throughout the Rural Southwest United States, and Preliminary Breath Study Results"

**June 15: Graham Feingold**

NOAA Environmental Technology Laboratory;

"How Can We Understand the Causes of the Variations of Earth's Global Energy and Water Cycle"

**August 17: Dave Randall**

Department of Atmospheric Science, Colorado State University;

"Counting the Clouds"

**September 15: Bill Frank**

Penn State University, Department of Meteorology;

"A Global Look at Waves and Tropical Cyclogenesis"

**November 3: V. Ramanathan**

Scripps Institution of Oceanography, University of California at San Diego;

"Global and Regional Climate Changes: The Next Few Decades"

**December 2: Robert A. Houze, Jr.**

University of Washington;

"Deep Convection in the Asian Monsoon"

## 6.4 Project Outreach

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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.

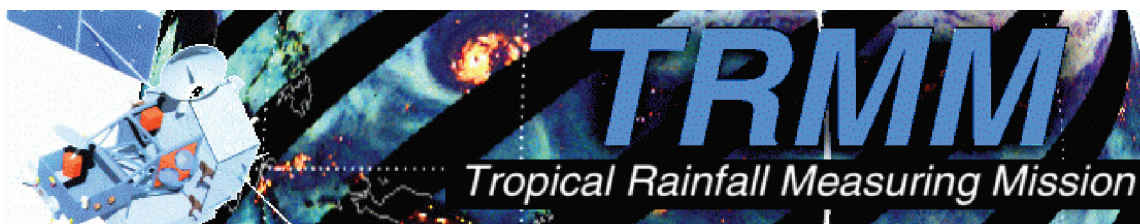
### TERRA



The EOS Terra outreach effort—under the direction of Yoram Kaufman (Code 613.2), Jon Ranson (Code 614.4), and David Herring (Code 613.2) 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. The home page also contains 14 direct links to topics maintained by the Earth Observatory, an outreach site of the Committee for Education and Public Outreach. These links discuss a wide range of topics including Antarctica, flood plains, glaciers, air pollution, and volcanoes discussing each in the context of Terra observations and why such observations are important.

### TRMM



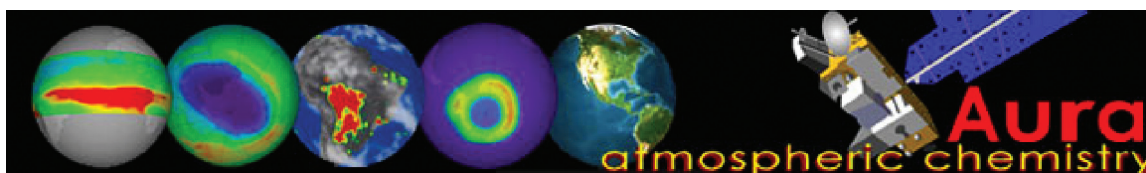
TRMM is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. TRMM continues its comprehensive Education/Outreach program, in which Laboratory personnel promote TRMM science and technology to the public under the leadership of TRMM Project Scientist Robert Adler (613), and TRMM Education and Outreach Scientist Jeffrey Halverson (613.1/UMBC). TRMM has also included the development of broadcast visuals and educational curriculum in its outreach activities. The Educational Resources 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 Earth Science Enterprise (ESE) Education product review. There are also 11 educational videos that give brief tutorials on various aspects of the TRMM project and on the atmosphere’s water and energy cycles.

## Global Precipitation Measurement (GPM)



The GPM is a follow-on and expanded mission of the current ongoing TRMM. GPM is one of the Earth Observation Satellite programs, mainly initiated by JAXA, the National Institute of Information and Communications Technology (NICT) and NASA. Both the ‘Science’ and ‘Public Outreach’ links on the GPM Web site (<http://gpm.gsfc.nasa.gov/index.html>) contain a wealth of educational materials. The Science page begins with a tutorial, ‘The Science of Measuring Precipitation: Why It Matters’ that is followed by links to seven additional discussions of the satellite, its instruments, and what will be measured.

## EOS Aura



The Aura satellite was launched from Vandenberg AFB on July 15, 2004. The Laboratory for Atmospheres has responsibility for conducting the Education and Public Outreach program for the EOS Aura mission. Aura’s Education and Public Outreach program has four objectives:

- (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.

To attain these objectives, the Aura project supports a strong educational and public outreach effort through formal and informal education partnerships with organizations that are leaders in science education and communication. Our partners include the Smithsonian Institution’s National Museum of Natural History (NMNH), the American Chemical Society (ACS), and the Global Learning and Observations to Benefit the Environment (GLOBE) Program. Our goals are to educate students and the public and inform industry and policy makers how Aura will lead to a better understanding of the global environment.

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.

The ACS has produced special issues of the publication *ChemMatters*. 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 Globe Program (Global Learning and Observations to Benefit the Environment) 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. Drexel University's (Philadelphia, PA) ground-based instruments will measure ultraviolet-A (UV-A) radiation and aerosols to support measurements taken from the Aura spacecraft. A tropospheric ozone measurement developed by Langley Research Center is also a GLOBE protocol.

Aura's Education and Project Outreach program will also be present at science and environmental fairs and science and technology conferences to demonstrate how Aura fits in to NASA's program to study the Earth's environment.

## 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 TOMS 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, others are directed to those in grades 9–12. There is also a link to five projects for independent research, which allow advanced students to learn more about atmospheric chemistry and dynamics.

There is also an online textbook at [http://www.ccpo.odu.edu/SEES/ozone/oz\\_class.htm](http://www.ccpo.odu.edu/SEES/ozone/oz_class.htm) written by Branch scientists and was 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.

A TOMS Engineering Model is part of a permanent exhibit entitled "Change is in the Air" at the Smithsonian's NMNH. This exhibit explores the interactions between atmospheric chemistry and climate, emphasizing ozone trends in the stratosphere and the effects of degrading air quality on the environment.



## 7. ACRONYMS

|           |                                                                                 |
|-----------|---------------------------------------------------------------------------------|
| 3DRT      | 3-D Radiative Transfer                                                          |
| AADS      | Atmosphere Archive and Distribution System                                      |
| ACAM      | Airborne Compact Atmospheric Mapper                                             |
| ACE-Asia  | Aerosol Characterization Experiment–Asia                                        |
| ACS       | American Chemical Society                                                       |
| AERONET   | Aerosol Robotic Network                                                         |
| AGU       | American Geophysical Union                                                      |
| AIAA      | American Institute of Aeronautics and Astronautics, Inc.                        |
| AirGLOW   | Air Goddard Lidar Observatory for Winds                                         |
| AIRS      | Atmospheric Infrared Sounder                                                    |
| AMMA      | African Monsoon Multidisciplinary Analysis                                      |
| AMS       | American Meteorological Society                                                 |
| AMSR      | Advanced Microwave Scanning Radiometer                                          |
| AMSR-E    | AMSR Earth Observing System (EOS)                                               |
| AMSU      | Advanced Microwave Sounding Unit                                                |
| AOML      | Atlantic Oceanographic and Meteorological Laboratory                            |
| AOT       | Aerosol Optical Thickness                                                       |
| ARC       | Ames Research Center                                                            |
| ARM       | Atmospheric Radiation Measurement (Program)                                     |
| ARM CART  | ARM Cloud and Radiation Test Bed                                                |
| AROTAL    | Airborne Raman Ozone, Temperature, and Aerosol Lidar                            |
| ASEAN     | Association of South East Asian Nations                                         |
| AT Lidar  | Aerosol and Temperature Lidar                                                   |
| ATMS      | Advanced Technology Microwave Sounder                                           |
| AVE       | Aura Validation Experiment                                                      |
| AVHRR     | Advanced Very High Resolution Radiometer                                        |
| 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                                              |
| CCSP      | Climate Change Science Program                                                  |
| CERES     | Clouds and the Earth’s Radiant Energy System                                    |
| CFCs      | Chlorofluorocarbons                                                             |
| CIMSS     | Cooperative Institute of Meteorological Satellite Studies                       |
| CLAIM-3D  | 3D-Cloud Aerosol Interaction Mission                                            |
| CLIVAR    | Climate Variability and Predictability Programme                                |
| CNES      | <i>Centre Nationale d’Etude Spatiales</i>                                       |
| Co-I      | Co-Investigator                                                                 |
| COMMIT    | Chemical, Optical, and Microphysical Measurements of <i>In situ</i> Troposphere |
| COVIR     | Compact Visible and Infrared Radiometer                                         |
| CPL       | Cloud Physics Lidar                                                             |
| CR-AVE    | Costa Rica AVE                                                                  |
| CrIS      | Crosstrack Infrared Sounder                                                     |

## ACRONYMS

|           |                                                                           |
|-----------|---------------------------------------------------------------------------|
| CRS       | Cloud Radar System                                                        |
| CSTEA     | Center for the Study of Terrestrial and Extraterrestrial Atmospheres      |
| CTM       | Chemical Transport Model                                                  |
| CU        | Chulalongkorn University                                                  |
| DAAC      | Distributed Active Archive Center                                         |
| DDF       | Director's Discretionary Fund                                             |
| DFRC      | Dryden Flight Research Center                                             |
| DIAL      | Differential Absorption Lidar                                             |
| DLR       | <i>Deutsches Zentrum für Luft und Raumfahrt</i> (German Aerospace Center) |
| DOAS      | Differential Optical Absorption Spectroscopy                              |
| DOE       | Department of Energy                                                      |
| DOI       | Digital Object Identifiers                                                |
| DSCOVN    | Deep Space Climate Observatory Project (formerly Triana)                  |
| DU        | Dobson Unit                                                               |
| ECMWF     | European Centre for Medium-Range Weather Forecasts                        |
| EDOP      | ER-2 Doppler Radar                                                        |
| ENSO      | El Niño Southern Oscillation                                              |
| EnviSat   | Environmental Satellite                                                   |
| EOS       | Earth Observing System                                                    |
| EOSDIS    | EOS Data and Information System                                           |
| EPA       | Environmental Protection Agency                                           |
| EPIC      | Earth Polychromatic Imaging Camera                                        |
| EP-TOMS   | Earth Probe TOMS                                                          |
| ERBE      | Earth Radiation Budget Experiment                                         |
| ESE       | Earth Science Enterprise                                                  |
| ESED      | Earth–Sun Exploration Division                                            |
| ESMF      | Earth Science Modeling Framework                                          |
| ESRL      | Earth System Research Laboratory (NOAA)                                   |
| ESSIC     | Earth System Science Interdisciplinary Center                             |
| ESTO      | Earth Science Technology Office                                           |
| ESTO/ACT  | Earth Science Technology Office/Advanced Component Technologies           |
| E-Theater | Electronic Theater                                                        |
| FOV       | Field of View                                                             |
| FPGA      | Field Programmable Gate-Array                                             |
| FPPA      | Field Programmable Processor Array                                        |
| FvGCM     | Finite volume GCM                                                         |
| GCE       | Goddard Cumulus Ensemble model                                            |
| GCM       | General Circulation Model                                                 |
| GEOS      | Goddard Earth Observing System                                            |
| GeoSpec   | Geostationary Spectrograph                                                |
| GEST      | Goddard Earth Sciences and Technology Center                              |
| GEWEX     | Global Energy and Water Cycle Experiment                                  |
| GFDL      | Geophysical Fluid Dynamics Laboratory                                     |
| 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                                        |
| GOCART    | Global Ozone Chemistry Aerosol Radiation Transport                |
| GOES      | Geostationary Operational Environmental Satellite                 |
| GOME      | Global Ozone Monitoring Experiment                                |
| GPCP      | Global Precipitation Climatology Project                          |
| GPM       | Global Precipitation Measurement                                  |
| GSFC      | Goddard Space Flight Center                                       |
| GSWP      | Global Soil Wetness Project                                       |
| GV        | Ground Validation                                                 |
| GVP       | Ground Validation Program                                         |
|           |                                                                   |
| HALOE     | Halogen Occultation Experiment                                    |
| HARLIE    | Holographic Airborne Rotating Lidar Instrument Experiment         |
| HBCUs     | Historically Black Colleges and Universities                      |
| HIRDLS    | High Resolution Dynamics Limb Sounder                             |
| HIRS      | High Resolution Infrared Sounder                                  |
| HIWRAP    | High-Altitude Imaging Wind and Rain Airborne Profiler             |
| HOE       | Holographic Optical Element                                       |
| HRD       | Hurricane Research Division                                       |
| HRDI      | High Resolution Doppler Image                                     |
| HSB       | Humidity Sounder Brazil                                           |
| HU        | Howard University                                                 |
| HUAV      | High-altitude UAV                                                 |
| HUPAS     | Howard University Program in Atmospheric Sciences                 |
| HY-SiB    | Hydrology and Simple Biosphere                                    |
|           |                                                                   |
| I3RC      | Intercomparison of 3D Radiation Codes                             |
| IAHS      | International Association of Hydrological Sciences                |
| IAMAS     | International Association of Meteorology and Atmospheric Sciences |
| ICCS      | International Conference on Conceptual Structures                 |
| IEEE      | Institute of Electrical and Electronics Engineers                 |
| IIP       | Instrument Incubator Program                                      |
| IMAPP     | International MODIS/AIRS Processing Package                       |
| IMN       | <i>Instituto Meteorologico Nacional</i> (Costa Rica)              |
| IMPROVE   | Interagency Monitoring of Protected Visual Environments           |
| IORD      | Integrated Operational Requirements Document                      |
| IPCC      | Intergovernmental Panel on Climatic Change                        |
| IPO       | Integrated Program Office                                         |
| IR        | Infrared                                                          |
| IRAD/IR&D | Independent Research and Development                              |
| ISAS      | Institute of Space and Aeronautical Science (Japan)               |
| ISCCP     | International Satellite Cloud Climatology Project                 |
| ISIR      | Infrared Spectral Imaging Radiometer                              |
|           |                                                                   |
| JAXA      | Japan Aerospace Exploration Agency                                |
| JCET      | Joint Center for Earth Systems Technology                         |

## ACRONYMS

|         |                                                                                                                                                          |
|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| JCOSS   | Joint Center for Observation System Science                                                                                                              |
| JCSDA   | Joint Center for Satellite Data Assimilation                                                                                                             |
| JPL     | Jet Propulsion Laboratory                                                                                                                                |
| JSC     | Johnson Space Center                                                                                                                                     |
| KILT    | Kiritimati Island Lidar Trailer                                                                                                                          |
| L2-SVIP | Lagrange-2 Solar Viewing Interferometer Prototype                                                                                                        |
| LaRC    | Langley Research Center                                                                                                                                  |
| LIS     | Land Information System                                                                                                                                  |
| LORE    | Limb Ozone Retrieval Experiment                                                                                                                          |
| LRR     | Lightweight Rainfall Radiometer                                                                                                                          |
| LRR-X   | LRR-X band                                                                                                                                               |
| McRAS   | Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme                                                                                          |
| MISR    | Multi-Angle Imaging Spectroradiometer                                                                                                                    |
| MIT     | Massachusetts Institute of Technology                                                                                                                    |
| MJO     | Madden-Julian Oscillation                                                                                                                                |
| MLS     | Microwave Limb Sounder                                                                                                                                   |
| MLT     | Mesosphere-Lower Thermosphere                                                                                                                            |
| MMF     | Multimodel Framework                                                                                                                                     |
| MM5     | Mesoscale Model 5                                                                                                                                        |
| MODAPS  | MODIS Operations Data Processing System                                                                                                                  |
| MODIS   | Moderate Resolution Imaging Spectroradiometer                                                                                                            |
| MOZART  | Model for Ozone and Related Chemical Tracers                                                                                                             |
| MPL     | Micro-Pulse Lidar                                                                                                                                        |
| MPLNET  | Micro-Pulse Lidar Network                                                                                                                                |
| MSU     | Microwave Sounding Unit                                                                                                                                  |
| NAS     | National Academy of Sciences                                                                                                                             |
| NASA    | National Aeronautics and Space Administration                                                                                                            |
| NASDA   | National Space Development Agency                                                                                                                        |
| NCAR    | National Center for Atmospheric Research                                                                                                                 |
| NCAS    | NOAA Center for Atmospheric Science (part of Howard University)                                                                                          |
| NCEP    | National Center for Environmental Prediction                                                                                                             |
| NESDIS  | National Environmental Satellite Data and Information Service                                                                                            |
| NICT    | National Institute of Information and Communications Technology                                                                                          |
| NIEM    | Russian Scientific Research Institute of Electromechanics                                                                                                |
| NIR     | Near Infrared                                                                                                                                            |
| NIST    | National Institute of Standards and Technology                                                                                                           |
| NMNH    | National Museum of Natural History                                                                                                                       |
| NMS     | Neutral Mass Spectrometer                                                                                                                                |
| NOAA    | National Oceanic and Atmospheric Administration                                                                                                          |
| NOAH    | <u>N</u> ational Centers for Environmental Prediction, <u>O</u> regon State University, <u>A</u> ir Force,<br><u>H</u> ydrologic Research Lab of the NWS |
| NPOESS  | National Polar Orbiting Environmental Satellite System                                                                                                   |
| NPP     | NPOESS Preparatory Project                                                                                                                               |
| NRC     | National Research Council                                                                                                                                |
| NSF     | National Science Foundation                                                                                                                              |

|            |                                                                            |
|------------|----------------------------------------------------------------------------|
| OGO        | Orbiting Geophysical Observatory                                           |
| OLR        | Outgoing Longwave Radiation                                                |
| OMI        | Ozone Monitoring Instrument                                                |
| OMPS       | Ozone Mapper and Profiler System                                           |
| OOAT       | Ozone Operational Algorithm Team                                           |
| PAVE       | Polar Aura Validation Experiment                                           |
| PHASERS    | Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing |
| PI         | Principal Investigator                                                     |
| POES       | Polar Orbiting Environmental Satellite                                     |
| POLDER     | Polarization Detecting Environmental Radiometer                            |
| QuikSCAT   | (NASA's) Quick Scatterometer satellite                                     |
| QWIP       | Quantum Well Infrared Photodetectors                                       |
| RASL       | Raman Airborne Spectroscopic Lidar                                         |
| RCDF       | Radiometric Calibration and Development Facility                           |
| RDPP       | Reconfigurable Data Path Processor                                         |
| RFP        | Request for Proposal                                                       |
| RMS        | Root mean Squared                                                          |
| 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       |
| SDS        | Scientific Data Set                                                        |
| SEB        | Source Evaluation Board                                                    |
| ShADOE     | Shared Aperture Diffractive Optical Element (telescope)                    |
| SMART      | Surface-sensing Measurements for Atmospheric Radiative Transfer            |
| SOAT       | Sounder Operation Algorithm Teams                                          |
| SOLSE/LORE | Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment     |
| SOLSTICE   | Solar/Stellar Irradiance Comparison Experiment                             |
| SOLVE      | SAGE III Ozone Loss and Validation Experiment                              |
| SORCE      | Solar Radiation and Climate Experiment                                     |
| SPIE       | Society of Photo-Optical Instrumentation Engineers                         |
| SRL        | Scanning Raman Lidar                                                       |
| SSAI       | Science Systems and Applications, Inc.                                     |
| SSBUV      | Shuttle Solar Backscatter Ultraviolet                                      |
| SSI        | Spectral Solar Irradiance                                                  |
| SSM/I      | Special Sensor Microwave Imager                                            |
| SSU        | Spectral Sensor Unit                                                       |
| STROZ LITE | Stratospheric Ozone Lidar Trailer Experiment                               |
| SUSIM      | Solar Ultraviolet Spectral Irradiance Monitor                              |
| SVIP       | Solar Viewing Interferometer Prototype                                     |
| TCSP       | Tropical Cloud Systems and Processes                                       |
| THOR       | cloud THickness from Offbeam Returns                                       |
| TIROS      | Television Infrared Observation Satellite                                  |
| TMPA       | TRMM Multi-satellite Precipitation Analysis                                |

## ACRONYMS

|                  |                                                                               |
|------------------|-------------------------------------------------------------------------------|
| TOGA-COARE       | Tropical Ocean Global Atmosphere–Coupled Ocean Atmosphere Response Experiment |
| TOMS             | Total Ozone Mapping Spectrometer                                              |
| TOPEX            | Topography Experiment                                                         |
| TOVS             | TIROS Operational Vertical Sounder                                            |
| TRMM             | Tropical Rainfall Measuring Mission                                           |
| TSI              | Total Solar Irradiance                                                        |
| TWiLiTE          | Tropospheric Wind Lidar Technology Experiment                                 |
| UAE <sup>2</sup> | United Arab Emirates Unified Aerosol Experiment                               |
| UARS             | Upper Atmosphere Research Satellite                                           |
| UAV              | Unmanned Aerial Vehicle                                                       |
| UCLA             | University of California, Los Angeles                                         |
| UMAD             | Uncooled Microbolometer Array Detector                                        |
| UMBC             | University of Maryland, Baltimore County                                      |
| UMCP             | University of Maryland, College Park                                          |
| URAD             | UAV Radar                                                                     |
| UTC              | Universal Coordinated Time                                                    |
| UV               | Ultraviolet                                                                   |
| UV-B             | Ultraviolet-B radiation                                                       |
| VINTERSOL        | Validation of International Satellites and study of Ozone Loss                |
| VIS              | Visible                                                                       |
| WCRP             | World Climate Research Programme                                              |
| WINDII           | Wind Imaging Interferometer                                                   |
| WRF              | Weather Research and Forecasting                                              |



## APPENDIX A1. PRESS RELEASES

Jan. 4, 2005 RELEASE: 05-002

### **NASA WILL OPERATE TRMM SATELLITE THROUGH SPRING 2005**

NASA will continue to operate the Tropical Rainfall Measuring Mission (TRMM) spacecraft through spring 2005.

TRMM has yielded significant scientific research data over the past seven years to users around the globe, four years beyond its original design life. TRMM data has aided the National Oceanic and Atmospheric Administration (NOAA) and other users in their scientific research, understanding of rainfall and storm prediction, and by demonstrating its benefits in operational forecasts.

The extension followed release of interim report recommendations today from the National Academy of Science's (NAS) Committee on the Future of the Tropical Rainfall Measuring Mission. The Committee "strongly recommended continued operation of TRMM, at least until such time as a decision on controlled reentry becomes unavoidable."

