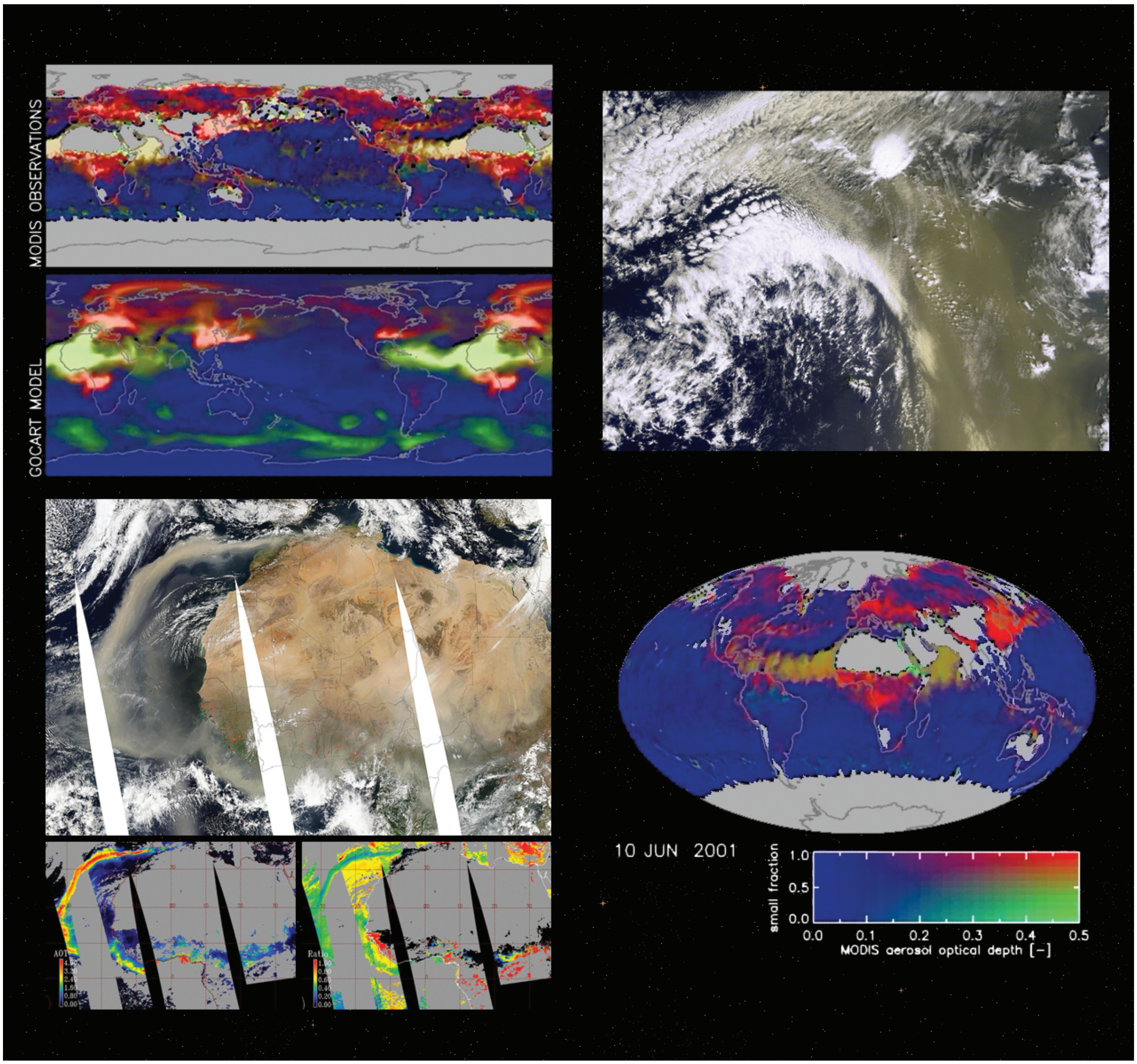
NASA/TM—2007–214150

Laboratory for Atmospheres

2006 Technical Highlights



April 2007

Cover Caption

Teams for the MISR and CERES instruments did not record data for a full minute on Sunday, June 4, 2006 as NASA's Terra and Aqua satellites flew over Goddard Space Flight Center in Greenbelt, MD. Likewise, the POLDER instrument aboard the French Space Agency's (CNES) PARASOL satellite and a global network of upward-looking sensors (called sun photometers) within NASA's Aerosol Robotic Network (AERONET) remained inactive during that same span. Each of these instruments observed a moment of data "silence" in honor of Dr. Yoram J. Kaufman. A pioneering climate researcher, Kaufman died on Wednesday, May 31, from injuries he received in a collision with a car while biking near the NASA Goddard campus on May 26.

The images showcased on our cover pay a respectful tribute to Yoram and the legacy he left behind for the Earth science community and mankind itself. These images are a small, yet powerful sample of his contributions and foci.

Yoram will be remembered as a brilliant scientist, a charismatic leader, and a positive influence within NASA. He collaborated with many scientists around the world in helping to advance our understanding of Earth's climate system. In the days before his untimely death, Yoram was not yet aware that he had been selected by the American Meteorological Society to receive its prestigious Verner E. Soumi Award, which is granted to one individual each year in recognition of highly significant technological achievement in the atmospheric (or related) sciences. We are deeply saddened to lose a valued friend, mentor and leader, and we are proud of Yoram's considerable accomplishments.

Cover Images

Top Left

The global aerosol system with the same color scheme as Image 3, but plotted on a different global projection. Blue colors denote low aerosol optical depth. Greenish tints and reddish tints of increasing intensity denote increasing aerosol optical depths of coarse mode and fine mode aerosols, respectively. The top panel is from aerosol retrievals derived from Terra-MODIS data, and the bottom panel from simulations of the GOddard Chemistry Aerosol Radiation and Transport (GOCART) Model.

Top Right

Satellite image acquired at 12:00 UTC (Universal Coordinated Time) on August 25, 2004 by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard the Earth Observing System (EOS) Terra satellite, and provided courtesy of the MODIS Rapid Response team. The image shows a huge yellowish-brown dust plume rising from the Sahara desert. The dust plume traverses parts of the Canary Islands, heading north. After approximately 1,000 km, it changes direction and heads west toward North America, but then, almost above the region of the Azores, something spectacular happens: the dust apparently begins to interact with clouds.

Bottom Left

A recirculating Saharan dust plume observed by MODIS from the Aqua satellite. True color composite (top panel), total aerosol optical thickness (bottom left panel), and fine mode optical thickness (bottom right panel)

These images of recirculating Saharan dust aerosol were retrieved by MODIS aboard Aqua, on March 6, 2004. Within the true color composite image (top panel), the dust is obviously sand colored, while clouds are white. By observing reflected sunlight in visible and longer wavelengths, MODIS is able to derive quantitative estimates of total aerosol optical thickness (a measure of aerosol concentration), and fine mode weighting (to differentiate between dust and other aerosol types). These quantities are represented by the two bottom panels. An optical thickness of 1.0 means that the aerosol obscures about two-thirds of the direct sunlight from reaching Earth's surface. A fine mode weighting less than 0.5 implies that dust is present. Areas in black are either masked by clouds, or are not observed by the satellite. Land or ocean surfaces too bright for aerosol detection (such as the desert or ocean sun glint) are shaded in gray. Due to the unique optical properties of dust aerosol (its brown color as shown in the top panel), MODIS is able to observe heavy dust over ocean sun glint. Here, the brown dust "finger" is quantitatively analyzed over the ocean sun glint.

Bottom Right

The global aerosol system derived from the data collected by MODIS aboard the Terra satellite. Coarse mode aerosols are generated by wind-driven processes and include sea salt and airborne desert dust. Fine mode aerosols are generated by combustion processes and include smoke and air pollution. The image is constructed from an eleven-day running average with a Gaussian weight centered on June 10, 2001. Gray regions indicate no retrievals in the eleven-day period.

NASA/TM—2007–214150

Laboratory for Atmospheres 2006 Technical Highlights

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

April 2007

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Price Code: A17

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

Laboratory Chief's Summary

Dear Reader:

Welcome to the Laboratory for Atmospheres' 2006 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 2006.

The Laboratory's approximately 230 scientists, technologists, and administrative personnel are part of the Earth Sciences 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. These efforts are helping us better understand our home planet's environment, and are increasing our knowledge of the complex chemistry of the atmosphere.

Several noteworthy events took place during 2006. Field campaigns contributing to Aura validation efforts in 2006 began with the Costa Rica Aura Validation Experiment (CR-AVE) in January. Others were the Intercontinental Chemical Transport Experiment – Part B (INTEX-B) and the Megacity Initiative: Local and Global Research Observations (MILAGRO) in Mexico, Scout-O3 UV in Greece, and the Water Vapor Validation Experiment-Satellites/Sondes (WAVES) at the Howard University Research Campus in Beltsville, MD. These, and several other field campaigns in which Laboratory members participated are described in detail in Section 4, Major Activities. WAVES, which involved students from Howard University as well as Laboratory members, is further discussed in Section 6, Education and Outreach.

As in previous years, Laboratory scientists garnered many top professional honors. The TOMS Science and Data Processing Team won the 2006 Pecora Award. This is given to individuals or groups that have made outstanding contributions toward understanding Earth through remote sensing. Pawan Bhartia accepted the award for the team at the AGU fall meeting in San Francisco. Yoram Kaufman (deceased) won the 2006 Verner E. Suomi Award granted to individuals in recognition of highly significant achievement in the atmospheric or related oceanic and hydrologic sciences. The TOMS and UARS Teams were selected by the NASA Headquarters Incentive Awards Board to receive Group Achievement Awards. These were presented in June at a ceremony held at Martin's Crosswinds in Greenbelt, MD. These, and numerous other awards received by Laboratory members are described in Section 5.6 of this report.

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

The year 2006 was also a time to bid farewell to Geary Schwemmer, a highly valued instrument scientist who was a member of our Laboratory for many years. I am pleased to greet Jackie Haywood, our new administrative assistant, as the only new civil servant member of the Laboratory hired during 2006.

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 2006 report and on the material displayed on our Web site. Your comments may be submitted online. Please check out our Web site.

Finally, we note that a major tragedy struck the Laboratory during 2006. Yoram Kaufman, a friend and colleague whose outstanding service to our Laboratory spanned a period of more than 25 years, died on May 31 from injuries he received in a collision with a car while biking near Goddard on May 26. His death has been a traumatic experience for all of us in the Laboratory. The cover of this year's report is dedicated to his work. His life and many accomplishments are reviewed immediately following this letter: Yoram Kaufman, A Retrospective.

It is to his memory that this report is respectfully dedicated.

In memory of Yoram,

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

March 2007

Yoram Kaufman,
A Retrospective

In Memory of
Yoram J. Kaufman
(1948–2006)

Dr. Yoram J. Kaufman, a senior atmospheric scientist in the Climate and Radiation Branch at NASA Goddard Space Flight Center, died on May 31 from injuries he received in a collision with a car while biking near Goddard on May 26.

Yoram was a highly regarded Goddard Senior Fellow in the Earth-Sun Exploration Division, now the Earth Sciences Division, who worked on a number of high-profile Earth Science missions developed by NASA or its international partners, especially CNES (French Space Agency) and ISA (Israel Space Agency).

He received his B.S. and M.S. degrees in physics from the Technion–Israeli Institute of Technology and his Ph.D. from the Tel-Aviv University in Israel. He came to NASA's Goddard Space Flight Center in 1979 on a National Research Council resident research fellowship.

Among his many accomplishments, he served as the Project Scientist for NASA's very successful Terra mission for four years, carrying this leadership role through its launch in December 1999 and into its first year of Earth observations. He developed methods for remote sensing of fires and aerosols, and he conducted field research on how emissions from fires play a major role in Earth's climate system. Yoram wrote or co-authored over 200 scientific papers published in refereed journals, including several papers in

Science, Nature, and the *Proceedings of the National Academy of Sciences.*

His recent work included theoretical and experimental research on atmospheric radiative transfer and remote sensing, including remote sensing of aerosol particles on a global scale, water vapor and their interaction with clouds, their impact on climate, and their relationship to their sources, for example, fires due to biomass burning in the tropics.

From 1993–1995 he conducted the Smoke/Sulfate, Clouds and Radiation (SCAR) field experiments in both Brazil and the U.S. to characterize smoke aerosol properties, their emissions from fires, and their effect on clouds and radiation.

He was a recipient of the NASA GSFC William Nordberg Award for Earth Science and has received the NASA Medal for Exceptional Scientific Achievement. In 2005, Yoram was presented the NASA GSFC Special Act Award, and was elected a Fellow of the American Meteorological Society. Additionally, during his career at NASA, he received six meritorious awards, including the Peer Award, Exceptional Achievement, Exceptional Performance, and Best Mentor Awards.

His colleagues at NASA and the worldwide Earth science community mourn the loss of an exceptional scientist, a compassionate man, a charismatic leader, and a true visionary with a passion for protecting our planet.

Yoram is survived by his wife Jean, his son Nadav, and his daughter Daphne.

TABLE OF CONTENTS

PREFACE

The Technical Highlights for 2006 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 several 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. Andy Negri contributed to sections of this report, gathered material for other sections and helped with its organization. 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: Caroline Maswanganye, 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 formatting, turning this report into a polished product in a timely manner.

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 Sciences Division (Code 610), formerly the Earth–Sun Exploration Division, 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 atmosphere.

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 modeling activities include climate model simulations, modeling the chemistry and transport of trace species on regional to global scales, cloud-resolving models, and development of next-generation Earth system models. Interdisciplinary research is carried out in collaboration with other laboratories and research groups within the Earth Sciences Division, across the Sciences and Exploration Directorate and with partners in universities and other government agencies.

The Laboratory for Atmospheres is a vital participant in NASA's research agenda. Our Laboratory often has relatively large programs, sizable satellite missions, and 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.

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 2006. 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 228.

The civil servant composition of the Laboratory consists of 57 members; 50 are scientists, 2 are engineers, 3 administrative support, 1 a technical manager, and 1 a technician. Of the 52 civil servant scientists and engineers, 92% 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 Sciences Division and nearby university associations, e.g., the Joint Center for Earth Systems Technology (JCET), the Goddard Earth Sciences and Technology Center (GEST), and the Earth System Science Interdisciplinary Center (ESSIC), or are employed by universities with which the Laboratory has a collaborative relationship, such as George Mason University, University of Arizona, and Georgia Tech. Of the 76 research associates, 81% hold Ph.D.'s. The onsite contractors are a very important component of the staffing of the Laboratory. Out of the total of 89 onsite contractors, 20% hold Ph.D.s. The makeup of our Laboratory, therefore, is 28% civil servants, 33% associates, and 39% contractors.

The number of refereed publications (from 1992) and proposals (from 1997) written by Laboratory members is shown in Figure 2.1. The number in each category is shown above the bars. The difference between the red and blue bars gives the number of papers that our scientists co-authored with outside scientists and is one measure of our extensive collaboration. The yellow 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.

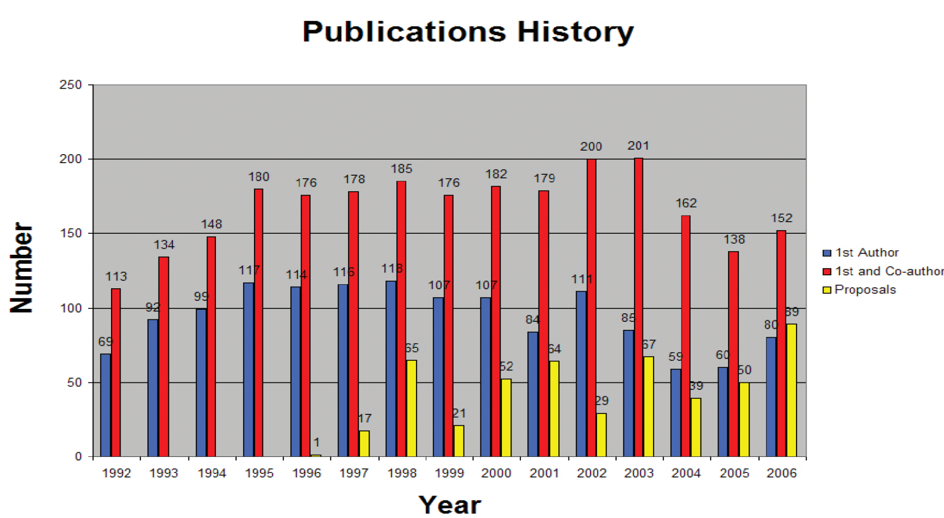


Figure 2.1. Number of proposals and refereed publications by Laboratory for Atmospheres members over the years. The red bar is the total number of publications where a Laboratory member is the first author or co-author, and the blue bar is the number of publications where a Laboratory member is first author. Proposals submitted are shown in yellow.

2.2 Organization

The management and branch structure for the Laboratory for Atmospheres at the end of 2006 is shown in Figure 2.2.

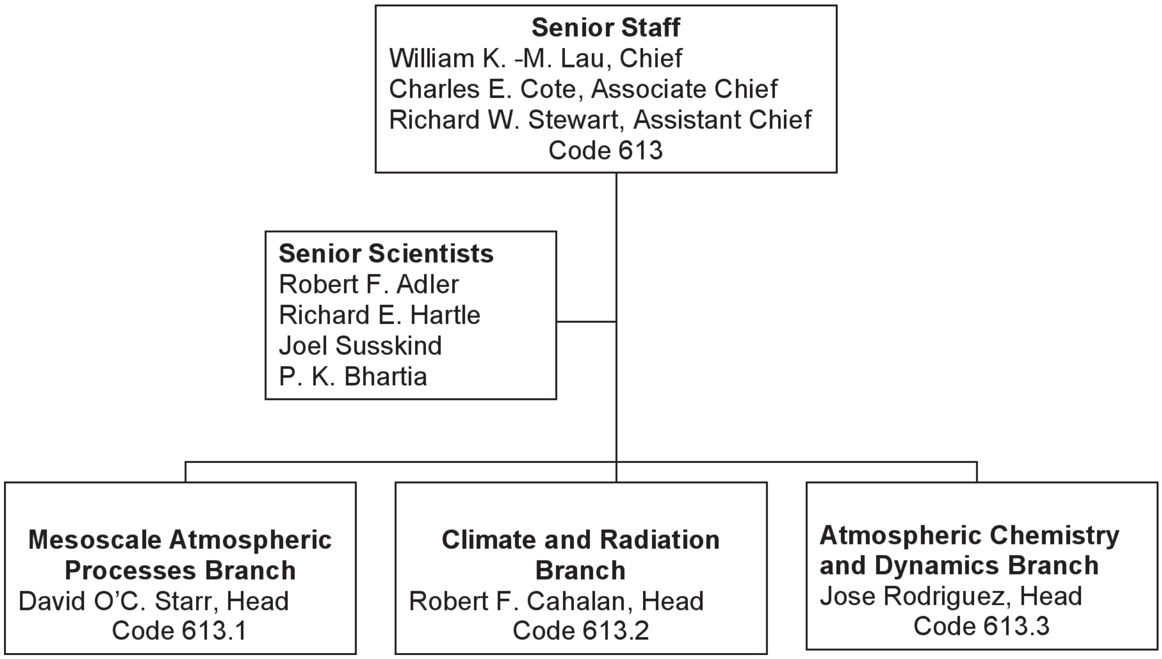


Figure 2.2. Laboratory for Atmospheres organization chart at the end of calendar year 2006.

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 laboratories, 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.

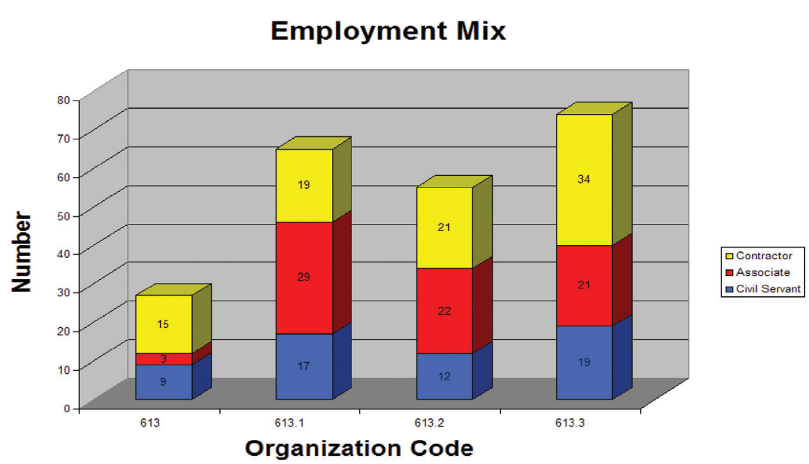


Figure 2.3. Employment composition of the members of the Laboratory for Atmospheres.

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 news items, 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 model simulations. Development of advanced remote sensing instrumentation (primarily lidar and radar) and techniques to measure aerosols, clouds, water vapor and winds in the troposphere is an important focus. Key areas of investigation are cloud and precipitation systems (including aerosol/cloud interaction) and their environments, ranging from the scale of individual clouds and thunderstorms to mesoscale convective systems and cyclonic storms. The climate impacts at regional and global scales, e.g., El Niño Southern Oscillation (ENSO), are a major focus. State-of-the-art efforts involve coupling various NASA Goddard physical packages (microphysics, radiation, and land surface models) into a next generation weather forecast model (known as the weather and research forecast model or WRF), and implementing a mesoscale cloud-resolving model (Goddard Cumulus Ensemble Model) into a global model. In summary, the Branch focuses its research on all aspects of the atmospheric hydrologic cycle, its connections to the global energy cycle, and associated hazards, such as hurricanes, floods and landslides. The Branch plays a key science leadership role in satellite missions, such as the Tropical Rainfall Measurement Mission (TRMM) and the Geoscience Laser Altimeter System (GLAS) on ICESat. Similarly, we contribute to the formulation of new mission concepts, such as the Global Precipitation Mission (GPM). Participation in field campaigns such as the NASA African Monsoon Multidisciplinary Analysis (NAMMA), Costa Rica Aura Validation Experiment (CR-AVE), and the Calipso/CloudSat Validation Experiment (CC-VEx) continues to be a high priority. 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 forcing 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 range of scales is studied, from the spatial microscales of nucleation processes to the Sun–Earth distance, and from microsecond to geologic time scales. Research focus areas include observational and modeling studies of tropospheric aerosols, cloud processes, rainfall, solar radiation, and surface properties. Key disciplines are radiative transfer, both as a driver for climate studies 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 other NASA centers, government agencies, and with university partners include development and assessment of observational climate data records, incorporation of microphysical cloud-aerosol interactions in climate models, addressing 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 at 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 , changes in global air quality caused by human activity, and the interaction between atmospheric composition 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. Modeling activities in the branch will continue to focus on simulations for the analysis of Aura data, and assessment of the impact of anthropogenic activity on the atmospheric composition and climate. 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 home page http://atmospheres.gsfc.nasa.gov/.

2.4 Facilities

Computing Capabilities

Computing capabilities used by the Laboratory range from high-performance supercomputers to scientific workstations to desktop personal computers. Each Branch maintains its own system of computers, which are a combination of Windows, Linux, and Mac OS X computers. A major portion of scientific data analysis and manipulation, and image viewing is still done on Unix 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 also available on the Laboratory's 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 Backscatter 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.

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 2006 Strategic Plan available at http://www.nasa.gov/pdf/142302main_2006_NASA_Strategic_Plan.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 and 2005. The former seven strategic enterprises have been transformed into four directorates: Science Mission Directorate, Space Operations Mission Directorate, Exploration Systems Mission Directorate, and Aeronautics Mission Directorate. These directorates are charged with accomplishing six goals described in the 2006 Strategic Plan.

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 four Divisions under the new Sciences and Exploration Directorate are Earth Sciences (Code 610), Heliophysics Science (Code 670), Solar System Exploration (Code 690), and Astrophysics Science (Code 660). The Laboratory for Atmospheres is under the Earth Sciences Division (ESD). 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, now ESD, published a strategic plan outlining the Division's mission and goals in greater detail than the Agency plan http://webserv.gsfc.nasa.gov/images/esappdocs/ESED-stratplanv2.pdf. The Laboratory's research is guided by the goals contained in these plans. 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 and Cassini missions and the current Earth Observing System (EOS) 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
Aerosol Atmospheric Chemistry Carbon Cycle Climate Change Global Water and Energy Cycle Weather and Short-term Climate Forecasting	• Aerosol • Atmospheric Chemistry and Ozone • Atmospheric Hydrologic Cycle • Carbon Cycle • Clouds and Radiation • Climate Variability and Prediction • Mesoscale Processes • Precipitation Systems • Severe Weather • Chemistry-Climate Modeling • Global and Regional Climate Modeling • Data Assimilation • Tropospheric Winds

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

Classification in the four major activity areas: measurements, data sets, data analysis, and modeling, is somewhat artificial, in that the activities are strongly interlinked and cut across science priorities and the organizational structure of the Laboratory. The grouping corresponds to the natural processes of carrying out scientific research: ask the scientific question, identify the variable needed to answer it, conceive the best instrument to measure the variable, generate data set, 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 some 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 atmosphere of Earth require a comprehensive set of observations, relying on instruments borne on spacecraft, aircraft, balloons, or those that are ground-based. Our instrument systems 1) provide information leading to basic understanding of atmospheric processes, and 2) serve as calibration references for satellite instrument validation.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations. Airborne instruments provide critical *in situ* and remote measurements of atmospheric trace gases, aerosol, ozone, and cloud properties. Airborne instruments also serve as stepping-stones in the development of spaceborne instruments, and serve an important role in validating spacecraft instruments.

Table 4.1 shows the principal instruments that were built in the Laboratory, for which a Laboratory scientist has had responsibility as Instrument Scientist, or for which Laboratory scientists are responsible for algorithm development, calibration and data analysis. 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 which is also available on the Laboratory's home page, http://atmospheres.gsfc.nasa.gov/.

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

	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation
Space	GLAS TRMM	OMI	GLAS TRMM MODIS
Aircraft/Balloon	EDOP HARLIE TWiLiTE (IIP) URAD HIWRAP (IIP)	AROTAL RASL (IIP) ACAM	CPL THOR Lidar CRS UAV CPL

Ground/ Laboratory/ Development	SRL GLOW	STROZ LITE AT Lidar Brewer UV Spectrometer KILT Pandora Spectrometers L2-SVIP GeoSpec (IIP)	MPL COVIR SMART COMMIT

ACAM	Airborne Compact Atmospheric Mapper
AROTAL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ATL	Aerosol and Temperature Lidar
COMMIT	Chemical, Optical, and Microphysical Measurements of *In situ* Tropopause
COVIR	Compact Visible and Infrared Radiometer
CPL	Cloud Physics Lidar
CRS	Cloud Radar System
EDOP	ER-2 Doppler Radar
GeoSpec	Geostationary Spectrograph
GLAS	Geoscience Laser Altimeter System
GLOW	Goddard Lidar Observatory for Winds
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
IIP	Instrument Incubator Program
KILT	Kiritimati Island Lidar Trailer
L2-SVIP	Lagrange-2 Solar Viewing Interferometer Prototype
MODIS	Moderate Resolution Imaging Spectroradiometer
MPL	Micro-Pulse Lidar
OMI	Ozone Monitoring Instrument
RASL	Raman Airborne Spectroscopic Lidar
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SRL	Scanning Raman Lidar
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
THOR	cloud THickness from Offbeam Returns
TRMM	Tropical Rainfall Measuring Mission
TWiLiTE	Tropospheric Wind Lidar Technology Experiment
UAV	Unmanned Aerial Vehicle
URAD	Unmanned Aerial Vehicle Radar
UV	Ultraviolet

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 2006, Laboratory personnel supported eleven such activities as scientific investigators, or as mission participants, in the planning and coordination phases.

4.2.1 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: the Ozone Monitoring Instrument (OMI), Tropospheric Emission Spectrometer (TES), Microwave Limb Sounder (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.

During 2004 and 2005 three AVE missions were flown using the NASA WB-57F and NASA DC-8 aircraft. These missions have continued in 2006 with the Costa Rica Aura Validation Experiment (CR-AVE).

4.2.2 Costa Rica Aura Validation Experiment (CR-AVE)

The Costa Rica Aura Validation Experiment (CR-AVE), running from January 15 to February 14, 2006 was the fourth in a series of similar NASA-led science missions to acquire high quality measurements of the tropical atmosphere to validate data from NASA's Aura satellite. Such experiments allow scientists to directly measure the transport of gases and aerosols in the lower atmosphere (or troposphere) and their exchange with the lower stratosphere. This data is then compared with that from Aura to enable improved modeling of global-scale air quality and climate change predictions.

The fourth AVE campaign was staged in Costa Rica in January and February 2006. The NASA WB-57F carried a total of 29 instruments in two separate payloads. The first payload was composed of both *in situ* and remote sensing instruments. A total of six flights were conducted that were precisely timed to coincide with the Aura overpass. For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov).

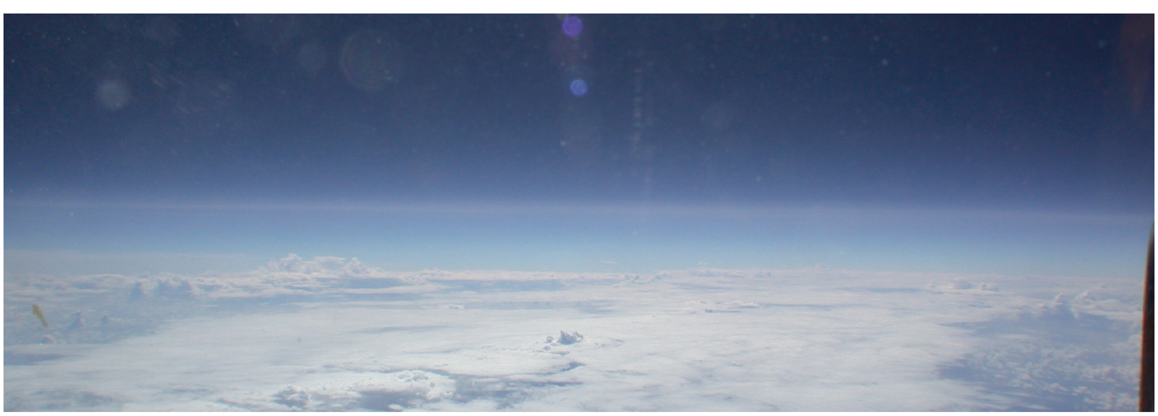


Figure 4.1. Photograph of a thin layer of cirrus clouds taken from the NASA WB-57F from an altitude of 60,000 feet on January 14, 2006. This extensive but thin layer of cirrus is not visible from the ground. Photo by John Bain (NASA JSC).

4.2.2.1 Cloud Physics Lidar (CPL)

In January 2006, the CPL instrument was part of the Costa Rica Aura Validation Experiment (CR-AVE). This experiment was based in San Jose, Costa Rica for the express purpose of validating instruments onboard the Aura satellite. Seven science flights were conducted to acquire high quality test data for the CloudSat and CALIPSO satellites using well characterized simulators for the primary satellite sensors. CloudSat and CALIPSO were subsequently launched in spring of 2006. For CR-AVE, the CPL was operated on the WB-57F aircraft. 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).

4.2.2.2 Cloud Radar System (CRS)

The CRS is a Doppler radar developed for autonomous operation in the NASA ER-2 high-altitude aircraft and for ground-based operation. It was flown for the first time during CR-AVE on the WB-57F aircraft. The goals for CPL and CRS were to prepare a remote sensing package for the CloudSat and CALIPSO satellites after their launch in Spring 2006. For further information on the CRS visit http://rsd.gsfc.nasa.gov/912/edop/crs_id_description.htm or contact Gerry Heymsfield, Gerald.M.Heymsfield@nasa.gov.

4.2.3 Tropical Warm Pool–International Cloud Experiment (TWP-ICE)

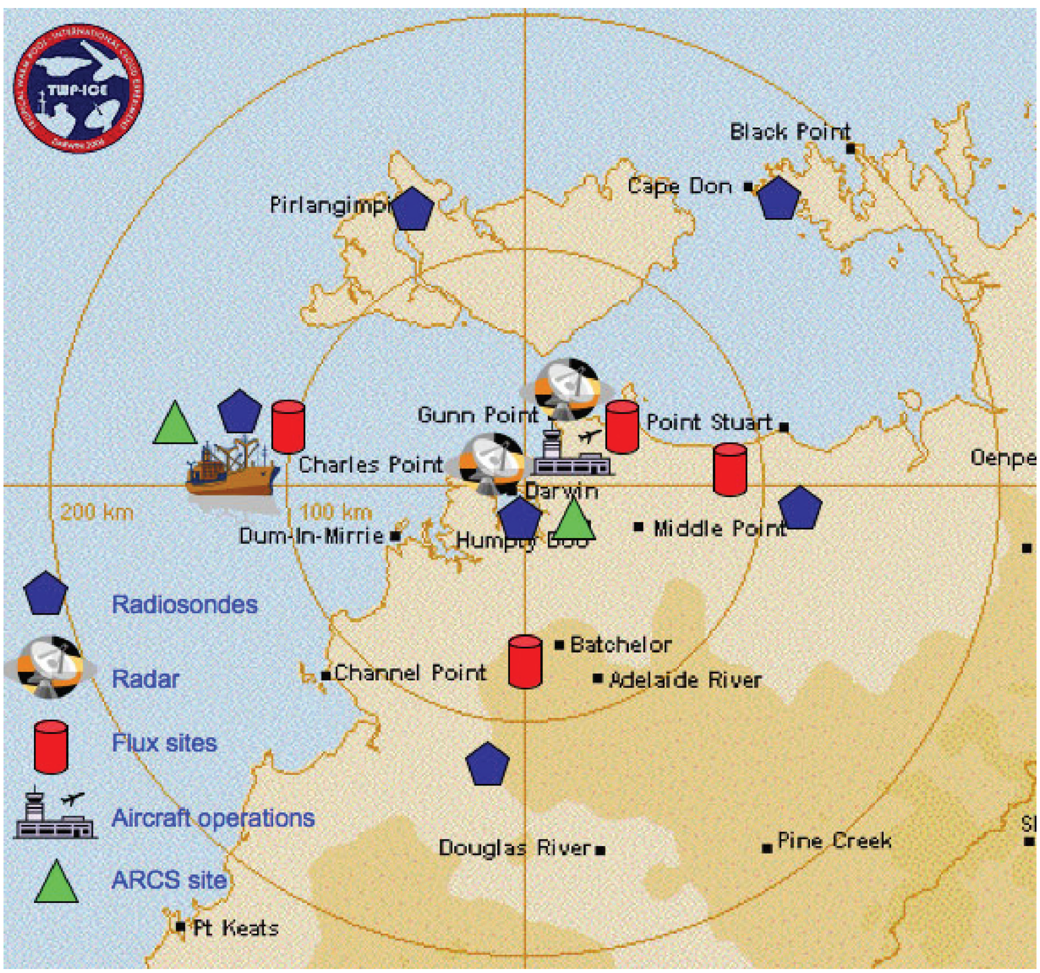


Figure 4.2. The map shows the extensive ground network of cloud sensing radar. Lidar, and passive instruments were located on a ship as well as several ground sites throughout the TWP-ICE experimental domain.

David Starr, Code 613.1, served on the Mission Management Team for TWP-ICE that took place in the area around Darwin, Australia in early 2006. Andy Ackerman, and Anne Fridlind, both Code 611 (GISS), participated in the in-field theory team. David Starr contributed to the daily mission planning and real-time operational execution of this complex airbone experiment which involved a fleet of 5 aircraft. The aim of the experiment was to examine convective cloud systems from their initial stages through to the decaying and thin high-level cirrus and measure their impact on the environment. The experiment design included an unprecedented array of soundings, research-grade volumetric radar coverage, and other information to support cloud-resolving and other modeling studies as well as *in situ* and remote sensing airborne observation platforms. This large multi-agency experiment involved substantial contributions from the following entities:

- U.S. Department of Energy, ARM Program;
- U.S. National Aeronautics and Space Administration (NASA);
- Australian Bureau of Meteorology (BoM); and
- Commonwealth Scientific and Industrial Research Organization (CSIRO)

A number of universities and a group sponsored by the European Union also contributed instrumentation to the experiment.

A key component of the field campaign was the fleet of aircraft including the Dornier for sampling aerosols and chemistry in the boundary layer, the Dimona for flux measurements in the boundary layer, the Egrett and Proteus for high-altitude *in situ* and remote sensing measurements, and a Twin Otter which carried lidar and radar for CloudSat and CALIPSO validation studies. The Egrett and Dornier comprised the European Union sponsored ACTIVE (Aerosol and Chemical Transport In tropical conVEction) component of TWP-ICE. The Proteus and Twin Otter were sponsored by ARM with support from the CloudSat and CALIPSO projects. Together, these aircraft collected measurements of cloud properties and the meteorological environment from the planetary boundary layer up to 15 km, often in-anvil at the upper levels. The airborne sampling was coordinated with observations from cloud sensing radar, lidar and passive instruments located at the ARM facility site, operated at Darwin by the BoM, and on a ship in the Timor Sea approximately 100 km northeast of Darwin. The experiment was a great success with data collected for a variety of convective systems and in upper tropospheric clouds at various stages of their lifecycle from freshly generated to quite aged. Cirrus outflow from both monsoon systems and highly continental systems were extensively sampled. In November, a post-experiment science workshop was held at GISS. The reported data quality was quite good and significant progress was being made on a number of key science issues such as characterizing differences in microphysical properties of cirrus based on age and nature of convective source.

For further information contact David Starr, David.Starr@nasa.gov.

4.2.4 Intercontinental Chemical Transport Experiment – Part B (INTEX-B) and Megacity Initiative: Local and Global Research Observations (MILAGRO)

The main mission goals of INTEX-B were to study the export of pollutants out of the Mexico City region, to study the transport of pollutants from Asia, across the Pacific Ocean to North America, and to provide data for the validation of Aura instrument products. The mission ran from March to May, 2006 and included local flights from three locations: Houston, TX, Honolulu, HI, and Anchorage, AK. The Houston, TX deployment coincided with the MILAGRO campaign in Mexico (see below). For mission details see: http://www-air.larc.nasa.gov/missions.htm.

Ken Pickering (Code 613.3) and Tom Kucsera (SSAI) developed, produced, and interpreted a set of trajectory- and satellite-based forecast products to aid in flight planning for the INTEX-B experiment. These products were run for all three deployments and were interpreted and presented to the flight planning team in the field.

Products included the OMI Aerosol Index (AI) observations and a forecast product predicting aerosol exposure based on a field of back trajectories run through the AI data. Lightning observations from a global network and a trajectory-based forecast of exposure to lightning NO_x emissions were also made available to the team. Other products included forecast meteorological fields from Goddard's Global Modeling and Assimilation Office (GMAO), a reverse-domain-fill forecast of potential vorticity, and maps of total column ozone and tropospheric NO_2 from OMI.

The Code 613.3 AROTAL instrument was deployed on the NASA/UND DC-8 aircraft (UND is University of North Dakota) for the INTEX-B mission. The AROTAL instrument makes vertical profile measurements of ozone, aerosols and temperature above the aircraft. For further information on this aspect of INTEX-B contact Tom McGee (Thomas.J.McGee@nasa.gov).

Lorraine Remer (Code 613.2) and D. Allen Chu (JCET/UMBC) joined the forecast team for INTEX-B, preparing satellite imagery and analysis for flight planning. Their particular specialty was the forecast of aerosol events using MODIS data. During the deployment in Anchorage, AK they noted several Asian dust events entering the Pacific study area and also an interesting biomass burning event from Siberia that moved over Scandinavia and into the Arctic. During the analysis phase Remer and Chu will use data collected during the deployments to make estimates of aerosol radiative effects and forcing.

Megacity Initiative: Local And Global Research Observations (MILAGRO) Mexico City, March 2006

The MILAGRO field campaign represents an umbrella initiative that encompassed simultaneous campaigns from NCAR, ASP/DOE, MIT, NASA and several Mexican agencies and universities. The campaign took place during March 2006, centered on Mexico City, but extended throughout central Mexico. The NASA component of MILAGRO was the first phase of INTEX-B. The objectives of the campaign were to characterize the pollutant exports of the world's second largest megacity (18 million people). Ground-based, airborne, and satellite measurements complemented an extensive modeling effort.

The Laboratory, in collaboration with UMBC, participated in making measurements on the ground and as part of NASA's payload on the J31 aircraft (PI: P. Russell of NASA/Ames). The composite image, Fig. 4.3, shows the Sky Research Jetstream-31 (J31) as it was deployed during the MILAGRO experiment in Mexico during March 2006.

The objectives of MILAGRO included characterizing the pollutant plume that originates in the greater Mexico City area and the evolution of that plume as it exits the basin. The J31 was just one of six aircraft participating in the experiment, along with three main ground sites, several auxiliary ground sites and several tethered balloons. Five of the aircraft, including the J31, were based in Veracruz on the east coast of Mexico.

The J31 was unique in that it was equipped to measure solar energy and how that energy is affected by the pollution and the Earth's surface. The aircraft carried six instruments. The Ames Airborne Tracking Sunphotometer-14 (AATS-14) provided total column spectral aerosol optical depth and precipitable water vapor, and vertical profiles of aerosol extinction and water vapor density. The Research Scanning Polarimeter (RSP) measured the spectral and polarized radiance from the surface and atmosphere beneath the plane. The Solar Spectral Flux Radiometer (SSFR) measured the upwelling and downwelling spectral hemispheric irradiance. The Cloud Absorption Radiometer (CAR) measured spectral and angular distribution of scattered light by clouds and aerosols. It also provided bidirectional reflectance of various surfaces, and imagery of cloud and Earth surface features. The Position and Orientation System (POS) and the Met Sensors and Navigation Data System (NavMet) provided useful information on aircraft position, orientation and meteorological variables.