NASA and NOAA asked the NAS last summer to convene a workshop to advise on the best use of TRMM's remaining spacecraft life; the overall risks and benefits of the TRMM mission extension options; the advisability of transfer of operational responsibility for TRMM to NOAA; any requirement for a follow-on operational satellite to provide comparable TRMM data; and optimal use of Global Precipitation Measurement mission, a follow-on research spacecraft to TRMM, planned for launch at decade's end. The ad hoc expert NAS Committee will issue a final report next summer.

"NASA recognizes the sustained value of TRMM data to the community and appreciates the Academy's thorough and thoughtful consideration of the future of this mission," said Deputy Associate Administrator for Science of NASA's Science Mission Directorate, Dr. Ghassem Asrar. "With this additional mission extension, however, we continue to be vigilant in maintaining our requirement for an eventual safe, controlled re-entry and deorbit of the spacecraft," he said.

Launched in 1997, TRMM was originally designed as a three-year research mission. Following four years of extending TRMM, NASA and its mission partner, the Japan Aerospace Exploration Agency, planned to decommission TRMM and proceed with a safe, controlled deorbit. NASA's extension of TRMM last fall ensured observations through the hurricane season. The extension accommodated a request from NOAA.

For more information about TRMM on the Web, visit:

<http://trmm.gsfc.nasa.gov/> For information about NASA and Agency programs on the Web, visit:

<http://www.nasa.gov>

Jan. 27, 2005 RELEASE: 05-029

## **INTERNATIONAL SCIENCE TEAM MEASURES ARCTIC'S ATMOSPHERE**

An international team of scientists embarked this week on a journey to improve modeling of global-scale air quality and climate change predictions by conducting high quality measurements of the Arctic region's atmosphere.

The Polar Aura Validation Experiment (PAVE) will gather information to validate data from NASA's Aura satellite, launched in July 2004. PAVE is the third in a series of planned Aura validation and science missions. These missions will help understand the transport and transformation of gases and aerosols in the lower atmosphere (troposphere), and their exchange with those in the lower stratosphere, the layer just above the troposphere. PAVE takes place from Jan. 24 to Feb. 9.

"In addition to providing important validation for the various Aura data products, PAVE brings together a full NASA complement of space-based and suborbital measurements to study the atmospheric chemistry and transport of gases and aerosols in this sensitive region of our planet," said Dr. Michael Kurylo, Program Scientist for PAVE, at NASA Headquarters in Washington. "The information from this campaign will aid in understanding how changing atmospheric composition, associated with climate change, might affect the recovery of the Earth's ozone layer that is anticipated to occur over the next several decades," he said.

In particular, PAVE focuses on the Arctic region of the Northern Hemisphere, where winter chemistry has led to significant seasonal reduction of the stratospheric ozone layer in many years, over more than a decade. The ozone layer restricts the amount of the sun's ultraviolet radiation that reaches the Earth. Depletion of this protective layer can have harmful effects on humans and other ecosystems.

NASA's DC-8 flying laboratory and high-altitude balloons are collecting valuable science data, especially on ozone and ozone-destroying chemicals, using a suite of atmospheric remote sensing and "in situ" instruments. The aircraft, operated by NASA's Dryden Flight Research Center, Edwards, Calif., is flying the PAVE mission from Pease International Tradeport, Portsmouth, N.H. Balloons are being launched from the European Sounding Rocket Range (ESRANGE) facility in Sweden.

The study is focusing on obtaining in situ and remote sensing measurements of the arctic region for validation of the Aura satellite. Information gathered during PAVE will be combined with data from Aura to improve modeling of global-scale air quality, ozone and climate change predictions.

Instruments on board the DC-8 are characterizing upper tropospheric and stratospheric gases inside and outside the Arctic polar region to study ozone depletion chemistry. Such flights also permit measurement of the outflow of gases from the North American continent, thereby contributing to an understanding of how regional pollutants are distributed in the hemisphere.

Scientists will make remote sensing measurements (extending many kilometers away from the aircraft) of tropospheric and stratospheric ozone, aerosols, temperature, nitric acid, HCl, ClO and other ozone-related chemicals. These are complemented by measurements of components such as ozone, methane, water vapor, carbon monoxide, nitric acid and nitrous oxide, in the atmosphere immediately surrounding the aircraft.

Major PAVE partners include the University of New Hampshire, Durham; University of California-Berkeley; University of Bremen, Germany; National Center for Atmospheric Research (NCAR), Boulder, Colo.; the U.S. Naval Research Laboratory in Washington; Koninklijk Netherlands Meteorological Institute; and Los Gatos Research, Inc., Mountain View, Calif.

For more information about the Aura mission on the Internet, visit:

<http://aura.gsfc.nasa.gov/> For more information about PAVE on the

Internet, visit: <http://cloud1.arc.nasa.gov/ave-polar/>

May 20, 2005 RELEASE: 05-129

## NASA SUCCESSFULLY LAUNCHES ENVIRONMENTAL SATELLITE

NASA successfully launched a new environmental satellite today for the National Oceanic and Atmospheric Administration (NOAA). It will improve weather forecasting and monitor environmental events around the world.

The NOAA-18 (N) spacecraft lifted off at 6:22 a.m. EDT from Vandenberg Air Force Base, Calif., on a Boeing Delta II 7320-10 expendable launch vehicle. Approximately 65 minutes later, the spacecraft separated from the Delta II second stage.

“The satellite is in orbit and all indications are that we have a healthy spacecraft,” said Karen Halterman, the NASA Polar-orbiting Operational Environmental Satellites (POES) Project Manager, Goddard Space Flight Center (GSFC), Greenbelt, Md. “NASA is proud of our partnership with NOAA in continuing this vital environmental mission,” she added.

Flight controllers tracked the launch vehicle’s progress using real-time telemetry data relayed through NASA’s Tracking and Data Relay Satellite System (TDRSS) starting about five minutes after launch. Approximately 26 minutes after launch, controllers acquired the spacecraft through the McMurdo Sound ground station, Antarctica, while the spacecraft was still attached to the Delta II. Spacecraft separation was monitored by the TDRSS.

The solar array boom and antennas were successfully deployed, and the spacecraft was placed in a near-perfect orbit. The satellite was acquired by the NOAA Fairbanks Station, Alaska, 86 minutes after launch and deployments, and a nominal spacecraft power system was confirmed. NOAA-N was renamed NOAA-18 after achieving orbit.

NOAA-18 will collect data about the Earth’s surface and atmosphere. The data are input to NOAA’s long-range climate and seasonal outlooks, including forecasts for El Nino and La Nina. NOAA-18 is the fourth in a series of five Polar-orbiting Operational Environmental Satellites with instruments that provide improved imaging and sounding capabilities.

NOAA-18 has instruments used in the international Search and Rescue Satellite-Aided Tracking System, called COSPAS-SARSAT, which was established in 1982. NOAA polar-orbiting satellites detect emergency beacon distress signals and relay their location to ground stations, so rescue can be dispatched. SARSAT is credited with saving approximately 5,000 lives in the U.S. and more than 18,000 worldwide.

Twenty-one days after spacecraft launch, NASA will transfer operational control of NOAA-18 to NOAA. NASA’s comprehensive on-orbit verification period is expected to last approximately 45 days.

NOAA manages the POES program and establishes requirements, provides all funding and distributes environmental satellite data for the United States. GSFC procures and manages the development and launch of the satellites for NOAA on a cost-reimbursable basis.

NASA’s Kennedy Space Center, Fla., was responsible for the countdown management and launch of the Delta II, which was provided by Boeing Expendable Launch Systems, Huntington Beach, Calif.

For images of the launch, information about NOAA-N and the polar-orbiting satellites, visit:

<http://www.nasa.gov/noaa-n>

<http://goespoes.gsfc.nasa.gov>

<http://www.noaa.gov>

<http://nws.noaa.gov>

June 16, 2005 MEDIA ADVISORY: M05-098

**NASA ANNOUNCES DANGEROUS WEATHER MEDIA CONFERENCE**

NASA hurricane researchers are available for a media teleconference at noon EDT, Thursday, June 23 to discuss the month-long Tropical Cloud Systems and Processes (TCSP) mission to Costa Rica.

TCSP starts July 1, and mission scientists expect to observe the genesis of some of the world's most dangerous weather formations in the Pacific Ocean. Five NASA centers, 10 American universities and the National Oceanic and Atmospheric Administration (NOAA) are participating.

For the call-in number, password, Internet site where graphics and other materials will be posted, reporters should call Tomeka Scales at: 202/358-0781, by 5 p.m. EDT, Wednesday.

Briefing Participants:

- Dr. Ramesh Kakar: Weather Focus Area leader for NASA's Science Mission Directorate
- **Dr. Gerry Heymsfield**: cloud radar expert and research meteorologist at NASA's Goddard Space Flight Center, Greenbelt, Md.
- Dr. Edward Zipser: chairman and professor of the Department of Meteorology at the University of Utah, Salt Lake City
- Dr. Frank Marks, director of the Hurricane Research Division for NOAA's Atlantic Oceanographic and Meteorological Laboratory, Miami

For information about TCSP on the Internet, visit:

[http://www.nasa.gov/vision/earth/lookingatearth/hurricane\\_2005.html](http://www.nasa.gov/vision/earth/lookingatearth/hurricane_2005.html)

or

<http://tcsp.nsstc.nasa.gov/tcsp/>

July 26, 2005 RELEASE: 05-199

## NASA'S GOES-N SATELLITE READY FOR LAUNCH

NASA announced the Geostationary Operational Environmental Satellite-N (GOES-N) is ready to launch. The GOES-N launch window is from 6:23 to 7:01 p.m. EDT, Friday, July 29, 2005. Liftoff is from Space Launch Complex 37, Cape Canaveral Air Force Station, Fla.

GOES-N joins a system of weather satellites that provide timely environmental information to meteorologists and the public. The GOES system graphically displays the intensity, path and size of storms. Early warning of impending severe weather enhances the public's ability to take shelter and protect property.

NASA is proud to provide this tool for the National Oceanic and Atmospheric Administration's (NOAA) use in weather operations," said Martin Davis. He is the GOES program manager at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Md. The GOES system serves the central and eastern Pacific Ocean; North, Central, and South America; and the central and western Atlantic Ocean.

The system includes GOES-10, 11 and 12. GOES-11 is in an on-orbit storage mode. GOES-N becomes GOES-13 shortly after launch. It will be checked out, stored on-orbit and available for activation should either GOES-10 or 12 fails or exhausts its fuel. The satellite is the first in the GOES N-P series of spacecraft that will continuously observe and measure meteorological phenomena in real time. The series will provide the meteorological community and atmospheric scientists improved observational and measurement data.

GOES-N will be launched on a Boeing Delta IV (4, 2) vehicle under an FAA commercial license. The satellite will be turned over to NASA after a successful checkout is completed by Boeing Space and Intelligence Systems.

NOAA manages the GOES program, establishes requirements, provides all funding and distributes environmental satellite data for the United States.

GSFC procures and manages the development and launch of the satellites for NOAA on a cost reimbursable basis. GSFC also manages the design, development and launch of NOAA satellites. Boeing, acting as lead contractor, built GOES-N.

For more information about the GOES-N mission and program on the Web, visit:

<http://www.nasa.gov/goes-n>

<http://goespoes.gsfc.nasa.gov>

<http://www.noaa.gov/> For information about NASA and agency programs on the Web, visit:

<http://www.nasa.gov/home/index.html>

August 24, 2005 RELEASE: 05-231

### **NASA/NOAA ANNOUNCE MAJOR WEATHER FORECASTING ADVANCEMENT**

NASA and the National Oceanic and Atmospheric Administration (NOAA) today outlined research that has helped to improve the accuracy of medium-range weather forecasts in the Northern Hemisphere.

NASA and NOAA scientists at the Joint Center for Satellite Data Assimilation (JCSDA) in Camp Springs, Md., came up with procedures to improve forecasting accuracy. The scientists worked with experimental data from the Atmospheric Infrared Sounder (AIRS) instrument on NASA's Aqua satellite.

They found incorporating AIRS data into numerical weather prediction models improves the accuracy range of experimental six-day Northern Hemisphere weather forecasts by up to six hours, a four percent increase. AIRS is a high-spectral resolution infrared instrument that takes 3-D pictures of atmospheric temperatures, water vapor and trace gases.

The instrument data have officially been incorporated into NOAA's National Weather Service's operational weather forecasts.

"NASA is assisting the world's weather prediction agencies by providing very detailed, accurate observations of key atmospheric variables that interact to shape our weather and climate," said Dr. Mary Cleave, associate administrator for NASA's Science Mission Directorate. "The forecast improvement accomplishment alone makes the AIRS project well worth the American taxpayers' investment."

"This AIRS instrument has provided the most significant increase in forecast improvement in this time range of any other single instrument," said retired U.S. Navy Vice Adm. Conrad C. Lautenbacher, Jr., Ph.D., Undersecretary of Commerce for Oceans and Atmosphere and NOAA administrator.

"Climate and weather forecasts are dependent upon our understanding current global ocean and atmosphere conditions. If we want to be able to predict what the weather will be like in the future, we must adequately define the global conditions today. Satellite data, like AIRS provides, is a vital link for NOAA to continuously take the pulse of the planet."

"A four percent increase in forecast accuracy at five or six days normally takes several years to achieve," said JSCDA Director, Dr. John LeMarshall. "This is a major advancement, and it is only the start of what we may see as much more data from this instrument is incorporated into operational forecast models at NOAA's Environmental Modeling Center."

The European Center for Medium Range Weather Forecasts began incorporating data from AIRS into their operational forecasts in October 2003. The center reported an improvement in forecast accuracy of eight hours in Southern Hemisphere five-day forecasts.

AIRS is the result of more than 30 years of atmospheric research. It is led by Dr. Moustafa Chahine of NASA's Jet Propulsion Laboratory, Pasadena, Calif. AIRS is the first in a series of advanced infrared sounders that will provide accurate, detailed atmospheric temperature and moisture observations for weather and climate applications.

The JCSDA is operated by NOAA, NASA, the U.S. Air Force and Navy. The goals of the center are to accelerate the use of observations from Earth-orbiting satellites to improve weather and climate forecasts, and to increase the accuracy of climate data sets.

For information about AIRS on the Internet, visit:

<http://airs.jpl.nasa.gov/>

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

<http://www.nasa.gov/home/index.html>

August 26, 2005 STATUS REPORT: E05-009

**NASA EXPENDABLE LAUNCH VEHICLE STATUS REPORT: E05-009**

Mission: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation and CloudSat (CALIPSO/CloudSat) Launch Vehicle: Boeing Delta 7420 w/Dual Payload Attach Fitting (DPAF) Launch Pad: Space Launch Complex 2 (SLC2), Vandenberg Air Force Base, Calif. Launch Date: NET, September 29, 2005

The CloudSat spacecraft was fueled Aug. 14 and the fuel tanks pressurized Aug. 15; CALIPSO was fueled Aug. 24 and the fuel tanks pressurized Aug. 25. CloudSat was mated to the DPAF Aug 23. Installation of the upper half of the DPAF for CALIPSO was completed today. The CALIPSO Mission Readiness Review was today. The CloudSat Mission Readiness Review is scheduled for Thursday, Sept. 1.

As a part of the NASA Earth System Science Pathfinder program, CALIPSO is a collaborative effort with the French space agency Centre National d'Etudes Spatiales, Ball Aerospace, Hampton University, Va. and France's Institut Pierre Simon Laplace.

Ball Aerospace is responsible for CALIPSO's scientific instrument and communications suite, including the lidar and Wide Field Camera. NASA's Launch Services Program at KSC provides government launch services for this mission through Boeing Expendable Launch Systems.

Previous status reports are available on the Web at:

<http://www.nasa.gov/centers/kennedy/launchingrockets/status/2005> For information about NASA and agency programs on the Web, visit:

<http://www.nasa.gov/home/index.html>

September 2, 2005 RELEASE: 05-246

## **NASA'S SCIENCE RESOURCES HELP AGENCIES RESPOND TO KATRINA**

NASA science instruments and Earth-orbiting satellites are providing detailed insight about the environmental impact caused by Hurricane Katrina. Images and data are helping characterize the extent of flooding; damage to homes, businesses and infrastructure; and potential hazards caused by the storm and its aftermath.

NASA, along with academic institutions and partner agencies, is working to ensure the Department of Homeland Security and the Federal Emergency Management Agency (FEMA) have the best available information to aid in responding to this catastrophic event.

NASA's partner agencies in this endeavor include the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the National Geospatial Intelligence Agency, the Environmental Protection Agency, and the U.S. Department of Agriculture.

Coordinated assistance by numerous academic institutions and laboratories working under NASA grants will be employed by the Gulf Coast relief and recovery efforts to provide geospatial information useful to first responders and decision makers.

NASA aircraft are providing detailed observations of the disaster area. The aircraft are taking high-resolution observations that can be used to assess the amount of damage to communities and the environment. For example at the request of USGS in cooperation with FEMA and the Army Corps of Engineers, NASA's Experimental Advanced Airborne Research LIDAR (EAARL) system is surveying the gulf coastline.

The EAARL system, carried on a Cessna 310, surveyed the northern gulf coastline on Thursday. Tomorrow the aircraft is scheduled to fly over the perimeter and surrounding levee around New Orleans to assist in damage assessment of the system.

While making its observations of the land, EAARL has the ability to "see" through vegetation, like trees and shrubs, to view the land underneath. Near the coast it can map the beach surface under water. This will help in the recovery of the shoreline infrastructure; determine hazard areas and environmental loss.

The Terra, Aqua and Tropical Rainfall Measuring Mission (TRMM) satellites have already provided Earth observations for land cover and rainfall. Terra's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is providing data on the magnitude and extent of damage and flooding to the USGS Emergency Response Team through its Earth Resources Observation Systems Data Center in Sioux Falls, S.D.

NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the Terra and Aqua satellites provided images of flooding, pre and post disaster comparisons. Data from NASA's QuikScat satellite was one source of wind observations used by NOAA's Hurricane Research Division to analyze the wind field of the storm and to track its path.

Another NASA satellite in use is the Earth Observing Mission 1 (EO-1). The Advanced Land Imagery (ALI) multispectral instrument on EO-1 provided land use and land cover observations useful in determining hurricane damage areas and in aiding in recovery, response and mitigation.

NASA satellites are used to improve weather predictions, to study climate and natural hazards. The knowledge gained during these missions aids assessment and recovery operations.

For satellite images and additional information on the Web, visit:

<http://www.nasa.gov/hurricane>

[http://www.aoml.noaa.gov/hrd/Storm\\_pages/katrina2005/wind.html](http://www.aoml.noaa.gov/hrd/Storm_pages/katrina2005/wind.html). For information about NASA and agency programs on the Web, visit:

<http://www.nasa.gov/home>



September 15, 2005 RELEASE: 05-261

## NASA SATELLITES WILL REVEAL SECRETS OF CLOUDS AND AEROSOLS

Two NASA satellites, planned for launch no earlier than Oct. 26, will give us a unique view of Earth's atmosphere. CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) are undergoing final preparations for launch from Vandenberg Air Force Base, Calif.

CloudSat and CALIPSO will provide a new, 3-D perspective on Earth's clouds and airborne particles called aerosols. The satellites will answer questions about how clouds and aerosols form, evolve and affect water supply, climate, weather and air quality.

CloudSat and CALIPSO employ revolutionary tools that will probe Earth's atmosphere. Each spacecraft carries an "active" instrument that transmits pulses of energy and measures the portion of the pulses scattered back to the instrument.

CloudSat's cloud-profiling radar is more than 1,000 times more sensitive than typical weather radar. It can detect clouds and distinguish between cloud particles and precipitation. "The new information from CloudSat will answer basic questions about how rain and snow are produced by clouds, how rain and snow are distributed worldwide and how clouds affect the Earth's climate," said Dr. Graeme Stephens, CloudSat principal investigator at Colorado State University, Fort Collins, Colo.

CALIPSO's polarization lidar instrument can detect aerosol particles and can distinguish between aerosol and cloud particles. "With the high resolution observation that CALIPSO will provide, we will get a better understanding of aerosol transport and how our climate system works," said Dr. David Winker, CALIPSO principal investigator at NASA's Langley Research Center, Hampton, Va.

The satellites will be launched into a 438-mile circular, sun-synchronous polar orbit, where they will fly in formation just 15 seconds apart as members of NASA's "A-Train" constellation with three other Earth Observing System satellites. The A-Train includes NASA's Aqua and Aura satellites and France's PARASOL satellite.

The usefulness of data from CloudSat, CALIPSO and the other A-Train satellites will be much greater when combined. The combined set of measurements will provide new insight into the global distribution and evolution of clouds that will lead to improvements in weather forecasting and climate prediction.

CloudSat is managed by NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif. The radar instrument was developed at JPL, with hardware contributions from the Canadian Space Agency. Colorado State University provides scientific leadership and science data processing and distribution.

Other contributions include resources from the U.S. Air Force and the U.S. Department of Energy. Ball Aerospace and Technologies Corp. designed and built the spacecraft. A host of U.S. and international universities and research centers provides support to the science team. Some of these activities are contributed as partnerships with the project.

CALIPSO was developed through collaboration between NASA and the French Space Agency, *Centre National d'Etudes Spatiales* (CNES). NASA's Langley Research Center leads the CALIPSO mission and provides science team leadership, systems engineering, payload mission operations, and validation, processing and archiving of data. Langley also developed the lidar instrument in collaboration with the Ball Aerospace and Technologies Corp., which developed the onboard visible camera.

NASA's Goddard Space Flight Center, Greenbelt, Md., provides project management, system engineering support and overall program management. CNES provides a PROTEUS spacecraft developed by Alcatel, the imaging infrared radiometer, payload-to-spacecraft integration and spacecraft mission operations. The Institut Pierre Simon Laplace in Paris provides the imaging infrared radiometer science oversight, data validation and archival. Hampton University provides scientific contributions and manages the outreach program.

For more information on CloudSat and CALIPSO on the Internet, please visit:

<http://www.nasa.gov/cloudsat> and <http://www.nasa.gov/calipso> 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.



## APPENDIX A2. REFEREED ARTICLES

This appendix lists all the refereed articles published by Laboratory for Atmospheres members (names in bold type) in 2005. References marked with an asterisk (\*) are highlighted in Appendix 3.

### 613 Senior Staff and Senior Scientists

Frey, M.M., **R.W. Stewart**, J.R. McConnell, and R.C. Bales, 2005: Atmospheric hydroperoxides in West Antarctica: links to stratospheric ozone and atmospheric oxidation capacity, *J. Geophys. Res.*, **110**, D23301, doi:10.1029/2005JD006110.

\*Yu, Jin-Yi and **K.-M. Lau**, 2005: Contrasting Indian Ocean SST variability with and without ENSO influence: A coupled atmosphere-ocean GCM study, *Meteorol. Atmos. Phys.*, **90**, 179–191, doi: 10.1007/s00703-004-0094-7.

**Lau, K.-M., K.-M. Kim**, and Y.T. Li, 2005: Interannual variability, global teleconnection and potential predictability associated with the Asian summer monsoon, in *East Asian Monsoon*, C.P. Chang, Ed., World Scientific, 153–176.

Xue, Y.K., S. Sun, **K.-M. Lau**, J. Ji, I. Pocard, R. Zhang, H. Kang, G.X. Wu, J.C. Shaake, J. Zhang, and Y. Jiao, 2005: Multiscale Variability of the River Runoff System in China and Its Long-Term Link to Precipitation and Sea Surface Temperature, *J. Hydrometeor.*, **6**, 550–570.

\***Lau, K.-M.**, H.T. Wu, **Y.C. Sud**, and G.K. Walker, 2005: Effects of cloud microphysics on tropical atmospheric hydrologic processes and intraseasonal variability in the GEOS GCM, *J. Climate*, **18**, 4731–4751.

**Lau, K.-M.**, 2005: Aerosol-hydrologic cycle interaction: a new challenge in monsoon climate research, *WCRP GEWEX Newsletter*, **15**(1), 7–9, 20.

**Lau, K.-M.**, and K.-M. Kim, 2005: Characterizing monsoon systems using CEOP data, *CEOP Newsletter*, **8**, 5–7.

**Lau, K.-M., K.-M. Kim**, and **N. C. Hsu**, 2005: Observational evidence of effects of absorbing aerosols on seasonal-to-interannual anomalies of the Asian monsoon, *CLIVAR Exchanges*, **10**(3), 7–9.

Sittler, E.C., **R.E. Hartle**, A.F. Viñas, R.E. Johnson, H.T. Smith, and I. Mueller-Wodard, 2005: Titan interaction with Saturn's magnetosphere: Voyager 1 results revisited, *J. Geophys. Res.*, **110**, A09302, doi:10.1029/2004JA010759.

Szego, K., Z. Bebisi, G. Erdos, L. Foldy, F. Crary, D.J. McComas, D.T. Young, S. Bolton, A.J. Coates, A. M. Rymer, **R.E. Hartle**, E.C. Sittler, D. Reisinger, J.J. Bethelier, R.E. Johnson, H.T. Smith, T.W. Hill, J. Vilppola, J. Steinberg, and N. Andre, 2005: The global plasma environment of Titan as observed by Cassini Plasma Spectrometer during the first two close encounters with Titan, *Geophys. Res. Lett.*, **32**, L20S05, doi: 10.1029/2005GL022646.

#### 613.1 Mesoscale Atmospheric Processes Branch

**Amitai, E.**, L. Liao, X. Llort, and R. Meneghini, 2005: Accuracy verification of spaceborne radar estimates of rain rate, *Royal Meteor. Soc. Atmos. Sci. Lett.*, **6**, 2–6 doi: 10.1002/asl.82.

\*Burian, S., and **J.M. Shepherd**, 2005: Effects of urbanization on the diurnal rainfall pattern in Houston, *Hydrological Processes: Special issue on rainfall and hydrological processes*, **19**, 1089–1103.

- Burian, S. J., **J.M. Shepherd**, and P. Hooshalsadat, 2005: Urbanization impacts on Houston rainstorms, in: *Innovative Modeling of Urban Water Systems, Monograph 12*, W. James, Ed., 1–22.
- Chepfer, H., V. Noel, P. Minnis, D. Baumgardner, L. Nguyen, G. Raga, **M. McGill**, and P. Yang, 2005: Particle habit in tropical ice clouds during CRYSTAL-FACE: Comparison of two remote sensing techniques with in situ observations, *J. Geophys. Res.*, **110**, D16204, doi:10.1029/2004JD005455.
- \***Demoz, B., D. Starr**, K. Evans, A. Lare, **D. Whiteman, G. Schwemmer**, R. Ferrare, J. Goldsmith, and S. Bisson, 2005: The cold front of 15 April 1994 over central U.S. Part I: Observations, *Mon. Weather. Rev.*, **133**(6), 1525–1543.
- Evans, K.F., J.R. Wang, P.E. Racette, and **G. Heymsfield**, 2005: Ice cloud retrievals and analysis with the Compact Scanning Submillimeter Imaging Radiometer and the Cloud Radar System during CRYSTAL FACE, *J. Appl. Meteor.*, **44**, 839–859.
- Gao, S, X. Cui, Y. Zhou, X. Li, and **W.-K. Tao**, 2005: A Modeling study of moist and dynamic vorticity vectors associated with two-dimensional tropical convection, *J. Geophys. Res.*, **110** (D17104), doi:10.1029/2004JD005675.
- Gebremichael, M., W.F. Krajewski, M.L. Morrissey, **G. Huffman**, and **R. Adler**, 2005: Detailed evaluation of GPCP one-degree daily rainfall estimates over the Mississippi River Basin, *J. Appl. Meteorol.*, **44**, 665–681.
- Gu, G., R. Adler**, and A. Sobel, 2005: The Eastern Pacific ITCZ during the Boreal Spring, *J. Atmos. Sci.*, **62**, 1157–1174.
- \*Hart, W., **J. Spinhirne**, S. Palm, and D. Hlavka, 2005: Height distribution between cloud and aerosol layers from GLAS Spaceborne Lidar in the Indian Ocean region, *Geophys. Res. Lett.*, **32** (L22S06), doi: 10.1029/2005GL023671.
- Hlavka, D.L., S.P. Palm, W.D. Hart, **J.D. Spinhirne**, **M.J. McGill**, and **E.J. Welton**, 2005: Aerosol and cloud optical depth from GLAS: Results and verification for an October 2003 California fire smoke case, *Geophys. Res. Lett.*, **32** (L22S07), doi: 10.1029/2005GL023413.
- Hoff, R.M., S. Palm, J.A. Engel-Cox, and **J. Spinhirne**, 2005: GLAS long-range transport observation of the 2003 California forest fire plumes to the Northeastern U.S., *Geophys. Res. Lett.*, **32** (L22S008), doi: 10.1029/2005GL023723.
- Jensen, E., L. Pfister, T. Bui, A. Weinheimer, E. Weinstock, J. Smith, J. Pittman, D. Baumgardner, P. Lawson, and **M. McGill**, 2005: Formation of a tropopause cirrus layer observed over Florida during CRYSTAL-FACE, *J. Geophys. Res.*, **110** (D03208), doi:10.1029/2004JD004671.
- Lancaster, R., **J.D. Spinhirne**, and S.P. Palm, 2005: Laser pulse reflectance of the ocean surface from the GLAS satellite lidar, *Geophys. Res. Lett.*, **32** (L22S10), doi: 10.1029/2005GL023732.
- Larsen, M., A.B. Kostinski, and **A. Tokay**, 2005: Observations and analysis of uncorrelated rain, *J. Atmos. Sci.*, **62** (11), 4071–4083.
- Li, J., **W.-K. Tao**, et al., 2005: Comparisons of EOS MLS cloud ice measurements with ECMWF analyses and GCM simulations, *Geophys. Res. Lett.*, **32** (L18710), doi: 10.1029/2005GL023788.

- \*Li, L., **G.M. Heymsfield**, L. Tian, and P.E. Racette, 2005: Measurements of ocean surface backscattering using an airborne 94-GHz cloud radar-implication for calibration of the airborne and spaceborne W-band radars, *J. Atmos. Ocean. Tech.*, **22**, 1033–1045.
- \*Lin, R.-F., and **D.O. Starr**, J. Reichardt, P.J. DeMott, 2005: Nucleation in synoptically forced cirrostratus, *J. Geophys. Res.*, **110** (D8), D08208, doi: 10.1029/2004JD005362.
- Mahesh, A., J.R. Campbell, and **J.D. Spinhirne**, 2005: Multi-year measurements of cloud base heights at South Pole by lidar, *Geophys. Res. Lett.*, **32** (L09812), doi:10.1029/2004GL021983.
- Mitrescu, C., J. M. Haynes, G. L. Stephens, S. D. Miller, **G. M. Heymsfield**, and **M. J. McGill**, 2005: Cirrus cloud optical, microphysical, and radiative properties observed during the CRYSTAL-FACE experiment: A lidar-radar retrieval system, *J. Geophys. Res.*, **110**, D9 (D09208), doi:10.1029/2004JD005605.
- Negri, A.**, N. Burkardt, J. Golden, **J. Halverson**, **G. Huffman**, M. Larsen, J. McGinley, R. Updike, J. Verdin, and G. Wiczorek, 2005: The Hurricane-Flood-Landslide Continuum, *Bull. Am. Meteor. Soc.*, **86**, 1241–1247.
- \*Palm, S.P., A. Benedetti, **J.D. Spinhirne**, **W. Hart**, and **D. Hlavka**, 2005: Validation of ECMWF global forecast model parameters using GLAS atmospheric channel measurements, *Geophys. Res. Lett.*, **32** (L22S09), doi:10.1029/2005GL023535.
- Palm, S.P., **J.D. Spinhirne**, and A. Benedetti, 2005: Observations of Antarctic polar stratospheric clouds by GLAS, *Geophys. Res. Lett.*, **32** (L22S04), doi:10.1029/2005GL023524.
- \***Spinhirne, J.**, S.P. Palm, **W.D. Hart**, D. L. Hlavka, and **E.J. Welton**, 2005: Cloud and aerosol measurements from GLAS: Overview of initial results, *Geophys. Res. Lett.*, **32** (L22S03), doi:10.1029/2005GL023507.
- Spinhirne, J.D.**, S.P. Palm, and **W.D. Hart**, 2005: Antarctica cloud cover for October 2003 from GLAS satellite lidar profiling, *Geophys. Res. Lett.*, **32** (L22S05), doi:10.1029/2005GL023782.
- Stenchikov, G., **K. Pickering**, A. DeCaria, **W.-K. Tao**, J. Scala, L. Ott, D. Bartels, and T. Matejka, 2005: Simulation of the fine structure of the 12 July 1996 Stratosphere-Troposphere Experiment: Radiation, Aerosols and Ozone (STRAO-A) storm accounting for effects of terrain and interaction with mesoscale flow, *J. Geophys. Res.*, **110** (D14304), doi:10.1029/2004JD005582.
- Tokay, A.**, P. Bashor, and K.R. Wolff, 2005: Error characteristics of rainfall measurements by collocated Joss-Waldvogel disdrometers, *J. Atmos. Ocean. Tech.*, **22**, 513–527.
- \*Wolff, D., D.A. Marks, **E. Amitai**, B.L. Fisher, D.S. Silberstein, **A. Tokay**, J. Wang, and J.L. Pippitt, 2005: Ground validation for the Tropical Rainfall Measuring Mission (TRMM), *J. Atmos. Ocean. Technol.*, **22**, 365–380.
- \*Wu, L., and B. Wang, **S.A. Braun**, 2005: Impacts of air-sea interaction on tropical cyclone track and intensity, *Mon. Wea. Rev.*, **133**, 3299–3314.
- Wu, Z.-J., and **A. Tokay**, 2005: Are Z-R power-law relations very likely artifacts due to undersampling? *Quart. J. Roy. Meteor. Soc.* **131**, 381–383.
- Yuter, S.E., R.A. Houze, Jr., **E.A. Smith**, T.T. Wilheit, and E. Zipser, 2005: Physical Characterization of Tropical Oceanic Convection Observed in KWAJEX, *J. Appl. Meteor.*, **44**, 385–415.
- Zeng, X.**, **W.-K. Tao**, and J. Simpson, 2005: An Equation for Moist Entropy in a Precipitating and Icy Atmosphere, *J. Atmos. Sci.*, **62**(12), 4293–4309.

Zhou, D.K., W.L. Smith, X. Liu, A.M. Larar, H.-L.A. Huang, J. Li, **M.J. McGill**, S.A. Mango, 2005: Thermodynamic and cloud parameter retrieval using infrared spectral data, *Geophys. Res. Lett.*, **32** (L15805), doi:10.1029/2005GL023211.

### 613.2 Climate and Radiation Branch

\*Al-Saadi, J., J. Szykman, R.B. Pierce, C. Kittaka, D. Neil, D.A. Chu, **L. Remer**, L. Gumley, E. Prins, L. Weinstock, C. MacDonald, R. Wayland, F. Dimmick, and J. Fishman, 2005: Improving national air quality forecasts with satellite aerosol observations, *Bull. Am. Met. Soc.*, **86**(9), 1249–1261.

Alpert, P., P. Kishcha, **Y.J. Kaufman**, and R. Schwarzbard, 2005: Global dimming or local dimming? Effect of urbanization on sunlight availability, *Geophys. Res. Lett.*, **32** (L17802), doi:10.1029/GL023320.

Anderson, D.E., and **R.F. Cahalan**, 2005: The Solar Radiation and Climate Experiment (SORCE) Mission for the NASA Earth Observing System (EOS), *Solar Phys.*, **203**(1), 3–6.

Anderson, T.L., R.J. Charlson, N. Bellouin, O. Boucher, **M. Chin**, S.A. Christopher, J. Haywood, **Y.J. Kaufman**, S. Kinne, J.A. Ogren, **L.A. Remer**, T. Takemura, D. Tanre, **O. Torres**, C.R. Trepte, B.A. Wielicki, D.M. Winker, and H. Yu, 2005: A-Train strategy for quantifying direct climate forcing by anthropogenic aerosols, *Bull. Am. Meteorol. Soc.*, **86**(12), 1795–1809.

Baum, B.A., P. Yang, **A.J. Heymsfield**, **S. Platnick**, M.D. King, Y.X. Hu, and S. . Bedka, 2005: Bulk scattering properties for the remote sensing of ice clouds. 2: Narrowband models, *J. Appl. Meteor.*, **44**, 1896–1911.

Brennan, J.I., **Y.J. Kaufman**, **I. Koren**, and R.-R. Li, 2005: Aerosol-cloud interaction—misclassification of MODIS clouds in heavy aerosol, *IEEE Trans. Geosci. Remote Sens.*, **43**(4), 911–915.

**Cahalan, R.F.**, 2005: Effective cloud properties for large-scale models in *3D Radiative Transfer in Cloudy Atmospheres*, A. Marshak and A. Davis, eds., Springer, New York, 686 pp.

**Cahalan, R.F.**, **M. McGill**, J. Kolasinski, **T. Varnai**, and **K. Yetzer**, 2005: THOR—Cloud Thickness from Offbeam Lidar Returns, *J. Atmos. Ocean. Tech.*, **22**(6), 605–627.

\***Cahalan, R.F.**, **L. Oreopoulos**, **A. Marshak**, K.F. Evans, A. Davis, R. Pincus, K. Yetzer, B. Mayer, R. Davies, T. Ackerman, H. Barker, E. Clothiaux, R. Ellingson, M. Garay, E. Kassianov, S. Kinne, A. Macke, W. OHirok, P. Partain, S. Prigarin, A. Rublev, G. Stephens, F. Szczap, E. Takara, **T. Varnai**, G. Wen, and T. Zhuravleva, 2005: The International Intercomparison of 3D Radiation Codes (I3RC): Bringing together the most advanced radiative transfer tools for cloudy atmospheres, *Bull. Amer. Meteor. Soc.*, **86**(9), 1275–1293.

**Chu, D.A.**, **L.A. Remer**, **Y.J. Kaufman**, B. Schmid, J. Redemann, K. Knobelspiesse, J.D. Chern, J. Livingston, P.B. Russell, X. Xiong, and W. Ridgway, 2005: Evaluation of aerosol properties over ocean from Moderate Resolution Imaging Spectroradiometer (MODIS) during ACE-Asia, *J. Geophys. Res.*, **110** (D07308), doi:10.1029/2004/JD005208.

**Cuddapah, P.**, R. Iacovazzi, J.-M. Yoo, and **K.-M. Kim**, 2005: A model for estimation of rain rate on tropical land from TRMM Microwave Imager Radiometer observations, *J. Meteor. Soc. Japan*, **83**(4), 595–609.

Evans, K.F., and **A. Marshak**, 2005: Numerical Methods in *3D Radiative Transfer in Cloudy Atmospheres*, A. Marshak and A. Davis, eds., Springer, New York, 686 pp.

- Gatebe, C.K.**, M.D. King, A.I. Lyapustin, G.T. Arnold, and J. Redemann, 2005: Airborne spectral measurements of ocean directional reflectance, *J. Atmos. Sci.*, **62**, 1072–1092.
- Gerard, B., J.-L. Deuze, M. Herman, **Y.J. Kaufman**, P. Lallart, C. Oudard, **L.A. Remer**, B. Roger, B. Six, and D. Tanre, 2005: Comparisons between POLDER 2 and MODIS/Terra aerosol retrievals over ocean, *J. Geophys. Res.*, **110** (D24211), doi:10.1029/2005JD006218.
- Hao, W.M., D.E. Ward, R.A. Susott, R.E. Babbitt, B.L. Nordgren, **Y.J. Kaufman**, B.N. Holben, and D.M. Giles, 2005: Comparison of aerosol optical thickness measurements by MODIS, AERONET sun photometers, and Forest Service handheld sun photometers in southern Africa during the SAFARI 2000 campaign, *Inter. J. Remote Sens.*, **26**(19), 4169–4183.
- \***Ichoku, C.**, and **Y.J. Kaufman**, 2005: A method to derive smoke emission rates from MODIS fire radiative energy measurements, *IEEE Trans. Geosci. Remote Sens.*, **43**(11), 2636–2649.
- Ichoku, C.**, **L.A. Remer**, and T.F. Eck, 2005: Quantitative evaluation and intercomparison of morning and afternoon MODIS aerosol measurements from Terra and Aqua, *J. Geophys. Res.*, **110** (D10S03), doi:10.1029/2004JD004987.
- Ignatov, A., P. Minnis, N. Loeb, B. Wielicki, W. Miller, S. Sun-Mack, D. Tanre, **L.A. Remer**, I. Laszlo, and E. Geier, 2005: Two MODIS aerosol products over ocean on the Terra and Aqua CERES SSF datasets, *J. Atmos. Sci.*, **62**, 1008–1031.
- Jin, M.**, R.E. Dickinson, and D.-L. Zhang, 2005: The footprint of urban areas on global climate as characterized by MODIS, *J. Climate*, **18**, 1551–1565.
- \***Jin, M.**, and **J.M. Shepherd**, 2005: Inclusion of urban landscape in a climate model—How can satellite data help? *Bull. Amer. Meteor. Soc.*, **86**, 681–896.
- Jin, M.**, **J.M. Shepherd**, and M.D. King, 2005: Urban aerosols and their interaction with clouds and rainfall: A case study for New York and Houston, *J. Geophys. Res.*, **110** (D10S20), doi:10.1029/2004JD005081.
- \***Kaufman, Y.J.**, O. Boucher, D. Tanre, **M. Chin**, **L.A. Remer**, and T. Takemura, 2005: Aerosol anthropogenic component estimated from satellite data, *Geophys. Res. Lett.* **32** (L17804), doi:10.1029/2005GL023125.
- Kaufman, Y.J.**, **I. Koren**, **L.A. Remer**, D. Rosenfeld, and Y. Rudich, 2005: The effect of smoke, dust and pollution aerosol on shallow cloud development over the Atlantic Ocean, *Proc. Nat. Acad. Sci.*, **102**(32), 11,207–11,212.
- \***Kaufman, Y.J.**, **I. Koren**, **L.A. Remer**, D. Tanre, P. Ginoux, and S. Fan, 2005: Dust transport and deposition observed from the Terra–Moderate Resolution Imaging Spectroradiometer (MODIS) spacecraft over the Atlantic Ocean, *J. Geophys. Res.*, **110** (D10S12), doi:10.1029/2003JDO04436.
- Kaufman, Y.J.**, **L.A. Remer**, D. Tanre, R.-R. Li, R. Kleidman, **S. Mattoo**, **R. Levy**, T. Eck, B.N. Holben, **C. Ichoku**, J. Martins, and **I. Koren**, 2005: A critical examination of the residual cloud contamination and diurnal sampling effects on MODIS estimates of aerosol over ocean, *IEEE Trans. Geosci. Remote Sens.*, **43**(12), 2886–2897.
- \***Kleidman, R.G.**, N.T. O’Neill, **L.A. Remer**, **Y.J. Kaufman**, T.F. Eck, D. Tauré, O. Dubovick, and B.N. Holden, 2005: Comparison of Moderate Resolution Imaging Spectroradiometer (MODIS) and aerosol robotic network (AERONET) remote-sensing retrievals of aerosol fine mode fraction over ocean, *J. Geophys. Res.*, **110** (D22205), doi:10.1029/2005JD005760.