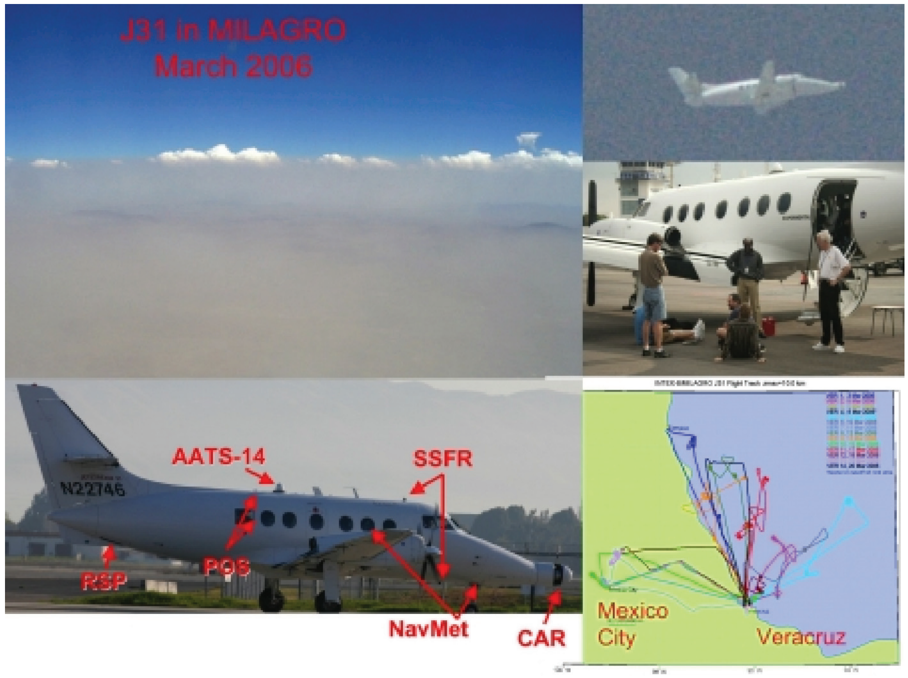


Figure 4.3. Remote Sensing Aircraft, J31, during MILAGRO. The images starting from the top left show the heavily polluted environment that was encountered in the basin north of Mexico City on March 19, 2006., the J31 scientists and engineers waiting to board the aircraft, the flight tracks of all of the J31's flights during MILAGRO, and instrument locations on the aircraft. Images were provided by Phil Russell (NASA/Ames) who was PI of the aircraft, Kirk Knobelspiesse (Columbia Univ.) and Dominik Cieslak (UMBC).

The Laboratory's participation was led by Lorraine Remer, J. Vanderlei Martins (JCET/UMBC), Michael King, and Charles Gatebe (GEST/UMBC). Our particular interests were to characterize the absorption properties of the aerosol, the extinction of the aerosol as a function of humidity, the bidirectional reflectance of the surface, especially the highly urban surface of Mexico City, and to test a new remote sensing technique for deriving aerosol absorption over ocean sun glint. We deployed instrumentation and team members at one of the MILAGRO sites to the northeast of Mexico City, but still within the caldera. We also deployed instrumentation at three sites along the Mexican east coast. The J31 flew 14 missions from the city of Veracruz, some over the ocean to intercept the outgoing pollution plume and some over Mexico City to characterize the pollution near the source and to characterize the bidirectional reflectance distribution function (BRDF) of the urban landscape.

In Fig. 4.4, the photograph in the background shows aged pollution from Mexico City over a ground-based station in the city of Pachuca, Hidalgo State, which is located about 150 km north of Mexico City. The relatively low visibility, fading the mountains in the background, is a result of the scattering of solar radiation by the aerosol particles in suspension in the atmosphere. These particles scatter and absorb solar radiation contributing to cooling the Earth's surface and potentially heating some atmospheric layers. These aerosols also act as cloud condensation nuclei, initiating the formation of cloud droplets in the Earth's atmosphere. The graph shows an example of the interaction between these aerosols and water vapor in the atmosphere measured with a humidified scattering/extinction cell during the March 2006 MILAGRO Field Experiment

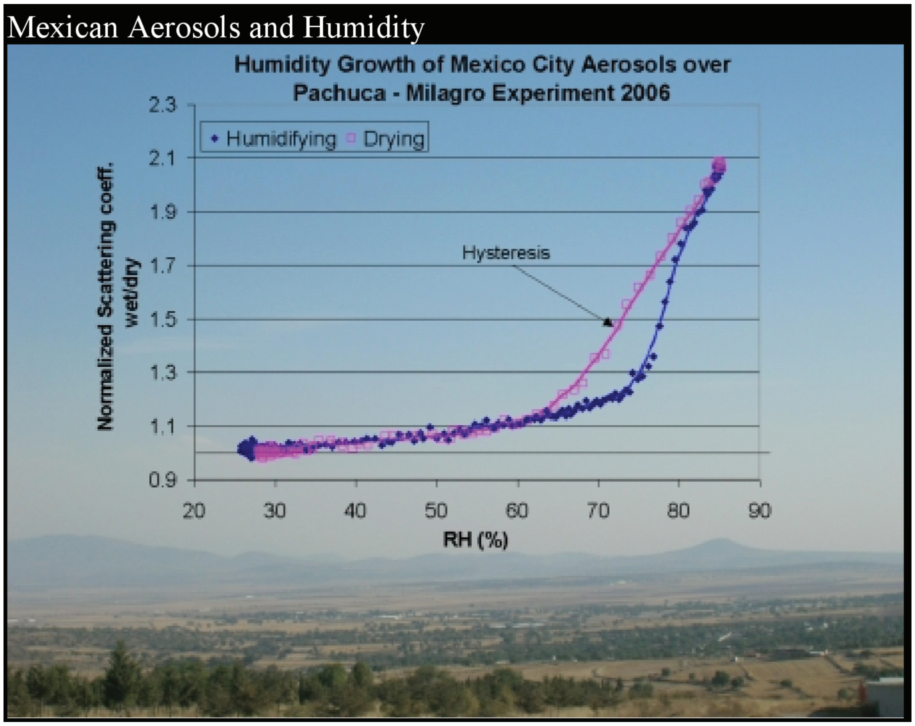


Figure 4.4. Growth of Mexico City aerosols vs. relative humidity superimposed on a picture of background pollution .

For further information contact Ken Pickering, Kenneth.E.Pickering@nasa.gov or Lorraine Remer, Lorraine.A.Remer@nasa.gov. For additional information on MILAGRO and the CAR instrument visit http://www.eol.ucar.edu/projects/milagro/ and http://car.gsfc.nasa.gov/data/.

4.2.5 Biomass-burning Aerosols in South East Asia: Smoke Impact Assessment Field Experiment (BASE-ASIA)

Biomass burning has been a regular practice for land clearing and land conversion in many countries, especially those in Africa, South America, and Southeast Asia. Southeast Asia, home to more than 60% of the world's population, is one of the fastest growing regions in population density and economic activity and is experiencing vital changes in land use and land cover. This leads to increases in fossil fuel, coal, and biomass burning with consequent increases in man-made aerosols in the atmosphere.

"Are Smoke Aerosols responsible for changing Cloud Life-Cycle and redistributing Fresh Water? *Since light-absorbing particles (e.g., smoke, soot, or black carbon) warm the atmosphere, they reduce surface evaporation and cut off convection, essential parts of the hydrologic cycle."*

In the spring of 2006, a joint U.S.-Thailand research group conducted the BASE-ASIA pilot study, seeking to better understand regional aerosol radiation forcing on the Earth-Atmosphere system. Participants include scientists from the U.S., NASA GSFC Laboratory for Atmospheres, Univ. Hawaii, Univ. Maryland; from Thailand, Chulalongkorn University, Bureau of Royal Rainmaking and Agricultural Aviation; and many individuals from the regions. Accurately assessing the impact of smoke aerosols on aerosol-cloud interactions requires continuous observations from satellites and networks of ground-based instruments as well as dedicated field experiments utilizing aircraft and ground-based instruments. Figure 4.5 illustrates the operations of BASE-ASIA, including the utilization of NASA's Terra, A-Train satellites and other satellite data sets in Southeast Asia, NASA GSFC hyperspectral imagers (solar and thermal) flown aboard Thai's rainmaking fleet (CASA-100 aircraft, based at Khora, Thailand), and GSFC's SMART (Surface-sensing Measurements for Atmospheric Radiative Transfer) & COMMIT (Chemical, Optical, Microphysical Measurements of *In situ* Troposphere) mobile observatory (http://smart-commit.gsfc.nasa.gov/) and COPAA (Chemistry & Optical Properties of Absorbing Aerosols) facility from University of Hawaii deployed in the middle of agricultural fields at Phimai, Thailand. During the peak-burning season (e.g., February–March–April), a frequently observed phenomenon is smoke-induced clouds (Fig. 4.5), even in small-scale burning. On a cloud-free day (visually in the zenith direction), the temperature profiles (panel g, blue line for noontime, red for afternoon) often depict one (noontime) or multiple (afternoon) inversion layers. It may be that local biomass-burning practices are relatively more active in the afternoon, leading to elevated levels of light-absorbing aerosols in the boundary layer and a subsequent warming within such layers. A challenging task in understanding aerosol-cloud interactions is underway by combining these surface *in situ* and remote-sensing measurements, aircraft and satellite observations, together with modeling efforts. For further information, contact Si-Chee Tsay (si-chee.tsay@nasa.gov).

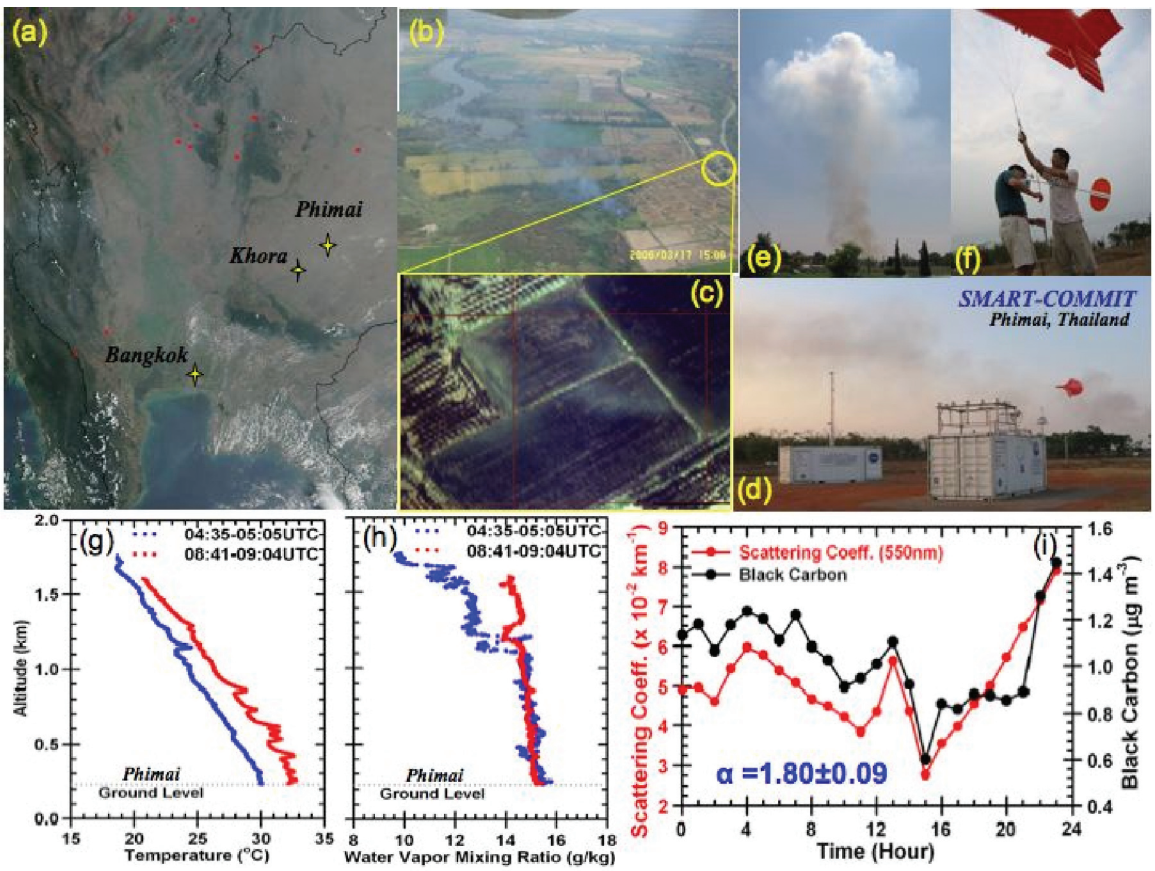


Figure 4.5. (a) Satellite image (Terra/MODIS for red, 0.66 µm; green, 0.55 µm; blue, 0.47 µm) depicts active fires (red dots) and extensive layer of haze/smoke aerosols over Southeast Asia. (b, c) A GSFC solar hyperspectral imager explores spectral and spatial features of biomass burning. (d) GSFC's SMART-COMMIT mobile observatory was deployed in the middle of agricultural fields at Phimai, Thailand, from the pre-burning, peak-burning, to the pre-monsoon seasons. (e, f, g, h, i).

Many attempts were made to investigate the atmospheric state parameters (e.g., pressure, temperature, water vapor, and wind) by launching tethered balloons (up to 2 km within 30 min) in the boundary layer, as well as the optical, microphysical, and chemical measurements (e.g., aerosol optical depth, Ångström exponent, black carbon mass concentration) associated with frequently observed smoke-induced clouds.

4.2.6 Sodankylä Total Column Ozone Intercomparison (SAUNA)

Validation of ground-based and satellite total ozone measurements are usually performed under ideal measurements conditions at mid-latitudes where total ozone is near 300 DU. In general, agreement between ground-based instruments is within 2%, giving confidence to the methods and algorithms under these conditions. However, total column ozone retrievals at high latitudes show persistent differences of 5–10%, especially under conditions of low sun, high total column ozone (> 400DU) and high column variability. Satellite and ground-based measurements must be compared under a greater variety of ozone column amounts and profile shapes if such differences are to be resolved.

The objective of the Sodankylä Total Column Ozone Intercomparison was to assess the comparative performance of the ground-based instruments and algorithms that measure total column ozone at large solar zenith angles and high total column ozone amounts. SAUNA was organized by the NASA GSFC Laboratory for Atmospheres, in collaboration with the Finnish Meteorological Institute Arctic Research Center (FMI-ARC) and the European Space Agency (ESA-ESRIN), and involved 30 participants from 10 institutions in 9 countries. A list of participants and instruments is given in Table 4.2. The SAUNA campaign was carried out from March 20 to April 14 at the FMI-ARC located 120 km north of the Arctic Circle at Sodankylä, Finland (Figure 4.6).

Table 4.2: List of SAUNA Instruments and Principal Investigators.

Instrument	Principal Investigator	Affiliation
Brewer: single monochromator	E. Kyrö	FMI-ARC (Finland)
Brewer: 1 single (World standard), 1 double	T. McElroy	MSC (Canada)
Brewer: double	A. Cede R. McPeters	NASA GSFC (USA)
Brewer: 1 double (European Standard)	A. Redondas E. Cuevas	INM-Izana (Spain)
Dobson (Traveling standard)	R. Evans	NOAA/ESRL/GMD (USA)
Dobson (European standard)	U. Koehler	DWD-MOHp (Germany)
DOASs: 1 UV, 1 vis, 1 miniDOAS	M. van Roozendael	BIRA-IASB (Belgium)
miniDOAS	E. Brinksma	KNMI (Netherlands)
SAOZ (permanently at FMI-ARC)	F. Goutail	CNRS-SA (France)
STROZ-LITE LIDAR (NDSC standard)	T. McGee	NASA-GSFC (USA)
Ozonesondes	R. Kivi B.R. Bojkov	FMI-ARC (Finland) NASA-GSFC (USA)

Figure 4.6. Finland and the location of Sodankylä, 120 km north of the Arctic Circle (67.37°N, 26.63°E).

The early springtime at this high latitude provides the ideal large solar zenith angles for the mission, and total ozone is consistently higher than 400 DU over Sodankylä at this time of year. The timing of the SAUNA mission took advantage of these geophysical conditions.

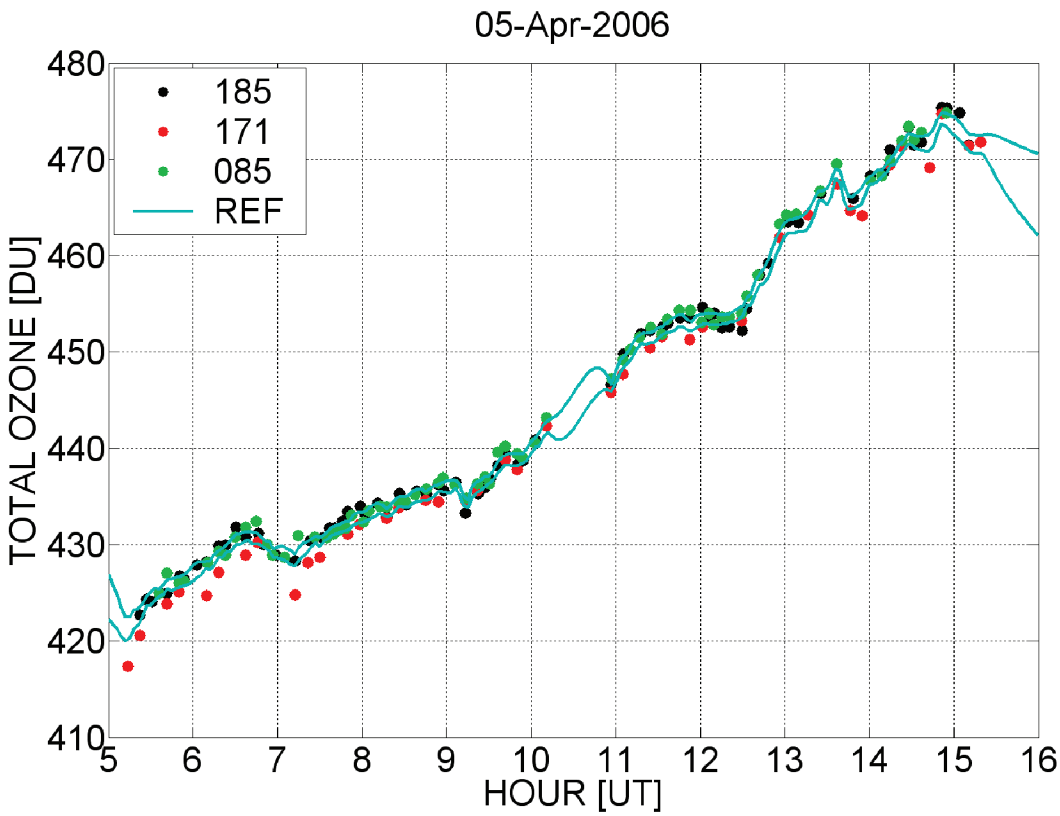


Figure 4.7. Measurements of the three participating Brewer double monochromator spectrophotometers as seen for April 5, 2006. This high column increase through the course of the day was typical for the SAUNA campaign.

A typical measurement day is depicted in Figure 4.7 showing a variability of 60 DU in 9 hours. Observations made by space based instruments aboard several satellites are tightly integrated into the intercomparison strategy of the mission as well. The effect of ozone and temperature profile on total column measurements will also be explored using LIDAR and ozone sonde observations. The Laboratory STROZ Lidar participated in this campaign to provide stratospheric vertical profiles of ozone and temperature during each of the clear nights during the campaign. Ozone and temperature profiles were retrieved during six nights, and were compared to the profiles from sondes launched from Sodankylä (although these were not always coincident in time.) Figure 4.8 shows the results of these lidar/sonde comparisons. The overall mean difference was 0.86% ± 0.28%. The majority of the difference is due to the extreme variability of the atmosphere and the different measurement geometries.

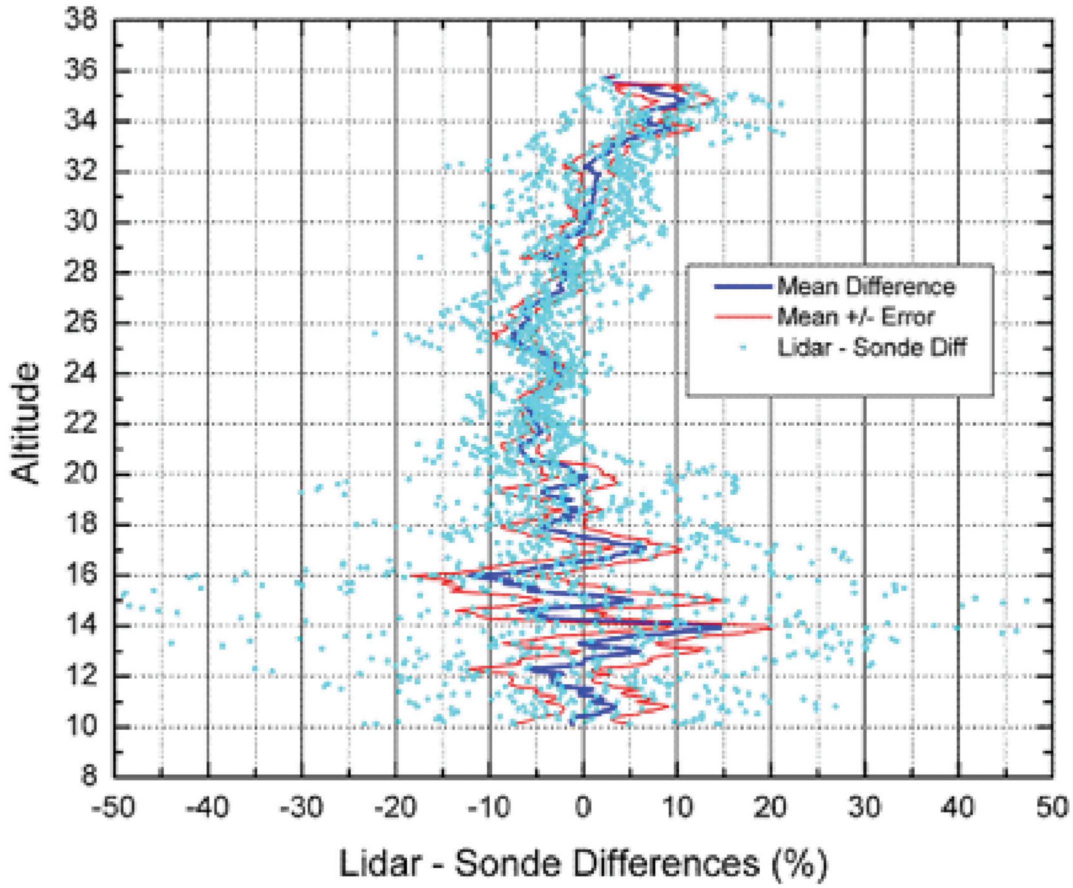


Figure 4.8. Lidar/Sonde differences in O_3 profiles during SAUNA.

The scientific findings from the SAUNA mission should improve the absolute accuracy of historic and future total ozone observations made under the extreme conditions of high ozone and large solar zenith angles. A data workshop was held in November 2006 and consensus was reached to redeploy at Sodankylä in February 2007 to focus on the profile shape dependence of the ground-based and satellite algorithms at very large solar zenith angles (> 80 deg.). In addition to the ground-based instruments of the first SAUNA campaign, intensive STROZ Lidar measurements and about 50 ozonesondes will be launched during the 4 week SAUNA-2 campaign.

For further information on SAUNA contact Bojan R. Bojkov (UMBC/GEST, Bojan.Bojkov@gsfc.nasa.gov) and for information on the STROZ Lidar, contact Tom McGee, Thomas.J.McGee@nasa.gov).

4.2.7 NASA African Monsoon Multidisciplinary Analysis (NAMMA)

This mission, running from August 15 to mid-September, examined the formation and evolution of tropical hurricanes in the eastern and central Atlantic and their impact on the U.S. East Coast, the composition and structure of the Saharan Air Layer (SAL), and whether aerosols affect cloud precipitation and influence cyclone development. During the 2006 hurricane season, a group of scientists spent a month in Cape Verde, a republic of 10 small islands off the western coast of Africa, to learn more about the birth of these storms. Some of most intense hurricanes that cause serious influence over the East Coast and Caribbean Islands originate from African Easterly Wave(s) (AEWs), which are disturbances moving westward from the African continent over the

Atlantic Ocean. Only a limited number of disturbances grow into hurricanes. How these disturbances become hurricanes, or more generally tropical cyclones, is not well known. The SAL, a warm, dry and often dust-laden air mass, is believed to influence tropical cyclones according to some theories. This intrigues scientists studying the structure and composition of the SAL and its interaction with AEWs. Several instruments participating in NAMMA and a sampling of some of their results are shown in Figure 4.9.

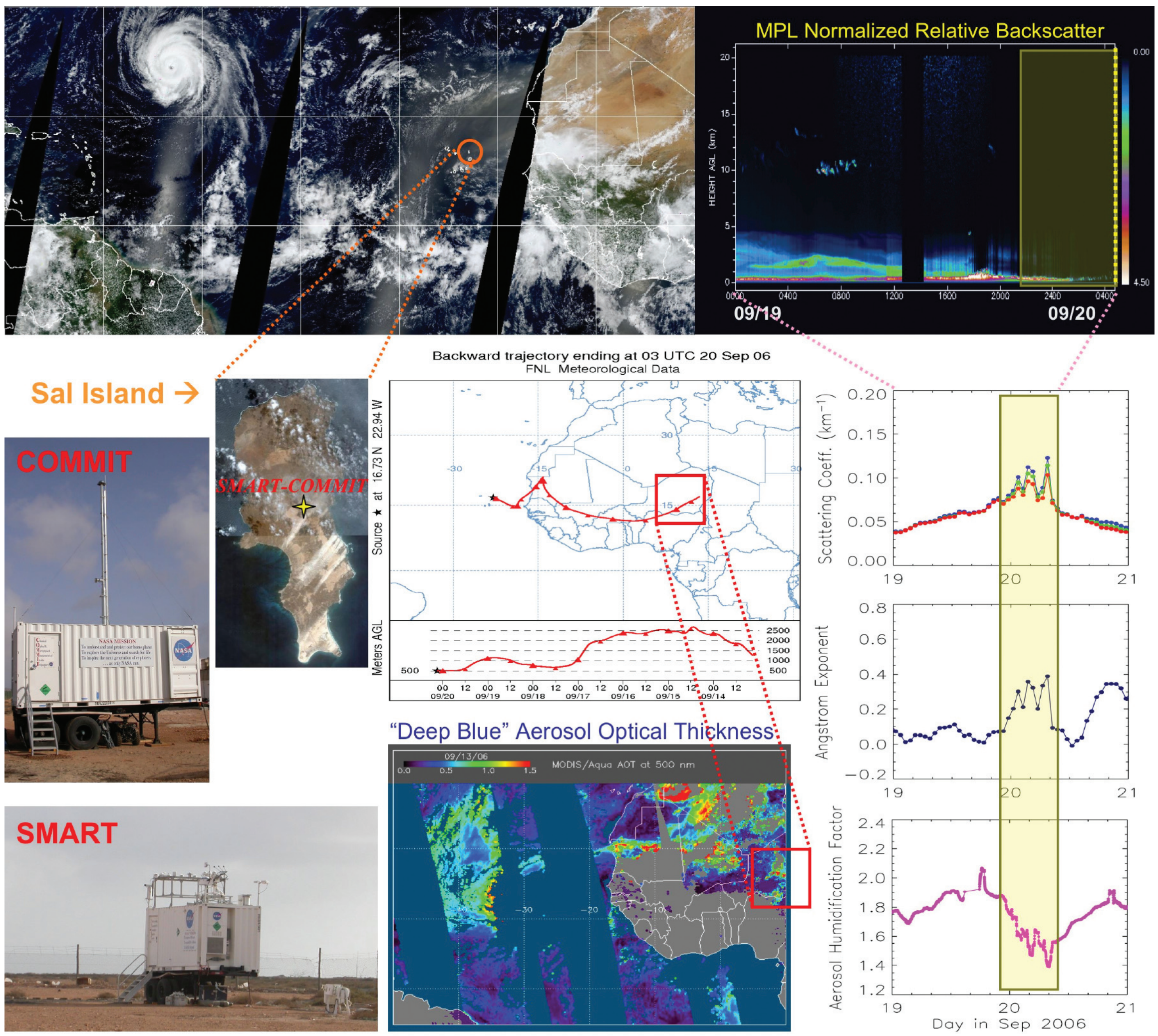


Figure 4.9. Schematic of Laboratory instruments participating in the NAMMA field campaign.

Two mobile laboratories, SMART (Surface-sensing Measurements for Atmospheric Radiative Transfer; bottom-left) and COMMIT (Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere; middle-left) were deployed at Sal Island, Cape Verde to continuously monitor the structure and composition of the atmosphere in the major path of the SAL and the AEWs.

Hurricane Helene in the North Atlantic Ocean and a dust storm passing over Sal Island were observed by NASA's Terra/MODIS satellite (Top-left). When Saharan dust descended down near the surface, its physical and chemical properties were captured by SMART-COMMIT. An instrument in SMART, Micro-Pulse Lidar (MPL), which continuously measures the vertical distribution of atmospheric particulates, caught such an episode (top-right image). Backward trajectory analysis, which traces a parcel of air mass back to find out where it came from, suggests the dust aerosol layer seen by the MPL may have originated from a dust storm over Niger (middle-center). “Deep Blue” satellite-based aerosol retrievals to infer the optical properties of aerosols also support this result from the backward trajectory analysis (bottom-center). The three graphs in the bottom-right show measurements from COMMIT at the near surface (10 meter), which represent the amount of aerosols (scattering coefficient), their size (Angstrom exponent; the smaller values, the larger aerosols), and a measure of their capability to take up water vapor and grow in size as humidity increases (aerosol humidification factor, ratio of scattering coefficients measured at two distinct relative humidity values—normally at 85% and 40%), respectively. These graphs indicate changes in aerosol optical properties as dust particles increase with time in the marine boundary layer where sea-salt particles would be a dominant type of aerosol otherwise. These preliminary measurements will be used to characterize properties of dust and the SAL to help understand their interactions with AEWs and their impact on hurricane genesis.

NASA’s DC-8 medium altitude research aircraft also participated in the NAMMA investigations. Sensors on-board the aircraft measured cloud and particle sizes and shapes, wind speed and direction, rainfall rates, atmospheric temperature, pressure and relative humidity. The DC-8 aircraft made 13 research missions that sampled 7 different waves/circulations, most of them for 2 different days. They included about 3 developing and 4 non-developing systems. The last system studied developed into Hurricane Helene. There were a number of dedicated missions or modules that addressed microphysics and SAL issues.

For further information contact Gerry Heymsfield, Gerald.M.Heymsfield@nasa.gov.

4.2.8 Scout-O3 UV: Total Column NO_2

Measurements of direct-sun irradiances were made at the city of Thessaloniki, in Greece (latitude 40.5° North, longitude 22.9° East). The instrument was set up on an elevated platform on top of the Thessaloniki University Physics building, about 60 meters above sea level, as part of the Greek-EU Scout-O3 campaign in July 2006. After instrument setup, a Brewer, PAN-1, Ultraviolet Multifilter Rotating Shadowband Radiometer (UV-MFRSR), and a CIMEL made measurements throughout the day from July 13 to 23 under all sky conditions. All four instruments measured 2 out of 3 aerosol parameters (optical depth, Ångstrom coefficient, and absorption coefficient) in different ways, the Brewer and PAN-1 measured NO_2, PAN-1 and the CIMEL measured H_2O, and the Brewer and the UV-MFRSR measured O_3. The measurements of interest are those mainly related to NO_2, with the measurements of other gases and aerosols serving as auxiliary data. The auxiliary data permits us to remove Rayleigh scattering, aerosol effects, and ozone absorption, leaving the NO_2 residual in the data.

Recent satellite measurements have shown the relationship between industrial activity and the apparent amount of NO_2 in the atmosphere. However, comparisons between satellite NO_2 column amounts obtained from the Aura/OMI spacecraft instrument with accurate ground-based direct-sun measurements made with a Brewer double monochromator show a 50% OMI underestimate of NO_2 in moderately polluted areas like Greenbelt, MD and Thessaloniki, Greece. We have used a new technique based on DS-DOAS (Direct Sun–Differential Optical Absorption Spectroscopy) to retrieve ground-based measurements of NO_2 at high precision (0.01 DU) and good accuracy (0.1 DU). The measurements are made using a newly developed portable system (PANDORA) based on a small temperature stabilized commercial 1024 element CMOS-detector spectrometer connected by fiber optic cable to a 1.6° field of view collimator and filter wheel assembly. A precision pointing mechanism, 0.01°, is used to track the sun. The spectrometer simultaneously measures sun irradiances $I(\lambda)$ from 265 to 500 nm at $\Delta\lambda = 0.4$ nm spectral resolution with ~3 pixels per 0.4 nm. We average 2500 cloud-free spectra obtained over 20 seconds to obtain high signal to noise. New data were obtained from a field campaign in Thessaloniki, Greece during July 2006 that have a clear-sky precision of 0.01 DU of NO_2, which is sufficient to track minute by minute changes in column NO_2 throughout each day with typical values of 0.5 to 3 DU. Since PANDORA NO_2 measurements can be made in the presence of light to moderate clouds with reduced precision (~0.2 DU for moderate cloud cover), a nearly continuous record can be obtained, which is important for matching the OMI overpass time.

The daily NO_2 data for the period July 14 to 24, 2006 are shown (Figure 4.10) for both the Brewer and for PAN-1. The Brewer data are obtained approximately every 20 minutes while the PAN-1 data are obtained every 2 minutes. Some of the days when the data were obtained were partly cloudy, with the sun going in and out of thin clouds. Thin clouds do not affect the PAN-1 data, since the wavelengths are obtained simultaneously. The same is not true for the Brewer, where the 6 wavelengths are obtained sequentially over a short interval. The result is additional scatter in the Brewer estimates of NO_2 as is clearly shown in Figure 4.10. This effect is particularly seen on Saturday July 15 where the PAN-1 data are highly correlated from measurement to measurement, while the Brewer data show substantial random scatter that is greater than their estimated error. It is important to have time resolved measurements to correspond to the OMI overpass time to remove the bias effect of the hourly variation in NO_2 for observations at other times, especially early morning observations (DOAS). Current satellite measurements have shown that there is a great deal of spatial variability in NO_2 amounts because of its relatively short chemical lifetime and its dependence on proximity to sources of NO_2, mostly automobiles and power plants.

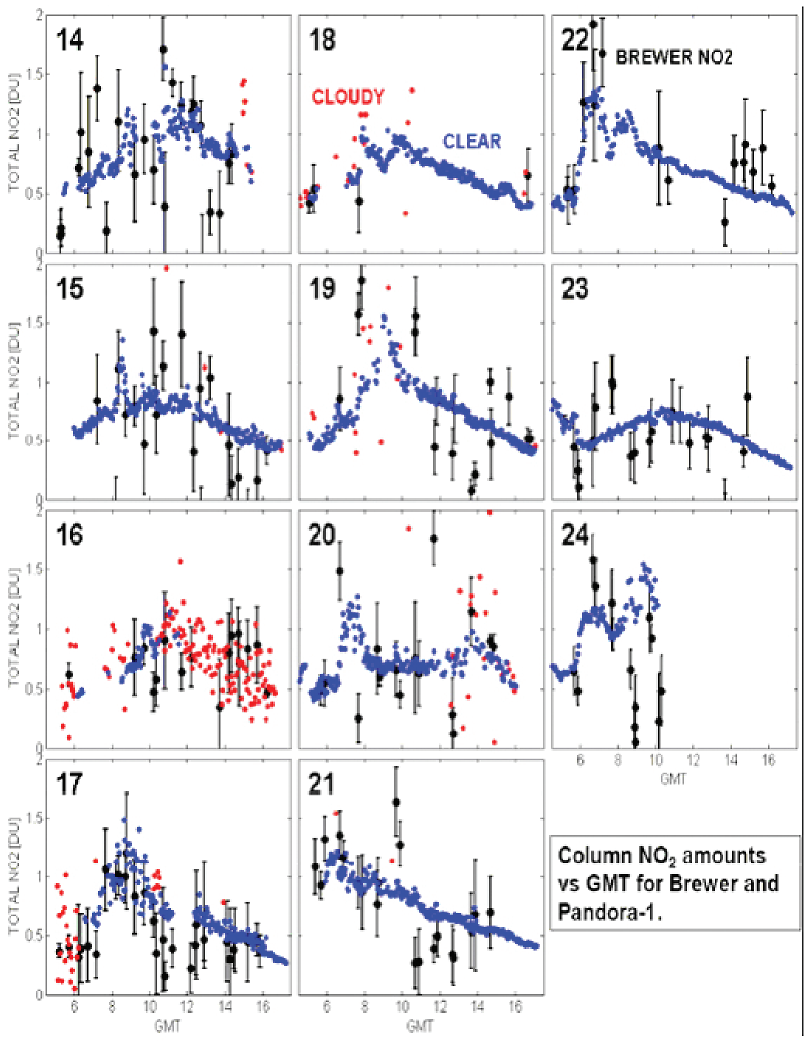


Figure 4.10. NO_2 daily course for Friday July 14 to Monday July 24, 2006 at Thessaloniki, Greece as a function of GMT (Local time = GMT + 3). The blue dots represent clear-sky PAN-1 data and black dots and error bars are from the Brewer spectrometer. Red dots indicate the presence of clouds. The precision of the PAN-1 NO_2 values is 0.01 DU. The OMI overpass time is about 13:30 local time or 10:30 GMT.

For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

4.2.9 CALIPSO-CloudSat Validation Experiment (CC-VEx)

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations satellite (CALIPSO)-CloudSat Validation Experiment (CC-VEx) was conducted over the southeastern United States and adjacent waters from July 26 to August 14, 2006. The GSFC Cloud Physics Lidar (CPL) and Cloud Radar System (CRS) were flown on the high-altitude ER-2 aircraft for validation of the newly-launched CALIPSO and CloudSat satellites. The mission was conducted from Warner Robins Air Force Base in Warner Robins, GA to enable flights over a variety of cloud scenes, including sub-tropical cirrus off the coast of Florida. A total of 13 satellite underflights were obtained (4 were night flights to ascertain minimum detectable signal levels). The MODIS Airborne Simulator (MAS) was also part of the ER-2 payload. The CPL is a primary validation tool (nearly exact satellite sensor simulator) for the CALIPSO lidar and the CRS is a primary validation tool for the CloudSat radar.

This was a joint validation mission lead by LaRC (CALIPSO) and JPL/Colorado State (CloudSat) with participation by GSFC, DFRC, and others. All mission requirements were met.

The following figures, Figures 4.11, 4.12, and 4.13 provide additional details.

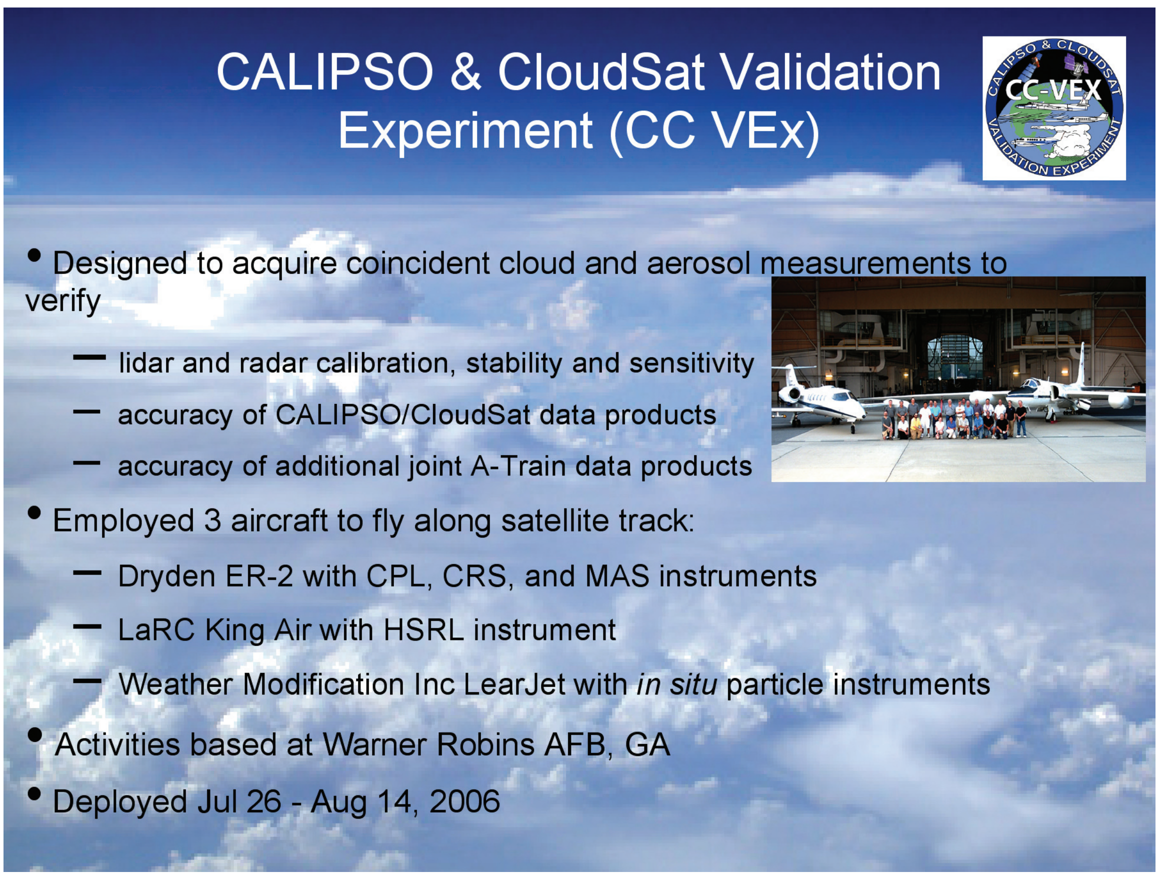


Figure 4.11. Overview of the CC-VEx objectives. The inset shows CC-VEx participants and two aircraft based at Warner Robins AFB, GA. The NASA ER-2, housing the CRS, CPL, and MAS, is on the right. The WMI Learjet, which carried various cloud probes for in situ sampling is on the left.

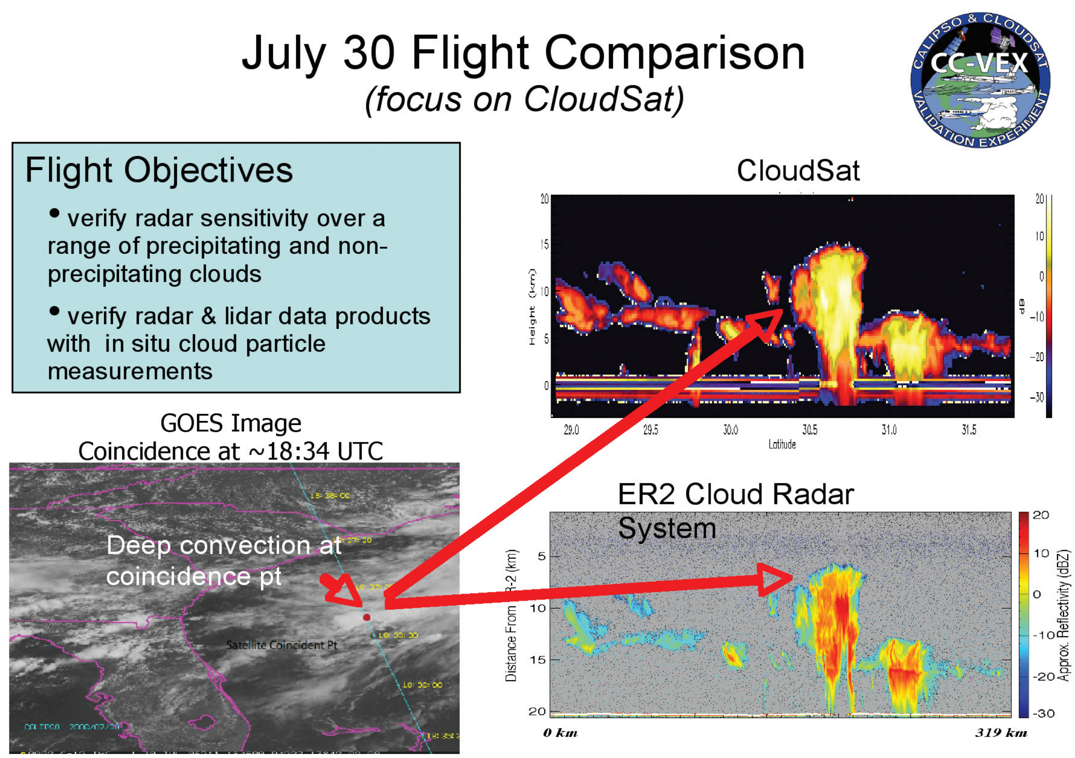


Figure 4.12. Comparison of CRS reflectivity with results from the CloudSat Cloud Profiling Radar. The satellite coincidence point is shown in the image at the lower left of the figure.

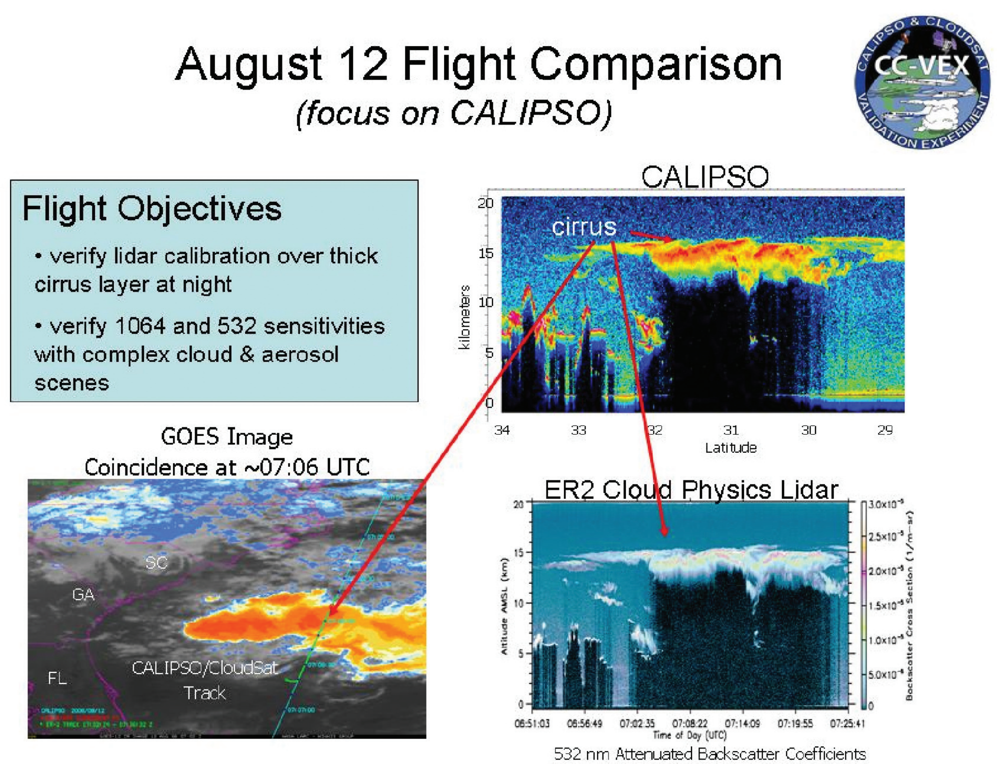


Figure 4.13. Comparison of the CPL 532 nm attenuated backscatter coefficients with results from the primary CALIPSO sensor, Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP).

For furthe information on the CPL instrument or for access to CPL data contact Matt McGill, Matthew,J,McGill@nasa.gov. For further information on the CRS instrument or for access to CRS data contact Gerry Heymsfield, Gerald.M.Heymsfield@nasa.gov.

4.2.10 Water Vapor Validation Experiment–Satellite/Sondes (WAVES)

The WAVES 2006 field campaign took place at the Howard University Research Campus in Beltsville, MD from July 7 to August 10. The field campaign goals were to:

- Acquire a statistically robust set of summer time measurements of atmospheric water vapor, aerosols and trace gases for Aura/Aqua satellite retrieval assessment.
- Inter-compare balloon-borne sensors (vapor and temperature) with ground-based lidars
- Assess the Tropospheric Emission Spectrometer (TES) ozone algorithm using ozonesondes
- Characterize sub-pixel water and aerosol variability
- Compare Penn State Nittany Atmospheric Trailer and Integrated Validation Experiment (NATIVE) aerosol and trace gas measurements with Maryland Department of the Environment (MDE).
- Characterize the daytime/nighttime aerosol and water vapor measurements from the new HU Raman Lidar.
- Study the performance of the National Weather Service (NWS) Radiosonde Replacement System (RRS)

The operations include intensive observations by multiple radiosonde/ozonesonde sensors and several lidar systems during overpasses of the Aura satellite. Lidar measurements are acquired by four lidar systems: NASA GSFC Scanning Raman Lidar (SRL), NASA GSFC Aerosol/Temperature Lidar (ATL), a Micropulse Lidar from Penn State, and Howard University Raman Lidar (HRL). Coordinated lidar measurements took place as well with the University of Maryland, Baltimore County (backscatter and Raman lidars) in order to provide information about the spatial variability of the aerosol and water vapor. In addition to the lidar/radiosondes operations, continuous measurements were taken by a 31m instrumented tower (temperature, flux, wind etc.), various broadband and spectral radiometers, microwave radiometer, Doppler C-band radar (Fox TV Channel 5), chemical and aerosol measurements, a wind profiler operated by the Maryland Department of Environment (MDE), a sun photometer (USDA), and a Suominet GPS system. A total of about 14 graduates, 7 undergraduates and many scientists from 16 institutions participated in the field work. A further description of student involvement in WAVES is contained in Section 6, Education and Outreach.

For further information contact Belay Demoz, Belay.B.Demoz@nasa.gov.

4.2.11 Measurements Of Humidity in the Atmosphere and Validation Experiment (MOHAVE)

The Aerosol and Temperature Lidar was deployed to JPL's Table Mountain facility for a water vapor measurements campaign during October 2006. The main goal was to validate lidar measurements of water vapor into the stratosphere. Three lidars were involved in this campaign as well as a Cryogenic Frost point Hygrometer (CFH) and standard Vaisala RS-92 radiosondes. The campaign discovered that all three of these lidars had a fluorescence issue, which became apparent at very low water vapor concentrations. The mechanisms for the fluorescence were not all the same, and the cause of the fluorescence was discovered for each lidar. After mechanical modifications are made, a second MOHAVE campaign is planned for September 2007.

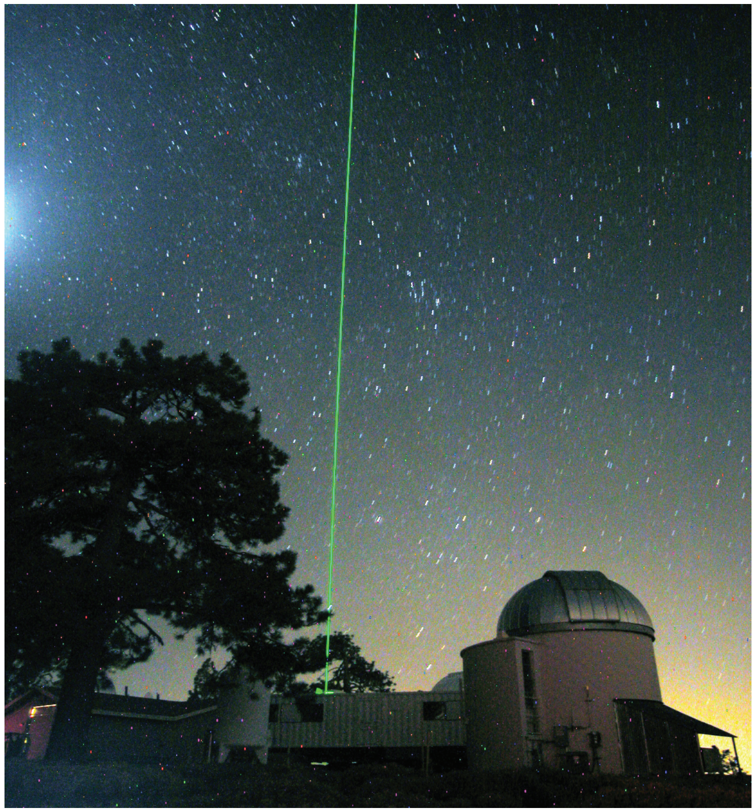


Figure 4.14. AT Lidar in action at JPL's Table Mountain facility.

For further information contact Tom McGee (Thomas.J.McGee@nasa.gov).

4.3 Data Sets

In the previous discussion, we examined the array of instruments and some of the field campaigns that produce the atmospheric data used in our research. The raw and processed data from these instruments and campaigns are 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. Some major data sets are described in the following paragraphs.

4.3.1 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 (3-D) chemistry and transport model. Boundary conditions were specified for chlorofluorocarbons, methane, and N_2O appropriate for the period 1973–2023. Sulfate aerosols were also specified, and represent the eruptions of El Chichón and Mt. Pinatubo. Simulations with constant chlorine (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° × 2.5° latitude/longitude horizontal resolution; the output is stored at 4° × 5° 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; 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, which provides information about the various simulations.

Output from the three-dimensional Chemistry and General Circulation Model (CGCM) is also available on the Code 613.3 science system. Like the CTM simulations, these include boundary conditions that are specified for various trace gases. The simulations use different data sets (some observed, some model output) for the ocean temperatures. Readers for this output, a description of the files that are available, and some details of the simulations are found on http://hyperion.gsfc.nasa.gov/Personnel/people/Frith/webdir/GEOSCCM/gcm_data_transfer.html. Questions or comments should be addressed to Anne Douglass (Anne.R.Douglass@nasa.gov).

4.3.2 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 nine-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-hour 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 hours at a spatial resolution of 0.25° latitude-longitude. 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).

4.3.3 Merged TOMS/SBUV Data Set

We have updated our merged satellite total ozone data set through late July of 2006. 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. It is expected that these data will be useful for trend analyses, for ozone assessments, and for scientific studies in general. We now have a preliminary data set that merges the measurements made by the OMI instrument on Aura. This will be made available to the public in early 2007. For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (smh@code916.gsfc.nasa.gov).

4.3.4 Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS operational Atmosphere Team algorithms produce both Level-2 (pixel-level or swath data) and Level-3 (gridded) products. There are six categories of Level-2 and Level-3 MODIS products collected from the Terra and Aqua platforms. Starting in April 2006, a new processing stream (referred to as “Collection 5”) began. Further details on this new MODIS data processing effort, which includes significant algorithm updates and enhancements, are discussed in Section 5.4.1.

The Level-2 product files are grouped by Cloud Mask, Cloud, Aerosol, Precipitable Water, and Atmospheric Profile geophysical retrievals. In addition, a joint Atmosphere Team file contains a spatial sample of the more popular Level-2 retrievals. Level-3 MODIS Atmosphere products provide statistics on a 1° × 1° 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 10×10, 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 5×5, 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 5×5, 1 km pixel resolution when a 5×5 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° × 1° 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) or visit the MODIS Web site at http://modis-atmos.gsfc.nasa.gov/.

4.3.5 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 as ground calibration/validation for NASA's first satellite lidar, the Geoscience Laser Altimeter System (GLAS), and also provide validation for the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) in the A-Train. 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 14 field campaign sites remain available as well. Planning is underway for future sites in 2007, 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.

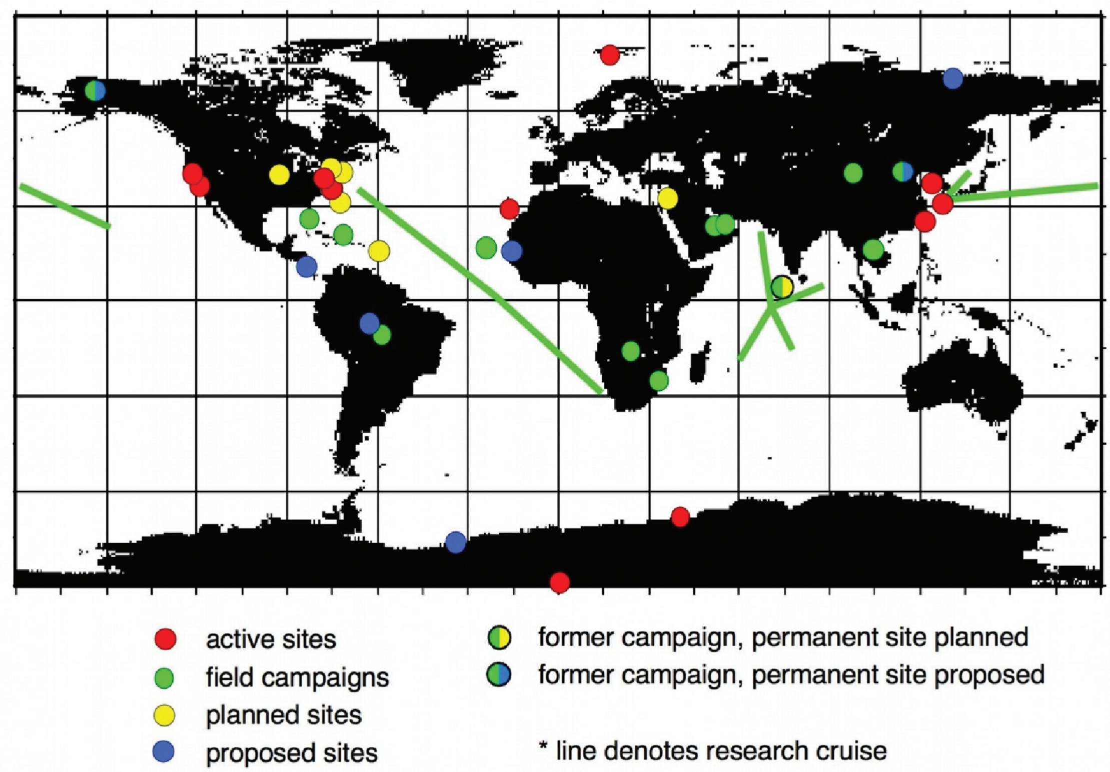


Figure 4.15 MPLNET sites as of December 2006.

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).

4.3.6 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. 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 improved algorithm, Version 5.0, was recently delivered to NASA's Jet Propulsion Laboratory (JPL.) The Goddard DAAC has been producing AIRS level-2 soundings beginning September 2002 using Version 4 of the AIRS science team retrieval algorithm. Version 5 should become operational at the Goddard DAAC in early 2007. All old AIRS data and future data will be processed with the Version 5 algorithm at the Goddard DAAC for use in climate studies. All products obtained in the TOVS Pathfinder data set are also produced from AIRS. The AIRS products are of higher quality than those of TOVS, but have been shown to be compatible in the anomaly sense. AIRS products can be used to extend the TOVS 25 year climate data set for longer term climate studies.

In joint work with Robert Atlas (now director of NOAA AOML), Version 4.0 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. New experiments are being conducted with Version 5 soundings and further improvement in forecast skill is expected. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

4.3.7 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. The following sections describe two of the recently developed OMI data sets. For more information, contact Rich McPeters, Richard.D.McPeters@nasa.gov.

4.3.7.1 Sulfur Dioxide, SO_2

Sulfur dioxide (SO_2) is a short-lived atmospheric constituent that is produced primarily by volcanoes, power plants, refinery emissions and burning of fossil fuels. It can be a noxious pollutant or a major player in global climate forcing, depending on altitude. Fossil fuel burning occurs at the surface where SO_2 is released in the boundary layer or, with tall smokestacks, into the lower troposphere. Where SO_2 remains near the Earth's surface, it has detrimental health and acidifying effects, but exerts little impact on global climate or radiative forcing. Emitted SO_2 is soon converted to sulfate aerosol by reaction with OH in air or by reaction with H_2O_2 in aqueous solutions (clouds). The mean lifetime varies from ~1–2 days or less near the surface to more than a month in the stratosphere. In the free troposphere, wind speeds are stronger and aerosol sulfate can be carried to remote regions where it can change radiative forcing directly as well as through altered cloud microphysics. The concentration of SO_2, the meteorological mechanisms that loft it above the PBL, and the efficiency of those mechanisms remain major unanswered questions in global atmospheric chemistry and climate science.

The first quantitative data on the mass of SO_2 in a major eruption (El Chichon, 1982) was obtained from the six-UV band NASA Nimbus-7 Total Ozone Mapping Spectrometer (TOMS). All significant eruptions since 1978 have now been measured by the series of TOMS instruments (Nimbus-7, Meteor-3, ADEOS I, Earth Probe (EP): http://toms.umbc.edu. The SO_2 detection sensitivity was limited to large volcanic clouds by the discrete TOMS wavelengths that were designed for total ozone measurements.

The Ozone Monitoring Instrument (OMI), launched in July 2004 on the polar-orbiting EOS/Aura satellite, offers unprecedented spatial and spectral resolution, coupled with global contiguous coverage, for space-based UV measurements of SO_2. The OMI SO_2 data set is continuing the TOMS record but the improved sensitivity and smaller footprint of OMI have extended the range of detection to smaller eruptions, degassing volcanoes, and older clouds, and to anthropogenic pollution. Heavy anthropogenic emissions and volcanic degassing in the lower troposphere and boundary layer can be detected on a daily basis, (e.g., http://aura.gsfc.nasa.gov). Using weekly, monthly or annual average SO_2 maps, one can evaluate longer-term trends and detect weaker degassing and pollution (e.g., http://aura.gsfc.nasa.gov/science/top10_smelters.html).

Visualization of daily OMI SO_2 data allows rapid appraisal of the most significant volcanic SO_2 emitters, which in 2006 included Merapi (Indonesia), Tungurahua (Ecuador), Soufriere Hills (Montserrat), Aoba (Vanuatu), Nyiragongo (Democratic Republic of Congo) and Ubinas (Peru). These measurements highlight the deficiencies of previous compilations of volcanic SO2 emissions, which were biased towards accessible, frequently monitored volcanoes. The eruption of Soufriere Hills volcano (Montserrat) on May 20, 2006 resulted in a stratospheric injection of ~0.2 Tg of SO_2. Despite the modest size of the SO_2 cloud (2 orders of magnitude lower in mass than Pinatubo), OMI was able to track it for over 3 weeks and ~16,000 miles as it traveled westwards from the volcano (Figure 4.16). Near-coincident CALIPSO lidar measurements of the stratospheric sulfate aerosol derived from SO_2 demonstrate the value of joint A-Train observations of volcanic clouds. The Soufriere Hills eruption and one of similar magnitude at Rabaul (Papua New Guinea) in October 2006 were the largest volcanic SO_2 injections of 2006. Other highlights include the detection of SO_2 emissions from the first historical activity of Fourpeaked volcano (Alaska) and the use of OMI data to constrain the timing of a submarine eruption at Home Reef in the Tonga archipelago.

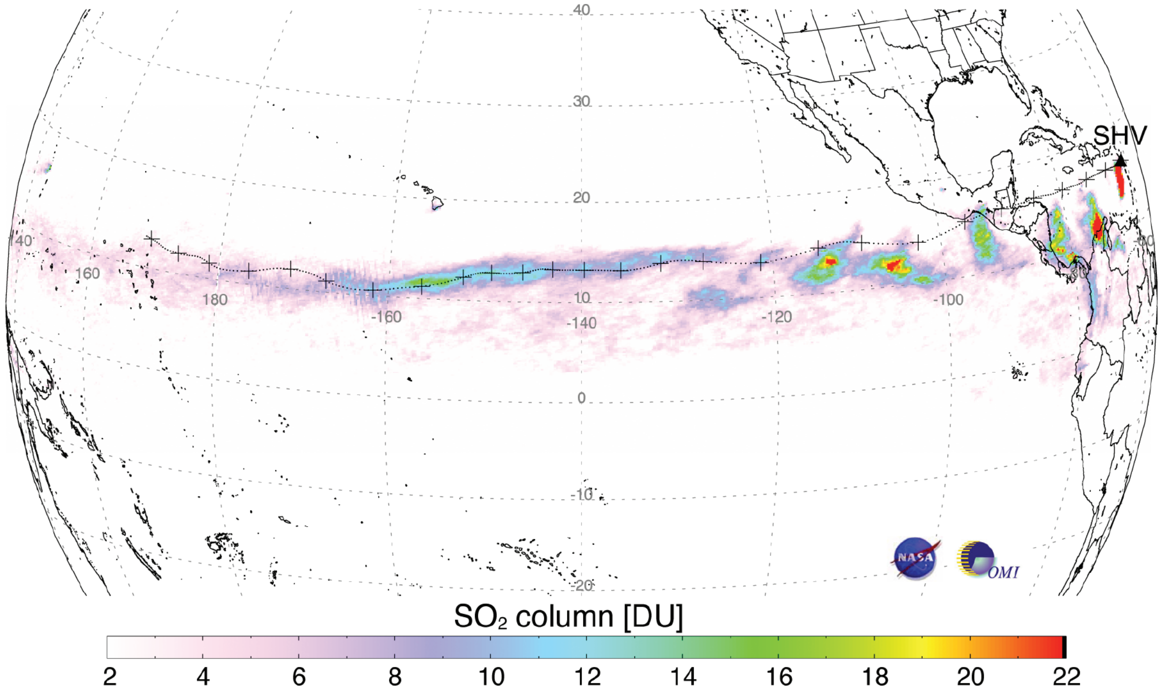


Figure 4.16 Cumulative SO_2 measured by OMI in the Soufriere Hills volcano (SHV Montserrat, Lesser Antilles) volcanic cloud from May 20 to June 6, 2006 as the cloud crossed the Pacific Ocean. The dotted line is a HYSPLIT forward trajectory for a cloud at 20 km altitude, initialized at 11UT on May 20 at SHV, with crosses plotted every 12 hours. The trajectory covers 315 hours (~13 days) of cloud transport.

Using OMI data, one can directly compare daily global SO_2 emissions from anthropogenic and volcanic sources for the first time, and thus provide important new constraints on the relative magnitude of these fluxes. Anthropogenic SO_2 has been detected over eastern China, South America and Europe. Such measurements are essential given the growing concern over the response of the Earth to anthropogenically-forced climate change and intercontinental transport of air pollution. Because SO_2 is the major precursor of sulfate aerosol, which has climate and air quality impact, OMI SO_2 measurements will contribute to better understanding of the sulfate aerosol distribution and its atmospheric impact. The fast OMI SO_2 retrieval is also amenable to operational SO_2 alarm development, and near real-time application for aviation hazards and volcanic eruption warnings.

For more information contact Nick Krotkov, Krotkov@tparty.gsfc.nasa.gov.

4.3.7.2 Cloud

The OMI cloud algorithm retrieves cloud pressures from the filling in of solar Fraunhofer lines in the ultraviolet due to rotational Raman scattering of air molecules. Clouds shield the atmosphere below them from Raman scattering as observed from a satellite above. Therefore, the higher the cloud, the less filling in that is observed. When there are multiple cloud decks and the upper deck is relatively thin, the retrieved cloud pressure is closer to the pressure of the lower cloud deck. In contrast, cloud pressures derived from the MODIS instrument are closer to the upper cloud deck. The cloud pressures derived from OMI are appropriate for use in retrievals of trace gases, such as ozone, that utilize similar spectral regions.

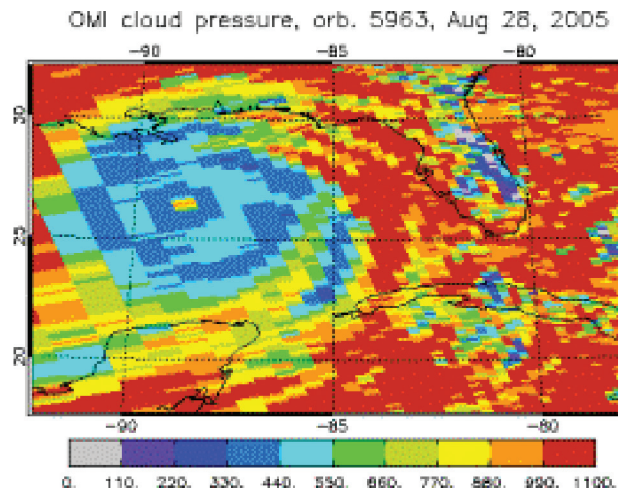


Figure 4.17. OMI cloud image over Hurricane Katrina, Aug. 28, 2005. The colors represent effective pressure of clouds, in hpa, as seen by OMI.

For more information contact Joanna Joiner, Joanna.Joiner@nasa.gov.

4.3.8 Southern Hemisphere ADditional OZonesondes (SHADOZ)

Initiated by NASA's Goddard Space Flight Center in 1998, in collaboration with NOAA and meteorological and space agencies from around the world, SHADOZ augments balloon-borne ozonesonde launches in the tropics and subtropics. SHADOZ presently includes 13 sites, including 2 that are north of the equator (Suriname and Malaysia). Launches are usually weekly at each station. SHADOZ archives ozone and temperature profile data at a user-friendly, open Web site: http://croc.gsfc.nasa.gov/shadoz. Data for 2006 are now available at this site. SHADOZ ozone data are used for a number of purposes:

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

SHADOZ has led to significant scientific advances. For example, satellite retrievals are using longitudinal and seasonal variations in tropical ozone for the first time. By having so many profiles, it has been possible to improve accuracy and precision of the ozonesonde measurement under tropical conditions. All SHADOZ stations fly a radiosonde Electrochemical Concentration Cell (ECC) ozonesonde combination. The World Meteorological Organization (WMO) uses SHADOZ as the paradigm for developing new ozone sounding stations in WMO's Global Atmospheric Watch (GAW) program.

Figure 4.18. Currently, 14 active sites are participating in SHADOZ. The sites are at Ascension Island; American Samoa; Fiji; Irene, South Africa; Watukosek, Java, Indonesia; Malindi and Nairobi, Kenya; Cotonou, Benin; Heredia, Costa Rica; Natal, Brazil; Paramaribo, Surinam; La Réunion, France; San Cristóbal, Galapagos; and Kuala Lumpur, Malaysia.

For additional details, contact Anne Thompson (anne@met.psu.edu) or Jacquie Witte, witte@gavial.gsfc.nasa.gov.

The archive URL is located at http://croc.gsfc.nasa.gov/shadoz.

4.3.9 Tropospheric O_3 Data

Ozone measurements from the OMI and Microwave Limb Sounder (MLS) instruments on board the new Aura satellite were used to develop nearly two years of daily global measurements of tropospheric ozone beginning late August 2004. The tropospheric ozone data, currently an experimental data product, are made available to anyone upon request. These measurements have been incorporated in several published or submitted scientific studies through 2006 including studies describing quantitative comparisons with chemical transport models.

Updates to figures and data, and information on obtaining OMI/MLS tropospheric ozone data are available from the TOMS homepage http://toms.gsfc.nasa.gov. The tropospheric ozone homepage also provides directly downloadable stratospheric and tropospheric column ozone measurements from TOMS for interested users. These measurements begin in January 1979 and go through December 2005 and include (1) gridded tropical data, and (2) Pacific-averaged measurements for latitudes 50°S to 60°N. For more information, contact Jerry Ziemke, Jerald.R.Ziemke.1@gsfc.nasa.gov, the Principal Investigator on the American OMI science team for tropospheric ozone.

4.4 Data Analysis

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

4.4.1 Aerosol and Water Cycle Dynamics

Aerosol can influence the regional and global water cycles 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-cloud-precipitation interaction, 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, and cloud liquid water (TRMM, AMSR), in conjunction with analyzed large scale circulation and estimated moisture convergence 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. Field campaigns for measurement of aerosol properties, including ground-based and aircraft measurement, play an important role in this research. Observations from satellite and field campaigns are being coordinated with numerical studies using global and regional climate models and cloud-resolving models coupled to land surface, vegetation, and ocean models. A major goal of this research activity is to develop a fully interactive earth 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 Multi-Model 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), Eric Wilcox (Eric.Wilcox@nasa.gov) or W.K. Tao (Wei-Kuo.Tao-1@nasa.gov).

4.4.2 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 anthropogenic global-change signal. Climate diagnostic studies use a combination of remote sensing and 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. Recently, the possible impact of anthropogenic aerosol on regional and global atmospheric water cycles has been 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), the Atmospheric Infrared Sounder (AIRS), 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).

4.4.3 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 was recently 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, diurnal variation of precipitation over both land and ocean, and the validation of global models.

For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

4.4.4 Rain Measurement Validation for TRMM

The objective of the TRMM Ground Validation Program 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).

4.5 Modeling

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

4.5.1 Aerosol Modeling

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 Goddard Chemistry Aerosol Radiation and 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 2006, global aerosol modeling in code 613.3 has been further enhanced in two ways. First, the aerosol modules developed in the GOCART model have been incorporated into the GMAO GEOS General Circulation Model. This development allows the aerosols to be calculated on-line with the meteorological simulation/assimilation, a capability that has made the real-time aerosol forecast possible. In fact, the GEOS model with on-line aerosol has been used to support several field experiments in 2006, such as the Aura validation experiments in Costa Rica (CR-AVE), the Intercontinental Chemical Transport Experiment–Part B (INTEX-B) in North America, and the NASA African Monsoon Multidisciplinary Analysis (NAMMA). In addition, within the NASA Modeling and Prediction (MAP) program, the GOCART aerosol modules are being implemented into the Global Modeling Initiative (GMI) framework. This development allows the aerosol modules to interface with different meteorological fields to better assess the range of uncertainties in addressing aerosol climate effects.

For more information on aerosol modeling contact Mian Chin (Mian.Chin@nasa.gov) or Peter Colarco (Peter.R.Colarco@nasa.gov).

4.5.2 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. We have run simulations of the past starting in 1950 and have extended them into the future to the year 2100. These simulations led to the discovery that ozone has increased in the middle stratosphere over the Antarctic during summers of the last two decades. The simulation was confirmed by examining data from the SBUV series of satellites. We are now testing the newest version of the general circulation model, GEOS-5. That version will be coupled to the combined stratosphere-troposphere chemistry model (COMBO) being developed under the Global Modeling Initiative (GMI).

Co-PIs are Richard Stolarski (Atmospheric Chemistry and Dynamics Branch) and Steven Pawson (Global Modeling and Assimilation Office). For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov), Steven Pawson (Steven.Pawson-1@nasa.gov), or Anne Douglass (Anne.R.Douglass@nasa.gov).

4.5.3 Cloud and Mesoscale Modeling (Multi-scale Modeling)

Three different coupled modeling systems were 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 rain-bands, 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 transport, air–sea, cloud–aerosol, cloud-chemistry, 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, intra-seasonal 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. WRF is being developed at NCAR by a consortium of government entities for research applications by the scientific community, and ultimately as the basis for a future operational forecast model at the National Center for Environmental Prediction (NCEP). This coupled modeling system allows for better forecasts (or simulations) of convective systems in Oklahoma and typhoons in the west Pacific. The WRF is being improved to provide real time forecasting for NASA field campaigns. This real-time system could give better guidance on flight missions for NASA aircraft.

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 and precipitation processes in the tropics, as well as to improve precipitation retrievals from NASA satellites and representation of moist processes in global and climate models.

The same microphysical, long- and shortwave radiative transfer, explicit cloud-radiation, and cloud-surface interactive processes are applied in all three modeling systems. The results from these modeling systems were compared to NASA high-resolution satellite data (i.e., TRMM, CloudSat) in terms of surface rainfall and vertical cloud and precipitation structures. The model results were also compared to NASA and non-NASA field campaigns. The scientific output from the modeling activities was again exceptional in 2006 with 11 new papers published, in press or accepted. For more information, contact Wei-Kuo Tao (WeiKuo.Tao.1@gsfc.nasa.gov).

4.5.4 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. Simulations for the Aura period have been carried out and used for comparison and diagnosis of observations from OMI, TES and MLS instruments. For more information, contact Jose Rodriguez (Jose.M.Rodriguez@nasa.gov).

4.5.5 Cloud Radiation Parameterization in Atmospheric GCM

The main stumbling block in climate evaluations with a General Circulation Model (GCM) is due to the inability of the GCM to simulate realistic climate change. Better accuracy of the sub-models of physical processes (commonly called physical parameterizations) is vital to improving simulations. Thus, more subtle unsolved problems require more accurate models that simulate smaller biases; this implies more attention to physical processes that were previously ignored or poorly represented. The cloud parameterizations are among the primary hurdles. We use the Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme (McRAS), an in-house developed prognostic cloud-scale dynamics and cloud water substance scheme. McRAS 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. It tries to capture physical attributes of cloud life cycles, effects of convective updrafts and downdrafts, cloud microphysics within convective towers and anvils, cloud-radiation interactions, and cloud inhomogeneity effects for radiative transfers. Most of these are based on algorithms developed by the Laboratory scientists.

Cloud-physics and aerosol-cloud-radiation interaction issues are among the primary interests of several scientists of the Goddard Laboratory for Atmospheres. New parameterizations are being developed for internally and externally mixed aerosols interacting with clouds. Since activated aerosols nucleate clouds as well as determine the number of cloud drops, at inception, aerosols species, mass concentrations and size distributions are central to cloud optical properties and precipitation microphysics. We have instituted a version of the Nenes and Seinfield aerosol-nucleation scheme for water clouds. The scheme, called McRAS-AC, is an upgrade to McRAS. The ice-cloud processes are much more complex; some of them are not well understood; however, empirical relations from satellite and other *in situ* field measurements help to bridge the gap. Active research is in progress to make fundamental advances in this area. Laboratory scientists are evaluating all aspects of the aerosol cloud and precipitation processes that include cloud optical properties, precipitation intensity, and cloud drop/particle size distribution, as well as validation of model simulations against *in situ* and satellite data.

For atmospheric radiation, we are developing efficient, more accurate, and modular longwave and shortwave radiation codes with the parameterized direct effects of man-made and natural aerosols, and clouds that depend upon aerosol nucleation and precipitation microphysics. The climate model simulates liquid/ice mass, the number and size-distribution of cloud drops whereas the radiation code converts this data into optical properties of clouds. The radiation codes are also upgraded for efficient computation of climate sensitivities to water vapor, cloud optical properties and aerosols to simulate the direct effects of aerosols on shortwave and longwave radiative forcing. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

Our simulation research involves the prognostic cloud-water schemes with aerosol cloud radiative effects using observations from the ARM Cloud and Radiation Test Bed (ARM CART) and Tropical Ocean Global Atmosphere–Coupled Ocean Atmosphere Response Experiment (TOGA COARE) intensive observing periods, as well as satellite data. Biases in the GCM-simulated diurnal cycle of rainfall are large and show widely different characteristics in different regions of the world. TRMM satellite rainfall retrievals also provide the essential validation statistics. We have conducted ensemble simulations for the West African Monsoon Modeling and Evaluation intercomparison project. Preparing the model for the above studies required major upgrades to the existing cloud physics in McRAS, as well as producing aerosol data sets for cloud-aerosol interactions and validation. We have utilized our model for a number of simulation studies that include two 10-year Atmospheric Model Intercomparison Project style simulations for investigating the local and remote influences of sea-surface temperatures on precipitation. Thus, focused model development and evaluations of aerosol-cloud-radiation sub models are the primary thrusts of model upgrades.

For more information, contact Yogesh Sud (Yogesh.C.Sud@nasa.gov).

4.5.6 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 Chemical Transport Models (CTMs) 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. We are participating in an on-going collaboration with GMAO through which the photochemical calculation of the CTM is combined with a general circulation model; changes in radiatively active gases feedback to the circulation through the radiative code. The chemistry and general circulation model (CGCM) is being used to investigate the impact of trace gases changes on ozone and climate on long time scales (multi-decadal to century).

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 multi-decadal 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.
(5) Three-dimensional CGCMs combine a complete representation of photochemical processes with a general circulation model.

The constituent fields calculated using winds from a new GCM developed jointly by the GMAO and NCAR exhibit many observed features. We are also using output from this GCM in the current CTM for multi-decadal simulations. The CGCM reproduces features in the ozone trends derived from SBUV observations that are not produced by the CTM because they are caused by interaction of ozone changes with the meteorological fields. Through the Global Modeling Initiative, 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. Within the next two years this combined mechanism will be implemented in the CGCM.

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

4.6 Support for NOAA Operational Satellites

In the preceding sections, 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).

4.6.1 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).

4.6.2 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) cross-track 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 trial 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 CrIS to determine atmospheric CO_2, CO, and CH_4. These studies indicate that total CO_2 can be obtained to 2 ppm (0.5%) from CrIS under clear conditions, total CH_4 to 1%, and total CO to 15%. This performance is comparable to what is being obtained from AIRS. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

4.6.3 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 accuracy of 1K in 1 km layers of the troposphere under partial cloud cover, are being met over the ocean. AIRS radiances are now assimilated operationally by the European Centre for Medium-Range Weather Forecasts (ECMWF) 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/ATMS, and results show comparable performance is expected.

Methodology has been developed and implemented to generate proxy CrIS/ATMS data based on AIRS/AMSU observations. This data is representative of what CrIS/ATMS “would see” given the actual geophysical conditions observed by AIRS/AMSU. We are using this data to test the performance of the Northrop Grumman Space Technology (NGST) prototype operational CrIS/ATMS retrieval algorithm and compare it with a government CriS/ATMS algorithm modeled after the AIRS Science Team (Joel.Susskind-1@nasa.gov).

4.6.4 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/Limb Ozone Retrieval Experiment (SOLSE/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. (Note: the limb profiler currently has been de-scoped from NPOESS for cost reduction reasons but may fly on NPP. A final decision is pending.)

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 post-launch 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).

4.6.5 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-II) 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 (GLOW) and airborne (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).

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 4.3 lists the project- and deputy project scientists for current missions; Table 4.4 lists the validation and mission scientists and major participants for various campaigns.

Table 4.3: 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	Christina Hsu	NPP
Robert Cahalan	EOS SORCE	Joanna Joiner	EOS Aura
Dennis Chesters	GOES	Hans Mayr	AIM
James Gleason	NPP	Steve Platnick	EOS Aqua
Jay Herman	DSCOVR	Si-Chee Tsay	EOS Terra
		Warren Wiscombe	ARM, Chief Scientist

Table 4.4: Laboratory for Atmospheres Validation and Mission Scientists, and Major Participants/Instruments.

EOS Validation Scientist		Field/Aircraft Campaigns	
Name	Mission	Name	Campaign/Leaders
David Starr	EOS	Paul Newman	AVE
		Si-Chee Tsay	NAMMA
		Si-Chee Tsay	BASE-ASIA
		Judd Welton	MPLNET
		Name	Campaign/Instrument
		Bojan Bojkov	SAUNA/Ozonesondes
		Alexander Cede	SAUNA/Double Brewer
		Rich McPeters	SAUNA/Double Brewer
		Tom McGee	SAUNA/STROZ-LITE INTEX-B/AROTAL MOHAVE/ATL
		Matt McGill	CR-AVE/CPL CC-VEx/CPL
		Gerry Heymsfield	CR-AVE/CRS CC-VEx/CRS
		Jay Herman	Scout-O3/PANDORA Spectrometer
		Si-Chee Tsay	BASE-ASIA SMART-COMMIT
		David Whiteman	WAVES/SRL

4.8 Interactions with Other Scientific Groups

4.8.1 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 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.

Prime examples of the collaboration between the academic community and the Laboratory are 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 (JCOSS) with the Scripps Institution of Oceanography, University of California, San Diego.
- Cooperative agreement with Colorado State University, Fort Collins, Colorado.

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 three years. Some of these appointments are supported by the NASA Postdoctoral Program administered by the Oak Ridge Associated Universities; 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.

4.8.2 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.

4.8.3 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 (NIIEM); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, Africa, and Asia. Another example of international collaboration was in the SOLVE II (SAGE III Ozone Loss and Validation Experiment) campaign, which was conducted in close collaboration with the Validation of International Satellites and study of Ozone Loss (VINTERSOL) campaign sponsored by the European Commission. More than 350 scientists from the United States, the European Union, Canada, Iceland, Japan, Norway, Poland, Russia, and Switzerland participated in this joint effort, which took place in January 2003. In 2004, another international collaboration started with the upload of instruments for the Polar Aura Validation Experiment (PAVE). PAVE is an Aura satellite validation involving instruments on the DC-8. Many of the experimenters from SOLVE II are involved in this campaign, which took place in late January and early February of 2005. This cooperation continued during 2006 in campaigns such as CR-AVE, INTEX-B, MILAGRO, Scout-O3, and others described in Section 4.2

Laboratory scientists interact with about 20 foreign agencies, about an equal number of foreign universities, and several foreign companies. The collaborations vary from extended visits for joint missions, to brief visits for giving seminars, or working on joint science papers.

4.9 Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government–Industry partnerships, SBIR projects, and technology transfer activities. Successful technology transfer has occurred on a number of programs in the past and new opportunities will become available in the future. Past examples include the MPL, holographic optical scanner technology, and Circle to Point Conversion Detector. New research proposals involving technology development will have strong commercial partnerships wherever possible.