- Knyazikhin, Y., **A. Marshak**, M. Larsen, **W. Wiscombe**, J. Martonchik, and R. Myneni, 2005: Small-scale drop size variability: Impact on estimation of cloud optical properties, *J. Atmos. Sci.*, **62**, 2555–2567.
- \***Koren, I.**, **Y.J. Kaufman**, D. Rosenfeld, **L.A. Remer**, and Y. Rudich, 2005: Aerosol invigoration and restructuring of Atlantic convective clouds, *Geophys. Res. Lett.*, **32** (L14828), doi:10.1029/2005GL023187.
- Levy, R.C.**, **L.A. Remer**, J.V. Martins, **Y.J. Kaufman**, A. Plana-Fattori, J. Redemann, P.B. Russell, and B. Wenny, 2005: Evaluation of the MODIS aerosol retrievals over ocean and land during CLAMS, *J. Atmos. Sci.*, **62**, 974–992.
- Li, R.-R., **L. Remer**, **Y.J. Kaufman**, **S. Mattoo**, B.-C. Gao, and E. Vermote, 2005: Snow and ice mask for the MODIS aerosol products, *IEEE Geosci. Remote Sens. Lett.*, **2**(3), 306–310.
- Mace, G.G., Y. Zhang, **S. Platnick**, M.D. King, P. Minnis, and P. Yang, 2005: Evaluation of cirrus cloud properties derived from MODIS data using cloud properties derived from ground-based observations collected at the ARM SGP site, *J. Appl. Meteor.*, **44**, 221–240.
- Marshak, A.**, and A.B. Davis, 2005: “Scale-by-Scale Analysis and Fractal Cloud Models,” in: *3D Radiative Transfer in Cloudy Atmospheres*, A. Marshak and A. Davis, eds., Springer, New York, 686 pp.
- Marshak, A.**, A. Davis, eds., 2005: *3D Radiative Transfer in Cloudy Atmospheres*, Springer, New York, 686 pp.
- Marshak, A.**, Yu. Knyazikhin, M.L. Larsen, and **W.J. Wiscombe**, 2005: Small-scale drop size variability: Empirical models for drop-size-dependent clustering in clouds, *J. Atmos. Sci.*, **62**, 551–558.
- Marshak, A.**, and A.B. Davis, 2005: “Horizontal Fluxes and Radiative Smoothing,” in: *3D Radiative Transfer in Cloudy Atmospheres*, A. Marshak and A. Davis, eds., Springer, New York, 686 pp.
- Moody, E.G., M.D. King, **S. Platnick**, C.B. Schaaf, and F. Gao, 2005: Spatially complete global spectral surface albedos: Value-Added datasets derived from Terra MODIS land products, *IEEE Trans. Geosci. Remote Sens.*, **43**, 144–158.
- Myhre, G., F. Stordal, M. Johnsrud, D.J. Diner, I.V. Geogdzhayev, J.M. Haywood, B. Holben, T. Holzer-Popp, A. Ignatov, R. Kahn, **Y.J. Kaufman**, N. Loeb, J. Martonchik, M.I. Mishchenko, N.R. Nalli, **L.A. Remer**, M. Schroedter-Homscheidt, et al., 2005: Intercomparison of satellite retrieved aerosol optical depth over ocean during the period September 1997 to December 2000, *Atmos. Chem. Physics*, **5**, 1697–1719.
- Oreopoulos, L.**, 2005: The impact of subsampling on MODIS Level-3 statistics of optical thickness and effective radius, *IEEE Trans. Geosci. Remote Sens.*, **43**(2), 366–373.
- \***Oreopoulos, L.**, and **R.F. Cahalan**, 2005: Cloud inhomogeneity from MODIS, *J. Climate*, **18**(23), 5110–5124, doi:10.1175/JCLI3591.1.
- Prigarin, S.M., and **A. Marshak**, 2005: Numerical model of broken clouds adapted to observations, *Atmos. Ocean. Opt.*, **18**, 236–242.
- Redemann, J., B. Schmid, J.A. Eilers, R. Kahn, **R.C. Levy**, P.B. Russell, J.M. Livingston, P.V. Hobbs, W.L. Smith, and B.N. Holben, 2005: Suborbital measurements of spectral aerosol optical depth and its variability at subsatellite grid scales in support of CLAMS 2001, *J. Atmos. Sci.*, **62**(4), 993–1007.



\***Remer, L.A., Y.J. Kaufman, D. Tanre, S. Mattoo, D.A. Chu, J.V. Martins, R.R. Li, C. Ichoku, R.C. Levy, R.G. Kleidman, T.F. Eck, E. Vermote, and B.N. Holben, 2005: The MODIS aerosol algorithm, products and validation, *J. Atmos. Sci.*, **62**, 947–973.**

**Shepherd, M., and M. Jin, 2005: A Summary of the 2003 Union Session, Human induced climate variations on urban areas: from observations to modeling. *EOS Trans.*, Paper #2004ES000657.**

Tanre, D., **Y. Kaufman**, T. Nakajima, and V. Ramanathan, 2005: Preface to special section on Global Aerosol System, *J. Geophys. Res.*, **110**, D10S01, doi:10.1029/2004JD005724.

**Vant-Hull, B., Z. Li, B.F. Taubman, R. Levy, L. Marufu, F.-L. Chang, B.G. Doddridge, and R.R. Dickerson, 2005: Smoke over haze: Comparative analysis of satellite, surface radiometer, and airborne in situ measurements of aerosol optical properties and radiative forcing over the eastern United States, *J. Geophys. Res.*, **110** (D10S21), doi:10.1029/2004JD004518.**

**Wiscombe, W.J., 2005: “Scales, Tools and Reminiscences,” in: *3D Radiative Transfer in Cloudy Atmospheres*, A. Marshak, and A. Davis, eds., Springer, New York, 686 pp.**

Xue, Y., S. Sun, **K.-M. Lau**, J. Ji, I. Pocard, R. Zhang, H.-S. Kang, G. Wu, J.C. Schaake, J.Y. Zhang, and Y. Jiao, 2005: Multiscale variability of the river runoff system in China and its long-term link to precipitation and sea surface temperature, *J. Hydrometeo.*, **6**(4), 550–570.

**Yu, H., Y.J. Kaufman, M. Chin, G. Feingold, L.A. Remer, T. Anderson, Y. Balkanski, N. Bellouin, O. Boucher, S. Christopher, P. DeCola, R. Kahn, D. Koch, N. Loeb, M.S. Reddy, M. Schultz, T. Takemura, and M. Zhou, 2005: A review of measurement-based assessment of aerosol direct radiative effect and forcing, *Atmos. Chem. Phys. Discuss.*, **5**, 7647–7768.**

Zhang, J., S.A. Christopher, **L.A. Remer, and Y.J. Kaufman, 2005: Shortwave aerosol radiative forcing over cloud-free oceans from Terra I: Angular models for aerosols, *J. Geophys. Res.*, **110** (D10S23), doi:10.1029/2004JD005008.**

Zhang, J., S.A. Christopher, **L.A. Remer, and Y.J. Kaufman, 2005: Shortwave aerosol radiative forcing over cloud-free oceans from Terra II: Seasonal and global distributions, *J. Geophys. Res.*, **110** (D10S24), doi:10.1029/2004JD005009.**

Zhou, M., **H. Yu**, R.E. Dickinson, O. Dubovik, and B. Holben, 2005: A normalized description of the direct effect of key aerosol types on solar radiation as estimated from AERONET aerosols and MODIS albedos, *J. Geophys. Res.*, **110** (D19202), doi:10.1029/2005JD005909.

Zhuravleva, T., and **A. Marshak, 2005: On the validation of the Poisson model of broken clouds, *Izvestiya Atmos. Ocean. Physics*, **6**, 783–797.**

### **Code 613.3 Atmospheric Chemistry and Dynamics Branch**

Anderson, T.L., R.J. Charlson, N. Bellouin, O. Boucher, **M. Chin**, S.A. Christopher, J. Haywood, **Y. Kaufman**, S. Kinne, J.A. Ogren, L.A. Remer, T. Takemura, D. Tanre, **O. Torres**, C.R. Trepte, B.A. Wielicki, D. Winker, and H. Yu, 2005: An A-Train strategy for quantifying direct aerosol radiative forcing, *Bull. Am. Meteor.*, **86**, 12, 1795–1809.

Arola, A., S. Kazadzis, **N. Krotkov**, A. Bias, **J. Herman**, and K. Lakkala, 2005: Assessment of TOMS UV bias due to the absorbing aerosols, *J. Geophys. Res.*, **110** (D23211), doi:10.1029/2005JD005913.

de Almeida Castanho, A.D., J.V. Martins, P.V. Hobbs, P. Artaxo, L. Remer, M. Yamasoe, and **P.R. Colarco**, 2005: Chemical characterization of aerosols on the East Coast of the United States using aircraft and ground based stations during the CLAMS Experiment, *J. Atmos. Sci.*, **62**, 934–946.

Fromm, M., R. Bevilacqua, R. Servranckx, J. Rosen, J.P. Thayer, **J.R. Herman**, and **D. Larko**, 2005: Pyrocumulonimbus injection of smoke to the stratosphere: Observations and impact of a super blowup in northwestern Canada on 3–4 August 1998, *J. Geophys. Res.*, **110** (D08205), doi:10.1029/2004JD005350.

Gurney, K.R., Y.-H. Chen, T. Maki, **S.R. Kawa**, **A.E. Andrews**, and **Z. Zhu**, 2005: Sensitivity of atmospheric CO<sub>2</sub> inversions to seasonal and interannual variations in fossil fuel emissions, *J. Geophys. Res.*, **110** (D10308), doi:10.1029/2004JD005373.

Hansen, J., M. Sato, R. Ruedy, L. Nazarenko, A. Lacis, G.A. Schmidt, G. Russell, I. Aleinov, M. Bauer, S. Bauer, N. Bell, B. Cairns, V. Canuto, M. Chandler, Y. Cheng, A. Del Genio, G. Faluvegi, **E. Fleming**, A. Friend, T. Hall, **C. Jackman**, M. Kelley, N. Kiang, D. Koch, J. Lean, J. Lerner, K. Lo, S. Menon, R. Miller, P. Minnis, T. Novakov, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, D. Shindell, P. Stone, S. Sun, N. Tausnev, D. Thresher, B. Wielicki, T. Wong, M. Yao, and S. Zhang, 2005: Efficacy of climate forcings, *J. Geophys. Res.*, **110** (D18104), doi:10.1029/2005JD005776.

**Huang, F.T., H.G. Mayr**, and C.A. Reber, 2005: Intra-seasonal oscillations (ISO) of zonal-mean meridional winds and temperatures as measured by UARS, *Ann. Geophys.*, **23**, 1131.

Irie, H., K. Sudo, H. Akimoto, A. Richter, J. P. Burrows, T. Wagner, **M. Wenig**, S. Beirle, Y. Kondo, V.P. Sinyakov, and F. Goutail, 2005: Evaluation of long-term tropospheric NO<sub>2</sub> data obtained by GOME over East Asia in 1996–2002, *Geophys. Res. Lett.*, **32** (L11810), doi:10.1029/2005GL022770.

\***Jackman, C.H., M.T. DeLand, G.J. Labow, E.L. Fleming**, D.K. Weisenstein, M.K.W. Ko, M. Sinnhuber, J. Anderson, and J.M. Russell, 2005: The influence of the several very large solar proton events in years 2000–2003 on the neutral middle atmosphere, *Adv. Space Res.*, **35**(3), 445–450.

**Jackman, C.H., M.T. DeLand, G.J. Labow, E.L. Fleming**, D.K. Weisenstein, M.K.W. Ko, M. Sinnhuber, and J.M. Russell, 2005: Neutral atmospheric influences of the solar proton events in October–November 2003, *J. Geophys. Res.*, **110** (A09S27), doi:10.1029/2004JA01088.

\***Joiner, J.**, and P. Poli, 2005: Note on the effects of horizontal gradients for nadir-viewing microwave and infrared sounders, *Quart. J. Roy. Meteor. Soc.*, **131**, 1784–1792.

\***Kawa, S.R., P.A. Newman, R.S. Stolarski**, and R.M. Bevilacqua, 2005: Fall vortex ozone as a predictor of springtime total ozone at high northern latitudes, *Atmos. Chem. Phys.*, **5**, 1655–1663.

Kazadsis, S., A. Bais, N. Kouremeti, E. Gerasopoulos, K. Garane, M. Blumthaler, B. Schallhart, and **A. Cede**, 2005: Direct spectral measurements with a Brewer spectroradiometer: absolute calibration and aerosol optical depth retrieval, *Appl. Optics*, **44**(9), 1681–1690.

Kinne, S., M. Schulz, C. Textor, S. Guibert, Y. Balkanski, S.E. Bauer, T. Berntsen, T.F. Berglen, O. Boucher, **M. Chin**, W. Collins, F. Dentener, **T. Diehl**, R. Easter, J. Feichter, D. Fillmore, S. Ghan, **P. Ginoux**, S. Gong, A. Grini, J. Hendricks, M. Herzog, L. Horowitz, I. Isaksen, T. Iversen, A. Kirkevåg, S. Kloster, D. Koch, J. E. Kristjansson, M. Krol, A. Lauer, J. F. Lamarque, G. Lesins, X. Liu, U. Lohmann, V. Montanaro, G. Myhre, J. Penner, G. Pitari, S. Reddy, O. Seland, P. Stier, T. Takemura, and X. Tie, 2005: An AeroCom initial assessment—optical properties in aerosol component modules of global models, *Atmos. Chem. Phys. Discuss.*, **5**, 8285–8330.

**Krotkov, N.A., P.K. Bhartia, J. Herman, J. Slusser, G. Scott, G. Janson, G. Labow, T. Eck, and B. Holben, 2005:** Aerosol UV absorption experiment (2002–04): 1. UV-MFRSR calibration and intercomparison with CIMEL sun photometers, *Opt. Eng.*, **44**(4), 041004.

**Krotkov, N.A., P.K. Bhartia, J. Herman, J. Slusser, G. Scott, G. Labow, A. Vasilkov, T. Eck, O. Dubovik, and B. Holben, 2005:** Aerosol UV absorption experiment (2002–04): 2. Absorption optical thickness, refractive index, and single scattering albedo, *Opt. Eng.*, **44**(4), 041005.

Kondragunta, S., L.E. Flynn, A. Neuendorffer, A.J. Miller, C. Long, R. Nagatani, S. Zhou, T. Beck, E. Beach, **R.D. McPeters, R.S. Stolarski, P.K. Bhartia, M.T. Deland,** and L.-K. Huang, 2005: Vertical structure of the anomalous 2002 Antarctic ozone hole, *J. Atmos. Sci.*, **62**, 801–811.

LeMarshall, J., J. Jung, J. Derber, R. Treadon, S.J. Lord, M. Goldberg, W. Wolf, H.C. Liu, **J. Joiner, J. Woollen, R. Todling,** and R. Gelaro, 2005: Impact of atmospheric infrared sounder observations on weather forecasts, *Eos*, **86**, 109–116.

LeMarshall, J., J. Jung, J. Derber, R. Treadon, S.J. Lord, M. Goldberg, W. Wolf, H.C. Liu, **J. Joiner, J. Woollen, R. Todling, P. van Delst,** and Y. Tahara, 2005: AIRS hyperspectral data improves Southern Hemisphere forecasts, *Austral. Meteor. Mag.*, **54**, 57–60.

Lopez-Puertas, M., B. Funke, S. Gil-Lopez, T. von Clarmann, G.P. Stiller, M. Hopfner, S. Kellmann, H. Fischer, and **C.H. Jackman**, 2005: Observations of NO<sub>x</sub> enhancement and ozone depletion in the Northern and Southern Hemispheres after the October–November 2003 solar proton events, *J. Geophys. Res.*, **110** (A09S43), doi:10.1029/2005JA011050.

Lopez-Puertas, M., B. Funke, S. Gil-Lopez, G. Mengistu Tsidu, H. Fischer, and **C.H. Jackman**, 2005: HNO<sub>3</sub>, N<sub>2</sub>O<sub>5</sub>, and ClONO<sub>2</sub> enhancements after the October–November 2003 solar proton events, *J. Geophys. Res.*, **110** (A09S44), doi:10.1029/2005JA011051.

\***Loughman, R.P., D.E. Flittner, B.M. Herman, P.K. Bhartia, E. Hilsenrath,** and **R.D. McPeters**, 2005: Description and sensitivity analysis of a limb scattering ozone retrieval algorithm, *J. Geophys. Res.*, **110**, doi:10.1029/2004JD005429.

**Mayr, H.G., and J.G. Mengel**, 2005: Interannual variations of the diurnal tide in the mesosphere generated by the quasi-biennial oscillation, *J. Geophys. Res.*, **110**, 10.1029/2004JD005055.

**Mayr, H.G., J.G. Mengel, E.R. Talaat, H.S. Porter,** and K.L. Chan, 2005: Mesospheric non-migrating tides generated with planetary wave: I Characteristics, *J. Atmos. Solar-Terr. Phys.*, **67**, 1187.

**Mayr, H.G., J.G. Mengel, E.R. Talaat, H.S. Porter,** and K.L. Chan, 2005: Mesospheric non-migrating tides generated with planetary wave: II Influence of gravity waves, *J. Atmos. Solar-Terr. Phys.*, **67**, 1287.

**Mayr, H.G., J.G. Mengel, C.L. Wolff**, 2005: Wave-driven equatorial annual oscillation induced and modulated by the solar cycle, *Geophys. Res. Lett.*, **32** (L20811), doi:10.1029/2005GL023090.

Meloni, D., A. di Sarra, **J.R. Herman, F. Monteleone,** and S. Piacentino, 2005: Comparison of ground-based and TOMS erythemal UV doses at the island of Lampedusa in the period 1998–2003: the role of tropospheric aerosols, *J. Geophys. Res.*, **110** (D01202), doi:10.1029/2004JD005283, 2005.

Melott, A.L., B.C. Thomas, D.P. Hogan, L.M. Ejzak, and **C.H. Jackman**, 2005: Climatic and biogeochemical effects of a galactic gamma-ray burst, *Geophys. Res. Lett.*, **32** (L14808), doi:10.1029/2005GL023073.

- Morris, G.A.**, M.R. Schoeberl, **B. Bojkov**, **L.R. Lait**, and M. Rex, 2005: A review of the Match technique as applied to SOLVE/THESEO and AASE-2/EASOE, *Atmos. Chem. Phys.* **5**, 2571–2592.
- Patra, P.K., S.K. Behera, **J.R. Herman**, S. Maksyutov, H. Akimoto, and T. Yamagata, 2005: The Indian summer monsoon rainfall: interplay of coupled dynamics, radiation and cloud microphysics, *Atmos. Chem. Phys. Discuss.*, **5**, 2879–2895.
- Rosenfield, J.E.**, and M.R. Schoeberl, 2005: Recovery of the tropical lower stratospheric ozone layer, *Geophys. Res. Lett.*, **21**, doi:10.1029/2005GL023626.
- \***Rosenfield, J.E.**, **S.M. Frith**, and **R.S. Stolarski**, 2005: Version 8 SBUV ozone profile trends compared with trends from a zonally averaged model, *J. Geophys. Res.*, **110**, doi:10.1029/2004JD005466.
- Rohen, G., C. von Savigny, M. Sinnhuber, E.J. Llewellyn, J.W. Kaiser, **C.H. Jackman**, M.-B. Kallenrode, J. Schroter, K.-U. Eichmann, H. Bovensmann, and J.P. Burrows, 2005: Ozone depletion during the solar proton events of October/November 2003 as seen by SCIAMACHY, *J. Geophys. Res.*, **110** (A09S39), doi:10.1029/2004JA010984.
- Semeniuk, K., J.C. McConnell, and **C.H. Jackman**, 2005: Simulation of the October–November 2003 solar proton event in the CMAM GCM comparison with observations, *Geophys. Res. Lett.*, **32** (L15S02), doi:10.1029/2005GL022392.
- Stevens, M.H., C.R. Englert, **M.T. DeLand**, and M. Hervig, 2005: The polar mesospheric cloud mass in the Arctic summer, *J. Geophys. Res.*, **110** (A02306), doi:10.1029/2004JA010566.
- Stevens, M.H., R.R. Meier, X. Chu, **M.T. DeLand**, and J.M.C. Plane, 2005: Antarctic mesospheric clouds formed from space shuttle exhaust, *Geophys. Res. Lett.*, **32** (L13810), doi:10.1029/2005GL023054.
- Textor, C., M. Schulz, S. Guibert, S. Kinne, Y. Balkanski, S. Bauer, T. Berntsen, T. Berglen, O. Boucher, **M. Chin**, F. Dentener, **T. Diehl**, R. Easter, H. Feichter, D. Fillmore, S. Ghan, **P. Ginoux**, S. Gong, A. Grini, J. Hendricks, L. Horowitz, P. Huang, I. Isaksen, T. Iversen, S. Kloster, D. Koch, A. Kirkevåg, J.E. Kristjansson, M. Krol, A. Lauer, J.F. Lamarque, X. Liu, V. Montanaro, G. Myhre, J. Penner, G. Pitari, S. Reddy, O. Seland, P. Stier, T. Takemura, T. and X. Tie, 2005: Analysis and quantification of the diversities of aerosol life cycles within AeroCom, *Atmos. Chem. Phys. Discuss.*, **5**, 8331–8420.
- Thomas, B.C., **C.H. Jackman**, A.L. Melott, C.M. Laird, **R.S. Stolarski**, N. Gehrels, J.K. Cannizzo, and D.P. Hogan, 2005: Terrestrial Ozone Depletion due to a Milky Way Gamma-Ray Burst, *Astrophys. J.*, **622**, L153–L156.
- \***Torres, O.**, **P.K. Bhartia**, A. Syniuk, **E. Welton**, and B. Holben, 2005: Total Ozone Mapping Spectrometer measurements of aerosol absorption from space: Comparison to SAFARI 2000 ground-based observations, *J. Geophys. Res.*, **110**, D10S18, doi:10.1029/2004JD004611.
- Vasilkov, A.P.**, **J.R. Herman**, **Z. Ahmad**, M. Kahru, and G. Mitchell, 2005: Assessment of the ultraviolet radiation field in ocean waters from space-based measurements and full radiative transfer calculations, *Appl. Optics*, **44**(14), 2863–2869.
- Vautard, R., B. Bessagnet, **M. Chin**, and L. Menut, 2005: On the contribution of natural Aeolian sources to particulate matter concentrations in Europe: Testing hypothesis with a modeling approach, *Atmos. Envi.*, **39**, 3291–3303.

Viereck, R.A., L.E. Floyd, P.C. Crane, T.N. Woods, B.G. Knapp, G. Rottman, M. Weber, L.C. Puga, and **M.T. DeLand**, 2005: A composite Mg II index spanning from 1978 to 2003, *Space Weather*, **3** (S10005), doi:10.1029/2004SW 000084.

\***Wenig, M.**, B. Jähne, and U. Platt, 2005: Operator representation as a new differential optical absorption spectroscopy formalism, *Appl. Optics*, **44**(16), 3246–3253.