5. HIGHLIGHTS OF LABORATORY ACTIVITIES IN 2006

This section highlights the Laboratory's accomplishments for 2006. The summaries are written by the Branch Heads, and give examples of the research carried out by Branch scientists and engineers. Additional activities are described in Section 5.4, Laboratory Research Highlights. These highlights are supplemented by news items related to the Laboratory in Appendix 1, by a complete listing of refereed articles that appeared in print in 2006 in Appendix 2, and by the first page of highlighted journal articles in Appendix 3. 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

The Mesoscale Atmospheric Processes Branch (MAPB) 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 micro-scales, 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 variety of data.

The MAPB currently consists of 64 people. Demographically, there are 14 civil service scientists (11 with Ph.D.s) and one civil servant clerical. Three retired civil servants maintain Emeritus positions within the branch. Two more Project Scientists (Arthur Hou/GPM and Robert Adler /TRMM) are co-located in the Branch. The Branch maintains Cooperative Agreements with four institutions (UMBC/GEST, UMBC/JCET, GMU and UMCP/ESSIC), which collectively, comprise 28 scientists and programmers (21 Ph.D.'s). Since 1990, the Branch has had a contractual relationship with SSAI of Lanham, MD, for scientific, engineering, computer and administrative support. The level of support is currently 17 on-site and 3 off-site personnel. Four other support personnel are employed by ADNET, SGT, SAIC and Ecotronics.

The Branch maintains a Web site at http://atmospheres.gsfc.nasa.gov/meso/, where current information of projects, field campaigns, publications, and personnel listings can be found. An important Branch asset is the GOES Project Science Web site (http://goes.gsfc.nasa.gov/) which displays real-time GOES imagery, and provides free high-quality data to the scientific community. For example, in a non-hurricane month (May 2006), the site served 50 GBytes/day to 46 thousand distinct hosts at the average rate of 2 requests per second. During a hurricane, the Web server typically maxes-out at its limit of 10 requests per second to 150 simultaneous guests. The TRMM Web site (http://trmm.gsfc.nasa.gov/) provides near-real-time precipitation estimations every 3 hours (with daily and weekly accumulations) as well as flood potential maps http://trmm.gsfc.nasa.gov/publicatons_dir/potential_flood.html. A brief synopsis of virtually every major hurricane, typhoon, and flood event around the globe with attendant maps of accumulated precipitation can be found at http://trmm.gsfc.nasa.gov/publications_dir/multi_resource_tropical.html.

The Branch activities fall into three main subject areas, precipitation (and attendant climate-scale research), instrument development and data analysis (primarily lidars and radars), and numerical modeling. These are described in more detail below.

Precipitation

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 achievement of continued operation of the TRMM satellite. In particular, there were significant publications on the TRMM Microwave Imager precipitation and latent heating profile products. The overall 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. This team provides reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Eight years of high quality data are now available through the Goddard DAAC. TRMM and other precipitation/latent heating data are used within the Branch for a wide spectrum of studies on precipitating cloud systems and the global water and energy cycles. 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, particularly the diurnal cycle. 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 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. New approaches to validation, including physical validation of the precipitation parameterizations used in algorithms are being investigated. An experimental global monitoring system for rainfall-triggered floods and landslides using the 3-hour TRMM precipitation product is currently under development. See the Laboratory Research Highlights, Section 5.4.2, for more information on this important effort.

Instrument Development and Data Analysis

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 Cloud Radar System (CRS), millimeter-wavelength radar for profiling cloud systems, have been integrated on NASA's high altitude WB-57F research aircraft for use in sensing the microphysical properties of cirrus and other cloud types. During July and August, 2006 the CPL and CRS were flown on the high-altitude ER-2 aircraft for the specific purpose of validating the newly launched CALIPSO and CloudSat satellites. The CPL and CRS are simulator and validation tools for CALIPSO and CloudSat, respectively (see Section 4.2.9), and their importance to the satellite validation activity underscores the role of suborbital instrumentation in the Branch.

Development of three instruments funded from the IIP continued. These were: TWiLiTE, an airborne direct detection Doppler lidar to measure wind profiles through the troposphere (0–17 km) using the laser signal 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.

GLAS (the Geoscience Laser Altimeter System) was successfully launched aboard the Ice, Cloud and Land Elevation Satellite (ICESat) in early 2003. GLAS is an important part of NASA's Earth Science Enterprise (ESE), which includes a series of satellites to measure Earth's atmosphere, oceans, land, ice, and biosphere for a period of 10 to 15 years. During 2006, GLAS data analysis contributed to five submitted journal publications. Among the topics covered by these papers were observations of tropopause level thin cirrus, the comparison of these observations with model-derived (MM5) clouds, and a comparison of cloud cover statistics between GLAS and HIRS. See the Laboratory Research Highlights, Section 5.4.3, for more information.

The Micro-Pulse Lidar Network (MPLNET – see Section 4.3.5) is a federated network of lidars co-located with sun photometers in the Aerosol Robotic Network (AERONET). MPLNET provides continuous profiles of aerosol and cloud distribution at a number of sites worldwide for various science applications and CALIPSO validation. Layer height and extinction products are also provided; all data and network information are available on our Web site: (http://mplnet.gsfc.nasa.gov/). 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 field campaigns are also available. Planning is underway for future sites in 2007-2010, 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 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 quantities and processes. The major activities of the group concern 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 the University of Maryland College Park (UMCP) are supported and a total of three visiting scientists have worked with the group during this past year: one each from Russia, Bolivia and Brazil.

There is also a substantial effort and collaboration with Howard University (HU) graduate students and faculty at the HU Beltsville Research Campus. The Raman group designed and taught a lidar techniques and analysis course offered as a special topics course within the Physics Department, an Introduction to Meteorological Instruments (PHYS 590) as well as Aerosol and Cloud Physics (PHYS 525) at HU. The WAVES-2006, (see Sections 4.2.10 and 6.2) campaign was held at the HU Beltsville Research Campus, not far from GSFC. The goals of WAVES-2006 were to bring a diverse instrumentation set to one place for validation of satellite water vapor, ozone and clouds. Validation activities that address AIRS and CALIPSO instruments are also in progress using the data. About twenty undergraduate and graduate students and many scientists from Howard University, GSFC, Penn State, Univ. of Virginia, Univ. of Colorado, NCAR, Maryland Department of Environment, USDA, NWS and scientists from Italy, Bolivia, and Brazil participated in WAVES-2006. Details of WAVES-2006, including links to activities, goals, pictures and more can be found at http://ecotronics.com/lidar-misc/WAVES.htm.

The lidar group also participated in the Measurements of Humidity in the Atmosphere: Validation Experiments (MOHAVE, see Section 4.2.11) experiment at JPL's Table Mountain Facility near Pasadena, CA. The MOHAVE deployment was to support the validation of satellite measurements under the framework of the Network for the Detection of Atmospheric Composition Change (NDACC), formerly known as the Network for the Detection of Stratospheric Change (NDSC). Scientists and students from Howard University and JPL joined the Raman lidar team at MOHAVE. MOHAVE involved several remote sensing and *in situ* techniques and was very successful with more than 40 balloon launches and over 240 hours of lidar measurements.

Numerical Modeling

The branch is active in the development, improvement and application of atmospheric modeling systems. Three major development efforts were achieved in the past year. The finite volume General Circulation Model (fvGCM, see also Section 5.4.4) and Goddard Cumulus Ensemble (GCE) model, a cloud-resolving model, were coupled in a multi-scale 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, diurnal variation of rainfall over land and ocean and intra-seasonal 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 (known as the Weather Research and Forecast model or WRF). The new, coupled modeling system allows better forecasting (or simulation) of convective systems and tropical cyclones. 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 processes on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and the 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.

The same microphysical, long- and shortwave radiative transfer, explicit cloud-radiation, and cloud-surface interactive processes are applied in all three modeling systems. The results from these modeling systems were compared to NASA high-resolution satellite data (i.e., TRMM, CloudSat) in terms of surface rainfall and vertical cloud and precipitation structures. The model results were also compared to NASA and non-NASA field campaigns. The scientific output from the modeling activities was again exceptional in 2006 with 11 new papers published, in press, or accepted.

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 results for Hurricane Erin (CAMEX-4, 2001) led to improved understanding of precipitation organization, storm structure, and their relationship to intensity change and environmental influences. A study of the formation of Tropical Storm Gert (TCSP, 2005) is leading to improved knowledge of the processes that contribute to storm formation. 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).

Retrieved temperature and humidity profiles from the AIRS instrument suite on the NASA Aqua satellite were used to simulate the Saharan Air Layer (SAL) and its influence on the formation of Hurricane Isabel (2003) with the MM5 model. By incorporating the AIRS data, MM5 better simulates the large-scale flow patterns and the activity of Hurricane Isabel in terms of the timing and location of formation and the subsequent track. It was demonstrated that the SAL suppresses Atlantic tropical cyclone activity by increasing the vertical wind shear, reducing the mean relative humidity, and stabilizing the environment at lower levels.

5.2 Climate and Radiation Branch, Code 613.2

One of the most pressing issues we face is to understand the Earth's climate system and how it is affected by human activities now and in the future. This has been the driving force behind many of the activities in the Climate and Radiation Branch. We have made major scientific contributions in five key areas: hydrologic processes and climate, aerosol–climate interaction, clouds and radiation, model physics improvement, and technology development. Examples of these contributions may be found in the list of refereed articles in Appendix 2 and in the material on the Code 613.2 Branch Web site, http://climate.gsfc.nasa.gov.

Key satellite observational efforts from the branch include MODIS algorithm development and data analysis. The new MODIS "collection 5" processing stream began in April 2006, starting with Aqua MODIS data. This processing stream includes substantial enhancements and updates to the operational cloud and aerosol products developed in the branch (see Sections 4.3.4 and 5.4.1). The availability of MODIS cloud and aerosol products is opening new pathways of research in climate modeling and data assimilation in the Laboratory. MODIS data analysis efforts included the role of 3D radiative effects on aerosol retrievals and a number of studies of 3D and non-plane parallel effects on cloud retrievals.

The MODIS-derived global annual direct aerosol radiative forcing over clear sky oceans was estimated to be -5.3 ± 0.6 Wm^{-2}. Attempts to quantify aerosol indirect effects on clouds included combining in-situ cloud microphysics in California marine stratocumulus with TOA broadband CERES observations. An approach to quantifying the indirect effect on precipitation involved continuing analysis of six years of TRMM data which shows the existence of a weekly cycle. Over the continental U.S. in summer, rain intensity and area increase midweek when pollution is at its maximum while the opposite behavior occurs over nearby waters. This finding provides new insight into the influence of human activities on rainfall. The effect of aerosol loading on cloud cover using AERONET ground-based observations showed a positive correlation, in agreement with previous satellite studies.

Efforts to include explicit aerosol nucleation processes in climate models continued. Yogesh Sud led the McRAS (Microphysics of Clouds with Relaxed Arakawa-Schubert Scheme) effort. The new McRAS modules provide an end-to-end aerosol-cloud-radiation and precipitation scheme that explicitly handles CCN/IN activation and cloud formation, wet deposition, and cloud particle size distribution in fractional clouds for radiative calculations. The goal is to develop an aerosol- cloud-radiation interaction scheme that can credibly simulate direct and indirect aerosol effects.

In the applications area, high-resolution MODIS Aerosol Optical Depth (AOD) products (1, 2, and 5 km) are currently under evaluation as part of an on-going 3-dimensional air quality monitoring system project over the U.S. This 3-year effort (2006-2008) is funded by the NASA Application Program (Code YO), with a strong partnership with EPA (data system) and NOAA (air quality forecast). In addition, a 3-year Advanced Monitoring Initiative project (2006-2008) led at Goddard by Allen Chu (GEST/613.2), in support of GEOSS and funded by the EPA Pilot Program using high-resolution MODIS AOD products, is in full swing to study the air quality in the San Joaquin Valley, California. Both projects will incorporate CALIPSO, airborne, and ground-based lidar measurements to study the vertical distribution of aerosol. These two projects will provide insights into the relationship of satellite-derived AOD and *in situ* PM2.5 mass concentration (for particles sizes less than 2.5 μm).

Branch members continued participation in NASA sponsored field campaigns, including the deployments of the SMART-COMMIT ground-based platform in BASE-ASIA and NAMMA, and the MODIS Airborne Simulator on the ER-2 in the summer 2006 CALIPSO-CloudSat validation experiment (see Section 4.2.9). Branch members are expected to participate in NASA's Tropical Composition, Cloud and Climate Coupling (TC4) campaign (summer 2007) and the DOE ARM Cloud and LAnd Surface Interaction Campaign (CLASIC - June 2007).

We continue to serve in key leadership positions on international programs, panels, and committees. Robert Cahalan chaired the Observations Working Group of the Climate Change Science Program (CCSP) Office, tasked to evaluate and coordinate multi-agency contributions to the U.S. Government climate observing system. In addition, he was on a full-time detail at CCSP from August to December 2006. Cahalan received the Outstanding Leadership and Service Award by the Climate Change Science Program in 2006. Cahalan also chairs the 3-Dimensional Radiative Transfer Working Group of the International Radiation Commission and directs the International Intercomparison of 3-Dimensional Radiation Codes. Warren Wiscombe began his tenure as the DOE Atmospheric Radiation Measurement (ARM) Chief Scientist in October 2005; this appointment includes his half-time residence at Brookhaven National Laboratory. Wiscombe is also the American Geophysical Union (AGU) Atmospheric Sciences Section president.

Branch personnel continue to serve in key project positions. Robert Cahalan serves as project scientist of SOlar Radiation and Climate Experiment (SORCE) launched on January 25, 2003. SORCE is measuring both Total Solar Irradiance (TSI) and Spectral Solar Irradiance (SSI) with unprecedented accuracy and spectral coverage during a 5-year nominal mission lifetime. Deputy project scientists include Si-Chee Tsay (Terra), Steven Platnick (Aqua), and

Christina Hsu (NPOESS Preparatory Project, starting in November 2006). Associate branch member Michael D. King is the EOS Senior project scientist.

We continue to make strides in many areas of science leadership, education, and outreach. Thanks to the organizational efforts of the late Yoram Kaufman and the involvement of Lorraine Remer, Charles Ichoku (ESSIC/613.2) and other branch members, the popular AeroCenter seminar series has continued into a sixth year. The biweekly seminars attract outside aerosol researchers from NOAA and the University of Maryland on a regular basis. The AeroCenter visitor program continues to reap benefits including joint paper submissions.

The Goddard Sun-Climate Center, like AeroCenter, is a cross-cutting activity within Goddard's Sciences and Exploration Directorate, and is co-hosted by the Climate and Radiation Branch and the Goddard Solar Physics Laboratory. 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 joined this effort, and the Center receives advice from an international panel of experts. The Center sponsored a seminar series this past year, and will encourage new collaborations between scientists studying Earth, the Sun, and Earth's moon. See http://sunclimate.gsfc.nasa.gov.

The branch benefits from our close association with the GSFC Earth Sciences Education and Outreach Program, most of whose members (including program manager David Herring, Code 610.3) reside in branch space and utilize branch resources. This group produces the Earth Observatory Web site that continues to provide the science community with direct communication gateways to the latest breaking news on NASA Earth Sciences, as well as the more recent NASA Earth Observations (NEO) data set visualization tool.

Finally, we continue with timely updates (often daily) to the Climate and Radiation Branch Web site (http://climate.gsfc.nasa.gov). Its "Image of the Week" and "Latest News" items highlight research by Branch members. A search page provides easy access to archived news, images, publications, and other climate information and data. The site supports calendar subscriptions and also has an extensive glossary of Earth science acronyms and a list of links to related sites.

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 and 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 generates 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, 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_2, SO_2, and O_3 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 and other research centers, to interpret global satellite and aircraft measurements of trace gases. Results of these studies are used to produce congressionally-mandated periodic international assessments of the state of the ozone layer, as well as to provide a strategic plan for guidance in developing the next generation of satellite and aircraft missions. A major new thrust of the Branch is to apply the unique synergy between Branch modeling and measurement groups, which proved very successful for the study of stratospheric chemistry, to study chemically and radiatively active tropospheric species, including aerosol, CO_2, O_3, CO, NO_x, and SO_2, which affect climate, air quality, and human health. The Branch's expertise in modeling atmospheric composition, including aerosols, has generated a new initiative to develop a coupled chemistry-climate model, using the GMAO Global Circulation Model.

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 150 years simulating the period from 1950 through 2100. Additional simulations have been carried out for 1950 through 2050. 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. A feedback was found that causes ozone to increase in the middle stratosphere during the summer following the depletion during the Antarctic ozone hole. This result was verified using data from the SBUV series of satellites. Work is now underway to couple the chemistry to the GEOS-5 version of the GCM.

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 Earth Science Modeling Framework. The GMI model is being evaluated through comparison to satellite, aircraft, and ground-based measurements. The combined stratospheric-tropospheric model (COMBO), has been very successful in simulating the temporal and spatial distribution of ozone measured by Aura instruments, both in the stratosphere and upper troposphere. A "tape recorder" effect in CO measurements from MLS is reproduced by the model. This "tape recorder" is driven by the seasonality of biomass burning. The model has also compared well with tropospheric ozone columns derived from OMI and MLS measurements, and with CO from the AIRS instrument. Work is in progress to extend the model validation to other constituents.

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 Branch scientists, of total ozone, tropospheric ozone, UVB, aerosols (primarily smoke and desert dust), and volcanic SO_2 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_2, anthropogenic SO_2, HCHO, and BrO, with improved spatial and temporal resolution compared to data from previous instruments, the Global Ozone Monitoring Experiment (GOME) and the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), on European satellites. Several Branch scientists are members of a NASA-funded U.S. science team, which is led by Pawan K. Bhartia. In 2005, 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_2. Several new products, not previously available from TOMS, have also been produced and are currently being validated. These include cloud parameters such as cloud pressure that are appropriate for use within the OMI trace-gas algorithms. Several scientific papers describing this work have appeared in journals in 2006 and more are expected in 2007.

Global Aerosol Studies

Aerosols affect climate by scattering and absorbing solar radiation and by altering cloud properties and lifetimes. They also exert large influences on weather, air quality, atmospheric chemistry, hydrological cycles, and ecosystems. To understand the roles that aerosols play in the Earth system and to determine the processes that control the aerosol distributions, Branch scientists have developed the GOddard Chemistry Aerosol Radiation and Transport (GOCART) model which simulates major types of atmospheric aerosols and relevant trace gases originating from both anthropogenic and natural sources, such as fossil fuel combustion, biomass burning, desert, ocean, vegetation, and volcanoes. In addition to the original off-line version of the model which is driven by the GEOS-DAS assimilated meteorological fields from the Goddard Modeling and Assimilation Office (GMAO), the GOCART modules have been implemented into the on-line GEOS-GCM model as well as the Global Modeling Initiative (GMI) modeling framework in the past year by the Branch scientists to further enhance the modeling capability.

The modeling activities have been strongly connected to observations. For example, the model has been continuously used to analyze and interpret aerosol observations from satellite instruments of MODIS and MISR and from ground-based sun photometers in the AERONET network; the model output has been integrated into satellite observations to provide the best description of global aerosol distributions; the model vertical profiles of SO_2 and absorbing aerosols are being tested to help OMI retrievals; and the on-line model has been generating aerosol and CO forecasts to support field experiments such as the Aura Validation Experiments (AVE) and the NASA African Monsoon Multidisciplinary Analysis (NAMMA). The model has been a part of the international project AEROCOM (AEROsol Comparisons between Observations and Models) and will participate in the new international activities of Hemispheric Transport of Atmospheric Pollutants and the Atmospheric Chemistry and Climate initiatives.

Measurement and Modeling of Atmospheric Carbon Dioxide

Recent Laboratory progress in carbon cycle science has come in the areas of atmospheric transport modeling and instrument construction and testing. The atmospheric chemistry and transport model, used for calculating global CO_2 transport, has incorporated a land biosphere emissions model and satellite data-constrained biomass burning emissions to produce CO_2 fields that are closely tied to actual meteorology and emission events. The modeling group is actively participating in an international model intercomparison exercise, TransComC, which is aimed at improving models' ability to utilize upcoming space-based CO_2 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 Solar System Exploration Division to develop an airborne CO_2 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_2 profiler, is also being developed in the Laboratory for Atmospheres. The laser profiler has recently achieved CO_2 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_2 within the planetary boundary layer. The real-time CO_2 observations will be compared with modeled distributions to improve our knowledge of the coupling between carbon cycle processes and climate change.

Sun–Earth Connections

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_2, H_2O, O_3, N_2O, and CH_4 in the Earth's atmosphere from a position at L2. The SVIP is designed for testing in the laboratory, outside at Goddard, and on a mountaintop. The GeoSpec is a dual spectrograph operating in the UV/VIS and VIS/Near-Infrared (NIR) wavelength regions to measure trace gas concentrations of O_3, NO_2, and SO_2, coastal and ocean pollution events, tidal effects, and aerosol plumes. GeoSpec is intended to support future missions in the combined fields of atmospheres, oceans, and land. GeoSpec is a collaboration of our Laboratory, Pennsylvania State University, Washington State University, and Research Support Instruments. GeoSpec activities during the current year included final assembly of the breadboard model, radiometric testing, and validation work. A final report to ESTO was delivered in December 2006.

A commercial Brewer double-grating spectrometer has been modified for nearly continuous measurement of column aerosols, NO_2, and SO_2, by the direct-Sun technique. This instrument has traditionally been used for measurements of total ozone and UV irradiance. Polarization and multi-angle 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 Branch scientists.

A new aircraft-based measurement program was started in 2005. ACAM was test flown onboard the NASA WB-57F during the AVE in June 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 spectrographic measurements in order to map trace gas concentrations of NO_2, O_3, and aerosols. These measurements will be used to validate similar measurements from the OMI onboard Aura. The improved ACAM was flown in the CR-AVE mission during January and February 2006. A second version of ACAM is now being developed for deployment on a NASA UAV.

5.4 Laboratory Research Highlights

5.4.1 MODIS Data Processing

The MODIS Atmosphere Team is responsible for generating cloud, aerosol, and clear sky Level-2 (pixel-level) and Level-3 (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 reflectance; (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 Michael. D. King (Code 610) and Steven Platnick (Code 613.2), as are the entire set of MODIS Atmosphere Team Level-3 (daily, eight-day, and monthly) algorithms.

The Aerosol Level-2 product (Lorraine. Remer, P.I., Code 613.2) includes a number of Collection 5 improvements, including new aerosol models and a new land algorithm. A new "Deep Blue" aerosol land algorithm, that includes use of the 412 nm MODIS band, will be implemented in Aqua MODIS Collection 5 processing (led by Christina Hsu, Code 613.2). Documents detailing individual Atmosphere Team algorithm modifications, improvements, and impacts are available at: http://modis-atmos.gsfc.nasa.gov/products_C005update.html.

The MODIS Atmosphere Team's Aqua Collection 5 reprocessing effort began in April 2006 (along with Aqua forward processing) and was completed in June 2006. Aqua forward processing also began at the same time. Terra reprocessing began in July and was finished in December 2006. All MODIS Atmosphere Team Level-2 and Level-3 Collection 5 files, as well as Level-1B data, are now being distributed by the MODIS processing system (referred to as MODAPS) instead of the Goddard DAAC. All data are on disk and accessible via ftp. A host of other capabilities, including subsetting, subscription services, etc. are also available. The Web interface to this data distribution system is called LAADS (Level-1 and Atmosphere Archive and Distribution System). The Web interface can be found at: http://ladsweb.nascom.nasa.gov/.

For further information contact Steven Platnick (Steven.Platnick@nasa.gov).

5.4.2 Flood/Landslide Detection for Disaster Preparedness

Floods and associated landslides account for the largest number of natural disasters and affect more people than any other type of natural disaster. With the availability of satellite rainfall analyses at high-time resolution, it has become possible to assess such hazards on a near-global basis. A framework (Figure 5.1) to detect floods and landslides related to heavy rain events in near-real-time has been proposed. The acronyms in this figure that are not defined elsewhere are: SRTM; Shuttle Radar Topography Mapper, DEM; Digital Elevation Model, FD; Flow Direction, and FA; Flow Accumulation.

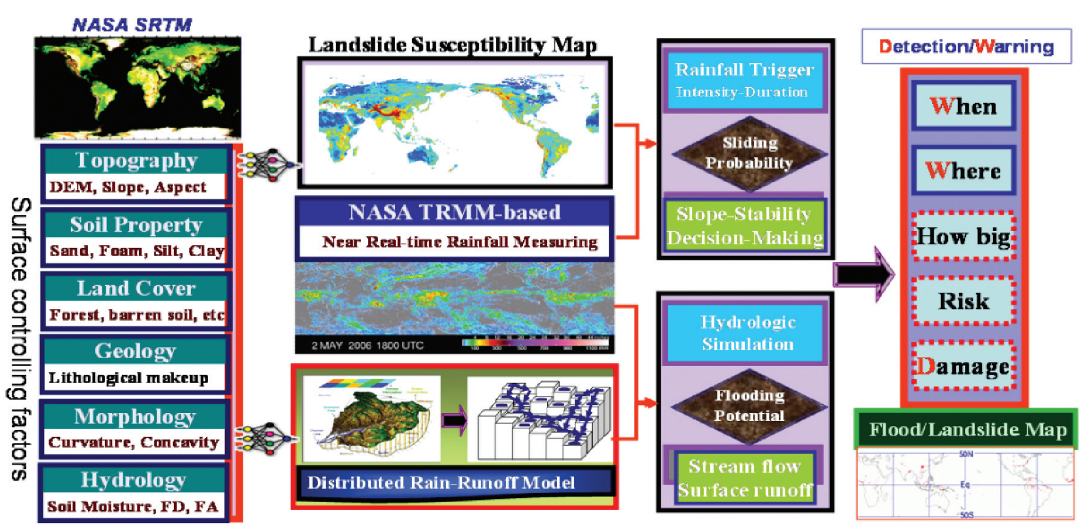


Figure 5.1. The conceptual framework for monitoring rainfall-triggered flood/landslides on a global scale.

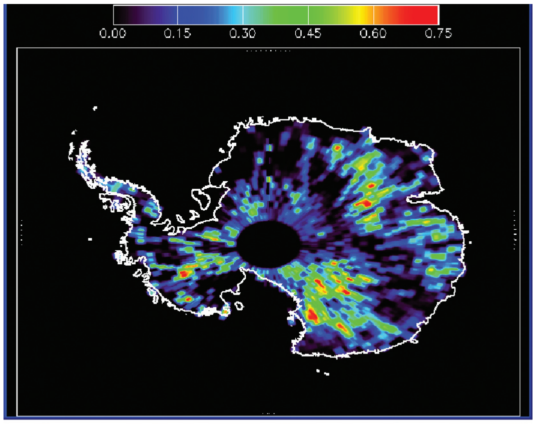
Key components of the framework are: a fine-resolution precipitation acquisition system; a comprehensive land surface database; a hydrological modeling component; and landslide and debris flow model components. A key data set for the integrated applications is the NASA TRMM Multi-satellite Precipitation Analysis. This data set provides near real-time precipitation at a temporal-spatial resolution of 3 hours and 0.25° x 0.25°. In combination with global land surface data sets it is now possible to expand regional hazard modeling components into a global identification/monitoring system for flood/landslide disaster preparedness and mitigation. For further information contact: Robert Adler (Code 613.1), Robert.F.Adler@nasa.gov.

5.4.3 The Geoscience Laser Altimeter System (GLAS)

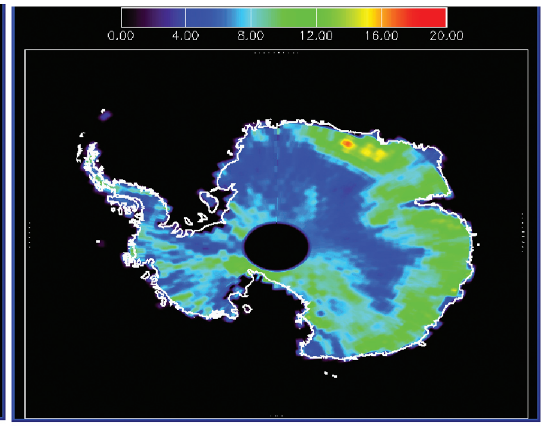
GLAS was launched aboard the Ice, Cloud, and Land Elevation Satellite (ICESat) in early 2003. GLAS is an important part of NASA's Earth Science Enterprise (ESE) which includes a series of satellites to measure Earth's atmosphere, oceans, land, ice, and biosphere for a period of 10 to 15 years. During 2006, GLAS data analysis contributed to five submitted journal publications. Among the topics covered by these papers were observations of tropopause level thin cirrus, the comparison of these observations with model (MM5) derived clouds, and a comparison of cloud cover statistics between GLAS and HIRS.

GLAS has provided the first global observations of the true height distribution of clouds and aerosols in the atmosphere. In addition to proposing and designing the atmospheric channels, data product algorithms have been developed that distinguish cloud and aerosol layers in the data and derive optical properties of layers. The GLAS data products have provided fundamentally new atmospheric science results. As the most accurate such measurement, GLAS shows the total global cloud cover is 76% and cloud overlap, defined as the detection of a second cloud layer before full optical attenuation, is found to be present in 40% of cloudy areas globally. From interpretation of the aerosol height distribution a unique global data product of planetary boundary layer (PBL) height has been produced. The PBL height data, and cloud distribution, have been applied to improve parameterization for the ECMWF and other global circulation models. In comparison to passive satellite retrievals, large improvements are provided in some crucial cloud and aerosol parameters. Major limitations in existing global cloud distribution climatology have been quantified, especially in polar regions. Many newly enabled studies in specialized areas are underway. A unique new result, highlighted below, is the detection of blowing snow across Antarctica, and its relation to winds.

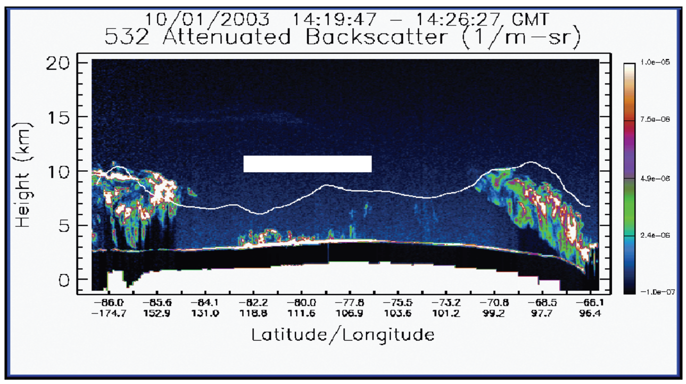
The GLAS mission is the first of four spaceborne laser remote sensing experiments currently underway or in development by NASA and the European Space Agency.



Blowing snow frequency of occurrence for Oct. 2003 from GLAS data analysis.



Surface wind speed from NSIDC model for Oct. 2003.



GLAS data track across Antarctica. The heavy white line is where blowing snow at the surface is detected. The thin white line shows the relative wind speed.

Figure 5.2. Relationship of wind speed to blowing snow across Antarctica.

5.4.4 Hurricane Research

The hurricane research carried out by the Laboratory helps address the central question of NASA's mission in this area: How can weather/hurricane forecasts be improved and made more reliable over longer periods of time using computer modeling? To address this question we have used the computational power of the Columbia supercomputer at AMES research center running the finite-volume General Circulation model (fvGCM) to study, for example, five-day track predictions and the intensity evolution of Hurricane Katrina in August 2005. The term 'fvGCM' has been historically used to refer to the model developed over 10 years at the NASA Goddard Space Flight Center and previously referred to as the NASA fvGCM. In addition to the finite-volume core it now includes the NCAR Community Climate Model 3 (CCM3) physics and the NCAR Community Land Model (CLM)

As of July 2006, three articles highlighting computations completed on Columbia since it came on-line in summer 2004 have been published. Two of them have been selected as American Geophysical Union Journal Highlights, and one has been cited as pioneering work (by Professor Roger Pielke, Sr. of Colorado State University). Recently, an article for the high-resolution simulations of Hurricane Katrina (2005) has been highlighted in Science magazine.

The 2005 Atlantic hurricane season was the most active in recorded history. There were 28 tropical storms and 15 hurricanes, four of which were rated Category 5. Hurricane forecasts pose challenges for General Circulation Models

(GCMs), the most important being the horizontal grid spacing. It is well known that GCMs' insufficient resolutions undermine intensity predictions. Thanks to the considerable computing power of Columbia, this limitation can now be overcome. The main goal of this research, supported by NASA's Weather Data Analysis and Assimilation Program, Earth Sciences Division, is to study the impacts of increasing resolution on numerical weather/hurricane forecasts, aimed at improving forecast accuracy. With the unprecedented computing resources provided by Columbia, it was possible to increase the horizontal resolution of the fvGCM to 1/4 degree in early 2004 and 1/8 degree in early 2005. Improvement stemming from higher resolution was illustrated by calculation of the intensity evolution of hurricane Katrina in which six 5-day forecasts with the 1/8-degree fvGCM obtained promising forecasts with small errors in center pressure of only ±12 hpa. It was also shown that the notable improvement in Katrina's intensity forecasts occurred when grid spacing decreased from 1/4 degree to 1/8 degree, which is sufficient to simulate the near-eye wind distribution and to resolve the radius of maximum winds. In addition to the computational issue, the validity of physics parameterizations poses a challenge to conducting ultra-high resolution simulations. Among these, convective parameterization (CP) is recognized as a crucial limiting factor affecting hurricane forecasts. The fvGCM was used with and without CP to simulate Katrina's track, intensity, and near-eye wind distribution.

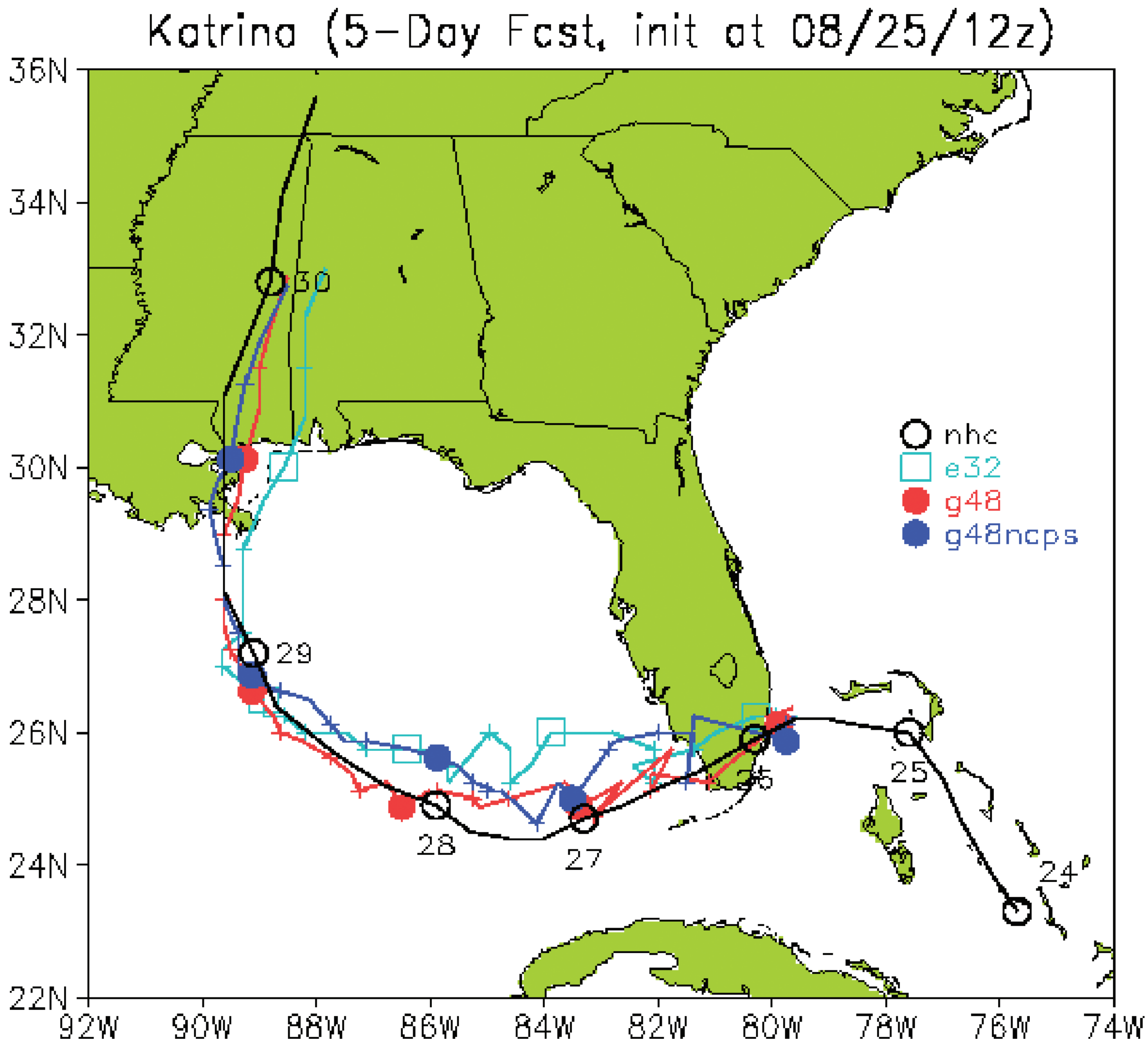


Figure 5.3. Five-day track predictions for hurricane Katrina initialized at 1200 UTC August 25, 2005. The light blue, red, and blue lines represent the tracks from 0.25°, 0.125° simulations, and 0.125° simulation with no CP. Each dot represents the center position at 3-hour time increments. The black line represents the advisory track with a 6-hour time increment from the National Hurricane Center.

Recently, the model's performance on intensity forecasts of major hurricanes was presented at the AGU 2006 Fall Meeting. In addition, the fvGCM at 1/12-degree resolution is being tested. The 1/12-degree fvGCM is the first global weather model with single digit resolution: 9 km at the equator and 6.5 km at mid-latitudes. For further information contact Bo-Wen Shen, Bo-Wen.Shen.1@gsfc.nasa.gov.

5.5 Instrument Development

The Instrument Systems Report, NASA/TP-2005-212783, described the status of instrument development in the Laboratory as of mid-2005. This section describes some of the developments since publication of that report.

5.5.1 High-Altitude Imaging Wind and Rain Airborne Profiler

A dual-wavelength (Ku and Ka band) High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) is under development for the NASA Instrument Incubator Program (IIP) for measuring tropospheric winds within precipitation regions and ocean surface winds in rain-free to light-rain regions. This instrument is being designed for operation on high-altitude manned aircraft and the Global Hawk UAV. Proposed lidar-based systems will provide measurements in cloud-free regions globally. Since many of the weather systems are in disturbed regions that contain precipitation and clouds, microwave-based techniques are more suitable in these regions. Airborne radars at NASA and elsewhere have shown the ability to measure winds in precipitation and clouds. These radars have not generally been suitable for deriving the full horizontal wind from above cloud systems (high-altitude or space) that would require conical scan. HIWRAP is a conical scan radar that uses new technologies that utilize solid state rather than tube-based transmitters. A prototype sensor will be completed and tested on the high-altitude WB-57F aircraft in late 2008 to demonstrate the system level performance of the instrument. For further information contact Gerry Heymsfield, Gerald.M.Heymsfield@nasa.gov.

5.5.2 Shared Aperture Diffractive Optical Element

ESTO funds 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 a factor of three. The objectives of the ShADOE project are as follows:

- 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.

For more information on this technology, visit the Web site at http://estips.gsfc.nasa.gov/qc/images/1158.jpg or contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

5.5.3 Tropospheric Wind Lidar Technology Experiment

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 is funded 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-57F, 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 on this technology, visit the Web site at http://estips.gsfc.nasa.gov/qc/images/1157.jpg or contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

5.5.4 Airborne Water, Aerosol, Cloud, and Carbon Dioxide Lidar

The Airborne Water, Aerosol, Cloud, and Carbon Dioxide Lidar is being developed under the NASA IIP program's 2005 award. It is an outgrowth of the Raman Airborne Spectroscopic Lidar (RASL) developed under the first NASA IIP in 1998. The objectives of this program are:

Extend the development of RASL from a laboratory system to an automated, airborne Raman lidar system to conduct:

(1) Day and night measurements of water vapor, aerosol backscatter, extinction, and depolarization.
(2) Night measurements of cloud liquid water and carbon dioxide.

RASL is scheduled for test flights in June and July, 2007 aboard a Beechcraft King Air based at Bridgewater, VA. Upon successful testing, RASL will provide the first simultaneous airborne profile measurements of boundary layer aerosols and water vapor, permitting studies of hygroscopic aerosol growth. Coupled with the experimental measurements of cloud liquid water during the nighttime, aerosol indirect effect studies will be possible. Successful testing of RASL on a KingAir will also demonstrate the feasibility of adapting Raman Lidar to high altitude aircraft such as the Global Hawk and WB-57F. For further information see the following references:

1. Whiteman, D. N., G. Schwemmer, T. Berkoff, H. Plotkin, L. Ramos-Izquierdo, G. Pappalardo, Performance modeling of an airborne Raman water vapor lidar, *Appl Opt.,* 40, No. 3, 375–390. (2001).
2. Whiteman, D. N., S. H. Melfi, Cloud liquid water, mean droplet radius and number density measurements using a Raman lidar, *J. Geophys. Res.,* Vol 104 No. D24, 31,411–31,419 (1999).

or contact David Whiteman, David.N.Whiteman@nasa.gov.

5.6 Awards

5.6.1 Individual Awards

Thomas Bell (Code 613.2) received the Laboratory for Atmospheres Scientific Research Award "For outstanding scientific contributions towards understanding the Spatiotemporal Behavior of Rainfall inferred from Satellite and *in situ* Data."

Scott Braun (Code 613.1) received a Goddard Honor Award for Earth Science Achievement "for significantly advancing the scientific understanding of tropical cyclones, especially the processes of hurricane intensification and genesis."

Robert Cahalan (Code 613.2) received a NASA Exceptional Service Medal "For scientific leadership and service to NASA in representing NASA within the Climate Change Science Program, the Global Climate Observing System, and the Group on Earth Observations."

Outstanding Leadership and Service Award, Climate Change Science Program

Belay B. Demoz (Code 613.1) was selected to receive the 2005 Editors' Citation for Excellence in Refereeing for JGR-Atmospheres at the May 2006 AGU meeting in Baltimore.

Yoram Kaufman (Code 613.2) received the Verner E. Suomi Award given by the AMS.

Andrew Negri (Code 613.1); Richard Stewart (Code 613); on October 16 received an Acquisition Improvement Award for exemplary efforts on the Laboratory for Atmospheres and Scientific Technical Support Source Evaluation Board (SEB). The Acquisition Improvement Award is the highest Agency acquisition award, given only to individuals who provide a significant contribution in the procurement process.

Dr. W.-K. Tao (Code 613.1) was selected to receive the National Central University of Taiwan Excellent Alumni Award for 2006.

5.6.2 Group Achievement Awards

The TOMS Science and Data Processing Team

The 2006 Pecora Award was presented to Pawan Bhartia (Code 613) and the TOMS team on December 13 at the AGU meeting in San Francisco. The William T. Pecora Award is presented annually to individuals or groups that have made outstanding contributions toward understanding the Earth by means of remote sensing.

The UARS Team

The UARS Team was selected by the NASA Headquarters Incentive Awards Board to receive a Group Achievement Award at a ceremony and luncheon that was held on June 21, 2006 at Martin's Crosswinds in Greenbelt, Maryland. UARS Project Scientist Charles Jackman (Code 613.3) accepted the award for the UARS team.

The TOMS Team

The TOMS team was awarded a Group Achievement Award at the same ceremony. EP-TOMS Principle Investigator Rich McPeters (Code 613.3) accepted the award for the TOMS team.

The Earth Observing System (EOS) Team

Bob Cahalan (Code 613.2) accepted the AIAA Space Systems Award on behalf of the Earth Observing System (EOS) Team.

NASA's Ozone Watch Web Site

This Web site, at (http://ozonewatch.gsfc.nasa.gov), was chosen as a finalist in the Annual Webby Awards, as selected by the International Academy of the Digital Arts and Sciences for the "Science" category. The site was conceived and built under the direction of Paul Newman (Code 613.3), with contributions from the Aura and NASA Atmospheric Chemistry Science Community, GSFC Public Affairs, and design by Robert Simmon (Code 613.2, SSAI).

6. EDUCATION AND OUTREACH

6.1 Introduction

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

The Laboratory's parent organization, The Earth Sciences Division (Code 610), has established a Committee for Education and Public Outreach, which is charged with coordinating these activities across the Division. Several Laboratory members are also on the ESD 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

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 Sciences 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. and 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.

During the summer of 2006, students from Howard University participated in the WAVES field campaign at the Beltsville site from July 7 to August 10 (see Section 4.2.10).

The field campaign was intended to provide quality measurements of water vapor and ozone for comparison with Aura satellite retrievals and to quantify the air quality. In addition to the Howard University Raman Lidar, the operations included intensive observations by multiple radiosonde/ ozonesonde sensors and other lidar systems during overpasses of the Aura satellite. Continuous measurements were also taken by a 31m instrumented tower, various broadband and spectral radiometers, microwave radiometer, Doppler C-band radar, Maryland Department of Environment instrumentation, wind profiler, sun photometer, and GPS system. Some of the instruments are pictured in Figure 6.1.

Figure 6.1. Overview of some of the instrumentation used in the WAVES field campaign.

HU students participated in several aspects of the measurement program. Student theses using WAVES measurements are shown in the following table.

Table 6.1 Howard University Students Participating in the WAVES Campaign

Student	Topic	Instrument
Rasheen Connell	Cirrus Cloud Measurements	HURL
Fonya Nzeffe	Aerosol Indirect Effect	Microwave Radiometer
Miliaritiana Robjohn	Modeled vs Observed Fluxes	Instrumented Tower
Segayle Walford	Mesoscale Convective Studies	MDE Wind Profiler

6.3 Summer Programs

6.3.1 The Summer Institute in Atmospheric, Hydrospheric, and Terrestrial Sciences

The Summer Institute in Atmospheric, Hydrospheric, and Terrestrial Sciences was held from June 12 to August 18, 2006. The Institute is organized by Per Gloersen (Code 614.1) and is hosted by the Earth Sciences 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 6.2.

Table 6.2. Laboratory Scientists Mentoring Students in the 2006 Summer Institute

Mentor/Code	Student/University	Topic
Eric Smith, 613.1	Amy Harless, UNC	Role of Gulf of Mexico and Caribbean Sea Hurricanes on Regional Water Budget
Charles Gatebe, 613.2	Daniel Kaufman, Univ. of MD	Cloud Absorption Radiometer (CAR)Web Input and Visualization
Guoyong Wen, 613.2	Julie Nguyen, Grove City College and Brendan Hermalyn, Fairfield Univ	Radiative Non-Equilibrium at the Lunar Surface
Lorrain Remer and Richard Kleidman, 613.2 Santiago Gasso, (613.2, UMBC)	Jamie Matusiak, Valparaiso Univ. Daniel Eipper, Millersville Univ.	Air Pollution in Selected Cities of Sub-Saharan Africa Exploring the Effects of Aerosols on Cloud's Precipitation and Brightness Properties

Figure 6.2. Participants in the 2006 Summer Institute. Per Gloersen is at the left.

6.3.2 Research & Discover: Summer Internship Program in Earth Sciences

Research & Discover is a summer internship program jointly sponsored by the University of New Hampshire (UNH) and GSFC. It is available to students who have completed their junior year of college. Participants receive a stipend, as well as room and board. Following the first summer internship, participants are encouraged to apply for a second summer internship held at the NASA Goddard Space Flight Center. Following this internship, participants will be eligible to receive a two-year fellowship for graduate study at UNH. During summer 2006, the following Laboratory scientists mentored UNH students in their research projects.

Table 6.3. Laboratory Scientists Mentoring Students in the 2006 Research & Discover Program

Mentor/Code	Student/University	Topic
David Whiteman, 613.1	Cassie Stearns, Smith College	EOS-Aura MLS Validation Using Radiosonde Profiles During the WAVES Campaign
Robert Cahalan, Alexander Marshak, 613.2	Brian Cook, U. C. Berkeley	Radiative Transfer Simulations for Clouds Analyzing 3D and 1D Approaches
Ken Pickering, 613.3	Jeremy Ott, Northland College	Convective Transport of Trace Gases and Lightning NO Production in Brazilian Thunderstorms
Susan Strahan, (613.3, SSAI) and Anne Douglass, 613.3	Andrea Crosby, Duke Univ.	Investigation of Cross-Tropopause Mixing in the Subtropics

6.3.3 Goddard Earth Sciences and Technology (GEST) Center Graduate Student Summer Program: GEST-GSSP

NASA Goddard Space Flight Center's Earth Sciences Division, in collaboration with the Goddard Earth Sciences and Technology (GEST) Center of the University of Maryland Baltimore County, offers a limited number of graduate student research opportunities through it's Graduate Student Summer Program (GSSP). This prestigious program is in its seventh year and is designed to stimulate interest in interdisciplinary Earth sciences studies by enabling selected students to carry out an intensive research project at GSFC's Earth Sciences Division, which can be applied to the student's graduate thesis.

Positions are available to students interested in any Earth sciences field conducive to the research of NASA GSFC's Earth Sciences Division. Each student is teamed with a NASA Goddard scientist mentor with parallel scientific interests. NASA mentors can be drawn from any of the participating Earth Sciences Laboratories which include: the Laboratory for Atmospheres, the Laboratory for Hydrospheric and Biospheric Sciences, the Global Modeling & Assimilation Office, the Global Change Data Center, and the Software Integration and Visualization Office. During the summer program, there is a lecture series aimed at current popular Earth sciences topics. At the conclusion of the program, students produce final oral and written reports on their summer research activities.

During the summer of 2006, Laboratory personnel acted as mentors for four GEST students. Mentors, students, and their research topics are given in Table 6.4.

Table 6.4. Laboratory Scientists Mentoring Students in the 2006 GEST-GSSP Program

Mentor/Code	Student/University	Topic
Oreste Reale, 613	Marangelly Fuentes, Howard Univ.	Barotropic Instability of the African Easterly Jet.
David O'C Starr, 613.1	Tamara Singleton, UMCP	Investigating Gravity Wave Effects on Cirrus Clouds using a One Dimensional Cirrus Cloud.
Mian Chin, 613.3	Mariya (Shcherbyna) Petrenko, Purdue Univ.	Estimating Carbonaceous Aerosol Emissions from Forest Fires in North American Boreal Forests in July 2004.
Joanna Joiner, 613.3	Partha Sarathi Bhattacharjee, George Mason University	Comparisons of Carbon Monoxide Measurements using Aircraft and Model Data.

6.3.4 GSFC High School Internship Program (HIP)

HIP is a research intensive program that allows interns to explore "real-time" applications of Science, Technology, Engineering, and Mathematics (STEM) disciplines. By the end of the summer, interns complete eight weeks of research on a project related to NASA's goals and deliver an oral technical presentation, sharing the results of their research with NASA management, scientists, and fellow interns.

Each HIP student is assigned a NASA scientist or engineer as a mentor and assists the mentor with his or her current project. The interns conduct research and use data for the projects, and the mentors guide the students and help them learn as much as possible from their experience at NASA Goddard.

This year's eight-week program ran from June 26 to August 18. Two Laboratory members mentored students in this program.

George Huffman (Code 613.1, SSAI) mentored Jeremy Lehmann in a project titled, "Quality Control of the ATLAS II Precipitation Gauge Data."

Prasan Kundu (Code 613.2, UMBC) mentored Mael Flament in a project titled, "Multifractal Properties of Time-averaged Rainfall Data."

6.3.5 AMS Fellowship Winners' Visit

On July 12, 2006 the Earth Sciences 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 clean room and other facilities in Building 29. 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 sponsored two of the seven visiting students' 2006 fellowships. The students, their areas of interest, and universities are listed in Table 6.5.

Table 6.5. 2006 AMS Fellowship Winners Visiting GSFC

Student	University	Research Interest
Andrew Hamm*	Univ. of Oklahoma	Use of Statistics in Atmospheric Science
Rebecca Adams	Colorado State Univ.	Meteorology
Danielle Manning	Florida State Univ.	Hurricane Classification
Matthew Van Den Brocke	Univ. of Oklahoma	Severe Storms
Maura Hahnenberger*	Univ. of Utah	Mountain Meteorology
Daniel Philip Lane	MIT – Woods Hole	Interaction between Tropical Cyclones and Climate
Stephanie Zick	Penn State Univ.	Tropical Cyclone Development

* Indicates NASA ESE 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:

Franco Einaudi: Director, Earth Sciences Division and President of the AMS
Welcome and opening remarks

Steven Pawson, Global Modeling and Assimilation Office (Code 610.1);
"Modeling the Interactions between Climate and Ozone: Successes and Challenges."

Jeff Morisette, Terrestrial Information Systems Branch, (Code 614.5)
"Evasive Species Forecast Systems."

Scott Braun, Mesoscale Atmospheric Processes Branch (Code 613.1)
"Overview of Hurricane Research at Goddard."

Rich Stolarski, Atmospheric Chemistry and Dynamics Branch, (Code 613.3)
"Interactions between Atmospheric Chemistry and Climate."

Matt Deland, Atmospheric Chemistry and Dynamics Branch, (Code 613.3)
"Current Status of Satellite PMC Observations."

Figure 6.3. Franco Einaudi, Director of the Earth Sciences Division and President of the AMS addresses the AMS fellowship winners at the beginning of their visit to GSFC.

During the afternoon the AMS students toured facilities at Building 29, guided by Barbara Lambert, flight hardware photographer with SGT Corp.

Figure 6.4. Barbara Lambert (left) and AMS Fellowship Winners tour the Building 29 centrifuge facility.

The final stop on the Building 29 tour was at a mockup of a shuttle control panel. Here Barbara demonstrated the use of gloves used by astronauts during spacewalks to change panel components, Figure 6.5. Students were invited to try changing various components while wearing these gloves.

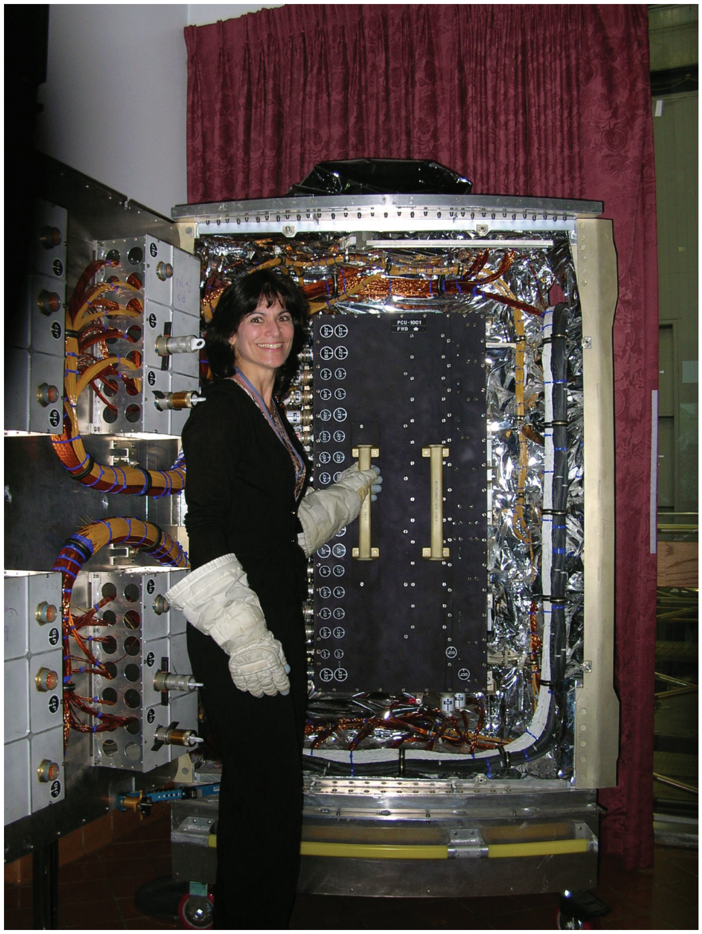


Figure 6.5. Barbara Lambert demonstrates the use of astronauts' gloves using a mockup of a shuttle control panel on the second floor of Building 29.

6.4 University Education

Laboratory members are active in supporting university education through teaching courses and advising graduate students. Table 6.6 lists instructors and courses taught.

Table 6.6. Courses Taught in 2006

University	Course	Instructor, Code
UMBC	Physics 721, Atmospheric Radiation	Lazaros Oreopoulos, 613.2
George Mason Univ.	Thermodynamics	Yogesh Sud, 613.2
UMBC	Physics 602, Statistical Mechanics	Prasun Kundu, 613.2
Johns Hopkins Univ.	Physics 615.415.31, Statistical Mechanics and Thermodynamics	Prasun Kundu, 613.2

The following, Table, 6.7, lists Laboratory members serving as graduate student advisors and/or on student Ph.D. committees. Committee members are indicated by an asterisk after the member's name/code. The actual or anticipated date of the student's dissertation defense, if available, is shown after the student name.

Table 6.7. Graduate Student Advising by Laboratory for Atmospheres Members

Member/Code	Student	Degree	Institution	Thesis Topic or Area
Richard Stewart, 613*	Natasha Green May 2006	Ph.D.	Howard Univ.	Examination of Particulate Matter and Heavy Metals and their Effects in At-Risk Wards in Washington, D.C.
Richard Stewart, 613* Belay Demoz, 613.1*	Lizette Roldan May 2006	Ph.D.	Howard Univ.	Characterization of Microphysical Properties of Saharan Dust Aerosols during Trans-Atlantic Transport.
David Starr, 613.1	Tamara Singleton	Ph.D.	UMCP	Influence of Gravity Waves on Cirrus Clouds.
Wei-Kuo Tao, 613.1*	Toshihisa Matsui November 2006	Ph.D.	Colorado State Univ.	Aerosol Effects on Cloud-Precipitation and Land-Surface Processes.
Wei-Kuo Tao, 613.1*	Jiwen Fan August 2007	Ph.D.	Texas A&M Univ.	Cloud-Chemistry-Aerosol Interactions.
Wei-Kuo Tao, 613.1*	Thomas L. O'Halloran Summer 2007	Ph.D.	Univ. of Virginia	Cloud-Land-Vegetation Interactions.
Steven Platnick, 613.2*	Joonsuk Lee Spring 2007	Ph.D.	Texas A&M Univ.	Not Defined.
Steven Platnick, 613.2*	Brent Maddox	Ph.D.	Univ. of Wisconson, Madison	Not Defined.
Charles Gatebe, 613.2	Juliao J. Cumbane	Ph.D.	Univ. of Johannesburg, South Africa	Investigations of Clean Air Slots over Southern Africa from Multiangular Measurements.
Charles Gatebe, 613.2 External Examiner	Patience Ngwaze	Ph.D.	Univ. of Johannesburg, South Africa	Physical and Chemical Properties of Aerosol Particles in the Troposphere: An Approach from Microscopy Methods.
Alexander Marshak, 613.2*	Dong Huang August 2006	Ph.D.	Boston Univ.	Not Defined.
Prasun Kundu, 613.2	Ravi Siddani	Ph.D.	UMBC	Space-time Statistics of Precipitation.

Table 6.8. Graduate Students Supported at the Joint Centers

Student	University	Topic	Advisor/Sponsor
Brittany McClure	UMCP	OMI SO_2 data validation with aircraft *in situ* data	Russell Dickerson (UMCP) Nickolay Krotkov (613.3, GEST)
Ravi Siddani	UMBC	Space-time Statistics of Precipitation	Prasan Kundu, 613.2

UMBC: University of Maryland, Baltimore County.
UMCP: University of Maryland, College Park.

6.5 Open Lecture Series

Distinguished Lecturer Seminar Series

One aspect of the Laboratory's public outreach is a Distinguished Lecturer Seminar Series, which is held each year and is announced to all our colleagues in the area. 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 2006.

January 26

Robert Adler, NASA GSFC, Laboratory for Atmospheres
Variations in Global Precipitation: Climate-scale to Floods.

February 16

Michael Prather, Jefferson Science Fellow, U.S. Dept. of State, and Kavli Professor, University of California at Irvine
Lifetimes, Time Scales and Feedbacks in Atmospheric Chemistry.

March 16

Andy Heymsfield, National Center for Atmospheric Research, Boulder, Colorado
Ice Cloud Properties from *In Situ* Observations and Application to Spaceborne Active Remote Sensors.

April 20

Paul Newman, NASA GSFC, Atmospheric Chemistry and Dynamics Branch
Recovery of the Antarctic Ozone Hole.

June 15

Greg Tripoli, University of Wisconson, Madison
Hybrid Spectral Habit Prediction Schemes - A new approach to explicit microphysics prediction.

July 27

Joyce Penner, University of Michigan Department of Atmospheric, Oceanic and Space Sciences
Aerosols and Climate: Can we quantify the effect of aerosols on climate change and does it matter?

August 17

Bruce Albrecht, University of Miami
Cloud-Aerosol-Drizzle Interactions Nature's Way.

October 20

Phil Rasch, National Center for Atmospheric Research
Geo-Engineering Climate Change with Sulfate Aerosols.

6.6 Public Outreach

In addition to teaching and committee work, Laboratory members give seminars to university and other student groups and to public audiences. Among the student groups are those participating in Goddard's Scientific and Engineering Student Internship program (SESI). SESI is a joint program with the Physics Department of the Catholic University of America and the Astrophysics Science Division and Science and Exploration Directorate at GSFC. In addition to their summer research activities students attend a weekly seminar given by a Goddard scientist. Two of these, dated June 21 and June 29, are described in the following list.

January 17

Wei-Kuo Tao (613.1) gave a talk at North Carolina State University entitled "A Coupled GCM-Cloud Resolving Modeling System, and A Regional Scale Model to Study Precipitation Processes."

February 2

Wei-Kuo Tao (613.1) gave a talk entitled "A coupled GCE-Cloud Resolving Modeling System and a Regional Scale Model to Study Precipitation Processes." at The Distinguished Lecturer Seminar Series of the Department of Meteorology, Penn Sate University.

May 1

Paul Newman (613.3) gave a talk at the Meteorology Department, University of Maryland entitled, "When will the Antarctic ozone hole recover?"

May 23–26

George Huffman (613.1, SSAI) reviewed two student posters and two student presentations as part of the student award process at the 2006 Joint Assembly of the AGU, 23-26 May 2006, Baltimore, MD.

June 5

Wei-Kuo Tao (613.1) gave a talk at National Central University entitled "Using Multi-scale Modeling System to Study the Interactions between Clouds, Precipitation, Aerosols, Radiation and Land Surface."

June 12

Robert Adler (613), Scott Braun (613.1), and David Adamec (614.2) participated in Media Day at NASA GSFC, an event geared toward introducing the media to NASA scientists involved in hurricane related research. Adler presented information on the TRMM satellite and its application to hurricane research (as well as the more general topic of heavy rainfall events). Braun presented highlights of his research on hurricanes, including numerical modeling, field research programs, and applications of TRMM data. Adamec presented a film highlighting last years active hurricane season and discussed prospects for the coming season. Adler and Adamec were interviewed by the media, with news stories carried on television. Braun was interviewed for an NPR radio story on hurricanes and the sometimes odd methods that scientists suggest for weakening them.

June 21

Steven Platnick 613.2 gave a talk to SESI students. The title was "An Overview of NASA Earth Science Observations: The View from Space."

June 28

Charles Jackman (613.3) gave a SESI talk titled "Has the Ozone Layer Changed."

July 20

Scott Braun (613.1) gave a presentation entitled "Monster Storms: NASA Research on Hurricanes." to two groups of teachers at the JASON Action Summit held in Washington D.C, July 18-20, 2006. The JASON Project is a nonprofit educational organization whose goal is to inspire student learning in science, math, and technology.

August 7

A media event was held at the Howard University Research Campus in Beltsville, MD as a part of the Aura validation effort called WAVES that was being hosted there. The links for several news reports are now posted on the WAVES Web site at http://ecotronics.com/lidar-misc/WAVES.htm under the link called "WAVES in the news". David Whiteman (613.1) and Belay Demoz (613.1) are the NASA leads of this satellite validation activity.

August 21 (Summer Visitors:)

David Bolvin (613.1, SSAI) served on the review panel on August 18, 2006 for two H.I.P Summer Intern presentations:

(1) "Rocks That Deliver Electric Currents: Activation by Stress" by Gerasimos Michalitsianos
(2) "Multifractal Properties of Time-Averaged Rainfall Data" by Mael Flament

September 5

Eyal Amitai (613.1, GMU) organized a 3-day training program on space-borne and ground-based radars for visitors from the Met. Service of Cyprus. The visit was sponsored by America-Mideast Educational & Training Services, Inc.

September 21

Scott Braun (613.1) gave two talks on Thursday, Sept. 21 on "Hurricane Research at Goddard". The first presentation was made to Dr. Charles Kennel, former member of the NASA Advisory Council, during his visit to Goddard. The second presentation was to graduate students participating in the Graduate Student Researchers Program Symposium being held Sept. 20-22 at Goddard.

September 25

Anne Douglass (613.3) was the 2006 Morris Katz Memorial Lecturer on Environmental Research at York University in Toronto, Canada. Her talk was entitled, "Discoveries from EOS Aura." The audience included faculty, students, members of Dr. Katz's family, and was open to the general public. She was the 16th lecturer and the first woman in this series and was given a commemorative plaque. A second copy of the plaque will be displayed at the university.

October 19

Clark Weaver (613.3,GEST) gave a talk on global warming to the 9th grade science class at the Washington International School, Washington, DC.

October 23

George Huffman (613.1,SSAI) gave a presentation to the Asia Pacific Satellite Training Seminar (APSATS), Melbourne, Australia. APSATS was a 2-week training event sponsored by the World Meteorological Organization for about 30 personnel from national meteorological services in the Asia-Pacific region. The title was 'Where to Find Precipitation Products, Including TOVAS' (TRMM Online Visualization and Analysis System).

October 31

Paul Newman (613.3) spoke about the 2006 Antarctic ozone hole with approximately 60 science writers.

November 2

Paul Newman (613.3) gave a talk at Penn State University entitled, "When will the Antarctic Ozone Hole Recover"?

November 11

George Huffman (613.1, SSAI) Thunderstorms 101. Presentation to United Methodist Men, St. Matthews United Methodist Church of Bowie, MD. This was a Public lecture for about 20 attendees.

November 27

Wei-Kuo Tao (613.1) gave a talk at University of Maryland entitled "Using Multi-scale Modeling System to Study the Interactions between Clouds, Precipitation, Aerosols, Radiation, and Land Surface".

December 4

Scott Braun (613.1) gave a talk to meteorology students at San Francisco State University on Dec. 7 entitled "Peering into the hurricane intensity problem using NASA satellites, aircraft, and models".

Undated

George Huffman (613.1, SSAI) served as a resource for the NASA/EOS Earth Observatory Web site's Ask A Scientist dept., writing 4 responses to questions in 2006.

Matthew Deland (613.3, SSAI) was named as a research principal investigator in an education and public outreach proposal titled "Exploring the Sun-Climate Connection through Student Observations". The team lead is Robert Cahalan (613.2).

6.7 Project Outreach

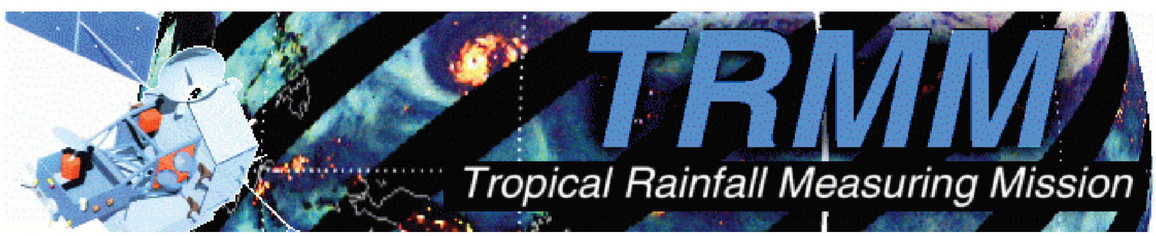
Funded projects in which Laboratory members participate contain elements of both education and public outreach that are described on the project Web sites. Some of these outreach efforts are summarized in the following sections.

TERRA

The EOS Terra outreach effort 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. The Terra Web site also contains a number of links under 'Features' to tutorials on topics of interest such as hurricanes and the cost of natural hazards. These tutorials are part of the NASA Earth Observatory Web site.

TRMM

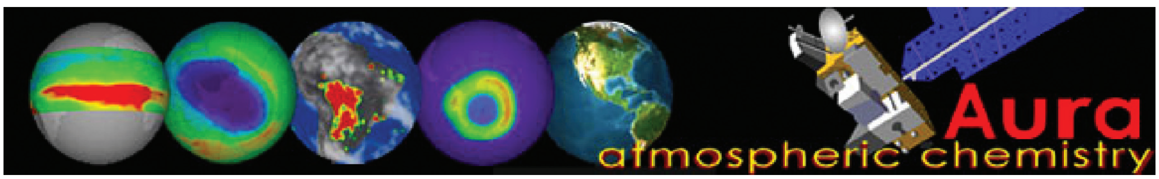


TRMM is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. TRMM continues its comprehensive Education/Outreach program, in which Laboratory personnel promote TRMM science and technology to the public under the leadership of TRMM Project Scientist Robert Adler (Code 613), and TRMM Education and Outreach Scientist Jeffrey Halverson (613.1, JCET). 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. 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 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, Pennsylvania) 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 into NASA's program to study the Earth's environment. The Aura Web site is http://aura.gsfc.nasa.gov/.

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 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. The TOMS Engineering Model was on exhibit from April through November of 2006.

7. ACRONYMS

Acronyms defined and used only once in the text may not be included in this list.

ACAM	Airborne Compact Atmospheric Mapper
ACS	American Chemical Society
ADEOS	ADvanced Earth Observing Satellite
AERONET	Aerosol Robotic Network
AEWs	African Easterly Wave(s)
AFB	Air Force Base
AGU	American Geophysical Union
AI	Aerosol Index
AIAA	American Institute of Aeronautics and Astronautics, Inc.
AIM	Aeronomy of Ice in the Mesosphere
AIRS	Atmospheric Infrared Sounder
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	AMSR Earth Observing System (EOS)
AMSU	Advanced Microwave Sounding Unit
AOD	Aerosol Optical Depth
APSATS	Asia Pacific Satellite Training Seminar
ARM	Atmospheric Radiation Measurement (Program)
ARM CART	ARM Cloud and Radiation Test Bed
AROTAL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ASP/DOE	Atmospheric Sciences Program/Department of Energy
ATL	Aerosol and Temperature Lidar
ATMS	Advanced Technology Microwave Sounder
AVE	Aura Validation Experiment
BASE-ASIA	Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment
BUV	Backscatter Ultraviolet
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	Convection And Moisture EXperiment
CAR	Cloud Absorption Radiometer
CCN	Cloud Condensation Nuclei
CCSP	Climate Change Science Program
CC-VEx	CALIPSO-CloudSat Validation Experiment
CERES	Clouds and the Earth's Radiant Energy System
CFCs	Chlorofluorocarbons
CGCM	Chemistry and General Circulation Model
CMOS	Complementary metal–oxide–semiconductor
COMBO	Combined Stratospheric-Tropospheric Model
COMMIT	Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere
COVIR	Compact Visible and Infrared Radiometer
CP	Convective Parameterization
CPL	Cloud Physics Lidar
CR-AVE	Costa Rica AVE
CrIS	Crosstrack Infrared Sounder

CRS	Cloud Radar System
CSTEA	Center for the Study of Terrestrial and Extraterrestrial Atmospheres
CTM	Chemical Transport Model
DAAC	Distributed Active Archive Center
DFRC	Dryden Flight Research Center
DOAS	Differential Optical Absorption Spectroscopy
DOE	Department of Energy
DSCOVR	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
EPA	Environmental Protection Agency
EPIC	Earth Polychromatic Imaging Camera
EP-TOMS	Earth Probe TOMS
ESE	Earth Science Enterprise
ESD	Earth Sciences Division
ESMF	Earth Science Modeling Framework
ESRL	Earth System Research Laboratory (NOAA)
ESSIC	Earth System Science Interdisciplinary Center
ESTO	Earth Science Technology Office
EU	European Union
FMI-ARC	Finnish Meteorological Institute – Arctic Research Center
FOV	Field of View
fvGCM	Finite volume GCM
GCE	Goddard Cumulus Ensemble model
GCM	General Circulation Model
GEOS	Goddard Earth Observing System
GeoSpec	Geostationary Spectrograph
GEOSS	Global Earth Observation System of Systems
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
GMT	Greenwich Mean Time
GMU	George Mason University
GOCART	Goddard Chemistry Aerosol Radiation and Transport
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment

GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
GSSP	Graduate Student Summer Program
GSWP	Global Soil Wetness Project
GV	Ground Validation
GVP	Ground Validation Program
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
HBCUs	Historically Black Colleges and Universities
HIP	High school Internship Program
HIRDLS	High Resolution Dynamics Limb Sounder
HIRS	High Resolution Infrared Sounder
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
HSB	Humidity Sounder Brazil
HU	Howard University
HUPAS	Howard University Program in Atmospheric Sciences
HY-SiB	Hydrology and Simple Biosphere
ICESat	Ice, Cloud, and Land Elevation Satellite
IIP	Instrument Incubator Program
INTEX-B	Intercontinental Chemical Transport Experiment – Part B
IPCC	Intergovernmental Panel on Climate Change
IPO	Integrated Program Office
JAXA	Japan Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology
JGR	Journal of Geophysical Research
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
LRR	Lightweight Rainfall Radiometer
LRR-X	LRR-X band
MAPB	Mesoscale Atmospheric Processes Branch
MAS	MODIS Airborne Simulator
McRAS	Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme
MDE	Maryland Department of the Environment
MFRSR	Multifilter Rotating Shadowband Radiometer
MILAGRO	Megacity Initiative: Local And Global Research Observations
MISR	Multi-Angle Imaging Spectroradiometer
MIT	Massachusetts Institute of Technology
MLS	Microwave Limb Sounder
MM5	Mesoscale Model 5

MODIS	Moderate Resolution Imaging Spectroradiometer
MOHAVE	Measurements Of Humidity in the Atmosphere and Validation Experiment
MPL	Micro-Pulse Lidar
MPLNET	Micro-Pulse Lidar Network
MSU	Microwave Sounding Unit
NAMMA	NASA African Monsoon Multidisciplinary Analysis
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
NATIVE	Nittany Atmospheric Trailer and Integrated Validation Experiment
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NICT	National Institute of Information and Communications Technology
NIIEM	Russian Scientific Research Institute of Electromechanics
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NMNH	National Museum of Natural History
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar Orbiting Environmental Satellite System
NPP	NPOESS Preparatory Project
NRC	National Research Council
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NWS	National Weather Service
OLR	Outgoing Longwave Radiation
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapper and Profiler System
OOAT	Ozone Operational Algorithm Team
PAVE	Polar Aura Validation Experiment
PBL	Planetary Boundary Layer
PI	Principal Investigator
PM2.5	Particulate Matter, diameter < 2.5 µm
PMC	Polar Mesospheric Clouds
POES	Polar Orbiting Environmental Satellite
QuikSCAT	(NASA's) Quick Scatterometer satellite
RASL	Raman Airborne Spectroscopic Lidar
RCDF	Radiometric Calibration and Development Facility
RMS	Root Mean Squared
RRS	Radiosonde Replacement System
SAGE	Stratospheric Aerosol and Gas Experiment
SBIR	Small Business Innovative Research
SAL	Saharan Air Layer
SAOZ	Système d'Analyse par Observation Zénithal
SAUNA	Sodankylä Total Column Ozone Intercomparison
SBUV	Solar Backscatter Ultraviolet

SBUV/2	Solar Backscatter Ultraviolet/version 2
SDS	Scientific Data Set
SEB	Source Evaluation Board
SESI	Scientific and Engineering Student Internship program
SGT	Stinger Ghaffarian Technologies
ShADOE	Shared Aperture Diffractive Optical Element (telescope)
SHADOZ	Southern Hemisphere ADditional OZonesondes
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SOLSE/LORE	Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment
SOLVE	SAGE III Ozone Loss and Validation Experiment
SORCE	SOlar Radiation and Climate Experiment
SRL	Scanning Raman Lidar
SSAI	Science Systems and Applications, Inc.
STEM	Science, Technology, Engineering, and Mathematics
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
STS	Space Transportation System
SVIP	Solar Viewing Interferometer Prototype
TCSP	Tropical Cloud Systems and Processes
TES	Tropospheric Emission Spectrometer
THOR	cloud THickness from Offbeam Returns
TIROS	Television Infrared Observation Satellite
TOA	Top Of Atmosphere
TOGA-COARE	Tropical Ocean Global Atmosphere–Coupled Ocean Atmosphere Response Experiment
TOMS	Total Ozone Mapping Spectrometer
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
TWiLiTE	Tropospheric Wind Lidar Technology Experiment
TWP-ICE	Tropical Warm Pool International Cloud Experiment
UAE2	United Arab Emirates Unified Aerosol Experiment
UARS	Upper Atmosphere Research Satellite
UAV	Unmanned Aerial Vehicle
UMBC	University of Maryland, Baltimore County
UMCP	University of Maryland, College Park
UNH	University of New Hampshire
URAD	UAV Radar
USDA	United States Department of Agriculture
UTC	Universal Coordinated Time
UV	Ultraviolet
UV-B	Ultraviolet-B radiation
UV-MFRSR	Ultraviolet Multifilter Rotating Shadowband Radiometer
VIS	Visible
WAVES	Water Vapor Validation Experiment – Satellite/Sondes
WCRP	World Climate Research Programme
WMI	Weather Modification Inc. ???

WMO	World Meteorological Organization
WRF	Weather Research and Forecasting

APPENDIX 1: THE LABORATORY IN THE NEWS

The following pages contain news articles and press releases that describe some of the Laboratory's activities during 2006.

Space network to track rainfall

By Richard Black

Environment Correspondent, BBC News Web site, in Vienna

The US and Japanese space agencies (NASA and Jaxa) are to launch a satellite network to measure rainfall around the world.

The Global Precipitation Measurement (GPM) project will provide three-hourly reports on rainfall.

It aims to improve weather forecasting and understanding of how the global water cycle affects climatic change.

Details of the $1.1bn (£636m) project, due to begin in 2011, were presented at a conference in Vienna, Austria.

"The aim is to provide the best possible global precipitation measurement available from any sources," said Arthur Hou, GPM project scientist at Nasa's Goddard Space Flight Center near Washington DC.

"It is primarily a science mission, but folded into the science objectives is to improve algorithms for weather forecasting," he told the BBC News Web site.

"It will help with climate, because rainfall is a fundamental element in the climate, and also measuring soil moisture feedback would improve climate prediction."

Higher resolution measurement in the future may also help forecast floods and landslides.

'Satellites of opportunity'

The heart of the GPM will be a "core" satellite equipped to measure rainfall in two ways, via a dual-frequency radar and a passive microwave radiometer.

It will also serve as a calibration reference for the rest of the satellite constellation.

These will come from a range of space agencies. Some will be designed explicitly for GPM, others "satellites of opportunity", launched for other projects but capable of putting data into the GPM system.

Between six and eight satellites will be involved altogether; using a range of instruments and in a variety of orbits, the idea is to provide a constantly-updated picture of rainfall around the world.

It extends a previous US-Japanese collaboration, the Tropical Rainfall Measuring Mission.

"This takes it from the tropics to a global extent," said Dr. Hou, "and also will enable us to measure lower rain rates as well as snow."

Dr. Hou's presentation formed part of a sequence here at the European Geosciences Union (EGU) meeting on improving measurement of rainfall.

There was general agreement that better data was badly needed, particularly for rain over the oceans, where surface-based measurement was not easy.

Eyal Amitai, also from Goddard Space Flight Center with an additional post at George Mason University in Washington DC, is working on a new detection method involving sound.

"It is difficult to measure rainfall at sea," he said. "Rain gauges on board ships and on surface moorings are unstable and subject to vandalism; satellite observations are poor in temporal coverage and have large spatial averaging, whereas rain is highly variable in time and space."

During 2004, Dr Amitai's team conducted experiments with hydrophones - underwater sound detection devices - in the Ionian Sea.

By calibrating their observations against radar observations, they concluded that placing hydrophones one or two kilometres underwater could be an effective way to measure rainfall on the sea.

Story from BBC NEWS:

http://news.bbc.co.uk/go/pr/fr/-/1/hi/sci/tech/4872606.stm

Published: 2006/04/03 12:53:52 GMT

April 7, 2006

Erica Hupp\Grey Hautaloma
Headquarters, Washington
(202) 358-1237\0668

Cynthia O'Carroll
Goddard Space Flight Center, Greenbelt, Md.
(301) 286-4647

CONTRACT RELEASE: C06-022

NASA AWARDS LABORATORY FOR ATMOSPHERES CONTRACT

NASA has selected Science Systems and Applications, Inc., Lanham, Md., for the Laboratory for Atmospheres Scientific and Technical Support Services contract.

The award is a five-year cost-plus award fee, indefinite delivery-indefinite quantity contract with a maximum value of $45 million. The work will be performed at NASA's Goddard Space Flight Center, Greenbelt, Md., and at the contractor's facility in Lanham.

The work includes scientific and technical support to three branches in the Laboratory for Atmospheres. The work involves using observations from NASA satellites to derive such important scientific and weather parameters as global rainfall distribution and the year-to-year trends of atmospheric ozone levels.

Also included in the contract is instrument development, such as state-of-the art lasers that accurately determine the vertical profiles of aerosols, clouds and water vapor in the atmosphere. Other scientific support includes numerical modeling of hurricane and cloud systems, the transport of trace gases and modeling to determine the role of aerosols and clouds on climate.

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

April 11, 2006

Grey Hautaluoma/Erica Hupp
Headquarters, Washington
(202) 358-0668/1237

Randall Kremer
National Museum of Natural History, Washington
(202) 633-0817

RELEASE: 06-182

NASA EARTH SCIENCE EXHIBITS OPEN IN SMITHSONIAN MUSEUM

NASA has announced two new exhibits, “Atmosphere: Change in the Air” and “Arctic: A Friend Acting Strangely,” opening April 15 at the Smithsonian National Museum of Natural History in Washington. The exhibits, part of the museum’s “Forces of Change” series, feature scientific data from NASA and other agencies on the Earth’s changing climate.

Scientists from NASA’s Goddard Space Flight Center in Greenbelt, Md., contributed movies, interactive computer data, and stunning satellite images to launch the two exhibits.

“Atmosphere: Change in the Air” focuses on the Earth’s atmospheric composition and chemistry. The latest results from NASA’s Aura satellite, the third in series of large Earth-observing satellites, are featured.

Ernest Hilsenrath, atmospheric scientist at NASA Headquarters, Washington, said, “The ‘Atmosphere’ exhibit highlights the research NASA is conducting to better understand the connection between atmospheric composition and climate change. We hope this exhibit will enhance the public’s awareness of how unique our atmosphere is and the impact humans can have on our global environment.”

Visitors can learn about these changes through several movies. The first movie takes the viewer from space through the solar system, highlighting the atmospheres of each planet. It ends on Earth in Washington, D.C. with a zoom in to the National Mall. The second movie is a lighthearted description of oxygen’s tendency to oxidize, or react with other molecules, which is how fires, rust and the ozone in air pollution are generated. Ground-level ozone also acts as an oxidizer and is harmful to human and ecosystem health. A third movie takes the viewer on a journey over 20 years to see how the ozone hole over Antarctica has changed.

The exhibit features an interactive computer, where visitors learn how changes in oxygen, carbon dioxide and ozone amounts can affect the Earth. Visitors see how carbon dioxide and ground-level ozone are associated with fossil fuel combustion and affect the air we breathe. Ozone near the Earth is a pollutant and a component of smog. Ozone high in the atmosphere protects life on Earth from the sun’s harmful ultraviolet radiation. Amounts of this ozone have been in decline due to the release of ozone-destroying chemicals.

Satellite images from NASA’s Aura satellite show visitors how pollution travels around the world. The images show how great dust storms crossing the Atlantic and Pacific oceans can affect air quality far from their sources. The exhibit also includes specimens from the museum’s paleobiology and meteorite collections.

NASA and the National Oceanic and Atmospheric Administration (NOAA) both contributed information to “Arctic: A Friend Acting Strangely,” the second exhibit in the “Forces of Change” gallery. This exhibit shows how a changing climate has affected Arctic temperatures, sea ice and area life.