## APPENDIX A3. HIGHLIGHTED ARTICLES PUBLISHED IN 2005

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LAU ET AL.

4731

## Effects of Cloud Microphysics on Tropical Atmospheric Hydrologic Processes and Intraseasonal Variability

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## ABSTRACT

The sensitivity of tropical atmospheric hydrologic processes to cloud microphysics is investigated using the NASA Goddard Earth Observing System (GEOS) general circulation model (GCM). Results show that a faster autoconversion rate leads to (a) enhanced deep convection in the climatological convective zones anchored to tropical land regions; (b) more warm rain, but less cloud over oceanic regions; and (c) an increased convective-to-stratiform rain ratio over the entire Tropics. Fewer clouds enhance longwave cooling and reduce shortwave heating in the upper troposphere, while more warm rain produces more condensation heating in the lower troposphere. This vertical differential heating destabilizes the tropical atmosphere, producing a positive feedback resulting in more rain and an enhanced atmospheric water cycle over the Tropics. The feedback is maintained via secondary circulations between convective tower and anvil regions (cold rain), and adjacent middle-to-low cloud (warm rain) regions. The lower cell is capped by horizontal divergence and maximum cloud detrainment near the freezing–melting ( $0^{\circ}\text{C}$ ) level, with rising motion (relative to the vertical mean) in the warm rain region connected to sinking motion in the cold rain region. The upper cell is found above the  $0^{\circ}\text{C}$  level, with induced subsidence in the warm rain and dry regions, coupled to forced ascent in the deep convection region.

It is that warm rain plays an important role in regulating the time scales of convective cycles, and in altering the tropical large-scale circulation through radiative–dynamic interactions. Reduced cloud–radiation feedback due to a faster autoconversion rate results in intermittent but more energetic eastward propagating Madden–Julian oscillations (MJOs). Conversely, a slower autoconversion rate, with increased cloud radiation produces MJOs with more realistic westward-propagating transients embedded in eastward-propagating supercloud clusters. The implications of the present results on climate change and water cycle dynamics research are discussed.

### 1. Introduction

Recently, there has been a growing body of evidence indicating the importance of tropical warm rain processes in the organization of tropical convection, modulation of clouds and rain types, and possibly global warming. Using 3 yr of data from the Tropical Rainfall Measuring Mission (TRMM), Short and Nakamura (2000) found that more than 20% of the total rain from the Tropics is derived from shallow convection. Johnson et al. (1999) showed that approximately 28% of the rainfall during the Tropical Ocean Global Atmosphere Couple Ocean–Atmosphere Research Experiment (TOGA COARE) may be accounted for by warm

rain from midlevel *cumulus congestus*, and pointed to the importance of a midtropospheric inversion layer, formed by the melting of ice-phase precipitation falling from above, in limiting the growth of penetrative deep convection. They proposed that a basic trimodal (high, middle, and low), rather than the commonly accepted bimodal (high and low), cloud distribution as a more realistic description of the tropical cloud system. They also pointed out the importance of the cumulus congestus in determining the adjustment time scale of convective cycles. Wu (2003) inferred from theoretical calculations that about 20% of the latent heating in the Tropics would be contributed by mid- to low-level condensation processes in order to maintain the observed moist static stability profile. Innes et al. (2001) demonstrated that significant improvement in the simulation of the Madden–Julian oscillation (MJO) can be achieved by increasing vertical resolution, which helps to better resolve the melting level in convection in the

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## Contrasting Indian Ocean SST variability with and without ENSO influence: A coupled atmosphere-ocean GCM study

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With 10 Figures

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### Summary

In this study, we perform experiments with a coupled atmosphere-ocean general circulation model (CGCM) to examine ENSO's influence on the interannual sea-surface temperature (SST) variability of the tropical Indian Ocean. The control experiment includes both the Indian and Pacific Oceans in the ocean model component of the CGCM (the Indo-Pacific Run). The anomaly experiment excludes ENSO's influence by including only the Indian Ocean while prescribing monthly-varying climatological SSTs for the Pacific Ocean (the Indian-Ocean Run). In the Indo-Pacific Run, an oscillatory mode of the Indian Ocean SST variability is identified by a multi-channel singular spectral analysis (MSSA). The oscillatory mode comprises two patterns that can be identified with the Indian Ocean Zonal Mode (IOZM) and a basin-wide warming/cooling mode respectively. In the model, the IOZM peaks about 3–5 months after ENSO reaches its maximum intensity. The basin mode peaks 8 months after the IOZM. The timing and associated SST patterns suggests that the IOZM is related to ENSO, and the basin-wide warming/cooling develops as a result of the decay of the IOZM spreading SST anomalies from western Indian Ocean to the eastern Indian Ocean. In contrast, in the Indian-Ocean Run, no oscillatory modes can be identified by the MSSA, even though the Indian Ocean SST variability is characterized by east–west SST contrast patterns similar to the IOZM. In both control and anomaly runs, IOZM-like SST variability appears to be associated with forcings from fluctuations of the Indian monsoon. Our modeling results suggest that the oscillatory feature of the IOZM is primarily forced by ENSO.

### 1. Introduction

The recent interests in the observed east–west contrast pattern in Indian Ocean sea-surface temperature (SST) anomalies have prompted the suggestion that the Indian Ocean has its own unstable coupled atmosphere-ocean mode like El Niño-Southern Oscillation (ENSO) (e.g., Saji et al, 1999; Webster et al, 1999). This interannual SST variability is often referred to as Indian Ocean Zonal Mode (IOZM) or Indian Ocean Dipole. The IOZM is characterized by opposite polarities of SST anomalies between the western and eastern parts of the equatorial Indian Ocean, and is accompanied with zonal wind anomalies in the central Indian Ocean. The strong wind-SST coupling associated with the IOZM has been used to argue for the similarity of the phenomenon to the delayed oscillator of ENSO (Webster et al, 1999). The fact that the temporal correlation between the observed IOZM and ENSO events is not strong and that several significant IOZM events have occurred in the absence of large ENSO events have lead to the suggestion that the IOZM is independent of ENSO (Saji et al, 1999). On the other hand, there are suggestions that the IOZM is not an



# Effect of urbanization on the diurnal rainfall pattern in Houston

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## Abstract:

Data from 19 rain gauges located within and nearby Houston were analysed to quantify the impact of urbanization of the Houston metropolitan area on the local diurnal rainfall pattern. The average annual and warm-season diurnal rainfall patterns were determined for one time period when Houston was relatively small and likely would not have had a significant effect on meteorological processes (1940–58) and for a second, more recent, time period after Houston had become a major metropolitan area (1984–99). The diurnal rainfall patterns within the hypothesized urban-affected region and an upwind control region were compared for the pre- and post-urban time periods. Results indicated that the diurnal rainfall distribution in the urban area is much different than that found for the upwind and downwind adjacent regions for the 1984 to 1999 time period. For an average warm season from 1984 to 1999, the urban area and downwind urban-impacted region registered 59% and 30% respectively greater rainfall amounts from noon to midnight than an upwind control region. Moreover, the urban area had approximately 80% more recorded rainfall occurrences between noon and midnight during the warm season than surrounding areas. Comparison of the pre- and post-urban rainfall patterns indicated that the diurnal rainfall distribution has changed in southeast Texas. The changes are most significant in the urban area, especially for the afternoon time increments during the warm season. The average warm-season rainfall amount registered in the urban area increased by 25% from the pre- to the post-urban time period, while the amount in the upwind control region decreased by 8%. The majority of the increase was observed for the noon to 4 p.m. and 4 p.m. to 8 p.m. time increments. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS inadvertent weather modification; urbanization; diurnal rainfall distribution

## INTRODUCTION

Urbanization alters the appearance of the natural landscape and perturbs Earth system processes. The hydrological cycle, in particular, is changed during construction as vegetation is removed, the soil layer is modified, and built structures and drainage infrastructure are introduced. In general, development activities within a watershed will reduce infiltration and groundwater recharge, increase surface runoff volumes and rates, reduce soil moisture, and modify the spatial distribution and magnitude of surface storage and fluxes of water and energy. The perturbed post-development hydrological processes can contribute to increased frequencies and magnitudes of nuisance and severe floods, accelerated geomorphologic changes to downstream waterways, and aquatic habitat impacts. Urban drainage controls are designed and constructed to mitigate hydrological impacts of development. Design procedures are based on providing adequate conveyance, infiltration, and/or storage capacity to control the modified surface runoff produced by rainstorms. The change in watershed characteristics between pre- and post-development is included in the design by performing the runoff calculations for post-development conditions. However, the change in the rainfall characteristics possibly caused by urbanization is not accounted for in the traditional design process, whereby the design storm is

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## The Cold Front of 15 April 1994 over the Central United States. Part I: Observations

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### ABSTRACT

Detailed observations of the interactions of a cold front and a dryline over the central United States that led to dramatic undulations in the boundary layer, including an undular bore, are investigated using high-resolution water vapor mixing ratio profiles measured by Raman lidars. The lidar-derived water vapor mixing ratio profiles revealed the complex interaction between a dryline and a cold-frontal system. An elevated, well-mixed, and deep midtropospheric layer, as well as a sharp transition (between 5- and 6-km altitude) to a drier region aloft, was observed. The moisture oscillations due to the undular bore and the mixing of the prefrontal air mass with the cold air at the frontal surface are all well depicted. The enhanced precipitable water vapor and roll clouds, the undulations associated with the bore, the strong vertical circulation and mixing that led to the increase in the depth of the low-level moist layer, and the subsequent lifting of this moist layer by the cold-frontal surface, as well as the feeder flow behind the cold front, are clearly indicated.

A synthesis of the Raman lidar-measured water vapor mixing ratio profiles, satellite, radiometer, tower, and Oklahoma Mesonet data indicated that the undular bore was triggered by the approaching cold front and propagated south-southeastward. The observed and calculated bore speeds were in reasonable agreement. Wave-ducting analysis showed that favorable wave-trapping mechanisms existed; a low-level stable layer capped by an inversion, a well-mixed midtropospheric layer, and wind curvature from a low-level jet were found.

### 1. Introduction

During evenings and early morning hours, the lower atmosphere commonly acts as a waveguide for the propagation of a variety of atmospheric waves that occur in a wide range of both temporal and spatial scales. The undular bore, a propagating disturbance characterized by an abrupt increase in ground-level pressure associated with an increase in ground-level temperature and a shift in wind direction often consisting of wavelike oscillations, is one example that uses the stably stratified layer within the lower atmosphere as a waveguide. Observations of bores have been reported by several authors including Clarke et al. (1981), Shreffler and Binkowski (1981), Smith et al. (1982),

Doviak and Ge (1984), Haase and Smith (1984), Simpson (1987), Cheung and Little (1990), Fulton et al. (1990), Koch et al. (1991), Locatelli et al. (1998), Koch and Clark (1999), and others. The Morning Glory, a frequent phenomenon near the Gulf of Carpentaria in northern Australia, reported extensively by Clarke et al. (1981), is an undular bore propagating along a temperature inversion generated by the interaction of a sea-breeze front with a nocturnal maritime inversion.

Several theories have been proposed as possible generation mechanisms for atmospheric bores. Numerical computations of density currents encountering strong stratification near the ground (Crook and Miller 1985; Crook 1986, 1988; Noonan and Smith 1986; Haase and Smith 1989), cool air behind colliding gravity currents (Clarke 1983; Noonan and Smith 1986; Wakimoto and Kingsmill 1995), thunderstorm outflows (Shreffler and Binkowski 1981; Doviak et al. 1989; Fulton et al. 1990), and mesoscale fronts (Smith et al. 1982; Koch et al.

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## Height distribution between cloud and aerosol layers from the GLAS spaceborne lidar in the Indian Ocean region

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[1] The Geoscience Laser Altimeter System (GLAS), a nadir pointing lidar on the Ice Cloud and land Elevation Satellite (ICESat) launched in 2003, now provides important new global measurements of the relationship between the height distribution of cloud and aerosol layers. GLAS data have the capability to detect, locate, and distinguish between cloud and aerosol layers in the atmosphere up to 40 km altitude. The data product algorithm tests the product of the maximum attenuated backscatter coefficient  $b'(r)$  and the vertical gradient of  $b'(r)$  within a layer against a predetermined threshold. An initial case result for the critical Indian Ocean region is presented. From the results the relative height distribution between collocated aerosol and cloud shows extensive regions where cloud formation is well within dense aerosol scattering layers at the surface. **Citation:** Hart, W. D., J. D. Spinhirne, S. P. Palm, and D. L. Hlavka (2005), Height distribution between cloud and aerosol layers from the GLAS spaceborne lidar in the Indian Ocean region, *Geophys. Res. Lett.*, 32, L22S06, doi:10.1029/2005GL023671.

### 1. Introduction

[2] Both cloud and aerosols have important direct effects on the radiation balance of the earth. They influence the incoming solar energy by changing the albedo of the earth-atmosphere system and if absorbing they provide an increase in atmospheric radiative heating rates through the vertical range of their distribution. In addition, cloud and aerosol particles can interact with each other to produce significant secondary influences. For instance, Twomey [1974] describes how certain types of aerosols can increase low-cloud droplet concentrations, which would reduce incoming energy by increasing albedo without reducing the compensatory thermally emitted energy as much, and hence would be a cooling influence. More recent modeling studies [Ackerman *et al.*, 2003] support this theory while some satellite observations [Platnick *et al.*, 2000] seem to counter it. Opposed to the enhancement of low cloud cover by aerosol layers, there is evidence [Ackerman *et al.*, 2000] that heating by aerosol particles such as soot can reduce low cloud cover by absorbing incoming solar radiation. This is done both by evaporating cloud particles and stabilizing the boundary layer by preferred heating of its top. The interaction between aerosol and clouds are now also thought to be a major influence on precipitation [Rosenfeld, 2000].

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[3] These examples of the opposing influences that the presence of aerosol has on the distribution and characteristics of cloud cover serve to illustrate the complexity of the atmospheric cloud-aerosol system. In order to quantify the effects that they impose on the earth's radiation balance, it is necessary that the global distribution of clouds and aerosol layers, especially with regard to their coincident occurrences, be well known. The height distribution of aerosol radiative forcing needs to be known separately and with correct clearing of cloud scattering [Coakley *et al.*, 2002]. In addition, the height distribution is an issue for the remote sensing of clouds. If there is significant aerosol scattering and absorption above cloud or elevated within clouds, passive multi-spectral techniques may be in error [Sekiguchi *et al.*, 2003]. Satellite observations provide a potential opportunity to find these distributions globally if the signals from the aerosols and clouds can be separated and vertically located. Spaceborne lidar offers a means to derive these kinds of products from backscatter measurements.

[4] The Geoscience Laser Altimeter System (GLAS) is a laser remote sensing instrument launched into orbit aboard ICESat in January, 2003. GLAS is a dual-purpose laser instrument, serving as both a precision surface elevation altimeter and atmospheric lidar [Spinhirne *et al.*, 2005]. Since February of 2003, GLAS has operated during discrete periods of approximately 33 days duration. When operating, it provides continuous and nearly pole-to-pole atmospheric lidar observations of clouds and aerosols through altitudes of 0–40 km. A complete description of cloud and aerosol observations and analysis resolutions is given by Palm *et al.* [2002]. GLAS is sensitive to very optically rarefied particulate layers, down to backscatter cross section below  $10^{-7}$  (m-sr)<sup>-1</sup> and is capable of detecting multiple layers to the limit of signal (optical depth < about 4.0).

[5] In this study, we introduce and present a brief summary of the GLAS cloud/aerosol algorithm. We show and discuss its strengths and weaknesses. Building on that, we present a case study in the heavily polluted Indian Ocean Region for the distribution of aerosol and clouds. We show GLAS's unique capability as a tool to accurately and comprehensively detect cloud and aerosols in the atmosphere and define their relative distribution.

### 2. Cloud/Aerosol Discrimination Technique

[6] A lidar signal is proportional to the attenuated backscatter coefficient,  $b'(r)$ . This is light backscattered from an atmospheric volume a distance  $r$  from the lidar multiplied by the intervening two way transmission. The GLAS cloud/aerosol detection and discrimination is based upon historically observed differences between cloud and aerosol layers in the magnitude of  $b'(r)$ , and the magnitude

## Measurements of Ocean Surface Backscattering Using an Airborne 94-GHz Cloud Radar—Implication for Calibration of Airborne and Spaceborne W-Band Radars

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### ABSTRACT

Backscattering properties of the ocean surface have been widely used as a calibration reference for airborne and spaceborne microwave sensors. However, at millimeter-wave frequencies, the ocean surface backscattering mechanism is still not well understood, in part, due to the lack of experimental measurements. During the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE), measurements of ocean surface backscattering were made using a 94-GHz (W band) cloud radar on board a NASA ER-2 high-altitude aircraft. This unprecedented dataset enhances our knowledge about the ocean surface scattering mechanism at 94 GHz. The measurement set includes the normalized ocean surface cross section over a range of the incidence angles under a variety of wind conditions. It was confirmed that even at 94 GHz, the normalized ocean surface radar cross section,  $\sigma_{\text{os}}$ , is insensitive to surface wind conditions near a  $10^\circ$  incidence angle, a finding similar to what has been found in the literature for lower frequencies. Analysis of the radar measurements also shows good agreement with a quasi-specular scattering model at low incidence angles. The results of this work support the proposition of using the ocean surface as a calibration reference for airborne millimeter-wave cloud radars and for the ongoing NASA CloudSat mission, which will use a 94-GHz spaceborne cloud radar for global cloud measurements.

### 1. Introduction

Clouds play a critical role in the earth's climate system. The vertical structure and spatial distributions of clouds are important in determining the earth's radiation budgets, which affect global circulations and ultimately

climate. However, the lack of finescale cloud data is apparent in current climate model simulations (Houghton et al. 1995; Stephens et al. 1990). Millimeter-wave cloud radars have gained favor for measuring the spatial distribution of clouds because of their high scattering efficiency, low power consumption, and compact size. A number of airborne millimeter-wave cloud radars have been developed (Pazmany et al. 1994; Sadowy et al. 1997; Li et al. 2004). Meanwhile, a 94-GHz spaceborne cloud radar is in preparation for the National Aeronautics and Space Administration's

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## Nucleation in synoptically forced cirrostratus

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[1] Formation and evolution of cirrostratus in response to weak, uniform, and constant synoptic forcing is simulated using a one-dimensional numerical model with explicit microphysics, in which the particle size distribution in each grid box is fully resolved. A series of tests of the model response to nucleation modes (homogeneous-freezing-only/heterogeneous nucleation) and heterogeneous nucleation parameters are performed. In the case studied here, nucleation is first activated in the prescribed moist layer. A continuous cloud-top nucleation zone with a depth depending on the vertical humidity gradient and one of the nucleation parameters is developed afterward. For the heterogeneous nucleation cases, intermittent nucleation zones in the mid-upper portion of the cloud form where the relative humidity is on the rise because existent ice crystals falling from higher nucleation zones do not efficiently deplete the excess water vapor and ice nuclei are available. Vertical resolution as fine as 1 m is required for realistic simulation of the homogeneous-freezing-only scenario, while the model resolution requirement is more relaxed in the cases where heterogeneous nucleation dominates. Bulk microphysical and optical properties are evaluated and compared. Ice particle number flux divergence, which is due to the vertical gradient of the gravity-induced particle sedimentation, is constantly and rapidly changing the local ice number concentration, even in the nucleation zone. When the depth of the nucleation zone is shallow, particle number concentration decreases rapidly as ice particles grow and sediment away from the nucleation zone. When the depth of the nucleation zone is large, a region of high ice number concentration can be sustained. The depth of nucleation zone is an important parameter to be considered in parametric treatments of ice cloud generation.

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### 1. Introduction

[2] The optical depth of cirrus, one of the controlling factors determining its associated net cloud radiative forcing, depends on the cloud ice water path (IWP) and effective particle size [e.g., *Foot*, 1988]. Some state-of-the-art general circulation models (GCMs) now predict hydro-meteor mixing ratios [e.g., *Del Genio et al.*, 1996; *Fowler et al.*, 1996]. However, realistic prediction of cirrus optical and microphysical properties requires accurate estimation of the number concentration of ice particles generated in the nucleation regime. Using an approximate analytical

solution validated by parcel model simulations, *Kärcher and Lohmann* [2002] developed a parameterization scheme for ice particle number concentration via homogeneous freezing nucleation of aerosol particles and implemented it into the European Center Hamburg (ECHAM) GCM [*Lohmann and Kärcher*, 2002] to examine the aerosol effects on the ice cloud and Earth-atmosphere radiative budgets. Despite advances in parameterization schemes of aerosol effects on ice initiation, our fundamental understanding of the evolution of synoptically forced cirrus still lags. Studies based on parcel models are typically not able to provide information about the entire cloud from cloud base to cloud top. Moreover, parcel model studies usually assume that the ice particles are lifted with the parcel (no particle fallout or fall-in) and that there is no exchange of mass or heat with the environment. Neglect of particle fallout/fall-in is questionable for weak forcing conditions, where nucleation may last several to more than 10 min. Thus a model of one-dimension (1-D) or higher [e.g., *Jensen et al.*, 1994a, 1994b; *Khvorostyanov et al.*, 2001; *Sassen et al.*, 2002] is needed to adequately estimate cloud bulk properties over the entire cloud depth. In our study a 1-D model with an explicit microphysical scheme is used to simulate a column of air lifted by a gentle updraft.

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## Validation of ECMWF global forecast model parameters using GLAS atmospheric channel measurements

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[1] Satellite lidar (LIght Detection And Ranging) data from GLAS is used to ascertain the performance of the European Center for Medium Range Weather Forecasts model predictions of cloud fraction, cloud vertical distribution, and boundary layer height. Results show that the model is reasonably accurate for low and middle clouds, but often misses the location and amount of high cirrus clouds. The model tends to overestimate high cloud fraction and this error grows with forecast length. The GLAS-derived boundary layer height over the oceans is generally 200–400 m higher than the model predictions, but small-scale and global patterns of PBL height show similar features. **Citation:** Palm, S. P., A. Benedetti, and J. Spinhirne (2005), Validation of ECMWF global forecast model parameters using GLAS atmospheric channel measurements, *Geophys. Res. Lett.*, 32, L22S09, doi:10.1029/2005GL023535.

### 1. Introduction

[2] In January 2003 the Geoscience Laser Altimeter System (GLAS) was launched into a near-polar orbit aboard the Ice Cloud and land Elevation Satellite (ICESat) [Zwally *et al.*, 2002]. In addition to a high resolution 1064 nm altimetry channel, GLAS contains both 1064 and 532 nm atmospheric backscatter lidar channels. The 532 nm atmospheric channel has been operating since September 25, 2003 providing unprecedented views of the vertical structure of atmospheric aerosol, cloud layers and the depth and structure of the planetary boundary layer (PBL) [Spinhirne *et al.*, 2005]. The high vertical (76 m) and horizontal (175 m) resolution of the GLAS data provide accurate measurements of cloud height and vertical structure, tropopause height and Planetary Boundary Layer (PBL) height. These measurements constitute a valuable data set for the validation of global weather forecast and climate models. Clouds play an integral role in the climate system, primarily through their role as modulators of radiative transfer and their contribution to diabatic heating. The accurate representation of clouds in these models is, therefore, extremely important. However, it is difficult, if not impossible, to verify its forecasts of cloud extent and coverage, especially in the vertical. Similarly, PBL height is an important model parameter that is difficult to validate due to a lack of global observations.

[3] GLAS represents a unique opportunity to verify cloud field forecasts of various models such as the European

Center for Medium-range Weather Forecasts (ECMWF) forecast model. Using an approach similar to the method presented here, Miller *et al.* [1999] validated ECMWF model output of cloud height and coverage using limited data from the shuttle Lidar In-space Technology Experiment (LITE). Randall *et al.* [1998] compared boundary layer height derived from the LITE data with output from the Colorado State University atmospheric general circulation model as well as the National Center for Atmospheric Research (NCAR) Community Climate Model 3 (CCM3). In this paper we demonstrate the utility of GLAS data for the verification of global ECMWF output fields of cloud height, fraction and PBL height. As orbiting lidar data from the ICESat Mission, CALIPSO [Winker *et al.*, 2003] and The Earth Explorer Atmospheric Dynamics Mission (ADM-Aeolus) [Duran *et al.*, 2004] and those to follow become commonplace, the value for not only model validation but also for data assimilation will greatly increase.

### 2. Data and Methodology

[4] The ECMWF spectral model contains a sophisticated cloud scheme that is highly regarded within the scientific community [Jakob, 2003]. It uses triangular truncation at wave number 511 (roughly 40 km resolution) and has 60 model levels in the vertical. This is a slight increase in resolution compared to the version of the ECMWF model used by Miller *et al.* [1999] in their analyses (60 × 60 km horizontal with 31 vertical levels). The GLAS data utilized for this study are the vertical cross-sections of calibrated attenuated backscatter along the ICESat ground track (GLA07) [Spinhirne *et al.*, 2005]. The 5 Hz data were first averaged to a 5 second horizontal resolution (35 km), and the 5s orbital position data were then supplied to ECMWF for a number of ICESat orbits. ECMWF 6 and 48 hour global forecasts were run such that the verification times are within 3 hours of the given ICESat orbit. The ECMWF forecast fields were extracted from the output grid box that intersects with the ICESat orbit. The ECMWF data consist of vertical profiles of the prognostic fields at each of 60 model pressure levels ranging from the surface to the 0.1 mb level, where each pressure surface corresponds to a specific geometric height. Linear interpolation was then used to vertically interpolate the ECMWF cloud fraction from the model levels to the vertical grid defined by the GLAS data (every 76 m) starting at sea level and extending to an altitude of 20 km. After this process is completed, the two data sets are vertically aligned and can be compared in a number of ways. Note that in the analysis presented here, no consideration is being made for the fact that we are comparing a thin cross-section through the atmosphere with

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## Cloud and aerosol measurements from GLAS: Overview and initial results

James D. Spinhirne,<sup>1</sup> Stephen P. Palm,<sup>2</sup> William D. Hart,<sup>2</sup> Dennis L. Hlavka,<sup>2</sup> and Ellsworth J. Welton<sup>1</sup>

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[1] Global space borne lidar profiling of atmospheric clouds and aerosol began in 2003 following the launch of the Geoscience Laser Altimeter System (GLAS) on the Ice, Cloud and land Elevation Satellite. GLAS obtains nadir profiles through the atmosphere in two wavelength channels, day and night, at a fundamental resolution of 76.8 m vertical and 172 m along track. The 532 nm channel uses photon-counting detectors and resolves profiles of observed backscatter cross sections to  $10^{-7}$  1/m-sr. The 1064 nm channel employs analog detection adequate to  $10^{-6}$  1/m-sr and with greater dynamic range. By 2005 approximately seven months of global data are available. Processing algorithms produce data products for the corrected lidar signal, cloud and aerosol layer boundaries and optical thickness and extinction and backscatter cross sections. Operational sensitivity is shown by the frequency distribution for cloud optical thickness peaking at approximately 0.02. **Citation:** Spinhirne, J. D., S. P. Palm, W. D. Hart, D. L. Hlavka, and E. J. Welton (2005), Cloud and aerosol measurements from GLAS: Overview and initial results, *Geophys. Res. Lett.*, 32, L22S03, doi:10.1029/2005GL023507.

### 1. Introduction

[2] Since the advent of satellite remote-sensing, passive imaging radiometers of multiple types have provided observations of global cloud and aerosol layer distributions. Yet there are issues of increasing importance where passive sensing alone is not adequate. Both cloud feedback and the influence of aerosol are considered major uncertainties for predictions of global warming. Global observations should be sufficient to provide adequate information for climate models, but also of sufficient sensitivity to monitor critical component variability in response to climate change. Passive instruments do not provide direct and accurate observations of the height distribution of aerosol along with accurate extinction and absorption information. Similarly for cloud cover, errors in height and coverage from passive retrieval are typically large in comparison to the impact on infrared forcing from increasing greenhouse gasses. Active laser remote sensing of the atmosphere has the major advantage of a direct and unambiguous detection and height measurement of all scattering layers, and thus space borne lidar observations will be an important addition to existing satellite observations.

[3] The first polar-orbiting satellite lidar instrument, the Geoscience Laser Altimeter System (GLAS), was launched on board the Ice, Cloud and land Elevation Satellite in January 2003 and has provided extensive global data on cloud and aerosol distributions. As part of the NASA Earth Observing System (EOS) project, the GLAS instrument is intended as a laser sensor fulfilling complementary requirements for several earth science disciplines [Zwally *et al.*, 2002; Spinhirne and Palm, 1996]. The overall approach takes advantage of the good technical compatibility of cloud and aerosol profiling with laser altimeter measurements for ice sheet and land requirements. In addition, a mission that combines surface altimetry and high quality atmospheric measurements best overcomes inter related remote sensing problems such as the effect of cloud scattering on precision altimetry [Duda *et al.*, 2001].

[4] In this paper we present an initial description of the GLAS atmospheric observations. Specific examples of the application of GLAS data to a range of issues are given in this special section [Hlavka *et al.*, 2005; Palm *et al.*, 2005a, 2005b; Spinhirne *et al.*, 2005; Hart *et al.*, 2005]. The stated measurement requirement for GLAS was to profile all radiative significant cloud and aerosol layers. The measurement result from the fully operational instrument meets the requirement. An important part of the development of the GLAS project was the construction and testing of automated data processing algorithms capable of operational production of higher-level research parameters. We describe the GLAS cloud and aerosol data products available to the science community, starting September 2004.

### 2. GLAS Observation Requirements and Examples

[5] The lidar measurement requirements for clouds and aerosol from space were based on a long experience with airborne and ground based observations. The stated requirement to profile all significant cloud and aerosol translates to detection at appropriate spatial resolution of layers of optical depth down to 0.01. The requirement then further translates to the observation of backscattering cross sections to below  $10^{-7}$  1/m-sr. Airborne observations indicate that there is a “background” aerosol mode into the troposphere with cross sections at visible wavelengths on the order of  $10^{-9}$ – $10^{-8}$  1/m-sr [Menzies *et al.*, 2002]. Thus some aerosol concentrations exist below the stated measurement requirement, but these aerosol are considered below the definition of radiative significant.

[6] The GLAS instrument is a dual-frequency, nadir-viewing laser radar system (J. Abshire *et al.*, Geoscience Laser Altimeter System (GLAS) on the ICESat mission:

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## Ground Validation for the Tropical Rainfall Measuring Mission (TRMM)

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### ABSTRACT

An overview of the Tropical Rainfall Measuring Mission (TRMM) Ground Validation (GV) Program is presented. This ground validation (GV) program is based at NASA Goddard Space Flight Center in Greenbelt, Maryland, and is responsible for processing several TRMM science products for validating space-based rain estimates from the TRMM satellite. These products include gauge rain rates, and radar-estimated rain intensities, type, and accumulations, from four primary validation sites (Kwajalein Atoll, Republic of the Marshall Islands; Melbourne, Florida; Houston, Texas; and Darwin, Australia). Site descriptions of rain gauge networks and operational weather radar configurations are presented together with the unique processing methodologies employed within the Ground Validation System (GVS) software packages. Rainfall intensity estimates are derived using the Window Probability Matching Method (WPMM) and then integrated over specified time scales. Error statistics from both dependent and independent validation techniques show good agreement between gauge-measured and radar-estimated rainfall. A comparison of the NASA GV products and those developed independently by the University of Washington for a subset of data from the Kwajalein Atoll site also shows good agreement. A comparison of NASA GV rain intensities to satellite retrievals from the TRMM Microwave Imager (TMI), precipitation radar (PR), and Combined (COM) algorithms is presented, and it is shown that the GV and satellite estimates agree quite well over the open ocean.

### 1. Introduction

The Tropical Rainfall Measuring Mission (TRMM) is a satellite-based program to measure tropical rainfall and to help quantify the associated distribution and transport of latent heat, which drives the global atmospheric system. TRMM is a joint United States–Japan mission launched from Tanegashima, Japan, on 27 November 1997 (Simpson et al. 1996; Kummerow et al. 1998). TRMM has provided state-of-the-art precipitation measurements since shortly after launch and was boosted from its original 350-km orbit to a new orbit of 402.5 km in August 2001 in order to extend science observations beyond the original time frame of 2000. A key effort of TRMM has been dedicated to providing ground validation (GV) of the satellite rainfall estimates. The GV program is based in the TRMM Satellite Validation Office (TSVO) at the NASA Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.

The GV program has been collecting radar and rain gauge measurements since 1988 and continues to collect datasets at a number of sites located throughout the Tropics.

The aim of this paper is to provide a summary of GV operations, algorithm descriptions, and data quality. A description of the primary GV sites and details of their operational configurations, including a description of the network of radar and rain gauge networks at each site, are provided in section 2. Section 3 discusses the software system and algorithms developed and maintained by TSVO for processing the data, details data sources and ingest methodologies, and provides a brief description of the level I–III TRMM GV Science Products (TSP) and how they are produced. Section 4 provides a discussion on the error statistics of the radar rainfall estimates versus both dependent and independent gauge measurements, as well as a comparison of rain rates and monthly accumulations between TSVO and those produced by the University of Washington. Section 5 provides validation comparisons between TRMM GV and satellite-retrieved rain intensities generated by the TRMM Microwave Imager (TMI), precipitation radar (PR), and Combined (COM) algorithms.

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## Impacts of Air–Sea Interaction on Tropical Cyclone Track and Intensity

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### ABSTRACT

While the previous studies of the impacts of air–sea interaction on tropical cyclones (TCs) generally agree on significant reduction in intensity and little change in track, they did not further explore the relative roles of the weak symmetric and strong asymmetric sea surface temperature (SST) anomalies relative to the TC center. These issues are investigated numerically with a coupled hurricane–ocean model in this study.

Despite the relatively small magnitude compared to the asymmetric component of the resulting cooling, the symmetric cooling plays a decisive role in weakening TC intensity. A likely reason is that the symmetric cooling directly reduces the TC intensity, while the asymmetric cooling affects the intensity through the resulting TC asymmetries, which are mainly confined to the lower boundary and much weaker than those resulting from large-scale environmental influences.

The differences in TC tracks between the coupled and fixed SST experiments are generally small because of the competing processes associated with the changes in TC asymmetries and the beta drift induced by air–sea interaction. The symmetric component of the SST drop weakens the TC intensity and outer strength, leading to a more northward beta drift. On the other hand, since the asymmetric component of the SST cooling is negative in the rear and positive in the front of a TC in the coupled experiments, the enhanced diabatic heating is on the southern side of a westward-moving TC, tending to shift the TC southward. In the coupled model the westward TCs with relatively weak (strong) outer strength tend to turn to the north (south) of the corresponding TCs without air–sea interaction.

### 1. Introduction

A tropical cyclone (TC) develops and is maintained by drawing energy from the underlying ocean surface. It can form only over waters of 26°C or higher and its intensity is very sensitive to the sea surface temperature (SST; e.g., Tuleya and Kurihara 1982; Emanuel 1986). Treating a tropical storm as a Carnot heat engine, Emanuel (1986) suggested that the TC maximum po-

tential intensity is primarily determined by the underlying SST. At the same time, the surface wind stress associated with a TC can generate strong turbulent mixing that deepens the ocean mixed layer (OML) by entraining cooler water into the surface layer, leading to significant SST decreases. Observations indicate that the SST cooling caused by TCs ranges from 1° to 6°C (Price 1981).

The feedback of the resulting cooling on TC intensity has been investigated using coupled hurricane–ocean models. Early experiments were performed with upper OML models forced by axisymmetric TC models (Elsberry et al. 1976; Chang and Anthes 1979; Sutyrin and Khain 1979). Because of the markedly rightward bias of

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# IMPROVING NATIONAL AIR QUALITY FORECASTS WITH SATELLITE AEROSOL OBSERVATIONS

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Satellite aerosol observations—which are particularly helpful in tracking long-range transport aloft—can overcome some of the limitations of surface monitoring networks and enhance daily air quality forecasts associated with particle pollution.

**P**ublic awareness of local air quality is growing rapidly. Air quality is often considered like the weather—it changes, and some days are better than others. While poor air quality impairs visibility and can damage vegetation and structures, most importantly it can cause serious health problems, including respiratory difficulties and even premature death. Accurate air quality forecasts can offer significant societal and economic benefits by en-

abling advance planning. Individuals can adjust their outdoor activities to minimize the adverse health impacts of poor air quality. The severity of local pollution episodes may even be reduced by allowing early implementation of mitigation procedures commonly referred to as “action days.” Yet air quality forecasting is quite complex. While pollution episodes are typically associated with local meteorological conditions and nearby emissions, it is increasingly recognized

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# THE I3RC

## Bringing Together the Most Advanced Radiative Transfer Tools for Cloudy Atmospheres

BY ROBERT F. CAHALAN, LAZAROS OREOPOULOS, ALEXANDER MARSHAK, K. FRANKLIN EVANS, ANTHONY B. DAVIS, ROBERT PINCUS, KEN H. YETZER, BERNHARD MAYER, ROGER DAVIES, THOMAS P. ACKERMAN, HOWARD W. BARKER, EUGENE E. CLOTHIAUX, ROBERT G. ELLINGSON, MICHAEL J. GARAY, EVGUENI KASSIANOV, STEFAN KINNE, ANDREAS MACKE, WILLIAM O'HIROK, PHILIP T. PARTAIN, SERGEI M. PRIGARIN, ALEXEI N. RUBLEV, GRAEME L. STEPHENS, FREDERIC SZCZAP, EZRA E. TAKARA, TÁMAS VÁRNAI, GUOYONG WEN, AND TATIANA B. ZHURAVLEVA

An international Intercomparison of 3D Radiation Codes (I3RC) underscores the vast progress of recent years, but also highlights the challenges ahead for routine implementation in remote sensing and global climate modeling applications.

**M**odeling atmospheric and oceanic processes is one of the most important methods of the earth sciences for understanding the interactions of the various components of the surface-atmosphere system and predicting future weather

and climate states. Great leaps in the availability of computing power at continuously decreasing costs have led to widespread popularity of computer models for research and operational applications. As part of routine scientific work, output from models built for

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# A Method to Derive Smoke Emission Rates From MODIS Fire Radiative Energy Measurements

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**Abstract**—Present methods of emissions estimation from satellite data often use fire pixel counts, even though fire strengths and smoke emission rates can differ by some orders of magnitude between pixels. Moderate Resolution Imaging Spectroradiometer (MODIS) measurements of fire radiative energy (FRE) release rates  $R_{fre}$  range from less than 10 to more than 1700 MW per pixel at 1-km resolution. To account for the effect of such a wide range of fire strengths/sizes on smoke emission rates, we have developed direct linear relationships between the MODIS-measured  $R_{fre}$  and smoke aerosol emission rates  $R_{sa}$  (in kilograms per second), derived by analyzing MODIS measurements of aerosol spatial distribution around the fires with National Center for Environmental Prediction/National Center for Atmospheric Research wind fields. We applied the technique to several regions around the world and derived a FRE-based smoke emission coefficient,  $C_e$  (in kilograms per megajoule), which can be simply multiplied by  $R_{fre}$  to calculate  $R_{sa}$ . This new coefficient  $C_e$  is an excellent remote sensing parameter expressing the emission strength of different ecosystems and regions. Analysis of all 2002 MODIS data from Terra and Aqua satellites yielded  $C_e$  values of 0.02–0.06 kg/MJ for boreal regions, 0.04–0.08 kg/MJ for both tropical forests and savanna regions, and 0.08–0.1 kg/MJ for Western Russian regions. These results are probably overestimated by about 50% because of uncertainties in some of the data, parameters, and assumptions involved in the computations. This 50% overestimation is comparable to uncertainties in traditional emission factors. However, our satellite method shows great promise for accuracy improvement, as better knowledge is gained about the sources of the uncertainties.

**Index Terms**—Aerosol, biomass burning, fire radiative energy (FRE), Moderate Resolution Imaging Spectroradiometer (MODIS), particulate matter, smoke emission.

## I. INTRODUCTION

**W**ILDFIRES and prescribed biomass-burning devastate vast areas of forest lands, grass lands, and agricultural lands across the globe, consuming an estimated 5500–9200 Tg of biomass annually [1], [2]. For instance, in Canada alone, it was estimated that about 4.9 million hectares burned in 1995 [3]. By so doing, fires directly exert adverse (and, in some cases, favorable) influences on ecology, population, habitat,

agriculture, transportation, and security. The 2001 report of the Intergovernmental Panel on Climate Change (IPCC) [4] states that “most climate scenarios indicate that the probability of large fires will increase” (IPCC, 2001, sec 13.2.2.1.2). The effects of fires on climate and the environment are not limited to the ravages of their flame but also include the impacts of the energy, aerosols (or particulate matter, PM), and trace gases emitted into the atmosphere. Fires release heat energy, which is propagated by conduction, convection, and radiation. Fire radiative energy (FRE), like other types of electromagnetic radiant energy, propagates in space and can be sensed from aircraft and satellites. The Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor, launched aboard the Earth Observing System (EOS) Terra and Aqua satellites on December 18, 1999 and May 4, 2002, respectively, is the first to operationally measure from space the FRE rate of release ( $R_{fre}$ ), using its 3.96- $\mu\text{m}$  channels, which do not saturate for most fires.

Commensurate with the large volumes of biomass consumed by fires, tremendous amounts of smoke are emitted into the atmosphere annually. Globally, an estimated  $3.1 \times 10^9$  t of biomass carbon is exposed to burning annually, of which  $1.1 \times 10^9$  t is emitted to the atmosphere through combustion [5]. Smoke comprises aerosol particles and trace gases (including  $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{CH}_4$ , and other species), which constitute air pollutants and contribute to the perturbation of the global radiative balance through the scattering and absorption of solar radiation. Andreae and Merlet [6] provide a detailed list of the various particulate and gaseous species emitted by fires. Although some trace gases ( $\text{CO}_2$  and  $\text{CH}_4$ ) have long been associated with climate change, atmospheric aerosols and, particularly, smoke aerosol (because of its considerable black carbon content) probably have a much greater impact, not only on climate, but also on weather, health, aviation, visibility, and environmental pollution. However, the global effects of fires and emitted smoke aerosols and trace gases are still poorly understood. To fully understand the effects of biomass burning on humans and the environment, it is important to acquire an accurate quantitative inventory of the fire locations and frequency, the amount of biomass they consume, and the energy, aerosols, and trace gases they release into the atmosphere.

Accurate assessment of the environmental and climate effects of smoke can only be achieved if the amount or the rate of emission of smoke is estimated accurately. It is a common saying that: “there is no smoke without fire.” Ironically, some of the initial attempts at estimating emissions did not include any quantitative measure of the fire, but were based on limited localized smoke measurements, which were then extrapolated

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# MEETING SUMMARIES

## INCLUSION OF URBAN LANDSCAPE IN A CLIMATE MODEL

### How Can Satellite Data Help?

BY MENGLIN JIN AND J. MARSHALL SHEPHERD

Urban regions, which cover only approximately 0.2% of the earth's land surface, contain about half of the human population (UNPD 2001). Modeling urban weather and climate is critical for human welfare, but has been hampered for at least two reasons: i) no urban landscape has been included in global and regional climate models (GCMs and RCMs, respectively), and ii) detailed information on urban characteristics is hard to obtain. With the advance of satellite observations, adding urban schemes into climate models in order to scale projections of global/regional climate to urban areas becomes essential. Inclusion of urbanized landscape into climate models was discussed in depth at the fall American Geophysical Union (AGU) meeting of 2003 in the session entitled "Human-induced climate variations linked to urbanization: From observations to modeling," which took place on 12 December 2003 in San Francisco, California (most of the presentations of this session can be found online at [www.atmos.umd.edu/~mjjin/AGU03urban.html](http://www.atmos.umd.edu/~mjjin/AGU03urban.html)). The

#### AGU MEETING SESSION—HUMAN-INDUCED CLIMATE VARIATIONS LINKED TO URBANIZATION: FROM OBSERVATIONS TO MODELING

**What:** The unique radiative characteristics of urban land cover are now being observed by satellites, with consequent improvements possible in surface schemes of climate models

**When:** 12 December 2003

**Where:** San Francisco, California

following notes summarize what is known and what needs to be advanced on this topic.