Much of the data and material for the images were provided by scientists at NASA and those in academia whose research is supported by NASA. “Satellite capabilities provide an important perspective for understanding how the Arctic is changing,” said Dr. Waleed Abdalati, head of the Cryospheric Sciences Branch at Goddard, who reviewed materials for the exhibit. “By providing new views of the entire Arctic against the backdrop of the larger Earth system, we provide a new appreciation and context for how this cold and remote region fits into the global picture.”

NOAA offered support for the exhibit and worked closely with the Smithsonian Institution to frame the content and develop specific topics and materials. The exhibit also explores how changes in the Arctic are monitored by scientists and polar residents. Visitors will see the challenges scientists face while working in extreme conditions and some of the technology that helps gather critical data to monitor changing conditions.

Visitors will also see objects from the Smithsonian's anthropology collections, photographs, scientific data such as the Arctic temperature record from 1900 to the present day, and a 2-3 minute video, "Eyewitness to Change." The video takes visitors to the Inuit community of Sachs Harbour in the Canadian Arctic. Residents discuss climate changes and how they have affected their lives. The exhibit is also funded in part by the National Science Foundation.

For more information about this exhibition the Web, visit:

http://www.mnh.si.edu/

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

May 24, 2006

Erica Hupp/Grey Hautaluoma

Headquarters, Washington

Phone: (202) 358-1237/0668

Edward Campion

Goddard Space Flight Center, Greenbelt, Md.

Phone: (301) 286-0697

RELEASE: 06-231

NEW SPACE OBSERVATIONS POISED TO SAVE LIVES FROM FLOODS, LANDSLIDES

Using NASA's advanced Earth-observing satellites, scientists have discovered a new opportunity to build early detection systems that might protect thousands from floods and landslides.

This potential breakthrough in disaster monitoring and warning links satellite observations of soil type, vegetation and land slope with observations of rainfall, rivers and topography.

"Flood and landslides are the most widespread natural hazards on Earth, responsible for thousands of deaths and billions of dollars in property damage every year," said Bob Adler, project scientist for the Tropical Rainfall Measuring Mission at NASA's Goddard Space Flight Center, Greenbelt, Md., and lead scientist of one of four projects that share a similar focus. "Between 1985 and 2000 over 300,000 people lost their lives to flooding and their associated landslides. Currently, no system exists at either a regional or a global scale to monitor rainfall conditions that may trigger these disasters."

"Our use of space as a vantage point to better understand floods and landslides will enable agencies and other public officials charged with doing so to actually apply what we're learning in ways that will make a tangible difference in a lot of lives all over the world," said Yang Hong, a research scientist at Goddard and lead scientist of one of the research projects. The research used data from several NASA satellites -- the Tropical Rainfall Measuring Mission, Aqua, the Shuttle Radar Topography Mission, QuikSCAT and Earth Observing-1 -- and NOAA's Geostationary Operational Environmental satellites.

The havoc of landslides and floods is felt most acutely in parts of the world without extensive flood and rainfall monitoring ground networks.

Scientists approached the study of how satellite remote sensing can be applied to create flood and landslide detection from several angles. Space-based remote sensing allows scientists to look at the whole earth from above, improving their understanding of how Earth's system components behave and interact with each other.

Robert Brakenridge and his colleagues at Dartmouth College, Hanover, N.H., are using satellite microwave sensors to estimate water discharge from rivers by measuring almost daily changes in river widths.

"This month much of New England suffered from its worst flooding since 1936, causing governors in several states to declare states of emergency," said Brakenridge. "Satellite observations can be absolutely essential in lessening the severity on the local economies and possible injuries in such future occurrences if they can be galvanized to create more reliable warning systems."

Kwabena Asante, a senior scientist at U.S. Geological Survey in Sioux Falls, S.D., led research that puts forward an innovative method of mapping floods around the globe using a combination of data from NASA's Tropical Rainfall Measuring Mission and the Shuttle Radar Topography Mission. This new development could offer a practical solution to the significant challenge of creating cost-effective early warning systems particularly needed in data scarce, rural areas.

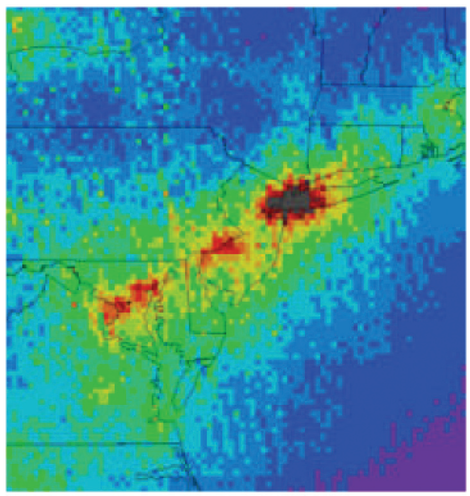
Researchers are presenting findings today during the American Geophysical Union meeting in Baltimore, Md. For information, images, and research abstracts from today's news briefing, visit:http://www.nasa.gov/vision/earth/lookingatearth/springagu_2006.html

National Aeronautics
and Space Administration

Washington Getting a Summertime Air Quality Exam 0 8.03.06

Summer in the city can often mean sweltering 'bad air days' that threaten the health of the elderly, children and those with respiratory problems. This summer the nation's capitol has been no stranger to such severe air-quality alerts.

Image below: NASA's Aura satellite can see several different forms of air pollution worldwide. This image shows high levels of nitrogen dioxide on the U.S. East Coast in 2005. Credit: NASA



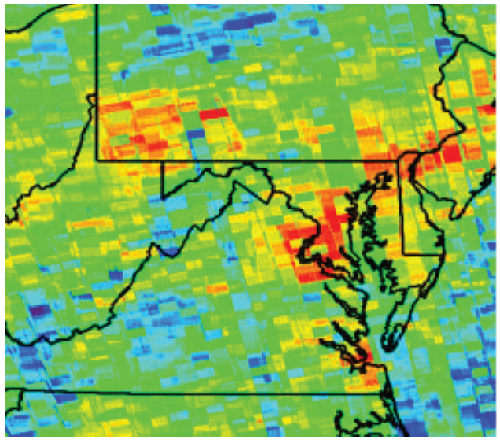
But since early July Washington area skies have been put under a unique microscope as scientists from NASA and around the country assembled a powerful array of scientific instruments -- in space and on the ground -- to dissect the region's atmosphere. The result will be not only a better understanding of intense urban air pollution episodes but also a better toolkit to track and probe air pollution worldwide from space.

Two years ago NASA launched the third of its major Earth Observing System satellites --Aura -- carrying a group of instruments designed to take global measurements of air pollution on a daily basis. Aura sensors can detect five of the six air pollutants regulated by the U.S. Environmental Protection Agency. But to make these 400-mile-high readings as accurate as possible, data from the sophisticated Aura instruments need to be compared to data from tried-and-true sensors on Earth.

NASA is sponsoring just such a 'ground-truth' experiment this summer. Howard University Research Campus, Beltsville, Md., is hosting visiting scientists, graduate students and instruments for a six-week-long series of intensive observations. The experiment is also evaluating the next generation of instruments used in daily weather forecasting, as well as tracking one of the strongest greenhouse gases involved in climate change: water vapor, which at increased levels we feel as humidity.

The Beltsville research facility grew out of collaborations between NASA, the National Oceanic and Atmospheric Administration (NOAA), and Howard University in Washington.

Image below: NASA's Aura spacecraft captured high summertime levels of the air pollutant nitrogen dioxide in the Washington metropolitan area last month. This image combines several Aura views from July 13-20. Nitrogen dioxide plays a key role in the formation of ground-level ozone pollution. Credit: NASA



The site is dotted with instruments from the National Weather Service, the Maryland Department of the Environment, and a local television station. For this summer's experiment, additional sensors have been brought in from NASA's Goddard Space Flight Center, Greenbelt, Md.; NASA's Wallops Flight Facility, Wallops Island, Va.; Pennsylvania State University, University Park; University of Colorado, Boulder; and Trinity University, Washington. Students from many of these institutions, as well as the University of Wisconsin, Madison, and Smith College, Northampton, Mass., are involved in the day-to-day operations.

'With a large collaboration like this you can really investigate a lot of interesting aspects of air quality,' says David Whiteman, who is leading Goddard's research team from the nearby NASA center. 'You can look straight down through the atmosphere to the ground from the satellite and at the same time you see in great detail the whole chemical soup of pollutants near the surface from the state's air quality monitoring site located here. Multi-instrument observations like this make the Howard site a real gem.'

The experiment is also focusing on a key measurement for both global climate change and local weather forecasting: water vapor. 'Measuring water vapor is a tricky business, because it varies greatly in quantity around the globe,' says Whiteman. But if our Earth is indeed warming, we need to understand how water vapor responds to that. Water vapor is a stronger greenhouse gas than carbon dioxide and could have a major impact on future climate.'

Water vapor measurements from NASA's Aura satellite and its companion Aqua, launched in 2002, are being compared with readings at the site from several laser-based instruments called lidars that can continuously observe water vapor levels in great detail directly overhead. In addition, balloon-borne instruments called radiosondes, a standard instrument used daily around the world, are being flown to compare their accuracy with the more sophisticated research tools.

'The moisture information we get every day from radiosondes is becoming more important in numerical weather prediction and climate monitoring,' says Joe Facundo, chief of the National Weather Service's Observing Systems Branch, who is participating in the Beltsville experiment. 'This type of instrument comparison project lets us test improved moisture sensors. 'Better water vapor data from radiosondes flown around the world can lead to more accurate weather forecasts and long-term climate predictions.

New knowledge is also emerging from the experiment about the daily rise and fall of ozone pollution, which involves a complex interplay between the 'chemical soup' of pollutants, sunlight, and meteorology. 'We have already observed examples of the influence of a narrow stream of strong winds during the night on surface-level ozone formation,' says Howard's Everette Joseph, who leads the university's team of scientists and students. "Better understanding of this process could lead to better air quality forecast methods and aid local governments in developing strategies to combat ozone pollution."

Stephen Cole

Goddard Space Flight Center

Find this article at: http://www.nasa.gov/centers/goddard/news/topstory/2006/washington_air.html

July 13, 2006

Erica Hupp/Grey Hautaluoma
Headquarters, Washington
202-358-1237/0668

Rob Gutro/Steve Cole
Goddard Space Flight Center, Greenbelt, Md.
301-286-4044/3026

RELEASE: 06-278

NASA EXPLAINS PUZZLING IMPACT OF POLLUTED SKIES ON CLIMATE

NASA scientists have determined the formation of clouds is affected by the lightness or darkness of air pollution particles. This also impacts Earth's climate.

In a breakthrough study published Thursday in the online edition of Science, scientists explain why aerosols -- tiny particles suspended in air pollution and smoke -- sometimes stop clouds from forming and in other cases increase cloud cover. Clouds deliver water around the globe, and they also help regulate how much of the sun's warmth the planet holds. The capacity of air pollution to absorb energy from the sun is the key.

"When the overall mixture of aerosol particles in pollution absorbs more sunlight, it is more effective at preventing clouds from forming. When pollutant aerosols are lighter in color and absorb less energy, they have the opposite effect and actually help clouds to form," said Lorraine Remer of NASA's Goddard Space Flight Center, Greenbelt, Md. Remer worked closely with the study's lead author, the late Yoram Kaufman of Goddard, on previous research into this perplexing "aerosol effect."

With this new understanding, scientists working to predict how the Earth's climate is changing will be able to take a big step forward. The effect of the planet's constantly changing cloud cover has long been a problem for climate scientists. How clouds change in response to greenhouse-gas warming and air pollution will have a major impact on future climate.

Using this new understanding of how aerosol pollution influences cloud cover, Kaufman and co-author Ilan Koren of the Weizmann Institute in Rehovot, Israel, estimate the impact world-wide could be as much as a 5 percent net increase in cloud cover. In polluted areas, these cloud changes can change the availability of fresh water and regional temperatures.

In previous research by the authors and their colleagues, both effects that aerosols have on clouds were seen with data from NASA satellites. Over the northern Atlantic Ocean, clouds that often produce heavy rain storms grew taller and were more frequent when plumes of pollution from North America or dust from Africa's Sahara Desert were present. However, when smoke from large fires billowed into the sky over South America's Amazon River basin, clouds were consistently fewer than when the air was relatively clear.

With these observations alone, the scientists could not be absolutely sure the aerosols themselves were causing the clouds to change. Other local weather factors such as shifting winds and the amount of moisture in the air could have been responsible, meaning the pollution was just along for the ride.

"Separating the real effects of the aerosols from the coincidental effect of the meteorology was a hard problem to solve," Koren said. In addition, the impact of aerosols is difficult to observe, compared to greenhouse gases like carbon dioxide, because aerosols only stay airborne for about one week, while greenhouse gases can linger for decades.

To tackle this problem, Kaufman and Koren assembled a massive database of global observations that strongly suggests it is the darkness (absorbs sunlight) or brightness (reflects sunlight) of aerosol pollution and not weather factors that cause pollution to act as a cloud killer or a cloud maker. These measurements were culled from the NASA-sponsored Aerosol Robotic Network of ground-based instruments at nearly 200 sites worldwide.

The scientists conducted an extensive survey of sky conditions at 17 locations (including Washington, Rome, Beijing, and Mexico City) that represented different types of air pollution and weather patterns. Automated instruments that act like a camera's light meter to record how much sunlight was coming from the sky took readings several times an hour at different times of the year.

No matter where in the world the measurements were taken or in what season, Kaufman and Koren saw the same pattern. There were lots of clouds when light-reflecting pollution filled the air, but many fewer clouds were recorded in the presence of light-absorbing aerosols. "The probability that such a consistent relationship between aerosols and their effects on clouds is due to some other factor is very unlikely," Koren said.

NASA's satellites, computer models, and technology will continue to advance our understanding of how aerosol pollution affects the Earth's climate. NASA's formation of flying satellites, with the cloud-piercing instruments onboard the Cloudsat and CALIPSO spacecraft, are helping answer challenging questions such as the role of clouds in global warming and the influence of aerosols on rainfall and hurricanes.

For more information, visit: http://www.nasa.gov/vision/earth/environment/pollution_clouds.html

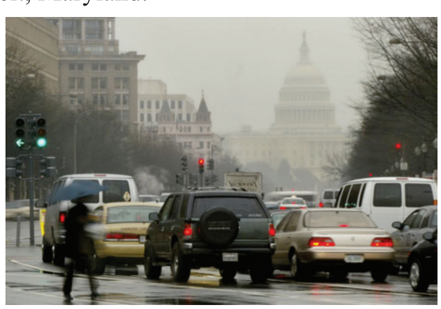
Rainy Days Driven by Traffic Patterns, Study Says

Richard A. Lovett

for National Geographic News

July 13, 2006

Think it rains only on the weekend? Not if you live in the Southeast United States. Summer rainfall in this region of the country appears to mimic the highs and lows of air pollution from weekday commuters, says Thomas Bell of the NASA Goddard Space Flight Center in Greenbelt, Maryland.



At the May meeting of the American Geophysical Union in Baltimore, Maryland, Bell reported that afternoon thundershowers are more frequent and more intense on weekdays than on weekends. Bell limited his study to summer thunderstorms, which, in theory, are most likely affected by changes in air pollution. Meteorologists believe smog contains tiny particles that spur the formation of water droplets, which eventually become raindrops. More smog, therefore, not only means more droplets, but also tinier ones—at least in the initial stages of storm formation. These smaller droplets are carried higher into the air before falling as rain, which ultimately increases storm intensity.

Wednesday Thunderstorms

Scientists have long speculated that pollution from weekday commuters might affect the storm cycle. But previous studies failed to detect a link. Bell says that past studies tended to focus on individual cities, particularly those in coastal areas where other factors may also influence storms. Seeking to examine the issue more broadly, Bell analyzed rainfall patterns from nine years of satellite data from the Southeast quadrant of the U.S. The region extends as far north as central Illinois and as far west as mid-Texas. The scientist found that during June, July, and August afternoon thunderstorms were most common on Wednesdays and least common on weekends. The showers exactly mirrored pollution intensity from vehicle traffic. According to the satellite data, midweek afternoon rainfall was nearly double weekend precipitation. Weekday storms were also more likely to be intense downpours.

Driving Patterns

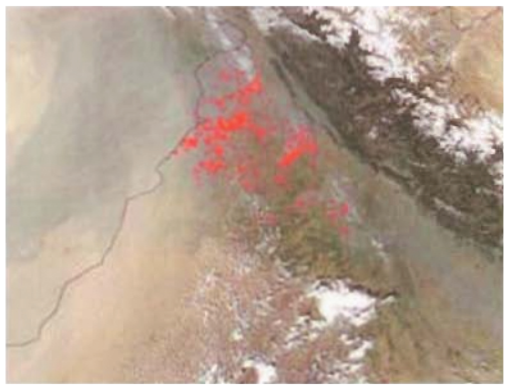
Bell and his colleagues say that atmospheric wind-speed data also indicate that stronger and more frequent storms occur on weekdays. Local weather station rainfall measurements backed the team's findings. Bell believes weekday commuter car traffic is unlikely to be the sole cause of the summer weather pattern. While people change their driving pattern on weekends, they still drive, he says. Monitoring by the U.S. Environmental Protection Agency has found that air pollution levels follow weekly cycles marked by mid-week peaks. But there appears to be only a 10 to 15 percent dip in pollution on weekends. Bell doesn't believe commuter car traffic alone is enough to explain the rain effect found by his study. "Truck traffic drops off a lot on weekends," the researcher said. "So it might be something related to pollution from truck traffic. But that's a pure guess."

National Aeronautics
and Space Administration

Hot Dust and Moisture Collide to Fuel Asian Summer Rainy Season 09.07.06

Who would think that something like dust in the air could trigger rain? According to a new NASA study, this is just what's happening over South Asia's Tibetan Plateau. Very small dust particles called aerosols blow in from desert regions and collect in the atmosphere over the plateau's slopes early in the region's monsoon season, helping trigger rainfall.

Image below: Dust and smoke from fires (red points) over northwestern India/Pakistan may contribute to a change in rainfall patterns over the region. Credit: NASA



A monsoon is a seasonal shift in wind direction that alternately brings very wet and then very dry seasons to India and much of Southeast Asia.

William Lau, research scientist at NASA's Goddard Space Flight Center, Greenbelt, Md. and his team studied the aerosols using computer models. They found aerosols in the form of dust lofted from the desert surface and transported to the monsoon region can heat the air by absorbing the sun's radiation, altering the Asian monsoon water cycle. Black carbon particles from industrial emissions, bio-fuel burning and forest fires can add to this warming effect by absorbing the sun's radiation and heating the air currents transporting those aerosols. In some instances, black carbon coats the dust amplifying the heating effect because black carbon absorbs solar radiation more efficiently than dust. Rains from this annual weather cycle are a lifeline to over 60 percent of the world's population. Up to now, scientists have understood very little about how aerosols interact with the atmosphere to influence monsoons. Lau's computer simulations indicate both of these light-absorbing and heat emitting aerosols, when mixed together with warm air currents and moisture, cause a heating effect in the air, triggering the rainy season earlier than usual and lengthening the wet monsoon season in Asia. The study was published the May 2006 issue of Climate Dynamics.

Image below: Space Shuttle view of haze and pollution over Northern India swept in from Tibet. Credit: NASA

"Traditionally, aerosols have been seen as only a local environmental problem. Until very recently, aerosols have not been viewed as an intervening presence in the atmosphere that could affect monsoon rains," said Lau. "This study is the first to link dust aerosols to monsoon rainfall changes and to claim a specific physical mechanism in the atmosphere, whereby the tiny dust particles interact with the monsoon heat and moisture."

The mechanism operates like an "elevated heat pump," according to Lau.

Increased dust aerosols blowing in from western China, Afghanistan, Pakistan and the Middle East coupled with black carbon emissions from northern India accumulate in the pre-monsoon late spring in the atmosphere over the northern and southern slopes of the Tibetan Plateau. When the dust absorbs the sun's radiation, it heats the surface air hovering above the mountainous slopes of the region. The heated air rises and draws warm, moist air in to northern India from the Indian Ocean, which helps create more rainfall. As the air warms and moves upward, new air is drawn in to take its place, which is also warmed - creating a process like a pump that pulls heated air upwards.

The "heat pump" effect actually starts the wet monsoon season prematurely in northern India, leading to a longer rainy season.

The rising motion associated with the "elevated heat pump" effect far above the ground will shift the monsoon's path toward the foothills of the Himalayas, meaning that more rain will fall earlier in the season (in May) in northern India as a result, and less over the Indian Ocean to the south. The intensified heat and rain may cause increased mountain glacier melt, leading to more erosion in Nepal and near the Ganges River.

"An improved understanding of the effects of aerosols on the monsoon seasonal cycle benefits both science and society," said Lau. "Understanding the relationship between aerosols and the cycle of rainfall has a potential impact on water resources all over the globe."

Lau and colleagues from Kongju National University in Gongju, Korea, and Science Systems and Applications, Inc. of Lanham, Md., included the occurrence of these light-absorbing and heat-emitting dust and black carbon aerosols in their computer simulation with wind, moisture, and rainfall to see how they would interact. "We've looked at the evolution of monsoons over a 10-year period. We're definitely seeing something new through this model," commented Lau.

According to Lau, most studies of monsoons are done first by way of observations. In this case, because of the lack of long-term aerosol information and the complicated nature of the monsoon climate system, the researchers concentrated on computer modeling first. They now plan to confirm their findings with observations from satellites and from NASA's Aerosol Robotic Network, more commonly known as AERONET, a global network of ground-level aerosol sensors. AERONET instruments will be deployed in Nepal for this research.

Lau's research team is currently examining the aerosol effect on rainfall over South America and West Africa, where they are also finding that the "elevated heat pump" mechanism seems to be at work.

Gretchen Cook-Anderson, NASA Goddard Space Flight Center

Find this article at: http://www. nasa.gov/centers/goddard/centers/topstory/2006/asian_rain.html

Oct. 19, 2006

Erica Hupp/Dwayne Brown
Headquarters, Washington
202-358-1237/1726

Anatta
NOAA, Earth System Research Laboratory, Boulder, Colo.
303-497-6288

RELEASE: 06-338

NASA AND NOAA ANNOUNCE ANTARCTIC OZONE HOLE IS A RECORD BREAKER

NASA and National Oceanic and Atmospheric Administration (NOAA) scientists report this year's ozone hole in the polar region of the Southern Hemisphere has broken records for area and depth.

The ozone layer acts to protect life on Earth by blocking harmful ultraviolet rays from the sun. The "ozone hole" is a severe depletion of the ozone layer high above Antarctica. It is primarily caused by human-produced compounds that release chlorine and bromine gases in the stratosphere.

"From September 21 to 30, the average area of the ozone hole was the largest ever observed, at 10.6 million square miles," said Paul Newman, atmospheric scientist at NASA's Goddard Space Flight Center, Greenbelt, Md. If the stratospheric weather conditions had been normal, the ozone hole would be expected to reach a size of about 8.9 to 9.3 million square miles, about the surface area of North America.

The Ozone Monitoring Instrument on NASA's Aura satellite measures the total amount of ozone from the ground to the upper atmosphere over the entire Antarctic continent. This instrument observed a low value of 85 Dobson Units (DU) on Oct. 8, in a region over the East Antarctic ice sheet. Dobson Units are a measure of ozone amounts above a fixed point in the atmosphere. The Ozone Monitoring Instrument was developed by the Netherlands' Agency for Aerospace Programs, Delft, The Netherlands, and the Finnish Meteorological Institute, Helsinki, Finland.

Scientists from NOAA's Earth System Research Laboratory in Boulder, Colo., use balloon-borne instruments to measure ozone directly over the South Pole. By Oct. 9, the total column ozone had plunged to 93 DU from approximately 300 DU in mid-July. More importantly, nearly all of the ozone in the layer between eight and 13 miles above the Earth's surface had been destroyed. In this critical layer, the instrument measured a record low of only 1.2 DU., having rapidly plunged from an average non-hole reading of 125 DU in July and August.

"These numbers mean the ozone is virtually gone in this layer of the atmosphere," said David Hofmann, director of the Global Monitoring Division at the NOAA Earth System Research Laboratory. "The depleted layer has an unusual vertical extent this year, so it appears that the 2006 ozone hole will go down as a record-setter."

Observations by Aura's Microwave Limb Sounder show extremely high levels of ozone destroying chlorine chemicals in the lower stratosphere (approximately 12.4 miles high). These high chlorine values covered the entire Antarctic region in mid to late September. The high chlorine levels were accompanied by extremely low values of ozone.

The temperature of the Antarctic stratosphere causes the severity of the ozone hole to vary from year to year. Colder than average temperatures result in larger and deeper ozone holes, while warmer temperatures lead to smaller ones. The NOAA National Centers for Environmental Prediction (NCEP) provided analyses of satellite and balloon stratospheric temperature observations. The temperature readings from NOAA satellites and balloons during late-September 2006 showed the lower stratosphere at the rim of Antarctica was approximately nine degrees Fahrenheit colder than average, increasing the size of this year's ozone hole by 1.2 to 1.5 million square miles.

The Antarctic stratosphere warms by the return of sunlight at the end of the polar winter and by large-scale weather systems (planetary-scale waves) that form in the troposphere and move upward into the stratosphere. During the 2006 Antarctic winter and spring, these planetary-scale wave systems were relatively weak, causing the stratosphere to be colder than average.

As a result of the Montreal Protocol and its amendments, the concentrations of ozone-depleting substances in the lower atmosphere (troposphere) peaked around 1995 and are decreasing in both the troposphere and stratosphere. It is estimated these gases reached peak levels in the Antarctica stratosphere in 2001. However, these ozone-depleting substances typically have very long lifetimes in the atmosphere (more than 40 years).

As a result of this slow decline, the ozone hole is estimated to annually very slowly decrease in area by about 0.1 to 0.2 percent for the next five to 10 years. This slow decrease is masked by large year-to-year variations caused by Antarctic stratosphere weather fluctuations.

The recently completed 2006 World Meteorological Organization/United Nations Environment Programme Scientific Assessment of Ozone Depletion concluded the ozone hole recovery would be masked by annual variability for the near future and the ozone hole would fully recover in approximately 2065.

“We now have the largest ozone hole on record,” said Craig Long of NCEP. As the sun rises higher in the sky during October and November, this unusually large and persistent area may allow much more ultraviolet light than usual to reach Earth’s surface in the southern latitudes.

National Aeronautics
and Space Administration

Airborne Dust Causes Ripple Effect on Climate Far Away 01.25.07

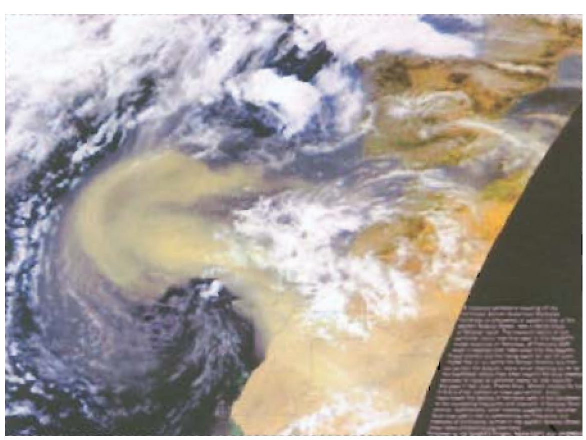
When a small pebble drops into a serene pool of water, it causes a ripple in the water in every direction, even disturbing distant still waters. NASA researchers have found a similar process at work in the atmosphere: tiny particles in the air called aerosols can cause a rippling effect on the climate thousands of miles away from their source region.

Image below: Dust from Africa's Saharan Desert lingers in high altitudes as it crosses the Atlantic Ocean. This picture was taken from an aircraft northeast of Barbados in 2006. Cumulus clouds can be seen poking through the tops of the dust layer, which is seen as a milky white haze. Credit: NOAA

The researchers found that dust particles from the desert regions in northern Africa can produce climate changes as far away as the northern Pacific Ocean. Large quantities of dust from North Africa are injected into the atmosphere by dust storms and rising air. Airborne dust absorbs sunlight and heats the atmosphere. The heating effect ripples through the atmosphere, affecting surface and air temperatures as the dust travels.

"These highs and lows in air temperatures caused by radiation-absorbing aerosols can lead to 'teleconnection', which refers to changes in weather and climate in one place caused by events happening far away, often more than half way around the globe," said William Lau, Chief of the Laboratory for Atmospheres at NASA's Goddard Space Flight Center, Greenbelt, Md., and author of a study published last fall in the American Meteorological Society's Journal of Climate. "North African dust can be lifted high into the atmosphere by storms and then transported across the Atlantic and Caribbean, where its effect can be far-reaching." From a climate point of view, aerosols can block solar radiation (incoming heat and light from the sun) from hitting the Earth's land surface. When sunlight is blocked, it can cause the Earth's surface to cool, and/or the aerosols can absorb solar radiation and cause the atmosphere in the vicinity of the airborne dust to get warmer.

Image below: A massive sandstorm blowing off the northwest African desert blanketed hundreds of thousands of square miles of the eastern Atlantic Ocean with Saharan Sand. It was seen from the SeaWiFS satellite on Feb. 26, 2000, as it reached 1,000 miles into the Atlantic Ocean. Credit: NASA GSFC and ORBIMAGE



According to Lau, researchers thought for years that heat changes in the atmosphere from aerosols only caused local changes in temperatures. However, “we now know they may cause more than local changes to climate,” he said. Lau’s computer model indicates that the heat changes caused by aerosols affect the heat balance in the air over North Africa. That change in heat creates large waves in the atmosphere that ripple as far away as Eurasia and the North Pacific.

Researchers have created complex numerical models to simulate the “still waters” of the atmosphere during North African spring – a season when climate conditions are relatively calm with light winds and light rain.

Lau’s team carried out a numerical model experiment that included aerosol forcing, and then another one with identical initial conditions and lower boundary conditions, except that the :aerosol forcing is removed. By comparing the weather patterns in the two experiments, they can deduce the effect of aerosol forcing. They observed the aerosols made an impact far away from their source region. In setting up their experiment, the researchers chose the northern Sahara Desert in springtime, when the weather conditions are relatively calm, allowing aerosols, like dust, to build up more in air.

An “atmospheric teleconnection” happens when unusual patterns of air pressure and air circulation happen in one place, and the energy is dispersed over large distances around the globe to other places. An atmospheric teleconnection can lead to changes in sea level pressure and temperature around the world. This study saw changes from North Africa through Eurasia to the North Pacific.

Most interesting, Lau’s team found that North African-dust teleconnection led to strong cooling over the Caspian Sea (a land-locked body of water between Russia and Europe) and warming over central and northeastern Asia, where man-made aerosol concentrations are low.

“Elevated aerosols in large quantities such as dust from North Africa, or biomass burning may have global impacts,” said Lau. “We expect to observe more and more real-world examples of this teleconnection phenomenon with the high volume of aerosols generated by nature and human activities around the world.”

Gretchen Cook Anderson

Goddard Space Flight Center

Find this article at:

http://www.nasa.gov/centers/gaidardinewsitopstory/2006/partide_ripple.html

APPENDIX A2. REFEREED ARTICLES

Asterisks indicate articles highlighted in Appendix 3.

Laboratory members' names are in boldface

613 Senior Staff and Senior Scientists

Bakalian, F. and **R. E. Hartle**, 2006: Monte Carlo Computations of the Escape of Atomic Nitrogen from Mars, *Icarus*, **183**, 55–68, 2006.

Chahine, M., T. Pagano, H. Aumann, R. Atlas, C. Barnet, **J. Blaisdell**, L. Chen, M. Divakarla, E. Fetzer, M. Goldberg, C. Gautier, S. Granger, S. Hannon, F. Irion, R. Kakar, E. Kalnay, B. Lambrigtsen, S-Y. Lee, J. LeMarshall, W. McMillan, L. McMillin, E. Olsen, H. Revercomb, P. Rosenkranz, W. Smith, D. Staelin, L. Strow, **J. Susskind**, D. Tobin, W. Wolf, and L. Zhou, 2006: AIRS Improving Weather Forecasting and Providing New Data on Greenhouse Gases, *Bull. Amer. Meteor. Soc.*, **87**, 911–926, 2006.

Hartle, R. E., E. C. Sittler Jr., F. M. Neubauer, R. E. Johnson, H. T. Smith, F. Crary, D. J. McComas, D. T. Young, A. J. Coates, D. Simpson, S. Bolton, D. Reisenfeld, K. Szego, J. J. Berthelier, A. Rymer, J. Vilppola, J. T. Steinberg, N. Andre, Preliminary Interpretation of Titan Plasma Interaction as Observed by the Cassini Plasma Spectrometer: Comparisons with Voyager 1, 2006: *Geophys. Res. Lett.,* **33**, L08201, doi:10.1029/2005GL024817.

Hartle, R. E., and R. Killen, Measuring Pickup Ions to Characterize the Surfaces and Exospheres of Planetary Bodies: Applications to the Moon, 2006: *Geophys. Res. Lett.,* **33**, L05201, doi:10.1029/2005GL02452.

Hartle, R. E., E. C. Sittler Jr., F. M. Neubauer, R. E. Johnson, H. T. Smith, F. Crary, D. J. McComas, D. T. Young, A. J. Coates, D. Simpson, S. Bolton, D. Reisenfeld, K. Szego, J. J. Berthelier, A. Rymer, J. Vilppola, J. T. Steinberg, N. Andre, 2006: Initial Interpretation of Titan Plasma Interaction as Observed by the Cassini Plasma Spectrometer: Comparisons with Voyager 1, *Planet. Space Sci.,* **54**, 1211–1224.

*Kim, M. K., **K. -M. Lau, M. Chin, K. -M. Kim**, **Y. C. Sud**, and **G. Walker**, 2006: Atmospheric teleconnection over Eurasia induced by aerosol radiative forcing during boreal spring, *J. Climate*, **19,** 4700–4718.

Lau, K.-M., and **K.-M. Kim**, 2006: Observational relationship between aerosol and Asian monsoon circulation rainfall. *Geophys. Res. Lett.*, **33**, L21810, doi:10.1029/2006GL027546.

***Lau, K.-M.**, M.-K. Kim, and **K.-M. Kim**, 2006: Asian summer monsoon anomalies induced by aerosol direct forcing - the role of the Tibetan Plateau. *Climate Dyn.* **36**(7–8), 855-864, doi: 10.1007/s00382-006-10114-z.

Lau, K.-M., S. S. P. Shen, **K.-M. Kim**, and H. Wang, 2006: A multimodel study of the twentieth century simulations of Sahel drought from the 1970s to 1990s. *J. Geophys. Res.*, **111**, D07111, doi: 10.1029/2005JDO006281.

Sittler, E. C. Jr., M. Thomsen, R. E. Johnson, **R. E. Hartle**, M. Burger, D. Chornay, M. D., Shappirio, D. Simpson, H. T. Smith, A. J. Coates, A. M. Rymer, D. J. McComas, D. T. Young, D. Reisenfeld, M. Dougherty, and N. Andre, 2006: Cassini Observations of Saturn's Inner Plasmasphere: Saturn Orbit Insertion Results, *Planet. Space Sci.,* **54,** 1197–1210.

Susskind, J., C. Barnet, **J. Blaisdell**, **L. Iredell**, **F. Keita**, **L. Kouvaris**, **G. Molnar**, and M. Chahine, Accuracy of Geophysical Parameters Derived from Atmospheric Infrared Sounder/Advanced Microwave Sounding Unit as a Function of Fractional Cloud Cover, 2006: *J. Geophys. Res.*, **111**, D09S17, doi:10.1029/2005JD006272, 2006.

Susskind, J., 2006: Introduction to AIRS and CrIS. Chapter in book, Earth Science Satellite Remote Sensing, Science and Instruments, Vol. 1, Editors: J. Qu, W. Gao, M. Kafatos, R. Murphy, V. Salomonson. Tsinghua University Press, Beijing and Springer-Verlag GmbH Berlin Heidelberg, 254–278.

613.1 Mesoscale Atmospheric Processes Branch

Aberson, S., and **J. Halverson**, 2006: Kelvin-Helmholtz billows in the eyewall of Hurricane Erin, *Mon. Wea. Rev.*, 134, 1036–1038.

Amitai, E., X. Lort, and D. Sempere-Torres, 2006: Opportunities and challenges for evluating precipitation estimates during GPM mission, *Meteor.Z.*, **15 (5)** (DOI: 10.1127/0941-2948/2006/0157), 551-557.

Amitai, E., **B. Fisher**, **D. Silberstein**, **D. Wolff**, and **D. Marks**, 2006: Evaluation of radar rainfall products Part I: Lessons learned from NASA TRMM validation program in Florida, *J. Atmos. Oceanic Technol.*, **23**, 1492–1505.

Anagnostou, E., and **M. Grecu**, 2006: X-band polarimetric radar rainfall measurements in Keys Area Microphysics Project, *J. Atmos. Sci.*, **68**, 187–203.

Braun, S., M. Montgomery, and Z. Pu, 2006: High-resolution simulation of Hurricane Bonnie (1998). Part I: The Organization of Eyewall Vertical Motion, *J. Atmos. Sci.*, **63**, 19–42.

Braun, S., 2006: High-resolution simulation of Hurricane Bonnie (1998). Part II: Water Budget, *J. Atmos. Sci.*, **63**, 43–64.

Curtis, S., **R. F. Adler**, **G. J. Huffman**, **G. Gu**, **D. T. Bolvin**, and **E. J. Nelkin**, 2006: Comments on "El Niño: Catastrophe or Opportunity", *J. Climate*, **19**(24), 6439–6442.

*__Demoz, B.__, C. Flamant, T. Weckwerth, **D. Whiteman**, K. Evans, F. Fabry, P. Di Girolamo, D. Miller, B. Geerts, W. Brown, G. Schwemmer, **B. Gentry**, W. Feltz, and Z. Wang, 2006: The Dryline on 22 May 2002 during IHOP_2002: Convective-Scale Measurements at the Profiling site, *Mon. Wea. Rev.,* **134**(1), 294–310.

Dessler, A., **J. Spinhirne**, **S. Palm**, and **W. Hart**, 2006: Tropical cloud-top height distributions revealed by ICESat/GLAS, *J. Geophys. Res.*, 111(D12215), doi: 10.1029/2005JD006705.

Dessler, A. , **J. Spinhirne**, **S. Palm**, and **W. Hart**, 2006: Tropopause-level thin cirrus coverage revealed by ICESat/GLAS, *J. Geophys. Res.*, 111(D08203), doi:10.1029/2005JD006586.

Fiorino, S.T., **and E.A. Smith**, 2006: Critical assessment of microphysical assumptions within TRMM-radiometer rain profile algorithm using satellite, aircraft and surface data sets from KWAJEX, *J. Appl. Meteor.*, **45**, 754–786.

Gao, S., **X. Li, W.-K. Tao**, and **C.-L. Shie**, 2006: Convective moist vorticity vectors associated with tropical oceanic convection: A three-dimensional cloud-resolving model simulation, *Geophys. Res. Lett.*, **112**, DOI: 10.1029/2006JD007179.

Grabowski, W., A. Cheng, G. Halliwell, J. Petch, K. Xu, M. Khairoutdinov, R. Forbes, R. Wong, **S. Lang**, T. Nasuno, **W.-K. Tao**, X. Wu, and P. Bechtold, 2006: Daytime convective developments over land: An idealized model intercomparison case based on LBA observations, *Quart. J. Roy. Meteor. Soc.*, **132**, 317–344.

***Grecu, M.**, and **W. S. Olson**, 2006: Bayesian estimation of precipitation from satellite passive microwave observations using combined radar-radiometer retrievals, *J. Appl. Meteor. and Clim.*, **45**(3), 416–433.

Gu, G., and **R. Adler,** 2006: Interannual rainfall variability in the tropical Atlantic region, *J. Geophys. Res.*, **111** (D02106), DOI: 10.1029/2005JD005944.

Haddad, Z., E. Im, **E. Smith**, J. Meagher, and S. Durden, 2006: Drop Size Ambiguities in the Retrieval of Precipitation Profiles from Dual-Frequency Radar Measurements, *J. Atmos. Sci.*, **63**(1), 204–217.

Halverson, J., **J. Simpson**, **G. Heymsfield**, **H. Pierce**, T. Hock, and L. Ritchie, 2006: Warm core structure of Hurricane Erin diagnosed from high-altitude dropsondes during CAMEX-4, *J. Atmos. Sci.*, **63**(1), 309–324.

Heymsfield, A. J., C. Scmitt, A. Bansemer, G.-J. van Zadelhoff, **M. J. McGill**, C. Twohy, and D. Baumgardner, 2006: Effective radius of ice cloud particle populations derived from aircraft probes, *J. Atmos. Oceanic Technol.*, **23**(3), 361–380.

***Heymsfield, G.**, J. Halverson, E. Ritchie, **J. Simpson**, J. Molinari, and **L. Tian**, 2006: Structure of the highly sheared Tropical Storm Chantal during CAMEX-4, *J. Atmos. Sci..*, **63**(1), 268–287.

Holz, R.E., S. Ackerman, P. Antonelli, F. Nagle, **M. McGill**, **D.L. Hlavka**, and **W. D. Hart**, 2006: An improvement to the high spectral resolution CO_2 slicing cloud top altitude retrieval, *J. Atmos. Oceanic Technol.*, **23**(5), 653–670.

Hong, Y., **R. Adler**, and **G. Huffman** , 2006: Evaluation of the Potential of NASA Multi-satellite Precipitation Analysis in Global Landslide Hazard Assessment, *Geophys. Res. Lett.*, **33**(L22402), doi:10.1029/2006GL028010.

Hong, Y., **R. Adler**, **G. Huffman**, and **A. Negri**, 2006: Use of Satellite Remote Sensing Data in mapping of global shallow landslides Susceptibility, *J. Nat. Haz.*, doi: 10.1007/s11069-006-9104-z.

Hong, Y., Y. Chiang, Y. Liu, K. Hsu, and S. Sorooshian, 2006: Satellite-based Precipitation Estimation using Watershed Segmentation and growing hierachical self-organizing feature mapping techniques, *Intl. J. Remote. Sens.*, **27**(23), 5165–5184 DOI: 10.1080/1431160600763428.

Hong, Y., K. Hsu, H. Moradkhani, and and S. Sorooshian, 2006: Uncertainty quantification of satellite precipitation estimation and Monte Carlo assessment of the error propagation into hydrologic response, *Water Resour. Res.*, **42**(W08421), doi: 10.1029/2005WR004398.

Hood, R., D. Cecil, F. LaFontatine, R. Blakeslee, D. Mach, **G. Heymsfield**, F. Marks, and E. Zipser, 2006: Classification of Tropical Oceanic Precipitation using High Altitude Aircraft Microwave and Electric Field Measurements, *J. Atmos. Sci.*, **63**(1), 218–233.

Hsu, K., **Y. Hong**, and S. Sorooshian , 2006: Rainfall Estimation using a Cloud Patch Classification Map, Measuring Precipitation from Space, *EURAINSAT and the Future Series: Advances in Global Change Research*, **28**(745), 978-1-4020-5834-9.

Jiang, H., and E. Zipser, 2006: Retrieval of hydrometeor profiles in tropical cyclones and convection from combined radar and radiometer observations, *J. Appl. Meteor. and Clim.*, **45**(8), 1096–1115.

Jin, M., 2006: MODIS observed seasonal and interannual variations of atmospheric conditions associated with hydrological cycle over Tibetan Plateau, *Geophys. Res. Lett.*, **33**(L19707), 10.1029/2006GL026713.

Manizade, K., **R. Lancaster**, and **J. Spinhirne**, 2006: Stereo Cloud Height Retrieval from ISIR Thermal Imagery via Region-of-Interest Segmentation Methods, *IEEE Trans. Geosci. Remote Sens.,* (TGRS-2005-00253, R1), 1–12.

Matsui, T., H. Masunaga, R. A. Pielke, S. M. Kreidenweis, **W.-K. Tao**, **M. Chin,** and **Y. Kaufman**, 2006: Satellite-based assessment of marine low cloud variability associated with aerosol, atmospheric stability, and the diurnal cycles, *J. Geophys. Res.*, **111 (D17)** (D17204, doi:10.1029/2005JD006097).

Matsui, T., H. Masunaga, S. Kreidenweis, R. Pielke Sr., **W.-K. Tao**, **M. Chin**, and **Y. Kaufman**, 2006: Correction to "Satellite-based assessment of marine low cloud variability associated with aerosol, atmospheric stability, and the diurnal cycle," *J. Geophys. Res*., **111**(D20202), doi: 10.1029/2006JD008056.

McFarquhar, G., H. Zhang, J. Dudhia, **G. Heymsfield**, R. Hood, J. Halverson, and F. Marks, 2006: Factors affecting the evolution of Hurricane Erin and distributions of hydrometeors: role of microphysical processes, *J. Atmos. Sci.*, **63**(1), 127–150.

Miloshevich, L.M., H. Voemel, **D. Whiteman**, B. Lesht, F.J. Schmidlin, and F. Russo, 2006: Absolute accuracy of water vapor measurements from six operational radiosonde types launched during AWEX-G and implications for AIRS validation, *J. Geophys. Res.*, **111**, doi: 10.1029/2005JD006083.

Moradkhani, Hamid, K. Hsu, **Y.Hong**, and and S. Sorooshian, 2006: Investigating the impact of remotely sensed precipitation and hydrological model uncertainties on the ensemble streamflow forecasting, *Geophys. Res. Lett.*, **33**(12, L12107), 10.1029/2006GL026855.

*__Olson, W.S.__, C. D. Kummerow, S. Yang, G. W. Petty, **W.-K. Tao**, **T. L. Bell**, **S. A. Braun**, Y. Wang, **S. E. Lang**, D. E. Johnson, and C. Chiu, 2006: Precipitation and latent heating distributions from satellite passive microwave radiometry. Part I: Improved method and uncertainties, *J. Appl. Meteor. and Clim.*, **45**(5), 702–720.

Rasch, P., M. Stevens, L. Ricciardulli, A. Dai, **A. Negri**, R. Wood, B. Boville, B. Eaton, and J. Hack, 2006: A Characterization of Tropical Transient Activity in the CAM3 Atmospheric Hydrologic Cycle, *J. Climate.*, **19**, 2222–2242.

Schmid, B., et al, **E. Welton**, 2006: How well do state-of-the-art techniques measuring the vertical profile of tropospheric aerosol extinction compare?, *J. Geophys. Res.*, **111**(D05S07), doi: 10.1029/2005JD005837.

Shen, B.-W., R. Atlas, **J.-D. Chern**, **O. Reale**, S.-J. Lin, T. Lee, and J. Change, 2006: The 0.125 degree Finite Volume General Circulation Model: Preliminary simulations of mesoscale vortices., *Geophys. Res. Lett.*, **33**(L05801), doi:10.1029/2005GL024594.

Shen, B.-W., R. Atlas, **O. Reale**, S.-J. Lin, **J.-D. Chern**, J. Chang, C. Henze, and J.-L. Li, 2006: Hurricane Forecasts with a Global Mesoscale-Resolving Model: Preliminary Results with Hurricane Katrina (2005), *Geophys. Res. Lett.*, **33**(L13813, doi: 10.1029/2005GL026143).

Shepherd, J.M., 2006: Evidence of urban-induced precipitation variability in arid climate regimes, *J. Arid Environ.*, 10.1016/j.jaridenv.2006.03.022.

Shie, C.-L., **W.-K. Tao**, and **J. Simpson**, 2006: A note on the relationship of temperature and water vapor over oceans, including sea surface temperature effects, A Special Issue of *Advances in Atmospheric Sciences*, **3**(1), 141–148.

Smith, T., P. Arkin, J. Bates, and **G. Huffman**, 2006: Estimating Bias of Satellite-Based Precipitation Estimates, *J. Hydromet.*, **7**(5), 841–856.

***Tao W.-K.**, **E. Smith**, **R. Adler**, Z. Haddad, **A. Hou**, T. Iguchi, R. Kakar, T. Krishnamurti, C. Kummerow, **S. Lang**, **R. Meneghini**, K. Nakamura, T. Nakazawa, K. Okamoto, **W. Olson**, S. Satoh, S. Shige, **J. Simpson**, Y. Takayabu, G. Tripoli, and **S. Yang**, 2006: Retrieval of latent heating from TRMM measurements, *Bull. Amer. Meteor. Soc.* **87**, 1555–1572.

Wang, J.-J., L. Carey, X.F. Li, 2006: Evolution, structure, cloud microphysical and surface rainfall processes of monsoon convection during the South China Sea Monsoon Experiment, *J. Atmos. Sci.*, **64**, 360–380.

Whiteman, D., **B. Demoz**, P. Di Girolamo, **J. Comer**, I. Veselovskii, K. Evans, Z. Wang, D. Sabatino, **G. Schwemmer**, **B. Gentry**, **R.-F. Lin**, A. Behrendt, V. Wulfmeyer, E. Browell, R. Ferrare, S. Ismail, and **J. Wang**, 2006: Raman Lidar Measurements during the International H_2O Project. Part II: Case Studies, *J. Atmos. Oceanic Technol.*, **23**(2), 170–183.

***Whiteman, D.**, **F. Russo**, **B. Demoz**, L. Miloshevich, I. Veselovskii, S. Hannon, Z. Wang, H. Vomel, F. Schmidlin, B. Lest, P. Moore, and A. Beeb, 2006: Analysis of Raman Lidar and radiosonde measurements from the AWEX-G field campaign and its relation to Aqua validation, *J. Geophys. Res.*, **111**(D09S09), doi: 10.1029/2005JD006429.

Whiteman, D., **B. Demoz**, P. Di Girolamo, J. Comer, I. Veselovskii, K. Evans, Z. Wang, M. Cardirola, K. Rush, **G. Schwemmer**, **B. Gentry**, S.H. Melfi, B. Mielke, D. Venable, and and T. Van Hove, 2006: Raman Lidar Measurements during the International H_20 Project. Part I: Instrumentation and Analysis Techniques, *J. Atmos. Oceanic Technol.*, **23**(2), 157–169.

Wu, L., **S. A. Braun**, J. J. Qu, and X. Hao, 2006: Simulating the formation of Hurricane Isabel (2003) with AIRS data, *Geophys. Res. Lett.*, **33**(L04804), doi:10.1029/2005GL024665..

Wu, Liguang, and Q. Zhang and Z. Jiang , 2006: Three Gorges Dam Affects Regional Precipitation, *Geophys. Res. Lett.*, **33**(L13806), doi:10.1029/2006GL026780.

*__Wu, Liguang__, **S. Braun**, J. Halverson, and **G. Heymsfield**, 2006: A numerical study of Hurricane Erin (2001). Part I: Model Verification and Storm Evolution, *J. Atmos. Sci.*, **63**(1), 65–86.

*__Yang, S.__, and **E. A. Smith**, 2006: Mechanisms for diurnal variability of global tropical rainfall observed from TRMM, *J. Climate*, **19**, 5190–5226.

*__Yang,S.__, **W. S. Olson**, **J. J. Wang**, **T. L. Bell**, **E.A. Smith**, and C. D. Kummerow, 2006: Precipitation and latent heating distributions from satellite passive microwave radiometry. Part II: Evaluation of estimates using independent data, *J. Appl. Meteor. and Clim.*, **45**(5), 721–739.

613.2 Climate and Radiation Branch

Abdou, W. A., S. H. Pilorz, M. C. Helmlinger, J. E. Conel, D. J. Diner, C. J. Bruegge, J. V. Martonchik**, C. K. Gatebe, M. D. King**, and P. V. Hobbs, 2006: Sua pan surface bidirectional reflectance: A case study to evaluate the effect of atmospheric correction on the surface products of the Multi-angle Imaging SpectroRadiometer (MISR) during SAFARI 2000. *IEEE Trans. Geosci. Remote Sens.*, **44**, 1699–1706.

*Baum, B., and **S. Platnick**, 2006: Introduction to MODIS cloud products, in Earth Science Satellite Remote Sensing, Science and Instruments, Vol I, edited by J. J. Qu, W. Gao, M. Kafatos, R. E. Murphy, and V. V. Salomonson, pp. 74–91, Tsinghua Uniersity Press (Beijing) and Springer-Verlag (Berlin).

Beer, J., M. Vonmoos, and **R. Muscheler**, 2006: Solar variability over the pst several millennia. *Space Science Reviews*, doi: 10.1007/s11214-006-9047-4.

Chiu, J. C., A. Marshak, Y. Knyazikhin, **W. Wiscombe**, H. Barker, J. C. Barnard, and Y. Luo, 2006: Remote sensing of cloud properties using ground-based measurements of zenith radiance. *J. Geophys. Res.*, **111**, D16201, doi:10.1029/2005JD006843.

Chiu, J. C., and G. W. Petty, 2006: Bayesian Retrieval of Complete Posterior PDFs of Oceanic Rain Rate from Microwave Observations. *J. Appl. Meteor. Clim.*, **45**, 1073–1095. doi:10.1175/JAM2392.1.

Chylek, P., M. K. Dubey, U. Lohmann, V. Ramanathan, **Y. J. Kaufman**, G. Lesins, G. Altmann, and S. Olsen, 2006: Aerosol indirect effect over the Indian Ocean. *Geophys. Res. Lett.* **33**(6), Art. No. L06806 doi:10.1029/2005GL025397.

Chylek, P., S. Robinson, M. K. Dubey, **M. D. King**, Q. Fu, and W. B. Clodius, 2006: Comparison of near-infrared and thermal infrared cloud phase detections. *J. Geophys. Res.*, **111**, D20203, doi:10.1029/2006JD007140.

Derimian, Y., A. Karnieli, **Y. J. Kaufman**, M. O. Andreae, T. W. Andreae, O. Dubovik, W. Maenhaut, **I. Koren**, and B. Holben, 2006: Dust and pollution aerosols over the Negev desert, Israel: Properties, transport, and radiative effect. *J. Geophys. Res.* **111**, D05205, doi: 10.1029/2005/D006549.

Feingold, G., R. Furrer, P. Pilewskie, **L. A. Remer**, Q. L. Min, and H. Jonsson, 2006: Aerosol indirect effect studies at Southern Great Plains during the May 2003 Intensive Operations Period. *J. Geophys. Res.*, **111** (D5), DOI: 10.1029/2004JD005648 , D05S14.

***Gasso, S.,** and N. ONeill, 2006: Comparisons of Remote Sensing Retrievals and In-Situ Measurements of Aerosol Fine Mode Fraction during ACE-Asia. *Geophys. Res. Lett.*, **33**, L05807, doi: 1029/2005GL024926.

Guo, Z.-C., P. A. Dirmeyer, R. D. Koster, G. Bonan, E. Chan, P. Cox, C. T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, C.-H. Lu, S. Malyshev, B. McAvaney, J. L. McGregor, K. Mitchell, **D. M. Mocko**, T. Oki, K. W. Oleson, A. Pitman, **Y. C. Sud**, et al., 2006: GLACE: The Global Land-Atmosphere Coupling Experiment. Part II: Analysis. *J. Hydrometeor.*, **7**(4), 611–625.

***Hsu, N. C., S. C. Tsay**, **M. D. King**, and **J. R. Herman**, 2006: Deep blue retrievals of Asian aerosol properties during ACE-Asia. *IEEE Trans. Geosci. Remote Sens.*, **44**, 3180–3195.

Jacobson, M. Z. and **Y. J. Kaufman**, 2006: Wind Reduction by Aerosol Particles. *Geophys. Res. Lett.*, **33**, L24814, doi:1029/2006GL027838.

Jin, M., and S. Liang, 2006: An Improved Land Surface Emissivity Parameter for Land Surface Models Using Global Remote Sensing Observations. *J. Climate*, **19**, 2867–2881.

Kaufman, Y. J., G. P. Gobbi, and **I. Koren**, 2006: Aerosol climatology using a tunable spectral variability cloud screening of AERONET data. *Geophy. Res. Lett.* **33**, L07817, doi: 10.1029/2005GL025478.

***Kaufman, Y. J., and I. Koren**, 2006: Smoke and Pollution Aerosol Effect on Cloud Cover. *Science*, **313**, 655-658, doi: 10.1126/science.1126232.

Kohler, P., **R. Muscheler**, and H. Fischer, 2006: A model-based interpretation of low-frequency changes in the carbon cycle during the last 120,000 years and its implications for the reconstruction of atmospheric $\Delta\,^{14}C$. *Geochemistry, Geophysics and Geosystems*, **7**, No. 11, doi:10.1029/2005GC001228.

Koster, R. D., Z.-C. Guo, P. A. Dirmeyer, G. Bonan, E. Chan, P. Cox, H. Davies, C. T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, C.-H. Lu, S. Malyshev, B. McAvaney, K. Mitchell, **D. M. Mocko**, T. Oki, K. W. Oleson, A. Pitman, **Y. C. Sud**, et al., 2006: GLACE: The Global Land-Atmosphere Coupling Experiment. Part I: Overview. *J. Hydrometeor.*, **7**(4), 590–610.

Kundu, P. K., and T. L. Bell, 2006: Space-time scaling behavior of rain statistics in a stochastic fractional diffusion model. *J. Hydrol.*, **322**, 49–58, doi:10.1016/j.jhydrol.2005.02.031.

Lee, J., P. Yang, A. E. Dessler, B. A. Baum, and **S. Platnick**, 2006: The influence of thermodynamic phase on the retrieval of mixed-phase cloud microphysical and optical properties in the visible and near-infrared region. *IEEE Geosci. Remote Sens. Lett.*, **3**, 287–291.

Liang, S., T. Zheng, R. Liu, H. Fang, **S. C. Tsay**, S. Running, and J. R. G. Townshend, 2006: Estimation of Incident Photosynthetically Active Radiation from MODIS Data. *J. Geophys. Res.*, **111**, D15208, doi: 10.1029/2005JDO06730.

Liu, H., J. H. Crawford, R. B. Pierce, P. Norris, **S. Platnick**, G. Chen, J. A. Logan, R. M. Yantosca, M. J. Evans, C. Kittaka, Y. Feng, and X. Tie, 2006: Radiative effect of clouds on tropospheric chemistry in a global three-dimensional chemical transport model. *J. Geophys. Res.*, **111**, D20303, doi:10.1029/2005JD006403

Marshak, A., J. V. Martins, **V. Zubko, and Y. J. Kaufman**, 2006: What does reflection from cloud sides tell us about vertical distribution of cloud droplet sizes?, *Atmos. Chem. and Phys*, **6**, 5295–5305.

***Marshak, A., S. Platnick, T. Varnai, G. Wen, and R. F. Cahalan**, 2006: Impact of 3D radiative effects on satellite retrievals of cloud droplet sizes. *J. Geophys. Res.*, **111**, DO9207, doi:10.1029/2005JD006686.

Muscheler, R., and J. Beer, 2006: Solar forced Dansgaard/Oeschger events?, *Geophys. Res. Lett*, **22**, L20706, doi: 10.1029/2006GLO06779.

Oreopoulos, L., A. Marshak, R. F. Cahalan, T. Varnai, A. B. Davis, and A. Macke, 2006: New Directions in the Radiative Transfer of Cloudy Atmospheres. *EOS*, **87**, No. 5, 31 January 2006.

***Remer, L. A., and Y. J. Kaufman, 2006**: Aerosol direct radiative effect at the top of the atmosphere over cloud free ocean derived from four years of MODIS data. *Atmos. Chem. and Phys.* **6**, 237–253.

Remer, L. A., Y. J. Kaufman, and R. G. Kleidman, 2006: Comparison of three years of Terra and Aqua MODIS Aerosol Optical Thickness Over the Global Oceans. *IEEE Trans. Geosci. Remote Sens. Lett.*, **3**(4), 537–540.

Renssen, H., H. Goosse, and **R. Muscheler**, 2006: Coupled climate model simulation of Holocene cooling events: oceanic feedback amplifies solar forcing. *Climate of the Past*, **2**, 79–90.

Satheesh, S. K., K. K. Moorthy, **Y. J. Kaufman**, and T. Takemura, 2006: Aerosol Optical Depth, Physical Properties and Radiative Forcing over the Arabian Sea. *Meteor. Atmos. Phys.*, **91** (1–4), 45–62.

Seneviratne, S. I., R. D. Koster, Z.-C. Guo, P. A. Dirmeyer, E. Kowalczyk, D. Lawrence, P. Liu, C.-H. Lu, **D. M. Mocko**, K. W. Oleson, and D. Verseghy, 2006: Soil moisture memory in AGCM simulations: Analysis of Global Land-Atmosphere Coupling Experiment (GLACE) data. *J. Hydrometeor.*, **7**(5), 1090–1112.

***Sud, Y. C., D. M. Mocko**, and S.-J. Lin, 2006: Performance of two cloud-radiation parameterization schemes in the fvGCM for anomalously wet May and June 2003 over the continental United States and Amazonia. *J. Geophys. Res.*, **111**(D6), 6201, doi:10.1029/2005JD006246.

Vallina, S., R. Simo, and **S. Gasso**, 2006: What controls CCN seasonality in the Southern Ocean?: A statistical analysis based on satellite-derived chlorophyll and CCN model-estimated OH radical and rainfall. *Global Biogeochem. Cycles*, **20**, GB1014, doi: 10.1029/2005GB002597.

Vonmoos, M., J. Beer, and **R. Muscheler**, 2006: Large variations in Holocene solar activity: Constraints from ^{10}Be in the Greenland Ice Core Project ice core. *J. Geophys. Res.*, **111**, A10105, doi: 10.1029/2005JA011500.

Wang, H., and **K.-M. Lau**, 2006: Atmospheric Hydrological Cycle in the Tropics in Twentieth Century Coupled Climate Simulations. *Intl. J. Climatol.*, **26**, 655–678.

Wang, J., D. Collins, D. Covert, R. Elleman, R. A. Ferrare, R. Gasparini, H. Jonsson, J. Ogren, P. Sheridan, and **S. C. Tsay**, 2006: Temporal Variation of Aerosol Properties at a Rural Continental Site and Study of Aerosol Evolution through Growth Law Analysis. *J. Geophys. Res.*, **111**, D18203, doi: 10.1029/2005JD006730.

Wen, G., A. Marshak, and R. F. Cahalan, 2006: Impact of 3D Clouds on Clear Sky Reflectance and Aerosol Retrieval in a Biomass Burning Region of Brazil. *IEEE Trans. Geosci. Remote Sens. Lett*, **3**, 169–172.

***Wilcox, E. M**., G. Roberts, and V. Ramanathan, 2006: Influence of aerosols on the shortwave cloud radiative forcing from north Pacific Oceanic Clouds: Results from the Cloud Indirect Forcing Experiment (CIFEX). *Geophys. Res. Lett.*, **33**, L21804, doi:10.1029/2006GL027150.

Yang, S., W. S. Olson, J.-J. Wang, **T. L. Bell**, E. A. Smith, and C. D. Kummerow, 2006: Precipitation and latent heating distributions from satellite passive microwave radiometry. Part II: Evaluation of estimates using independent data. *J. Appl. Meteor. Clim.*, **45** (5), 721–739.

Yu, H., Y. J. Kaufman, **M. Chin**, G. Feingold, **L. Remer**, T. Anderson, Y. Balkanski, N. Bellouin, O. Boucher, S. Christopher, P. DeCola, R. Kahn, D. Koch, N. Loeb, M. S. Reddy, M. Schulz, T. Takemura, and M. Zhou, 2006: A review of measurement-based assessments of aerosol direct radiative effect and forcing. *Atmos. Chem. and Phys.*, **6**, 613–666.

Zinner, T., and B. Mayer, 2006: Remote sensing of stratocumulus clouds: Uncertainties and biases due to inhomogeneity. *J. Geophys. Res.*, **111**, D14209, DOI: 10.1029/2005JD006955.

Zinner, T., B. Mayer, and M. Schroder, 2006: Determination of 3D cloud structures from high resolution radiance data. *J. Geophys. Res.*, **111**, D08204 DOI: 10.1029/2005JD006062.

613.3 Atmospheric Chemistry and Dynamics Branch

Arimoto, R., Y. J. Kim, Y. P. Kim, P. K. Quinn, T. S. Bates, T. L. Anderson, S. Gong, I. Uno, **M. Chin,** B. J. Huebert, A. D. Clarke, Y. Shinozuka, R. J. Weber, J. R. Anderson, S. A. Guazzotti, R. C. Sullivan, D. A. Sodeman, K. A. Prather, and I. N. Sokolik, 2006: Characterization of Asian dust during ACE-Asia, *Global and Planetary Change*, **52,** 23–56.

Baker, D. F., R. M. Law, K. R. Gurney, P. Rayner, P. Peylin, A. S. Denning, P. Bousquet, L. Bruhwiler, Y.-H. Chen, P. Ciais, I. Y. Fung, M. Heimann, J. John, T. Maki, S. Maksyutov, K. Masarie, M. Prather, B. Pak, S. Taguchi, and **Z. Zhu,** 2006: TransCom 3 inversion intercomparison: Impact of transport model errors on the interannual variability of regional CO_2 fluxes, 1988-2003, *Global Biochemical Cycles*, **20** (GB1002, doi:10.1029/2004GB002439), 1–17.

Beirle, S., N. Spichtinger, A. Stohl, K. Cummins, T. Turner, D. Boccippio, O. R. Cooper, **M. Wenig,** M. Grzegorski, U. Platt, and T. Wagner, 2006: Estimating the NO_x produced by lightning from GOME and NLDN data: a case study in the Gulf of Mexico, *Atmos. Chem. and Phys.*, **6,** 1075–1089.

Belanger, S., H. Xie, **N. Krotkov,** P. Larouche, W. F. Vincent, and M. Babin, 2006: Photomineralization of terrigenous dissolved organic matter in Arctic coastal waters from 1979 to 2003: Interannual variability and implications of climate change, *Global Biogeochemical Cycles*, **20** (GB4005, doi:10.1029/2006GB002708), .

***Bian, H., S. R. Kawa, M. Chin, S. Pawson, Z. Zhu,** P. Rasch, and S. Wu, 2006: A test of sensitivity to convective transport in a global atmospheric CO_2 simulation, *Tellus B*, **58** (5), 463–475.

Brasseur, G. P., M. Schultz, C. Granier, M. Saunois, **T. Diehl,** M. Botzet, E. Roeckner, and S. Walters, 2006: Impact of Climate Change on the Future Chemical Composition of the Global Troposphere, *J. Climate*, **19,** 3932–3951.

***Bucsela, E., E. A. Celarier, M. O. Wenig, J. F. Gleason,** J. P. Veefkind, K. F. Boersma, and E. Brinksma, 2006: Algorithm for NO_2 vertical column retrieval from the Ozone Monitoring Instrument, *IEEE Trans. Geosci. Remote Sens.*, **44** (5), 1245–1258.

***Cede, A., J. Herman,** A. Richter, **N. Krotkov,** and J. Burrows, 2006: Measurements of Nitrogen Dioxide Total Column Amounts Using a Brewer Spectrometer in Direct Sun Mode, *J. Geophys. Res.*, **111** (D05304, doi:10.1029/2005JD006585), .

Cede, A., S. Kazadzis, **M. Kowalewski,** A. Bais, N. Kouremeti, M. Blumthaler, and **J. Herman,** 2006: Correction of direct irradiance measurements of Brewer spectrophotometers due to the effect of internal polarization, *Geophys. Res. Lett.*, **33**(2), 10.1029/2005GL024860.

DeLand, M. T., E. P. Shettle, G. E. Thomas, and J. J. Olivero, 2006: A quarter-century of satellite PMC observations, *J. Atmos. Solar-Terr. Phys.*, **68,** 9–29.

***DeLand, M. T.,** E. P. Shettle, G. E. Thomas, and J. J. Olivero, 2006: Spectral measurements of PMCs from SBUV/2 instruments, *J. Atmos. Solar-Terr. Phys.*, **68,** 65–77.

Dobber, M. R., R. J. Dirksen, P. F. Levelt, G. H. J. van den Oord, R. H. M. Voors, Q. Kleipool, **G. Jaross, M. Kowalewski, E. Hilsenrath,** G. W. Leppelmeier, J. D. Vries, W. Dierssen, and N. C. Rozemeijer, 2006: Ozone Monitoring Instrument Calibration, *IEEE Trans. Geosci. Remote Sens.*, **44** (5), IGRSD2, 1209–1238.

***Douglass, A. R., R. S. Stolarski, S. E. Strahan,** and **B. C. Polansky,** 2006: Sensitivity of Arctic ozone loss to polar stratospheric cloud volume and chlorine and bromine loading in a chemistry and transport model, *Geophys. Res. Lett.*, **33** (L17809, doi:10.1029/2006GL026492), .

Grzegorski, M., **M. Wenig,** U. Platt, P. Stammes, N. Fournier, and T. Wagner, 2006: The Heidelberg iterative cloud retrieval utilities (HICRU) and its applications to GOME data, *Atmos. Chem. and Phys.*, **6,** 4461–4476.

Huang, F. T., **H. G. Mayr,** C. A Reber, J. M. Russell, M. Mlynczak, and **J. G. Mengel,** 2006: Stratospheric and mesospheric temperature variations for the quasi-biennial and semiannual (QBO and SAO) oscillations based on measurements from SABE (TIMED) and MLS (UARS), *Annales Geophysicae*, **24,** 2131–2149.

Huang, F. T., **H. G. Mayr,** C. A. Reber, J. Russell, M. Mlynczak, and **J. G. Mengel,** 2006: Zonal-mean temperature variations inferred from SABER measuremetns on TIMED compared with UARS observations, *J. Geophys. Res.*, **111** (A10S07, doi:10.1029/2005JA011427), .

Huang, F. T., **H. G. Mayr,** C. A. Reber, T. Killeen, J. Russell, M. Mlynczak, W. Skinner, and **J. G. Mengel,** 2006: Diurnal variations of temperature and winds inferred from TIMED and UARS measurements, *J. Geophys. Res.*, **111** (A10S04, doi:10.1029/2005JA011426), .

***Joiner, J.,** and **A. P. Vasilkov,** 2006: First Results from the OMI Rotational Raman Scattering Cloud Pressure Algorithm, *IEEE Trans. Geosci. Remote Sens.*, **44** (5), IGRSD2, 1272–1282.

Kazantzidis, A., A. F. Bais, J. Grobner, **J. R. Herman,** S. Kazadzis, **N. Krotkov,** E. Kyro, P. N. den Outer, K. Garane, P. Gorts, K. Lakkala, C. Meteli, H. Slaper, R. B. Tax, T. Turunen, and C. S. Zerefos, 2006: Comparison of satellite-derived UV irradiances with ground-based measurements at four European stations, *J. Geophys. Res.*, **111** (D13207, doi:10.1029/2005JD006672), .

Kinne, S., M. Schulz, C. Textor, S. Guibert, Y. Balkanski, S. E. Bauer, T. Berntsen, T. F. Berglen, O. Boucher, **M. Chin,** W. Collins, **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 Kirkevag, 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, X. Tie, and F. Dentener, 2006: An AeroCom initial assessment optical properties in aerosol component modules of global models, *Atmos. Chem. and Phys.*, **6,** 1815–1834.

Krotkov, N., S. A. Carn, A. J. Krueger, **P. K. Bhartia,** and **K. Yang,** 2006: Band Residual Difference Algorithm for Retrieval of SO_2 from the Aura Ozone Monitoring Instrument (OMI), *IEEE Trans. Geosci. Remote Sens.*, **44** (5), 1259–1266.

Kunhikrishnan, T., M. G. Lawrence, R. von Kuhlmann, **M. O. Wenig**, A. Richter, and J. P. Burrows, 2006: Regional NO_x emission strength from the Indian subcontinent and the impact of emissions from India and neighboring countries on regional O_3 chemistry in light of seasonal meteorology, *J. Geophys. Res.*, **111** (D15, D1530).

Lary, D., and **L. Lait,** 2006: Using Probability Distribution Functions for Satellite Validation, *IEEE Trans. Geosci. Remote Sens.*, **44** (5), IGRSD2, 1359–1366.

Levelt, P. F., **E. Hilsenrath,** G. W. Leppelmeier, G. H. J. van den Oord, **P. K. Bhartia,** J. Tamminen, J. F. de Haan, and J. P. Veefkind, 2006: Science objectives of the Ozone Monitoring Instrument, *IEEE Trans. Geosci. Remote Sens.*, **44** (5), IGRSD2, 1199–1208.

Luccini, E., **A. Cede,** R. D. Piacentini, C. Villanueva, and P. Canziani, 2006: Ultraviolet climatology over Argentina, *J. Geophys. Res.*, **111** (D17312, doi:10.1029/2005JD006580), .

***Mayr, H. G., J. G. Mengel,** C. L. Wolff, and H. S. Porter, 2006: The QBO as potential amplifier of solar cycle influence, *Geophys. Res. Lett.*, **33** (L05812,doi2005GL025650).

Morris, G.A., L. Branum-Martin, N. Harshman, S.D. Baker, E. Mazur, S. Dutta, T. Mzoughi, and V. McCauley, 2006: Testing the test: Item response curves and test quality, *Am. J. Phys.*, **74,** 449–453.

***Newman, P. A., E. R. Nash, S. R. Kawa,** S. A. Montzka, and S. M. Schauffler, 2006: When will the Antarctic ozone hole recover?, *Geophys. Res. Lett.*, **33 No. 12** (L12814, doi:10.1029/2005GL025232),

Olsen, M., A. . R. Douglass, R. S. Stolarski, and M. R. Schoeberl**,** 2006: On detecting a trend in the residual circulation from observations of column HC1, *Geophys. Res. Lett.*, **33** (L14815, doi:10.1029/2006GL026214),

Schmidt, H., G. P. Brasseur, M. Charron, E. Manzini, M. A. Giorgetta, **T. Diehl,** V. I. Fomichev, D. Kinnison, D. Marsh, and S. Walters, 2006: The HAMMONIA Chemistry Climate Model: Sensitivity of the Mesopause Region to the 11-year Solar Cycle and CO_2 Doubling, *J. Climate*, **19,** 3903–3931.

Schoeberl, M. R.**, A. R. Douglass, E. Hilsenrath, P. K. Bhartia,** R. Beer, J. W. Waters, M. R. Gunson, L. Froidevaux, J. C. Gille, J. J. Barnett, P. F. Levelt, and P. DeCola, 2006: Overview of the EOS Aura Mission, *IEEE Trans. Geosci. Remote Sens.*, **44** (5), IGRSD2, 1066–1074.

Schoeberl, M. R.**, S. R. Kawa, A. R. Douglass,** and **T. J. McGee,** 2006: Chemical observations of a polar vortex intrusion, *J. Geophys. Res.*, **111** (D20306, doi:10.1029/2006JD007134), .

Smirnov, A., B. N. Holben, S. M. Sakerin, D. M. Kabanov, I. Slutsker, **M. Chin, T. L. Diehl, L. A. Remer,** R. Kahn, A. Ignatov, L. Liu, M. Mishchenko, T. F. Eck, **T. L. Kucsera,** D. Giles, and O. V. Kopelevich, 2006: Ship-based aerosol optical depth measurements in the Atlantic Ocean: Comparison with satellite retrievals and GOCART model, *Geophys. Res. Lett.*, **33** (L14817, doi:10.1029/2006GL026051), .

Steinbrecht, W., H. Claude, F. Schonenborn, I. S. McDermid, T. Leblanc, S. Godin, T. Song, D. P. J. Swart, Y. J. Meijer, G. E. Bodeker, B. J. Connor, N. Kampfer, K. Hocke, Y. Calisesi, N. Schneider, J. de la Noe, A. D. Parrish, I. S. Boyd, C. Bruhl, B. Steil, M. A. Giorgetta, E. Manzini, L. W. Thomason, J. M. Zawodny, M. P. McCormick, J. M. Russell III, **P. K. Bhartia, R. S. Stolarski,** and **S. M. Hollandsworth-Frith,** 2006: Long-term evolution of upper stratospheric ozone at selected stations of the network for the detection of stratospheric change (NDSC), *J. Geophys. Res.*, **111** (D10308, doi:10.1029/2005JD006454), .

Stolarski, R. S., A. R. Douglass, S. Steenrod, and and S. Pawson, 2006: Trends in stratospheric ozone: Lessons learned from a 3-D chemical transport model, *J. Atmos. Sci.*, **63,** 1028–1041.

Stolarski, R. S., and **S. M. Frith,** 2006: Search for evidence of trend slow-down in the long-term TOMS/SBUV total ozone data record; the importance of instrument drift uncertainty, *Atmos. Chem. and Phys.*, **6,** 4057–4065.

***Stolarski, R. S., A. R. Douglass,** M. Gupta, **P. A. Newman, S. Pawson,** M. R. Schoeberl**,** and **J. E. Nielsen,** 2006: An ozone increase in the Antarctic summer stratosphere: A dynamical response to the ozone hole, *Geophys. Res. Lett.*, **33** (L21805, doi:10.1029/2006GL026820), .

Strahan, S. E., and **B.C. Polansky,** 2006: Meteorological implementation issues in chemistry and transport models, *Atmos. Chem. and Phys.*, **6,** 2895-2910.

Streets, D. G., Y. Wu, and **M. Chin,** 2006: Two-decadel aerosol trends as a likely explanation of the global dimming/brightening transition, *Geophys. Res. Lett.*, **33** (L15806, doi:10.1029/2006GL026471),

Tanskanen, A., **N. A. Krotkov, J. R. Herman,** and A. Arola, 2006: Surface Ultraviolet Irradiance from OMI, *IEEE Trans. Geosci. Remote Sens.*, **44** (5), IGRSD2, 1267–1271.

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. Montanaro, G. Myhre, J. Penner, G. Pitari, S. Reddy, O. Seland, P. Stier, T. Takemura, and X. Tie, 2006: Analysis and quantification of the diversities of aerosol life cycles within AeroCom, *Atmos. Chem. and Phys.*, **6,** 1777–1813.

Tie, X., **S. Chandra, J. R. Ziemke,** C. Granier, and G. P. Brasseur, 2006: Satellite measurements of tropospheric column O3 and NO2 in eastern and southeastern Asia: Comparison with a global model (MOZART-2), *J. Atmos. Chem.*, (doi:10.1007/S10874-006-9045-7), .

Tzortziou, M., J. Herman, C. Galleos, P. Neale, A. Subramaniam, L. Harding, and Z. Ahmad, 2006: Bio-optics of the Chespeake Bay from measuremetns and radiative transfer closure, *Estuarine Coastal and Shelf Science*, **68** (2), 348–362.

Tzortziou, M. A., M. Subramaniam, **J. Herman,** C. Gallegos, P. Neale, and L. Harding, 2006: Remote Sensing Reflectance and Inherent Optical Properties in the Mid Chesapeake Bay, *Estuarine, Coastal, and Shelf Science*, (doi:10.1016/j.ecss.2006.09.018), .

Wong, S., **P. R. Colarco,** and A. E. Dessler, 2006: Principal Component Analysis of the Evolution of the Saharan Air Layer and Dust Transport: Comparisons between a Model Simulation and MODIS Retrievals, *J. Geophys. Res.*, **111** (D20109, doi:10.1029/2006JD007093),

***Ziemke, J. R., S. Chandra, B. N. Duncan,** L. Froidevaux, **P. K. Bhartia,** P. F. Levelt, and J. W. Waters, 2006: Tropospheric ozone determined from Aura OMI and MLS: Evaluation of measurements and comparison with the Global Modeling Initiative's Chemical Transport Model, *J. Geophys. Res.*, **111, D19303** (doi:10.1029/2006JD007089).

APPENDIX A3. HIGHLIGHTED ARTICLES PUBLISHED IN 2006

4700 JOURNAL OF CLIMATE VOLUME 19

Atmospheric Teleconnection over Eurasia Induced by Aerosol Radiative Forcing during Boreal Spring

MAENG-KI KIM,* WILLIAM K. M. LAU,+ MIAN CHIN,# KYU-MYONG KIM,@ Y. C. SUD,& AND GREG K. WALKER**

*Department of Atmospheric Science, Kongju National University, Gongju, South Korea
+Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland
#Atmospheric Chemistry and Dynamics Branch, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland
@Science Systems and Applications, Inc., Lanham, Maryland
&Climate and Radiation Branch, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland
**SAIC/General Sciences Operation, Beltsville, Maryland

(Manuscript received 18 March 2005, in final form 22 November 2005)

ABSTRACT

The direct effects of aerosols on global and regional climate during boreal spring are investigated based on numerical simulations with the NASA Global Modeling and Assimilation Office finite-volume general circulation model (fvGCM) with Microphyics of Clouds with the Relaxed–Arakawa Schubert Scheme (McRAS), using aerosol forcing functions derived from the Goddard Ozone Chemistry Aerosol Radiation and Transport model (GOCART).

The authors find that anomalous atmospheric heat sources induced by absorbing aerosols (dust and black carbon) excite a planetary-scale teleconnection pattern in sea level pressure, temperature, and geopotential height spanning North Africa through Eurasia to the North Pacific. Surface cooling due to direct effects of aerosols is found in the vicinity and downstream of the aerosol source regions, that is, South Asia, East Asia, and northern and western Africa. Significant atmospheric heating is found in regions with large loading of dust (over northern Africa and the Middle East) and black carbon (over Southeast Asia). Paradoxically, the most pronounced feature in aerosol-induced surface temperature is an east–west dipole anomaly with strong cooling over the Caspian Sea and warming over central and northeastern Asia, where aerosol concentrations are low. Analyses of circulation anomalies show that the dipole anomaly is a part of an atmospheric teleconnection pattern driven by atmospheric heating anomalies induced by absorbing aerosols in the source regions, but the influence was conveyed globally through barotropic energy dispersion and sustained by feedback processes associated with the regional circulations.

The surface temperature signature associated with the aerosol-induced teleconnection bears striking resemblance to the spatial pattern of observed long-term trend in surface temperature over Eurasia. Additionally, the boreal spring wave train pattern is similar to that reported by Fukutomi et al. associated with the boreal summer precipitation seesaw between eastern and western Siberia. The results of this study raise the possibility that global aerosol forcing during boreal spring may play an important role in spawning atmospheric teleconnections that affect regional and global climates.

1. Introduction

Recent studies have shown that aerosols may play an important role in climate change through their interaction with the global water and energy cycles (e.g., Jacobson 2001a,b, 2002; Menon et al. 2002; Lohmann and Lesins 2002; Roberts and Jones 2004; Ramanathan et al. 2001). The effect of aerosols on the earth's radiative budget is not only limited to cooling by scattering but also heating by absorption of solar radiation, depending on aerosol types. Because of their ability to deplete surface insolation from either scattering or absorption, all aerosols cause cooling at the earth surface—the so-called "solar dimming" effect (Ramanathan et al. 2005). However, the sign of atmospheric temperature change induced by aerosol forcing can vary depending on the aerosol types, their elevation, and reflectivity of the

Corresponding author address: Dr. K. M. Lau, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Code 613, Greenbelt, MD 20771.
E-mail: lau@climate.gsfc.nasa.gov

JCLI3871

Climate Dynamics (2006) 26: 855–864
DOI 10.1007/s00382-006-0114-z

K. M. Lau · M. K. Kim · K. M. Kim

Asian summer monsoon anomalies induced by aerosol direct forcing: the role of the Tibetan Plateau

Received: 12 July 2005 / Accepted: 15 December 2005 / Published online: 9 February 2006

Abstract In this paper we present results of a numerical study using the NASA finite-volume GCM to elucidate a plausible mechanism for aerosol impact on the Asian summer monsoon involving interaction with physical processes over the Tibetan Plateau (TP). During the pre-monsoon season of March–April, dusts from the deserts of western China, Afghanistan/Pakistan, and the Middle East are transported into and stacked up against the northern and southern slopes of the TP. The absorption of solar radiation by dust heats up the elevated surface air over the slopes. On the southern slopes, the atmospheric heating is reinforced by black carbon from local emission. The heated air rises via dry convection, creating a positive temperature anomaly in the mid-to-upper troposphere over the TP relative to the region to the south. In May through early June in a manner akin to an "elevated heat pump", the rising hot air forced by the increasing heating in the upper troposphere, draws in warm and moist air over the Indian subcontinent, setting the stage for the onset of the South Asia summer monsoon. Our results suggest that increased dust loading coupled with black carbon emission from local sources in northern India during late spring may lead to an advance of the rainy periods and subsequently an intensification of the Indian summer monsoon. The enhanced rainfall over India is associated with the development of an aerosol-induced large-scale sea level pressure anomaly pattern, which causes the East Asia (*Mei-yu*) rain belt to shift northwestward, suppressing rainfall over East Asia and the adjacent oceanic regions.