In a GCM and RCM, land physical processes are simulated in a land surface model, which is coupled with the atmosphere model through exchanges of heat fluxes, water, and momentum. Currently, an urban classification is not included in any major GCM/RCM land surface model [e.g., the second National Center for Atmospheric Research (NCAR) Community Land Model (CLM2), National Aeronautics and Space Administration (NASA) Global Modeling and Assimilation Office (GMAO) unified land surface model, Biosphere–Atmosphere Transfer Scheme (BATS), simple Biosphere model, version 2 (SIB2), etc.]. This exclusion makes GCMs/RCMs inadequate for realistically simulating urban modifications to climate.

The same land surface model can be coupled to a GCM or RCM. For example, the NCAR CLM is coupled to both the NCAR community atmosphere

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## Aerosol anthropogenic component estimated from satellite data

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[1] Satellite instruments do not measure the aerosol chemical composition needed to discriminate anthropogenic from natural aerosol components. However the ability of new satellite instruments to distinguish fine (submicron) from coarse (supermicron) aerosols over the oceans, serves as a signature of the anthropogenic component and can be used to estimate the fraction of anthropogenic aerosols with an uncertainty of  $\pm 30\%$ . Application to two years of global MODIS data shows that  $21 \pm 7\%$  of the aerosol optical thickness over the oceans has an anthropogenic origin. We found that three chemical transport models, used for global estimates of the aerosol forcing of climate, calculate a global average anthropogenic optical thickness over the ocean between 0.030 and 0.036, in line with the present MODIS assessment of 0.033. This increases our confidence in model assessments of the aerosol direct forcing of climate. The MODIS estimated aerosol forcing over cloud free oceans is therefore  $-1.4 \pm 0.4 \text{ W/m}^2$ .  
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### 1. Introduction

[2] Climate change research [*Intergovernmental Panel on Climate Change (IPCC)*, 2001] and studies of the aerosol forcing on the hydrological cycle [*Ramanathan et al.*, 2001] require knowledge of the anthropogenic component of the aerosol. Natural aerosols can cause variability in the climate system and be part of its feedback mechanisms, e.g. larger amount of dust generated during drought conditions in the Sahel [*Prospero and Lamb*, 2003] can cause cooling of the earth system and changes in the drought conditions. Only anthropogenic aerosol can be considered as an external cause of climate change [*Charlson et al.*, 1992]. Aerosol exerts a radiative forcing of climate via direct absorption and reflection of sunlight to space and via induced changes in the cloud microphysics, water content, and coverage [*Gunn and Phillips*, 1957; *Twomey et al.*, 1984; *Albrecht*, 1989; *Rosenfeld*, 2000; *Koren et al.*, 2004].

[3] Yet assessments of the aerosol radiative forcing [*IPCC*, 2001] are based only on models since we do not have a

method to measure the amount and distribution of anthropogenic aerosol around the Earth. Previously [*Kaufman et al.*, 2002] we suggested that satellite data that distinguish fine from coarse aerosols can be used for this purpose. The reason is that natural and anthropogenic aerosols have different proportions of fine and coarse aerosols. Urban/industrial pollution and smoke from vegetation burning (mostly anthropogenic) have mostly fine aerosol, while dust and marine aerosols (mostly natural) are dominated by coarse aerosol but with significant fine aerosol fraction [*Tanré et al.*, 2001; *Kaufman et al.*, 2001].

[4] Here we use MODIS measurements over the oceans of the aerosol optical thickness and the fraction of the optical thickness contributed by fine aerosol [*Tanré et al.*, 1997; *Remer et al.*, 2005], to derive the anthropogenic optical thickness. The results are used to evaluate chemical transport models that are used to assess the aerosol forcing of climate.

### 2. Analysis

[5] The method for satellite based estimate of the aerosol anthropogenic component is based on the following assumptions:

[6] 1) The fraction of the aerosol optical thickness contributed by the fine aerosol is constant for a given aerosol type; e.g. fine aerosol dominates the optical properties for smoke and pollution and coarse aerosol dominates dust and maritime aerosol.

[7] 2) All smoke is from anthropogenic origin and all dust is natural. It is estimated that about 20% of biomass burning originates from wild fires [*Hobbs et al.*, 1997]. About 10% of the dust can be from anthropogenic sources [*Tegen et al.*, 2004]. We shall account for the smoke overestimate but not dust later in the paper.

[8] 3) MODIS derivation of the fine fraction is consistent: any errors in the derivation of the fine fraction are constant and the correlation with the true fine fraction is very good.

[9] 4) Based on AERONET and MODIS analysis [*Kaufman et al.*, 2001, 2005] it is assumed that the baseline marine aerosol optical thickness is  $0.06 \pm 0.01$ . This is the average marine optical thickness for calm conditions. Strong winds can elevate the sea salt concentration.

[10] We represent the total aerosol optical thickness  $\tau_{550}$  by its anthropogenic (air pollution and smoke aerosol) -  $\tau_{\text{anth}}$ , dust -  $\tau_{\text{dust}}$ , and baseline marine -  $\tau_{\text{mar}}$ , components:

$$\tau_{550} = \tau_{\text{anth}} + \tau_{\text{dust}} + \tau_{\text{mar}} \quad (1)$$

The fine aerosol optical thickness,  $\tau_f$ , measured by the satellite can be described as:

$$\tau_f = f_{550} \tau_{550} = f_{\text{anth}} \tau_{\text{anth}} + f_{\text{dust}} \tau_{\text{dust}} + f_{\text{mar}} \tau_{\text{mar}} \quad (2)$$

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## Dust transport and deposition observed from the Terra-Moderate Resolution Imaging Spectroradiometer (MODIS) spacecraft over the Atlantic Ocean

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[1] Meteorological observations, in situ data, and satellite images of dust episodes were used already in the 1970s to estimate that 100 Tg of dust are transported from Africa over the Atlantic Ocean every year between June and August and are deposited in the Atlantic Ocean and the Americas. Desert dust is a main source of nutrients to oceanic biota and the Amazon forest, but it deteriorates air quality, as shown for Florida. Dust affects the Earth radiation budget, thus participating in climate change and feedback mechanisms. There is an urgent need for new tools for quantitative evaluation of the dust distribution, transport, and deposition. The Terra spacecraft, launched at the dawn of the last millennium, provides the first systematic well-calibrated multispectral measurements from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument for daily global analysis of aerosol. MODIS data are used here to distinguish dust from smoke and maritime aerosols and to evaluate the African dust column concentration, transport, and deposition. We found that  $240 \pm 80$  Tg of dust are transported annually from Africa to the Atlantic Ocean,  $140 \pm 40$  Tg are deposited in the Atlantic Ocean, 50 Tg fertilize the Amazon Basin (four times as previous estimates, thus explaining a paradox regarding the source of nutrition to the Amazon forest), 50 Tg reach the Caribbean, and 20 Tg return to Africa and Europe. The results are compared favorably with dust transport models for maximum particle diameter between 6 and 12  $\mu\text{m}$ . This study is a first example of quantitative use of MODIS aerosol for a geophysical research.

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### 1. Introduction

[2] *Prospero and Carlson* [1972], *Prospero and Nees* [1977] and *Carlson* [1979] used meteorological observations, in situ data and satellite images (AVHRR) of dust episodes, to derive the first estimates of dust emission from Africa of 100 Tg of dust for a latitude belt  $5^{\circ}$ – $25^{\circ}\text{N}$  in the summer months June to August. This estimate was done before inaccuracies with AVHRR calibration were recognized and corrected [*Holben et al.*, 1990]. Owing to lack of systematic satellite measurements designed for aerosol studies, improvements in the estimates of dust emission were based mainly on models of the dust sources, emission and transport [*Teegen and Fung*, 1994; *Prospero et al.*, 1996;

*Ginoux et al.*, 2001]. With the launch of the first Moderate Resolution Imaging Spectroradiometer (MODIS) instrument at the end of 1999, quantitative and systematic measurements of dust transport are possible [*Gao et al.*, 2001; *Kaufman et al.*, 2002] and presented here for the Atlantic ocean.

[3] The constant flux of dust across the Atlantic Ocean is of considerable interest. In the last 10 years the citation index reports 500 papers about or related to Saharan dust, and shows an exponential increase in the publication rate, starting from the early works of *Prospero and Carlson* in the 1970s (see Figure 1). Iron contained in aeolian dust was shown to be an important micronutrient for ocean phytoplankton, which could contribute to fluctuation of  $\text{CO}_2$  on climatic timescales [*Martin et al.*, 1991] and contribute to climate variations. *Erickson et al.* [2003] measured, using satellite data, the effect of dust deposition on ocean productivity. Over the millennia, dust was suggested to be the main fertilizer of the Amazon forest [*Swap et al.*, 1992]. Desert dust, now considered to originate mainly from natural source [*Teegen et al.*, 2004] interact with solar and thermal radiation, thus can modulate the Earth radiation balance in response to changing climate conditions [*Prospero et al.*, 2002], i.e., changes in

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## Comparison of Moderate Resolution Imaging Spectroradiometer (MODIS) and Aerosol Robotic Network (AERONET) remote-sensing retrievals of aerosol fine mode fraction over ocean

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Received 5 January 2005; revised 8 April 2005; accepted 10 August 2005; published 22 November 2005.

[1] Aerosol particle size is one of the fundamental quantities needed to determine the role of aerosols in forcing climate, modifying the hydrological cycle, and affecting human health and to separate natural from man-made aerosol components. Aerosol size information can be retrieved from remote-sensing instruments including satellite sensors such as Moderate Resolution Imaging Spectroradiometer (MODIS) and ground-based radiometers such as Aerosol Robotic Network (AERONET). Both satellite and ground-based instruments measure the total column ambient aerosol characteristics. Aerosol size can be characterized by a variety of parameters. Here we compare remote-sensing retrievals of aerosol fine mode fraction over ocean. AERONET retrieves fine mode fraction using two methods: the Dubovik inversion of sky radiances and the O'Neill inversion of spectral Sun measurements. Relative to the Dubovik inversion of AERONET sky measurements, MODIS slightly overestimates fine fraction for dust-dominated aerosols and underestimates in smoke- and pollution-dominated aerosol conditions. Both MODIS and the Dubovik inversion overestimate fine fraction for dust aerosols by 0.1–0.2 relative to the O'Neill method of inverting AERONET aerosol optical depth spectra. Differences between the two AERONET methods are principally the result of the different definitions of fine and coarse mode employed in their computational methodologies. These two methods should come into better agreement as a dynamic radius cutoff for fine and coarse mode is implemented for the Dubovik inversion. MODIS overestimation in dust-dominated aerosol conditions should decrease significantly with the inclusion of a nonspherical model.

**Citation:** Kleidman, R. G., N. T. O'Neill, L. A. Remer, Y. J. Kaufman, T. F. Eck, D. Tanré, O. Dubovik, and B. N. Holben (2005), Comparison of Moderate Resolution Imaging Spectroradiometer (MODIS) and Aerosol Robotic Network (AERONET) remote-sensing retrievals of aerosol fine mode fraction over ocean, *J. Geophys. Res.*, *110*, D22205, doi:10.1029/2005JD005760.

### 1. Introduction

[2] Aerosols play an important role in determining the Earth's radiation budget and in modifying clouds and precipitation [Kaufman *et al.*, 2002; Rosenfeld and Lensky, 1998]. Aerosols also adversely affect human health [Samet *et al.*, 2000]. Understanding the aerosols' physical and optical characteristics as well as their distribution patterns is necessary in order to forecast air quality and make

estimates of potential climate change [Chu *et al.*, 2003; Kaufman *et al.*, 2002].

[3] One of the important physical characteristics of aerosols is their size. Knowing particle size distribution is critical to estimating the role of aerosols in Earth's energy balance, in determining the effect the particles will have on cloud development and on human health. In addition, aerosol size is the key to using satellite remote sensing to separate natural from man-made aerosols. Anthropogenic aerosol optical thickness is dominated by fine (mode) aerosol (effective radius between 0.1 and 0.25  $\mu\text{m}$ ), while natural aerosols contain a substantial component of coarse (mode) aerosol (effective radius between 1 and 2.5  $\mu\text{m}$ ) [Kaufman *et al.*, 2001; Tanré *et al.*, 2001]. Therefore measurement of the fine aerosol fraction or the ratio of fine to coarse mode can be used to identify and quantify the extent and role in climate of anthropogenic aerosol [Kaufman *et al.*, 2002].

[4] Aerosol particle size parameters such as fraction of the fine mode or the ratio of fine to coarse mode can be measured by in situ volumetric and optical sampling mea-

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## Aerosol invigoration and restructuring of Atlantic convective clouds

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[1] Clouds and precipitation play crucial roles in the Earth's energy balance, global atmospheric circulation and the availability of fresh water. Aerosols may modify cloud properties and precipitation formation by modifying the concentration and size of cloud droplets, and consequently the strength of cloud convection, and height of glaciation levels thus affecting precipitation patterns. Here we evaluate the aerosol effect on clouds, using large statistics of daily satellite data over the North Atlantic Ocean. We found a strong correlation between the presence of aerosols and the structural properties of convective clouds. These correlations suggest systematic invigoration of convective clouds by pollution, desert dust and biomass burning aerosols. On average increase in the aerosol concentration from a baseline to the average values is associated with a  $0.05 \pm 0.01$  increase in the cloud fraction and a  $40 \pm 5$  mb decrease in the cloud top pressure. **Citation:** Koren, I., Y. J. Kaufman, D. Rosenfeld, L. A. Remer, and Y. Rudich (2005), Aerosol invigoration and restructuring of Atlantic convective clouds, *Geophys. Res. Lett.*, 32, L14828, doi:10.1029/2005GL023187.

### 1. Introduction

[2] Based on a few case studies, it has been suggested [Andreae *et al.*, 2004; Williams *et al.*, 2002] that the suppression of warm rain by aerosol causes most of the condensates to ascend, freeze and release the latent heat of freezing before precipitating. Delayed precipitation leads to more persistent updrafts and to more vigorous clouds before the precipitation-induced downdrafts take over. In addition, smaller droplets freeze at higher altitudes and at lower temperatures [Rosenfeld and Woodley, 2000]; therefore more latent heat is released higher in the atmosphere. The magnitude and robustness of these aerosol effects have not yet been investigated in a variety of meteorological conditions.

[3] Here we report strong correlations between aerosol loading and convective cloud properties. We see the correlations in all scales, from droplet scale to the extent and shape of the entire cloud. We show using large statistics that an increase in aerosol concentration correlates with changes in the cover, height and anvil portion of convective clouds.

We show these correlations occur repeatedly in three latitude belts of the Atlantic Ocean each with its own unique cloud dynamics and aerosol type.

### 2. Analysis

[4] We use three months (June–August 2002) of MODIS (MODerate resolution Imaging Spectroradiometer) [Salomonson *et al.*, 1989] Level 3 data from the Terra satellite over the northern Atlantic Ocean from 60°N to the Equator (covering  $\sim 4$  billion km<sup>2</sup>). The satellite products include cloud fraction, optical thickness and droplet effective radius, each further partitioned by thermodynamic phase (ice/water), cloud top pressure and temperature [King *et al.*, 2003; Platnick *et al.*, 2003] and also by aerosol optical depth (AOD) at 550 nm [Tanré *et al.*, 1997; Kaufman *et al.*, 1997; Remer *et al.*, 2005]. MODIS measures daily cloud and aerosol reflection of sunlight with resolution of 0.25–1 km. The daily data are averaged into a 1-degree grid (MODIS algorithms, Level 3, available at <http://modis-atmos.gsfc.nasa.gov/DAILY/atbd.html>), that includes information on clouds and the surrounding aerosols (unless the grid box is completely overcast). We also used NCEP (National Center for Environmental Prediction) reanalysis [Kalnay *et al.*, 1996] and MODIS precipitable water vapor as a measure of the meteorology.

[5] In this study we focus on correlations between aerosols and the properties of deep convective and high cloud fields. Clouds were classified based on their top pressure, thermodynamic phase and cloud spatial homogeneity. Convective clouds are identified based on the variation in cloud top pressure among adjacent grid boxes and based on the optical depth of ice and water. The cloud classification algorithm was tuned on manually classified clouds followed by manual verification process of randomly selected cases. During the northern hemisphere summer, the average cloud fraction in the studied area is  $\sim 0.6$ , of which 75% are classified as deep convective and high clouds and 25% as marine stratocumulus and shallow cumulus (analyzed in a different study [Kaufman *et al.*, 2005]).

[6] We performed the analysis of the convective clouds separately for three regions characterized by different synoptic conditions: 0–15°N, including the ITCZ (Intertropical Convergence Zone), where the prevailing wind is easterly and carries mainly dust aerosol from the Sahara to the tropics of America; 16N–45N (sub tropical zone), where most of the deep convection develops in the southerlies along the Americas, transporting aerosols from the tropics to the mid-latitudes; and 46N–60N, where the system is dominated by the westerly wind that brings pollution aerosol from North America to Europe (mid-latitudes). In the tropical and mid-latitude zones the average flow is zonal (east-west) and the convective clouds are distributed

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## Cloud Inhomogeneity from MODIS

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### ABSTRACT

Two full months (July 2003 and January 2004) of Moderate Resolution Imaging Spectroradiometer (MODIS) Atmosphere Level-3 data from the *Terra* and *Aqua* satellites are analyzed in order to characterize the horizontal variability of vertically integrated cloud optical thickness (“cloud inhomogeneity”) at global scales. The monthly climatology of cloud inhomogeneity is expressed in terms of standard parameters, initially calculated for each day of the month at spatial scales of  $1^\circ \times 1^\circ$  and subsequently averaged at monthly, zonal, and global scales. Geographical, diurnal, and seasonal changes of inhomogeneity parameters are examined separately for liquid and ice phases and separately over land and ocean. It is found that cloud inhomogeneity is overall weaker in summer than in winter. For liquid clouds, it is also consistently weaker for local morning than local afternoon and over land than ocean. Cloud inhomogeneity is comparable for liquid and ice clouds on a global scale, but with stronger spatial and temporal variations for the ice phase, and exhibits an average tendency to be weaker for near-overcast or overcast grid points of both phases. Depending on cloud phase, hemisphere, surface type, season, and time of day, hemispheric means of the inhomogeneity parameter  $\nu$  (roughly the square of the ratio of optical thickness mean to standard deviation) have a wide range of  $\sim 1.7$  to 4, while for the inhomogeneity parameter  $\chi$  (the ratio of the logarithmic to linear mean) the range is from  $\sim 0.65$  to 0.8. The results demonstrate that the MODIS Level-3 dataset is suitable for studying various aspects of cloud inhomogeneity and may prove invaluable for validating future cloud schemes in large-scale models capable of predicting subgrid variability.

### 1. Introduction

The nonlinear interplay of solar and longwave radiation with cloud optical properties is a fundamental aspect of atmospheric radiative transfer with implications for the earth’s climate that were already noted many years ago (e.g., Harshvardhan and Randall 1985). In recent years, a plethora of studies examined various aspects of this interplay but, to our knowledge, only a handful was of global scope, namely the observational study of Rossow et al. (2002, hereafter RDC) and the model-based studies of Oreopoulos et al. (2004) and Räisänen et al. (2004). The present study, focusing only on a specific aspect of cloud variability, namely the horizontal fluctuations of total optical thickness  $\tau$

(hereafter “cloud inhomogeneity”), is also of global scope. Studies on this topic preceding RDC provided an incomplete and often conflicting picture of the magnitude of cloud inhomogeneity, as they were based on a limited number of scenes and different observational methods (Cahalan et al. 1994, 1995; Barker 1996; Oreopoulos and Davies 1998a; Pincus et al. 1999). In the following we make the case that, similar to the International Satellite Cloud Climatology Project (ISCCP) products used by RDC, higher-level cloud products from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the *Terra* and *Aqua* satellites can provide a detailed picture of cloud inhomogeneity.

Knowledge of the actual geographical and seasonal distribution of cloud inhomogeneity is essential in our effort to make it a diagnosed or predicted quantity that will improve representation of physical processes involving clouds in large-scale models (LSMs). These in-

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## The MODIS Aerosol Algorithm, Products, and Validation

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### ABSTRACT

The Moderate Resolution Imaging Spectroradiometer (MODIS) aboard both NASA's *Terra* and *Aqua* satellites is making near-global daily observations of the earth in a wide spectral range (0.41–15  $\mu\text{m}$ ). These measurements are used to derive spectral aerosol optical thickness and aerosol size parameters over both land and ocean. The aerosol products available over land include aerosol optical thickness at three visible wavelengths, a measure of the fraction of aerosol optical thickness attributed to the fine mode, and several derived parameters including reflected spectral solar flux at the top of the atmosphere. Over the ocean, the aerosol optical thickness is provided in seven wavelengths from 0.47 to 2.13  $\mu\text{m}$ . In addition, quantitative aerosol size information includes effective radius of the aerosol and quantitative fraction of optical thickness attributed to the fine mode. Spectral irradiance contributed by the aerosol, mass concentration, and number of cloud condensation nuclei round out the list of available aerosol products over the ocean. The spectral optical thickness and effective radius of the aerosol over the ocean are validated by comparison with two years of Aerosol Robotic Network (AERONET) data gleaned from 132 AERONET stations. Eight thousand MODIS aerosol retrievals collocated with AERONET measurements confirm that one standard deviation of MODIS optical thickness retrievals fall within the predicted uncertainty of  $\Delta\tau = \pm 0.03 \pm 0.05\tau$  over ocean and  $\Delta\tau = \pm 0.05 \pm 0.15\tau$  over land. Two hundred and seventy-one MODIS aerosol retrievals collocated with AERONET inversions at island and coastal sites suggest that one standard deviation of MODIS effective radius retrievals falls within  $\Delta r_{\text{eff}} = \pm 0.11 \mu\text{m}$ . The accuracy of the MODIS retrievals suggests that the product can be used to help narrow the uncertainties associated with aerosol radiative forcing of global climate.

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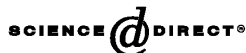
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## The influence of the several very large solar proton events in years 2000–2003 on the neutral middle atmosphere

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### Abstract

Solar proton events (SPEs) are known to have caused changes in constituents in the Earth's polar neutral middle atmosphere. The past four years, 2000–2003, have been replete with SPEs. Huge fluxes of high energy protons entered the Earth's atmosphere in periods lasting 2–3 days in July and November 2000, September and November 2001 and October 2003. The highly energetic protons produce ionizations, excitations, dissociations and dissociative ionizations of the background constituents, which lead to the production of HO<sub>x</sub> (H, OH, HO<sub>2</sub>) and NO<sub>y</sub> (N, NO, NO<sub>2</sub>, NO<sub>3</sub>, N<sub>2</sub>O<sub>5</sub>, HNO<sub>3</sub>, HO<sub>2</sub>NO<sub>2</sub>, ClONO<sub>2</sub>, BrONO<sub>2</sub>). The HO<sub>x</sub> increases lead to short-lived ozone decreases in the polar mesosphere and upper stratosphere due to the short lifetimes of the HO<sub>x</sub> constituents. Large mesospheric ozone depletions (>70%) due to the HO<sub>x</sub> enhancements were observed and modeled as a result of the very large July 2000 SPE. The NO<sub>y</sub> increases lead to long-lived stratospheric ozone changes because of the long lifetime of the NO<sub>y</sub> family in this region. Polar total ozone depletions >1% were simulated in both hemispheres for extended periods of time (several months) as a result of the NO<sub>y</sub> enhancements due to the very large SPEs.

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**Keywords:** Solar particle events; Odd nitrogen; Ozone; Middle atmosphere

### 1. Introduction

Explosions on the Sun sometimes result in large fluxes of high-energy solar protons at the Earth, especially near Solar Maximum. This period of time, when in the solar proton flux is generally elevated for a few days, is known as a solar proton event (SPE). Solar cycle

23 experienced a large number of extremely energetic SPEs in years 2000–2003. Huge fluxes of high-energy protons occurred in July and November 2000, September and November 2001 and October 2003.

Solar protons are guided by the Earth's magnetic field and impact both the northern and southern polar cap regions (>60° geomagnetic latitude), e.g., see Jackman and McPeters (2004). These protons can impact the neutral middle atmosphere (stratosphere and mesosphere) and produce ionizations, dissociative ionizations and excitations. Both HO<sub>x</sub> (H, OH, HO<sub>2</sub>) and NO<sub>y</sub> (N, NO, NO<sub>2</sub>,

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## Note on the effect of horizontal gradients for nadir-viewing microwave and infrared sounders

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### SUMMARY

Passive microwave and infrared nadir sounders such as the Advanced Microwave Sounding Unit-A (AMSU-A) and the Atmospheric InfraRed Sounder (AIRS), both flying on NASA's EOS polar-orbiting Aqua satellite, provide information about vertical temperature and humidity structure that is used in data assimilation systems for numerical weather prediction and climate applications. These instruments scan across track so that, at the satellite swath edges, the satellite zenith angles can reach  $\sim 60^\circ$ . The emission path through the atmosphere as observed by the satellite is therefore slanted with respect to the satellite footprint's zenith. Although radiative transfer codes currently in use at operational centres use the appropriate satellite zenith angle to compute brightness temperature, the input atmospheric fields are those from the vertical profile above the centre of the satellite footprint. If horizontal gradients are present in the atmospheric fields, the use of a vertical atmospheric profile may produce an error.

This note attempts to quantify the effects of horizontal gradients on AIRS and AMSU-A channels by computing brightness temperatures with accurate slanted atmospheric profiles. We use slanted temperature, water vapour, and ozone fields from data assimilation systems. We compare the calculated slanted and vertical brightness temperatures with AIRS and AMSU-A observations. We show that the effects of horizontal gradients on these sounders are generally small and below instrument noise. However, there are cases where the effects are greater than the instrument noise and may produce erroneous increments in an assimilation system. The majority of the affected channels have weighting functions that peak in the upper troposphere (water-vapour-sensitive channels) and above (temperature-sensitive channels) and are unlikely to significantly impact on tropospheric numerical weather prediction. However, the errors could be significant for other applications such as stratospheric analysis. Gradients in ozone and tropospheric temperature appear to be well captured by the analyses. In contrast, gradients in upper stratospheric and mesospheric temperature as well as upper-tropospheric humidity are less well captured. This is likely due in part to a lack of data to specify these fields accurately in the analyses. Advanced sounders, like AIRS, will help to better specify these fields in the future.

KEYWORDS: AIRS AMSU Assimilation Azimuth angle Radiances Satellite

### 1. INTRODUCTION

The Atmospheric Infra-Red Sounder (AIRS) and the Advanced Microwave Sounding Unit-A (AMSU-A) (Aumann *et al.* 2003) are nadir-viewing passive sounders currently flying on the National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS) polar-orbiting Aqua platform. AMSU-A also flies on the National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting Environmental Satellites along with the High-resolution InfraRed Sounder (HIRS). These and other similar sounders are the primary satellite instruments used in atmospheric data assimilation systems (DASs) for numerical weather prediction and the production of climate datasets.

Fast radiative transfer models are used to compute brightness temperatures from background fields in a DAS. Analysis increments are then generated based on the difference between the observed and the computed brightness temperatures. The effects of so-called limb-brightening or limb-darkening across a scan line for an instrument on a polar-orbiting satellite are accounted for in the radiative transfer model by using an appropriate satellite zenith angle. However, the input atmospheric profile is usually the vertical one above the satellite footprint centre. The correct atmospheric profile should account for the fact that the emission path through the atmosphere is slanted with respect to the footprint zenith. If horizontal gradients are present, an error may occur if the vertical atmospheric path is used.

Horizontal gradient effects are a well-known problem for limb-viewing sounders. For example, gradient effects were shown to be important for the limb-viewing Global Positioning Satellite Radio Occultation sounding technique (e.g. Poli 2004; Poli and Joiner 2004).

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## Fall vortex ozone as a predictor of springtime total ozone at high northern latitudes

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**Abstract.** Understanding the impact of atmospheric dynamical variability on observed changes in stratospheric O<sub>3</sub> is a key to understanding how O<sub>3</sub> will change with future climate dynamics and trace gas abundances. In this paper we examine the linkage between interannual variability in total column O<sub>3</sub> at northern high latitudes in March and lower-to-mid stratospheric vortex O<sub>3</sub> in the prior November. We find that these two quantities are significantly correlated in the years available from TOMS, SBUV, and POAM data (1978–2004). Additionally, we find that the increase in March O<sub>3</sub> variability from the 1980s to years post-1990 is also seen in the November vortex O<sub>3</sub>, i.e., interannual variability in both quantities is much larger in the later years. The cause of this correlation is not clear, however. Interannual variations in March total O<sub>3</sub> are known to correspond closely with variations in winter stratospheric wave driving consistent with the effects of varying residual circulation, temperature, and chemical loss. Variation in November vortex O<sub>3</sub> may also depend on dynamical wave activity, but the dynamics in fall are less variable than in winter and spring. We do not find significant correlations of dynamic indicators for November such as temperature, heat flux, or polar average total O<sub>3</sub> with the November vortex O<sub>3</sub>, nor with dynamical indicators later in winter and spring that might lead to a connection to March. We discuss several potential hypotheses for the observed correlation but do not find strong evidence for any considered mechanism. We present the observations as a phenomenon whose understanding may improve our ability to predict the dependence of O<sub>3</sub> on changing dynamics and chemistry.

### 1 Introduction

The polar regions are a bellwether for processes that affect stratospheric O<sub>3</sub> globally. Decadal decreases in total O<sub>3</sub> at high southern latitudes in spring (Fig. 1) are clearly attributable to increasing abundances of chlorine- and bromine-containing trace gases of anthropogenic origin, which are now regulated by international agreements (Solomon, 1999 and references within). Owing to more active meteorology in the northern hemisphere (NH), springtime O<sub>3</sub> decreases there are not as monotonic as those in the South (Fig. 1) and are attributed to a combination of chemical and dynamical forcings (Newman et al., 1997; Manney et al., 1997; Coy et al., 1997; Chipperfield and Jones, 1999; Anderson and Knudsen, 2002). The relative contribution, causal mechanisms, and time scales for dynamical O<sub>3</sub> change at high northern latitudes, as well as in the middle latitudes of both hemispheres, is currently the subject of active scientific debate (WMO, 2003).

During winter, O<sub>3</sub> is transported from the low-latitude photochemical production region by the poleward and downward Brewer-Dobson circulation. This circulation is primarily driven by planetary scale waves propagating into the stratosphere from the Northern extratropical troposphere (Rosenlof and Holton, 1993). These planetary waves affect polar O<sub>3</sub> in three ways: 1) directly, as noted above, by the Brewer-Dobson circulation which advects higher concentrations of O<sub>3</sub> into the lower stratosphere, 2) by occasionally mixing material into the polar vortex or by breaking up the polar vortex, and 3) indirectly by warming the polar region and reducing the occurrence of polar stratospheric clouds, which thereby decreases catalytic chemical loss of O<sub>3</sub>. Interannual variation of planetary wave activity has a major effect on O<sub>3</sub> levels in spring via both transport and photochemical loss.

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## Description and sensitivity analysis of a limb scattering ozone retrieval algorithm

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[1] We present the theoretical basis for an algorithm that retrieves vertical profiles of ozone concentration using measurements of light scattered from the limb of the atmosphere. Simulated radiances at wavelengths between 300 and 675 nm are inverted using the optimal estimation technique, producing a retrieved ozone number density profile between 10 and 55 km. A detailed sensitivity analysis of this ozone retrieval algorithm follows. The largest source of ozone retrieval error is tangent height misregistration (i.e., instrument pointing error), which is relevant throughout the altitude range of interest and produces retrieval errors on the order of 10–20% due to a tangent height registration error of 0.5 km. The retrieved profile is shifted in altitude relative to the true profile, with very little distortion of the profile shape. Sensitivity to stratospheric aerosol is also a significant source of error, with errors of 5–8% for altitudes less than 40 km under background aerosol conditions when an aerosol-free atmosphere is assumed by the algorithm. Using an incorrect a priori ozone estimate can produce errors up to 15% at altitudes near 10 km, but the a priori profile has little influence above that level. Addressing these error sources (e.g., with better instrument pointing knowledge, introduction of reliable aerosol information, and better instrument signal-to-noise to reduce the importance of the a priori ozone estimate, respectively) is the key to significantly improving the retrieval accuracy. Further improvement would then be limited by several secondary error sources that produce retrieval errors at the 5% level.

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### 1. Introduction

[2] Measurements of scattered radiance in the limb of the atmosphere have been used to determine a variety of atmospheric properties, including stratospheric aerosol [Cunnold *et al.*, 1973; Naudet and Thomas, 1987; McLinden *et al.*, 1999], stratospheric temperature [Rusch *et al.*, 1983], mesospheric ozone concentration [Rusch *et al.*, 1984], upper-stratospheric NO<sub>2</sub> concentration [Mount *et al.*, 1984], and sensor attitude [Janz *et al.*, 1996; Hilsenrath *et al.*, 1997; Sioris *et al.*, 2001; Kaiser *et al.*, 2004]. The limb scatter (LS) technique has been proposed as a possible source of ozone profile information in the upper troposphere and lower stratosphere. These measurements can be made throughout the sunlit portion of the orbit, allowing global spatial coverage comparable to back-scattered ultraviolet (BUV) and thermal

emission (TE) methods. LS vertical resolution is inherently lower than (but comparable to) solar occultation (SO) vertical resolution, with 1–3 km possible (depending on optical blurring), similar to TE resolution. Accurate ozone retrievals are possible throughout the stratosphere and possibly into the upper troposphere, again with performance similar to the SO and TE methods.

[3] Several groups have developed new radiative transfer (RT) models to calculate the LS radiance [Herman *et al.*, 1995; Oikarinen *et al.*, 1999; Griffioen and Oikarinen, 2000; Oikarinen, 2001; Kaiser, 2001; McLinden *et al.*, 2002a, 2002b; A. Rozanov *et al.*, 2002; V. Rozanov *et al.*, 2002]. A brief description of the Gauss-Seidel Limb Scattering (GSLs) RT model used in this study can be found in Appendix A of Loughman *et al.* [2004]. The body of that paper describes an intercomparison study among several RT models, which established that the GSLs model agrees well with several other methods for a variety of LS measurement conditions. However, detailed sensitivity studies are required to predict the achievable performance of the LS ozone retrieval technique. The purpose of this paper is to present the theoretical basis for a LS ozone inversion algorithm, as well as describe its sensitivity to various perturbations, in greater detail than was possible in the work of Flittner *et al.* [2000]. It must be stressed that the retrieval procedure described herein is meant to be fairly simple and generic

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## Version 8 SBUV ozone profile trends compared with trends from a zonally averaged chemical model

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[1] A statistical time series analysis was applied to the new version 8 merged Solar Backscatter Ultraviolet (SBUV) data set of ozone profiles for the years 1979–2003. Linear trends for the 1979–1997 time period are reported and are compared to trends computed using ozone profiles from the Goddard Space Flight Center (GSFC) zonally averaged coupled model. Observed and modeled annual trends between 50°N and 50°S were a maximum in the higher latitudes of the upper stratosphere, with Southern Hemisphere (SH) trends greater than Northern Hemisphere (NH) trends. The observed upper stratospheric maximum annual trend is  $-7.0 \pm 2.0\%$ /decade ( $2\sigma$ ) at 47.5°S and  $-4.7 \pm 1.3\%$ /decade at 47.5°N, to be compared with the modeled trends of  $-5.8 \pm 0.3\%$ /decade in the SH and  $-5.2 \pm 0.3\%$ /decade in the NH. Both observed and modeled trends are most negative in winter and least negative in summer, although the modeled seasonal difference is less than observed. Model trends are shown to be greatest in winter because of a repartitioning of chlorine species and the increasing abundance of chlorine with time. The model results illustrate the trend differences that can occur at 3 hPa depending on whether ozone profiles are in mixing ratio or number density coordinates and on whether they are recorded on pressure or altitude levels.

**Citation:** Rosenfield, J. E., S. M. Frith, and R. S. Stolarski (2005), Version 8 SBUV ozone profile trends compared with trends from a zonally averaged chemical model, *J. Geophys. Res.*, 110, D12302, doi:10.1029/2004JD005466.

### 1. Introduction

[2] Stratospheric ozone profile measurements have been made by the Solar Backscatter Ultraviolet instruments (SBUV and SBUV/2) since November 1978. Hood *et al.* [1993] estimated ozone trends using Nimbus 7 SBUV data for the period November 1978 to June 1990. They found maximum upper stratospheric annual trends, poleward of 50°, of approximately  $-8\%$ /decade in the Northern Hemisphere (NH) and approximately  $-12\%$ /decade in the Southern Hemisphere (SH). Depletions increased with increasing latitude in both hemispheres. They reported maximum upper stratospheric high-latitude negative trends in the late fall and early winter seasons.

[3] Hollandsworth *et al.* [1995] combined reprocessed Nimbus 7 SBUV ozone data with observations from the SBUV/2 instrument on NOAA 11, and computed updated profile trends for the period November 1978 through June 1994. They found a general pattern of ozone loss similar to that computed by Hood *et al.* [1993], but obtained smaller

negative trends with the additional data. Maximum high-latitude upper stratospheric trends were approximately  $-8\%$ /decade in the NH and approximately  $-10\%$ /decade in the SH. They also reported maximum high-latitude upper stratospheric negative trends in the late fall and early winter.

[4] A large group of research scientists [World Meteorological Organization (WMO), 1998; Randel *et al.*, 1999; Newchurch *et al.*, 2000; Cunnold *et al.*, 2000] reevaluated the vertical distribution of ozone trends for the period 1979 to 1996, including trends from the SBUV and the Stratospheric Gas and Aerosol Experiment (SAGE) instruments. They confirmed the previously reported latitudinal structure of trends, i.e., a maximum negative trend in the extra tropics and a minimum negative trend in the tropics, with a minimum downward trend at all latitudes at  $\sim 30$  hPa. They concluded that SAGE trends were more negative than SBUV trends at nearly all latitudes. In the midlatitudes maximum upper stratospheric trends were approximately  $-9\%$ /decade for SAGE and approximately  $-5\%$ /decade for SBUV. SAGE annual trends were shown to have no statistically significant interhemispheric difference. They found that although SBUV upper stratospheric annual trends were more negative in the SH than the NH, this difference



## Total Ozone Mapping Spectrometer measurements of aerosol absorption from space: Comparison to SAFARI 2000 ground-based observations

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[1] The capability to detect the presence of absorbing aerosols in the atmosphere using space-based near-UV observations has been demonstrated in the last few years, as indicated by the widespread use by the atmospheric sciences community of the Total Ozone Mapping Spectrometer (TOMS) aerosol index as a qualitative representation of aerosol absorption. An inversion procedure has been developed to convert the unique spectral signature generated by the interaction of molecular scattering and particle absorption into a quantitative measure of aerosol absorption. In this work we evaluate the accuracy of the near-UV method of aerosol absorption sensing by means of a comparison of TOMS retrieved aerosol single scattering albedo and extinction optical depth to ground-based measurements of the same parameters by the Aerosol Robotic Network (AERONET) for a 2-month period during the SAFARI 2000 campaign. The availability of collocated AERONET observations of aerosol properties, as well as Micropulse Lidar Network measurements of the aerosol vertical distribution, offered a rare opportunity for the evaluation of the uncertainty associated with the height of the absorbing aerosol layer in the TOMS aerosol retrieval algorithm. Results of the comparative analysis indicate that in the absence of explicit information on the vertical distribution of the aerosols, the standard TOMS algorithm assumption yields, in most cases, reasonable agreement of aerosol optical depth ( $\pm 30\%$ ) and single scattering albedo ( $\pm 0.03$ ) with the AERONET observations. When information on the aerosol vertical distribution is available, the accuracy of the retrieved parameters improves significantly in those cases when the actual aerosol profile is markedly different from the idealized algorithmic assumption.

**Citation:** Torres, O., P. K. Bhartia, A. Sinyuk, E. J. Welton, and B. Holben (2005), Total Ozone Mapping Spectrometer measurements of aerosol absorption from space: Comparison to SAFARI 2000 ground-based observations, *J. Geophys. Res.*, *110*, D10S18, doi:10.1029/2004JD004611.

### 1. Introduction

[2] The role of atmospheric aerosols in the global climate is one of the largest remaining sources of uncertainty in the assessment of global climate change. Aerosols directly affect the energy balance of the Earth-atmosphere system, through the processes of scattering of solar radiation, which redistributes the incoming solar energy in the atmosphere, and absorption (of both solar and infrared radiation), which transforms radiative energy into internal energy of the absorbing particles and heats up the atmosphere. In addition, aerosols, through their role as cloud condensation nuclei,

have an indirect effect on climate by affecting the albedo and lifetime of clouds [Haywood and Boucher, 2000].

[3] The cooling effect of aerosols, associated with the backscattering to space of a fraction of the incoming solar energy, is considered to be a very important counteracting factor of the well known warming effect of the greenhouse gases. The absorption by aerosol particles of a fraction of the incident sunlight and, for certain aerosol types, infrared radiation, results in a heating of the atmosphere. Thus aerosol absorption reduces the cooling effect commonly associated with aerosol particles. Although, the impact of aerosol absorption on climate is still a subject of considerable debate [Penner *et al.*, 2003], recently published theoretical analysis suggest that black carbon may be the second most important global warming substance (in terms of its direct radiative forcing effect) after carbon dioxide, and larger than methane [Jacobson, 2002]. The role of aerosol absorption effects on climate is, therefore, an issue that needs to be better understood in order to reduce the currently large uncertainties of its climatic effect.

[4] In this paper, we present and discuss the results of the application of the near-UV method to observations by

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# Operator representation as a new differential optical absorption spectroscopy formalism

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UV–visible absorption spectroscopy with extraterrestrial light sources is a widely used technique for the measurement of stratospheric and tropospheric trace gases. We focus on differential optical absorption spectroscopy (DOAS) and present an operator notation as a new formalism to describe the different processes in the atmosphere and the simplifying assumptions that compose the advantage of DOAS. This formalism provides tools to classify and reduce possible error sources of DOAS applications. © 2005 Optical Society of America

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## 1. Introduction

A spectral signal on its way from generation in the light source through the atmosphere to the instrument experiences many different transformations. In this paper we introduce a formalism allowing a comparison of those transformations and the corresponding features of differential optical absorption spectroscopy (DOAS).<sup>1</sup> In this comparison we especially aim at the sequencing of the different transformations, each described by an operator, and identify some combination of noncommuting operators that can be assigned to effects such as the  $I_0$  effect or the undersampling problem. Since these effects are based on different instrument and DOAS parameters, the classification of the main error sources can be helpful for the design of new DOAS instruments and to reduce the errors of existing DOAS applications.

## 2. Differential Optical Absorption Spectroscopy

In this section we describe the DOAS method. The absorption of radiation by matter is described by the Beer–Lambert law. The absorption of light of the intensity  $I(\lambda)$  at the wavelength  $\lambda$  as it passes through

an absorbing matter  $dl$  is

$$I(\lambda) = I_0(\lambda) \exp \left[ -\sigma(\lambda, T) \int c(l) dl \right]. \quad (1)$$

Here  $I_0(\lambda)$  is the incident light intensity,  $I(\lambda)$  is the transmitted light intensity,  $\sigma(\lambda, T)$  is the absorption cross section of the absorbing species that depends on the wavelength and temperature, and  $c(l)$  is its concentration. Here the first simplifying assumption is made, namely, the temperature independence of the absorption cross sections. The cross sections can vary with altitude and temperature; therefore excluding it from the integration produces an error. We can reduce this error by using several cross sections for different temperatures, or, if those are linear dependent, by performing *a posteriori* temperature corrections for known temperature profiles. For most applications it is sufficient to use the temperature at the number density maximum of the climatological profile of the corresponding trace gas.<sup>2</sup>

When absorptions are measured in the atmosphere, Eq. (1) has to be applied for the absorption of all trace gases and has to deal with influences of scattering:

$$I(\lambda) = I_0(\lambda) \exp \left[ -\sum_i \sigma_i(\lambda) \text{SCD}_i \right] g(\lambda). \quad (2)$$

where the factor  $g(\lambda)$  describes additional attenuation by the optical system and by Rayleigh and Mie scattering in the atmosphere and all other broadband structured influences, such as reflection on the ground. The sum in the exponential runs over all

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