K. M. Lau (✉)
Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, MD, USA
E-mail: lau@climate.gsfc.nasa.gov

M. K. Kim
Department of Atmospheric Science, Kongju National University, Gongju, Korea

K. M. Kim
Science Systems and Applications, Inc, Lanham, MD, USA

1 Introduction

Recent studies have shown that aerosols can cause substantial alteration in the energy balance of the atmosphere and the earth surface, thus modulating the hydrologic cycle (Hansen et al. 2000; Jacobson 2001; Ramanathan et al. 2001). In the Asian monsoon regions, aerosol is a major environmental hazard that is increasing at an alarming rate, and the monsoon water cycle is the lifeline to over 60% of the world's population. Yet the effects of aerosol and possible interactions with the monsoon dynamics remain largely unknown. Hence, a better understanding of interaction of aerosols on monsoon water cycle is paramount with huge science and society benefits. Numerical experiments from a general circulation model (GCM) have suggested that atmospheric circulation anomalies induced by black carbon from coal burning may be a cause of long-term drought over northern China, and excessive rainfall over southern China and India (Menon et al. 2002). Recently, Ramanathan et al. (2005) shows that on climate change time-scales, as a result of blocking of solar radiation reaching the surface by aerosol, i.e., global dimming, the earth surface cools, leading to a gradual spin-down of the tropical water cycle, and eventually weakening of the Asian monsoon. However on seasonal-to-interannual time scales, it is not clear how aerosols may impact the Asian monsoon. Absorbing aerosols such as dust and black carbon will heat the atmosphere due to shortwave absorption. Non-absorbing aerosols such as sulphate causes surface cooling by strongly scattering solar radiation, but have relatively little heating effects on the atmosphere itself. Overall, both absorbing and non-absorbing aerosols cool the earth surface by the global dimming effect. However, as we shall illustrate in this paper, for absorbing aerosols over elevated land with high surface albedo, in the presence of atmosphere and surface energy feedback, the effects may be quite different.

One of the key controls of the seasonal-to-interannual variability of the Asian summer monsoon is associated

The Dryline on 22 May 2002 during IHOP_2002: Convective-Scale Measurements at the Profiling Site

BELAY DEMOZ,* CYRILLE FLAMANT,+ TAMMY WECKWERTH,# DAVID WHITEMAN,* KEITH EVANS,@ FRÉDÉRIC FABRY,& PAOLO DI GIROLAMO,** DAVID MILLER,++ BART GEERTS,## WILLIAM BROWN,## GEARY SCHWEMMER,* BRUCE GENTRY,* WAYNE FELTZ,@@ AND ZHIEN WANG@

*NASA Goddard Space Flight Center, Greenbelt, Maryland
+Institut Pierre-Simon Laplace/Service Aéronomie, Paris, France
#National Center for Atmospheric Research, Boulder, Colorado
@University of Maryland, Baltimore County, Baltimore, Maryland
&McGill University, Montreal, Quebec, Canada
**Università degli Studi della Basilicata, Potenza, Italy
++Science Systems and Applications, Inc., Lanham, Maryland
##University of Wyoming, Laramie, Wyoming
@@CIMSS/SSEC, University of Wisconsin—Madison, Madison, Wisconsin

(Manuscript received 18 August 2004, in final form 5 July 2005)

ABSTRACT

A detailed analysis of the structure of a double dryline observed over the Oklahoma panhandle during the first International H_2O Project (IHOP_2002) convective initiation (CI) mission on 22 May 2002 is presented. A unique and unprecedented set of high temporal and spatial resolution measurements of water vapor mixing ratio, wind, and boundary layer structure parameters were acquired using the National Aeronautics and Space Administration (NASA) scanning Raman lidar (SRL), the Goddard Lidar Observatory for Winds (GLOW), and the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE), respectively. These measurements are combined with the vertical velocity measurements derived from the National Center for Atmospheric Research (NCAR) Multiple Antenna Profiler Radar (MAPR) and radar structure function from the high-resolution University of Massachusetts frequency-modulated continuous-wave (FMCW) radar to reveal the evolution and structure of the late afternoon double-dryline boundary layer. The eastern dryline advanced and then retreated over the Homestead profiling site in the Oklahoma panhandle, providing conditions ripe for a detailed observation of the small-scale variability within the boundary layer and the dryline. In situ aircraft data, dropsonde and radiosonde data, along with NCAR S-band dual-polarization Doppler radar (S-Pol) measurements, are also used to provide the larger-scale picture of the double-dryline environment.

Moisture and temperature jumps of about 3 g kg^{-1} and 1–2 K, respectively, were observed across the eastern radar fine line (dryline), more than the moisture jumps (1–2 g kg^{-1}) observed across the western radar fine line (secondary dryline). Most updraft plumes observed were located on the moist side of the eastern dryline with vertical velocities exceeding 3 m s^{-1} and variable horizontal widths of 2–5 km, although some were as wide as 7–8 km. These updrafts were up to 1.5 g kg^{-1} moister than the surrounding environment.

Although models suggested deep convection over the Oklahoma panhandle and several cloud lines were observed near the dryline, the dryline itself did not initiate any storms over the intensive observation region (IOR). Possible reasons for this lack of convection are discussed. Strong capping inversion and moisture detrainment between the lifting condensation level and the level of free convection related to an overriding drier air, together with the relatively small near-surface moisture values (less than 10 g kg^{-1}), were detrimental to CI in this case.

Corresponding author address: Belay B. Demoz, NASA GSFC, Code 613.1, Greenbelt, MD 20771.
E-mail: Belay.B.Demoz@nasa.gov

MWR3054

416 JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY VOLUME 45

Bayesian Estimation of Precipitation from Satellite Passive Microwave Observations Using Combined Radar–Radiometer Retrievals

MIRCEA GRECU

Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, and NASA Goddard Space Flight Center, Greenbelt, Maryland

WILLIAM S. OLSON

Joint Center for Earth Systems Technology, University of Maryland, Baltimore County, Baltimore, and NASA Goddard Space Flight Center, Greenbelt, Maryland

(Manuscript received 26 April 2005, in final form 14 October 2005)

ABSTRACT

Precipitation estimation from satellite passive microwave radiometer observations is a problem that does not have a unique solution that is insensitive to errors in the input data. Traditionally, to make this problem well posed, a priori information derived from physical models or independent, high-quality observations is incorporated into the solution. In the present study, a database of precipitation profiles and associated brightness temperatures is constructed to serve as a priori information in a passive microwave radiometer algorithm. The precipitation profiles are derived from a Tropical Rainfall Measuring Mission (TRMM) combined radar–radiometer algorithm, and the brightness temperatures are TRMM Microwave Imager (TMI) observed. Because the observed brightness temperatures are consistent with those derived from a radiative transfer model embedded in the combined algorithm, the precipitation–brightness temperature database is considered to be physically consistent. The database examined here is derived from the analysis of a month-long record of TRMM data that yields more than a million profiles of precipitation and associated brightness temperatures. These profiles are clustered into a tractable number of classes based on the local sea surface temperature, a radiometer-based estimate of the echo-top height (the height beyond which the reflectivity drops below 17 dBZ), and brightness temperature principal components. For each class, the mean precipitation profile, brightness temperature principal components, and probability of occurrence are determined. The precipitation–brightness temperature database supports a radiometer-only algorithm that incorporates a Bayesian estimation methodology. In the Bayesian framework, precipitation estimates are weighted averages of the mean precipitation values corresponding to the classes in the database, with the weights being determined according to the similarity between the observed brightness temperature principal components and the brightness temperature principal components of the classes. Because the classes are stratified by the sea surface temperature and the echo-top-height estimator, the number of classes that are considered for retrieval is significantly smaller than the total number of classes, making the algorithm computationally efficient. The radiometer-only algorithm is applied to TMI observations, and precipitation estimates are compared with combined TRMM precipitation radar (PR)–TMI reference estimates. The TMI-only algorithm, supported by the empirically derived database, produces estimates that are more consistent with the reference values than the precipitation estimates from the version-6 TRMM facility TMI algorithm. Cloud-resolving model simulations are used to assign a latent heating profile to each precipitation profile in the empirically derived database, making it possible to estimate latent heating using the radiometer-only algorithm. Although the evaluation of latent heating estimates in this study is preliminary, because realistic conditional probability distribution functions are attached to latent heating structures in the algorithm's database, a generally positive impact on latent heating estimation from passive microwave observations is expected.

Corresponding author address: Dr. Mircea Grecu, GEST/UMBC, NASA Goddard Space Flight Center, Code 613.1, Greenbelt, MD 20771.
E-mail: grecu@agnes.gsfc.nasa.gov

268 JOURNAL OF THE ATMOSPHERIC SCIENCES VOLUME 63

Structure of Highly Sheared Tropical Storm Chantal during CAMEX-4

G. M. HEYMSFIELD,* J. HALVERSON,+ E. RITCHIE,# JOANNE SIMPSON,* J. MOLINARI,@ AND L. TIAN+

*NASA Goddard Space Flight Center, Greenbelt, Maryland
+University of Maryland, Baltimore County, Baltimore, Maryland
#University of New Mexico, Albuquerque, New Mexico
@Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

(Manuscript received 16 October 2003, in final form 21 December 2004)

ABSTRACT

Tropical Storm Chantal during August 2001 was a storm that failed to intensify over the few days prior to making landfall on the Yucatan Peninsula. An observational study of Tropical Storm Chantal is presented using a diverse dataset including remote and in situ measurements from the NASA ER-2 and DC-8 and the NOAA WP-3D N42RF aircraft and satellite. The authors discuss the storm structure from the larger-scale environment down to the convective scale. Large vertical shear (850–200-hPa shear magnitude range 8–15 m s^{-1}) plays a very important role in preventing Chantal from intensifying. The storm had a poorly defined vortex that only extended up to 5–6-km altitude, and an adjacent intense convective region that comprised a mesoscale convective system (MCS). The entire low-level circulation center was in the rain-free western side of the storm, about 80 km to the west-southwest of the MCS. The MCS appears to have been primarily the result of intense convergence between large-scale, low-level easterly flow with embedded downdrafts, and the cyclonic vortex flow. The individual cells in the MCS such as cell 2 during the period of the observations were extremely intense, with reflectivity core diameters of 10 km and peak updrafts exceeding 20 m s^{-1}. Associated with this MCS were two broad subsidence (warm) regions, both of which had portions over the vortex. The first layer near 700 hPa was directly above the vortex and covered most of it. The second layer near 500 hPa was along the forward and right flanks of cell 2 and undercut the anvil divergence region above. There was not much resemblance of these subsidence layers to typical upper-level warm cores in hurricanes that are necessary to support strong surface winds and a low central pressure. The observations are compared to previous studies of weakly sheared storms and modeling studies of shear effects and intensification.

The configuration of the convective updrafts, low-level circulation, and lack of vertical coherence between the upper- and lower-level warming regions likely inhibited intensification of Chantal. This configuration is consistent with modeled vortices in sheared environments, which suggest the strongest convection and rain in the downshear left quadrant of the storm, and subsidence in the upshear right quadrant. The vertical shear profile is, however, different from what was assumed in previous modeling in that the winds are strongest in the lowest levels and the deep tropospheric vertical shear is on the order of 10–12 m s^{-1}.

1. Introduction

Observational studies have generally found that large-scale vertical shear is unfavorable for tropical storm formation and intensification (e.g., Gray 1968; Zehr 2003). The vertical shear that affects tropical storm intensity is the environmental shear defined as the difference between the 200- and 850-hPa winds averaged over a large area centered on the storm (e.g., DeMaria 1996). All storms have some amount of shear and why certain storms intensify is a fundamental question in hurricane research. Numerical modeling studies have suggested the primary mechanism forcing wavenumber-1 asymmetries in rainfall distributions is vertical shear (e.g., Frank and Ritchie 2001; Bender 1997; Jones 1995). Frank and Ritchie (2001) hypothesized that a large-scale shear imposed on a storm can cause high values of potential vorticity and equivalent potential temperature (θ_e) to mix outward rather than into the eye. This results in a loss of the upper tropospheric warm core in the eye and would tend to weaken the storm by increasing the central pressure. Frank and

Corresponding author address: Gerald M. Heymsfield, NASA GSFC, Code 613.1, Greenbelt, MD 20771.
E-mail: Gerald.heymsfield@nasa.gov

702 JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY VOLUME 45

Precipitation and Latent Heating Distributions from Satellite Passive Microwave Radiometry. Part I: Improved Method and Uncertainties

WILLIAM S. OLSON,[a] CHRISTIAN D. KUMMEROW,[b] SONG YANG,[c] GRANT W. PETTY,[d] WEI-KUO TAO,[e] THOMAS L. BELL,[e] SCOTT A. BRAUN,[e] YANSEN WANG,[a,*] STEPHEN E. LANG,[f] DANIEL E. JOHNSON,[g,#] AND CHRISTINE CHIU[a]

[a] *Joint Center for Earth Systems Technology, University of Maryland, Baltimore County, Baltimore, Maryland*
[b] *Department of Atmospheric Sciences, Colorado State University, Fort Collins, Colorado*
[c] *School of Computational Science, George Mason University, Fairfax, Virginia*
[d] *Department of Atmospheric and Oceanic Sciences, University of Wisconsin—Madison, Madison, Wisconsin*
[e] *Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland*
[f] *Science Systems and Applications, Inc., Lanham, Maryland*
[g] *Goddard Earth Sciences and Technology Center, Greenbelt, Maryland*

(Manuscript received 11 February 2005, in final form 2 September 2005)

ABSTRACT

A revised Bayesian algorithm for estimating surface rain rate, convective rain proportion, and latent heating profiles from satellite-borne passive microwave radiometer observations over ocean backgrounds is described. The algorithm searches a large database of cloud-radiative model simulations to find cloud profiles that are radiatively consistent with a given set of microwave radiance measurements. The properties of these radiatively consistent profiles are then composited to obtain best estimates of the observed properties. The revised algorithm is supported by an expanded and more physically consistent database of cloud-radiative model simulations. The algorithm also features a better quantification of the convective and nonconvective contributions to total rainfall, a new geographic database, and an improved representation of background radiances in rain-free regions. Bias and random error estimates are derived from applications of the algorithm to synthetic radiance data, based upon a subset of cloud-resolving model simulations, and from the Bayesian formulation itself. Synthetic rain-rate and latent heating estimates exhibit a trend of high (low) bias for low (high) retrieved values. The Bayesian estimates of random error are propagated to represent errors at coarser time and space resolutions, based upon applications of the algorithm to TRMM Microwave Imager (TMI) data. Errors in TMI instantaneous rain-rate estimates at 0.5°-resolution range from approximately 50% at 1 mm h^{-1} to 20% at 14 mm h^{-1}. Errors in collocated spaceborne radar rain-rate estimates are roughly 50%–80% of the TMI errors at this resolution. The estimated algorithm random error in TMI rain rates at monthly, 2.5° resolution is relatively small (less than 6% at 5 mm day^{-1}) in comparison with the random error resulting from infrequent satellite temporal sampling (8%–35% at the same rain rate). Percentage errors resulting from sampling decrease with increasing rain rate, and sampling errors in latent heating rates follow the same trend. Averaging over 3 months reduces sampling errors in rain rates to 6%–15% at 5 mm day^{-1}, with proportionate reductions in latent heating sampling errors.

1. Introduction

Over the last decade, diagnostics of time-/space-averaged satellite rainfall estimates have helped to create a better picture of the earth's climate and its variability (e.g., Rasmussen and Arkin 1993; Xie and Arkin 1997; Curtis and Adler 2000; Adler et al. 2003). These studies have relied upon remote sensing of precipitation from infrared, passive microwave, and spaceborne radar measurements, culminating in the Tropical Rainfall Measuring Mission (TRMM; 1997–present). Moreover, it has been amply demonstrated that precipitation measurements from space have had a beneficial impact on general circulation model assimilations and numerical weather prediction model forecasts using data assimilation methods

* Current affiliation: U.S. Army Research Laboratory, AMSRL-CI-EB, Adelphi, Maryland.

\# Current affiliation: Science Applications International Corporation, General Sciences Operation, Beltsville, Maryland.

Corresponding author address: William S. Olson, Goddard Space Flight Center, Code 613.1, Greenbelt, MD 20771.
E-mail: olson@agnes.gsfc.nasa.gov

JAM2369

RETRIEVAL OF LATENT HEATING FROM TRMM MEASUREMENTS

BY W.-K. TAO, E. A. SMITH, R. F. ADLER, Z. S. HADDAD, A. Y. HOU, T. IGUCHI, R. KAKAR, T. N. KRISHNAMURTI, C. D. KUMMEROW, S. LANG, R. MENEGHINI, K. NAKAMURA, T. NAKAZAWA, K. OKAMOTO, W. S. OLSON, S. SATOH, S. SHIGE, J. SIMPSON, Y. TAKAYABU, G. J. TRIPOLI, AND S. YANG

TRMM-based latent heating products—not long ago considered out of our technological reach—are beginning to contribute to global modeling, but the necessary retrieval algorithms produce varying results and will require further research.

Precipitation, in driving the global hydrological cycle, strongly influences the behavior of the Earth's weather and climate systems and is central to their variability. Two-thirds of the global rainfall occurs over the Tropics,[1] which leads to its profound effect on the general circulation of the atmosphere. This is because its energetic equivalent, latent heating (LH), is the tropical convective heat engine's primary fuel source as originally emphasized by Riehl and Malkus (1958). At low latitudes, LH stemming from extended bands of rainfall modulates large-scale zonal and meridional circulations and their consequent mass overturnings (e.g., Hartmann et al. 1984; Hack and Schubert 1990). Also, LH is the principal energy source in the creation, growth, vertical structure, and propagation of long-lived tropical

[1] The Tropics are liberally taken as the area bounded by the 25°N–25°S latitude zone.

AFFILIATIONS: TAO, SMITH, ADLER, HOU, MENEGHINI, AND SIMPSON—Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland; HADDAD—NASA Jet Propulsion Laboratory–California Institute of Technology, Pasadena, California; IGUCHI AND SATOH—National Institute of Information and Communications Technology, Tokyo, Japan; KAKAR—NASA Headquarters, Washington, DC; KRISHNAMURTI—Department of Meteorology, The Florida State University, Tallahassee, Florida; KUMMEROW—Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado; LANG—Science Systems and Applications, Inc., Greenbelt, Maryland; NAKAMURA—Hydrospheric Atmospheric Research Center, Nagoya University, Nagoya, Japan; NAKAZAWA—Japan Meteorological Agency, Meteorological Research Institute, Tsukuba, Japan; OKAMOTO AND SHIGE—Department of Aerospace Engineering, Osaka Prefecture University, Sakai, Osaka, Japan; OLSON—UMBC Joint Center for Earth Systems Technology, Baltimore, Maryland; TAKAYABU—Center for Climate System Research, University of Tokyo, Tokyo, Japan; TRIPOLI—Department of Atmospheric and Oceanic Sciences, University of Wisconsin—Madison, Madison, Wisconsin; YANG—School of Computational Sciences, George Mason University, Fairfax, Virginia
CORRESPONDING AUTHOR: Dr. Wei-Kuo Tao, NASA Goddard Space Flight Center, Code 613.1, Greenbelt, MD 20771
E-mail: tao@agnes.gsfc.nasa.gov

The abstract for this article can be found in this issue, following the table of contents.
DOI:10.1175/BAMS-87-11-1555

In final form 26 May 2006

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D09S09, doi:10.1029/2005JD006429, 2006

Analysis of Raman lidar and radiosonde measurements from the AWEX-G field campaign and its relation to Aqua validation

D. N. Whiteman,[1] F. Russo,[2] B. Demoz,[1] L. M. Miloshevich,[3] I. Veselovskii,[4] S. Hannon,[2] Z. Wang,[5] H. Vömel,[6] F. Schmidlin,[1] B. Lesht,[7] P. J. Moore,[8] A. S. Beebe,[9,10] A. Gambacorta,[2] and C. Barnet[11]

Received 27 June 2005; revised 14 September 2005; accepted 8 November 2005; published 12 April 2006.

[1] Early work within the Aqua validation activity revealed there to be large differences in water vapor measurement accuracy among the various technologies in use for providing validation data. The validation measurements were made at globally distributed sites making it difficult to isolate the sources of the apparent measurement differences among the various sensors, which included both Raman lidar and radiosonde. Because of this, the AIRS Water Vapor Experiment–Ground (AWEX-G) was held in October-November 2003 with the goal of bringing validation technologies to a common site for intercomparison and resolving the measurement discrepancies. Using the University of Colorado Cryogenic Frostpoint Hygrometer (CFH) as the water vapor reference, the AWEX-G field campaign permitted correction techniques to be validated for Raman lidar, Vaisala RS80-H and RS90/92 that significantly improve the absolute accuracy of water vapor measurements from these systems particularly in the upper troposphere. Mean comparisons of radiosondes and lidar are performed demonstrating agreement between corrected sensors and the CFH to generally within 5% thereby providing data of sufficient accuracy for Aqua validation purposes. Examples of the use of the correction techniques in radiance and retrieval comparisons are provided and discussed.

Citation: Whiteman, D. N., et al. (2006), Analysis of Raman lidar and radiosonde measurements from the AWEX-G field campaign and its relation to Aqua validation, *J. Geophys. Res.*, *111*, D09S09, doi:10.1029/2005JD006429.

1. Introduction and Background

[2] The Aqua satellite validation activity funded by NASA includes the use of different water vapor profiling radiosondes and Raman lidar systems for acquisition of measurements during Aqua overpasses. Numerous special measurement campaigns have been staged from various geographic locations in order to acquire data of the highest quality for calibration and validation of the satellite measurements and retrievals. It is fundamentally important that these special data sets possess higher absolute accuracy than required of the satellite data products for this validation technique to work. Early comparisons of many validation measurements with the Atmospheric Infrared Sounder (AIRS), through the use of the AIRS fast forward radiative transfer model, SARTA [*Strow et al.*, 2003], revealed apparent large calibration differences among the various water vapor profiling technologies being used. The differences were largest in the upper troposphere (UT) where differences between AIRS radiances and calculations of AIRS radiance using SARTA, when translated to UT relative humidity (RH), implied differences in the calibration of the water vapor measurement systems that exceeded 25% in some cases. This is to be contrasted with the Aqua retrieval accuracy goal, where a retrieval involves a minimization of differences between observed and calculated radiances, of 10% in 2-km layers. The apparent inadequacy of many of the validation measurement systems to provide data of sufficient quality to validate retrievals at this accuracy level created questions both about the validation sensor technologies and how to improve the quality of water vapor measurements used for Aqua validation. For this reason, a dedicated field program called the AIRS Water Vapor Experiment–Ground (AWEX-G) was held in October-November 2003 with the goal of resolving the measurement

[1]NASA/Goddard Space Flight Center, Greenbelt, Maryland, USA.
[2]Department of Physics, University of Maryland Baltimore County, Baltimore, Maryland, USA.
[3]National Center for Atmospheric Research, Boulder, Colorado, USA.
[4]Goddard Earth Science and Technology Center, University of Maryland Baltimore County, Baltimore, Maryland, USA.
[5]Department of Atmospheric Sciences, University of Wyoming, Laramie, Wyoming, USA.
[6]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado, USA.
[7]U.S. Department of Energy/Argonne National Laboratory, Chicago, Illinois, USA.
[8]LJT and Associates, Wallops Island, Virginia, USA.
[9]SGT, Inc., Greenbelt, Maryland, USA.
[10]Now at Department of Mathematics, University of Maryland Eastern Shore, Princess Anne, Maryland, USA.
[11]NOAA, Camp Springs, Maryland, USA.

0148-0227/06/2005JD006429$09.00

A Numerical Study of Hurricane Erin (2001). Part I: Model Verification and Storm Evolution

LIGUANG WU

Goddard Earth Science and Technology Center, University of Maryland, Baltimore County, Baltimore, Maryland

SCOTT A. BRAUN

Mesoscale Atmospheric Processes Branch, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland

J. HALVERSON

Joint Center for Earth Systems Technology, University of Maryland, Baltimore County, Baltimore, Maryland

G. HEYMSFIELD

Mesoscale Atmospheric Processes Branch, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland

(Manuscript received 7 November 2003, in final form 4 February 2005)

ABSTRACT

The fifth-generation Pennsylvania State University–National Center for Atmospheric Research (PSU–NCAR) Mesoscale Model (MM5) is used to simulate Hurricane Erin (2001) at high resolution (4-km spacing) from its early development as a tropical depression on 7 September 2001, through a period of rapid intensification into a strong hurricane (8–9 September), and finally into a stage during which it maintains its intensity on 10 September. These three stages of formation, intensification, and maintenance in the simulation are in good agreement with the observed evolution of Erin. The simulation shows that during the formation and early portions of the intensification stages, intensification is favored because the environmental wind shear is weak and the system moves over a warm tongue of water. As Erin intensifies, the wind shear gradually increases with the approach of an upper-level trough and strengthening of a low-level high pressure system. By 10 September, the wind shear peaks and begins to decrease, the storm moves over slightly cooler waters, and the intensification ends. Important structural changes occur at this time as the outer precipitation shifts from the northeastern and eastern sides to the western side of the eye. A secondary wind maximum and an outer eyewall begin to develop as precipitation begins to surround the entire eye.

The simulation is used to investigate the role of vertical wind shear in the changes of the precipitation structure that took place between 9 and 10 September by examining the effects of changes in storm-relative flow and changes in the shear-induced tilt. Qualitative agreement is found between the divergence pattern and advection of vorticity by the relative flow with convergence (divergence) generally associated with asymmetric inflow (outflow) in the eyewall region. The shift in the outer precipitation is consistent with a shift in the low-level relative inflow from the northeastern to the northwestern side of the storm. The changes in the relative flow are associated with changes in the environmental winds as the hurricane moves relative to the upper trough and the low-level high pressure system. Examination of the shear-induced tilt of the vortex shows that the change in the tilt direction is greater than that of the shear direction as the tilt shifts from a northerly orientation to northwesterly. Consistent with theory for adiabatic vortices, the maximum low-level convergence and upper-level divergence (and the maximum upward motion) occurs in the direction of tilt. Consequently, both mechanisms may play roles in the changes in the precipitation pattern.

Corresponding author address: Dr. Liguang Wu, Mesoscale Atmospheric Processes Branch, Laboratory for Atmospheres, NASA GSFC, Code 613.1, Greenbelt, MD 20771.
E-mail: liguang@agnes.gsfc.nasa.gov

Precipitation and Latent Heating Distributions from Satellite Passive Microwave Radiometry. Part II: Evaluation of Estimates Using Independent Data

SONG YANG

School of Computational Science, George Mason University, Fairfax, Virginia

WILLIAM S. OLSON

Joint Center for Earth Systems Technology, University of Maryland, Baltimore County, Baltimore, Maryland

JIAN-JIAN WANG

Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, Maryland

THOMAS L. BELL AND ERIC A. SMITH

Goddard Space Flight Center, Greenbelt, Maryland

CHRISTIAN D. KUMMEROW

Colorado State University, Fort Collins, Colorado

(Manuscript received 11 February 2005, in final form 2 September 2005)

ABSTRACT

Rainfall rate estimates from spaceborne microwave radiometers are generally accepted as reliable by a majority of the atmospheric science community. One of the Tropical Rainfall Measuring Mission (TRMM) facility rain-rate algorithms is based upon passive microwave observations from the TRMM Microwave Imager (TMI). In Part I of this series, improvements of the TMI algorithm that are required to introduce latent heating as an additional algorithm product are described. Here, estimates of surface rain rate, convective proportion, and latent heating are evaluated using independent ground-based estimates and satellite products. Instantaneous, 0.5°-resolution estimates of surface rain rate over ocean from the improved TMI algorithm are well correlated with independent radar estimates (r ~0.88 over the Tropics), but bias reduction is the most significant improvement over earlier algorithms. The bias reduction is attributed to the greater breadth of cloud-resolving model simulations that support the improved algorithm and the more consistent and specific convective/stratiform rain separation method utilized. The bias of monthly 2.5°-resolution estimates is similarly reduced, with comparable correlations to radar estimates. Although the amount of independent latent heating data is limited, TMI-estimated latent heating profiles compare favorably with instantaneous estimates based upon dual-Doppler radar observations, and time series of surface rain-rate and heating profiles are generally consistent with those derived from rawinsonde analyses. Still, some biases in profile shape are evident, and these may be resolved with (a) additional contextual information brought to the estimation problem and/or (b) physically consistent and representative databases supporting the algorithm. A model of the random error in instantaneous 0.5°-resolution rain-rate estimates appears to be consistent with the levels of error determined from TMI comparisons with collocated radar. Error model modifications for nonraining situations will be required, however. Sampling error represents only a portion of the total error in monthly 2.5°-resolution TMI estimates; the remaining error is attributed to random and systematic algorithm errors arising from the physical inconsistency and/or nonrepresentativeness of cloud-resolving-model-simulated profiles that support the algorithm.

Corresponding author address: Dr. Song Yang, Goddard Space Flight Center, Code 613.1, Greenbelt, MD 20771.
E-mail: ysong@agnes.gsfc.nasa.gov

JAM2370

5190 JOURNAL OF CLIMATE VOLUME 19

Mechanisms for Diurnal Variability of Global Tropical Rainfall Observed from TRMM

Song Yang

School of Computational Sciences, George Mason University, Fairfax, Virginia

Eric A. Smith

NASA Goddard Space Flight Center, Greenbelt, Maryland

(Manuscript received 8 April 2005, in final form 11 January 2006)

ABSTRACT

The behavior and various controls of diurnal variability in tropical–subtropical rainfall are investigated using Tropical Rainfall Measuring Mission (TRMM) precipitation measurements retrieved from the three level-2 TRMM standard profile algorithms for the 1998 annual cycle. Results show that diurnal variability characteristics of precipitation are consistent for all three algorithms, providing assurance that TRMM retrievals are producing consistent estimates of rainfall variability. As anticipated, most ocean areas exhibit more rainfall at night, while over most land areas, rainfall peaks during daytime; however, important exceptions are noted.

The dominant feature of the oceanic diurnal cycle is a rainfall maximum in late-evening–early-morning (LE–EM) hours, while over land the dominant maximum occurs in the mid- to late afternoon (MLA). In conjunction with these maxima are pronounced seasonal variations of the diurnal amplitudes. Amplitude analysis shows that the diurnal pattern and its seasonal evolution are closely related to the rainfall accumulation pattern and its seasonal evolution. In addition, the horizontal distribution of diurnal variability indicates that for oceanic rainfall, there is a secondary MLA maximum coexisting with the LE–EM maximum at latitudes dominated by large-scale convergence and deep convection. Analogously, there is a preponderancy for an LE–EM maximum over land coexisting with the stronger MLA maximum, although it is not evident that this secondary continental feature is closely associated with the large-scale circulation. Neither of the secondary maxima exhibit phase behavior that can be considered semidiurnal in nature. Diurnal rainfall variability over the ocean associated with large-scale convection is clearly an integral component of the general circulation.

Phase analysis reveals differences in regional and seasonal features of the diurnal cycle, indicating that underlying forcing mechanisms differ from place to place. This is underscored by the appearance of secondary ocean maxima in the presence of large-scale convection, along with other important features. Among these, there are clear-cut differences between the diurnal variability of seasonal rainfall over the mid-Pacific and Indian Ocean Basins. The mid-Pacific exhibits double maxima in spring and winter but only LE–EM maxima in summer and autumn, while the Indian Ocean exhibits double maxima in spring and summer and only an LE–EM maximum in autumn and winter. There are also evident daytime maxima within the major large-scale marine stratocumulus regions off the west coasts of continents. The study concludes with a discussion concerning how the observational evidence either supports or repudiates possible forcing mechanisms that have been suggested to explain diurnal rainfall variability.

1. Introduction

Diurnal variation of precipitation on planet Earth was first reported in the early twentieth century by Hann (1901, 338–346) and since that time has spawned an immense literature. In general, rainfall maxima in the late-evening–early-morning hours (LE–EM) have been reported for open-ocean environments (e.g., Kraus 1963; Andersson 1970; Gray and Jacobson 1977; Jordon 1980; Albright et al. 1985; Randall et al. 1991; Imaoka and Spencer 2000), while mid- to late afternoon (MLA) maxima have often been reported for land (e.g., Ray 1928; Cook 1939; Kousky 1980; Hamilton 1981; Garreaud and Wallace 1997). However, such generalities do not describe all the intricacies inherent to rainfall's diurnal cycle, and both past observational rainfall

Corresponding author address: Dr. Eric A. Smith, NASA Goddard Space Flight Center, Mail Code 613.1, Greenbelt, MD 20771. E-mail: eric.a.smith@nasa.gov

JCLI3883

Chapter 5 in **Earth Science Satellite Remote Sensing, Science and Instruments, Vol I**, edited by J. J. Qu, W. Gao, M. Kafatos, R. E. Murphy, and V. V. Salomonson, pp. 74-91, Tsinghua University Press (Beijing) and Springer-Verlag (Berlin).

5 Introduction to MODIS Cloud Products

Bryan A. Baum and Steven Platnick

5.1 Introduction

The Earth's radiative energy balance and hydrological cycle are fundamentally coupled with the distribution and properties of clouds. Therefore, the ability to remotely infer cloud properties and their variation in space and time is crucial for establishing climatologies as a reference for validation of present-day climate models and in assessing future climate change. Remote cloud observations also provide data sets useful for testing and improving cloud model physics, and for assimilation into numerical weather prediction models.

The MODerate Resolution Imaging Spectroradiometer (MODIS) imagers on the Terra and Aqua Earth Observing System (EOS) platforms provide the capability for globally retrieving these properties using passive solar reflectance and infrared techniques. In addition to providing measurements similar to those offered on a suite of historical operational weather platforms such as the Advanced Very High Resolution Radiometer (AVHRR), the High-resolution Infrared Radiation Sounder (HIRS), and the Geostationary Operational Environmental Satellite (GOES), MODIS provides additional spectral and/or spatial resolution in key atmospheric bands, along with on-board calibration, to expand the capability for global cloud property retrievals.

The core MODIS operational cloud products include cloud top pressure, thermodynamic phase, optical thickness, particle size, and water path, and are derived globally at spatial resolutions of either 1- or 5-km (referred to as Level-2 or pixel-level products). In addition, the MODIS atmosphere team (collectively providing cloud, aerosol, and clear sky products) produces a combined gridded product (referred to as Level-3) aggregated to a 1° equal-angle grid, available for daily, eight-day, and monthly time periods. The wealth of information available from these products provides critical information for climate studies as well as the continuation and improved understanding of existing satellite-based cloud climatologies derived from heritage instruments.

This chapter provides an overview of the MODIS Level-2 and -3 operational cloud products. All products described in this chapter are available from the NASA Goddard Earth Sciences Distributed Active Archive Center (GES DAAC). However, the MODIS instrument has direct broadcast capability on both the Terra and Aqua platforms. Ground stations that obtain the MODIS data as the spacecraft

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L05807, doi:10.1029/2005GL024926, 2006

Comparisons of remote sensing retrievals and in situ measurements of aerosol fine mode fraction during ACE-Asia

Santiago Gassó[1] and Norm O'Neill[2]

Received 19 October 2005; revised 16 December 2005; accepted 23 January 2006; published 8 March 2006.

[1] We present sunphotometer-retrieved and in situ fine mode fractions (FMF) measured onboard the same aircraft during the ACE-Asia experiment. Comparisons indicate that the latter can be used to identify whether the aerosol under observation is dominated by a mixture of modes or a single mode. Differences between retrieved and in situ FMF range from 5–20%. When profiles contained multiple layers of aerosols, the retrieved and measured FMF were segregated by layers. The comparison of layered and total FMF from the same profile indicates that columnar values are intermediate to those derived from layers. As a result, a remotely sensed FMF cannot be used to distinguish whether the aerosol under observation is composed of layers each with distinctive modal features or all layers with the same modal features. Thus, the use of FMF in multiple layer environments does not provide unique information on the aerosol under observation. **Citation:** Gassó, S., and N. O'Neill (2006), Comparisons of remote sensing retrievals and in situ measurements of aerosol fine mode fraction during ACE-Asia, *Geophys. Res. Lett.*, *33*, L05807, doi:10.1029/2005GL024926.

1. Introduction

[2] Automated retrievals of aerosol optical depth (AOD) by spaceborne detectors have significantly improved our knowledge of the global distribution of aerosols [*Kaufman et al.*, 2002]. In addition, they have provided a measurement based verification of aerosol forcing derived from global aerosol models [*Penner et al.*, 2002]. However, passive remote sensing techniques have not had the same degrees of success in detecting aerosol size distribution properties. A proper global characterization of size distribution properties is important because it would improve the simulation of microphysical properties in global aerosol models [*Zhang et al.*, 2002]. The concept of fine mode fraction (FMF) has been introduced to describe columnar aerosol modal features using passive spectral detectors such as MODIS [*Tanré et al.*, 1997]. FMF is defined as the ratio of the accumulation mode OD to the total OD at 550 nm. It provides quantitative information on the nature of the aerosol size distribution. The FMF is defined such that it ranges from 0 to 1. The extreme values represent pure conditions where the total radiance can be modeled by a single accumulation mode (FMF = 1) or a single coarse mode (FMF = 0). For intermediate values, both modes contribute to the total radiance with each contributing to the total AOD in proportion to FMF and 1-FMF respectively [*Remer et al.*, 2005]. Because of its close association with modal features, the MODIS FMF product has been used for discriminating between natural and anthropogenic aerosols [*Kaufman et al.*, 2005]. Few studies have been dedicated to comparisons of FMF with corresponding ground retrievals or in situ measurements. Because it is rather difficult to carry out campaigns of aircraft aerosol measurements synchronized to satellite overpass times, comparisons with in situ measurements have been limited to case studies [*Gassó and Hegg*, 2003]. *Kleidman et al.* [2005] compared MODIS FMF retrievals with collocated AOD measurements made by the AERONET network using two retrieval techniques, one based on the existing operational retrieval [*Dubovik and King*, 2000] and the other using the *O'Neill et al.* [2003] technique. The latter method relies on AOD spectral derivatives to extract FMF whereas the former is employed to retrieve aerosol modal properties from the angular and/or spectral variation of sky radiances and solar extinction measurements. Unlike the Dubovik method, the O'Neill retrieval technique is used to derive FMF directly from OD spectra. It is attractive given the significantly greater frequency and weaker cloud contamination of AOD measurements (as opposed to the less frequent measurements in the Dubovik inversion). It also has the potential of being easily implemented as a MODIS FMF retrieval algorithm, and thus provides an alternative to the existing technique. The latest version of the model is employed here [*O'Neill et al.*, 2005].

[3] We applied the O'Neill technique to AODs retrieved by the AATS-6 sunphotometer onboard the NCAR C130 aircraft deployed during the ACE-Asia campaign [*Redemann et al.*, 2003]. The same aircraft carried a suite of in situ aerosol instrumentation [*Clarke et al.*, 2004]. Of particular interest are the measurements of total and accumulation mode extinction coefficients from which it is possible to integrate over the column and obtain an in situ FMF. The analysis and comparison between these measurements and the collocated AATS-6 retrievals are reported in this study.

2. Data Set

[4] In this study, we employed the same profiles utilized by *Redemann et al.* [2003] with an additional criterion in the data selection: particle size distribution measurements had to be simultaneously available with the nephelometer and sunphotometer data. In this way, distinction of aerosol type could be made based on number and volume concentration. As a result, some of the profiles were discarded because the optical particle counter was not functioning or

[1]Goddard Earth Science and Technology Center, University of Maryland Baltimore County, Baltimore, Maryland, USA.
[2]Centre d'Applications et de Recherches en Télédétection, Université de Sherbrooke, Sherbrooke, Quebec, Canada.

0094-8276/06/2005GL024926$05.00

3180 IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 44, NO. 11, NOVEMBER 2006

Deep Blue Retrievals of Asian Aerosol Properties During ACE-Asia

N. Christina Hsu, Si-Chee Tsay, Michael D. King, *Senior Member, IEEE*, and Jay R. Herman

***Abstract*—During the ACE-Asia field campaign, unprecedented amounts of aerosol property data in East Asia during springtime were collected from an array of aircraft, shipboard, and surface instruments. However, most of the observations were obtained in areas downwind of the source regions. In this paper, the newly developed satellite aerosol algorithm called "Deep Blue" was employed to characterize the properties of aerosols over source regions using radiance measurements from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS). Based upon the Ångström exponent derived from the Deep Blue algorithm, it was demonstrated that this new algorithm is able to distinguish dust plumes from fine-mode pollution particles even in complex aerosol environments such as the one over Beijing. Furthermore, these results were validated by comparing them with observations from AERONET sites in China and Mongolia during spring 2001. These comparisons show that the values of satellite-retrieved aerosol optical thickness from Deep Blue are generally within 20%–30% of those measured by sunphotometers. The analyses also indicate that the roles of mineral dust and anthropogenic particles are comparable in contributing to the overall aerosol distributions during spring in northern China, while fine-mode particles are dominant over southern China. The spring season in East Asia consists of one of the most complex environments in terms of frequent cloudiness and wide ranges of aerosol loadings and types. This paper will discuss how the factors contributing to this complexity influence the resulting aerosol monthly averages from various satellite sensors and, thus, the synergy among satellite aerosol products.**

***Index Terms*—Aerosols, desert, Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging Spectro-Radiometer (MISR), remote sensing, satellite applications, Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Terra.**

I. INTRODUCTION

THE IMPACT of growing air pollution in Asia, and in other parts of the world, has gained attention from the scientific community in recent years. Among the many components that contribute to such pollution, airborne mineral dust plays an important role due to its biogeochemical impact on the ecosystem and its radiative-forcing effect on the climate system [8], [13]. In East Asia, dust storms frequently accompany the cold and dry air masses that occur as part of springtime cold front systems. China's capital, Beijing, and other large cities are on the primary pathway of these dust storm plumes, and their passage over such population centers causes flight delays, pushes grit through windows and doors, and forces people indoors. Furthermore, during spring, these anthropogenic and natural air pollutants, once generated over the source regions, can be transported out of the boundary layer into the free troposphere and can travel thousands of kilometers across the Pacific into the U.S. and beyond. Satellite views, as shown in Fig. 1, illustrate the vast distances over which these Asian dust plumes can extend. Once caught by the westerly jet, these pollutant clouds have been shown to reach as far as North America [28] and the French Alps [7].

Because of their complexity, it is especially important to understand the processes controlling the formation, transport, and fate of aerosol types occurring from East Asian source regions into areas downstream. The properties of Asian dust and anthropogenic pollution aerosols have been extensively studied using information collected during the ACE-Asia field campaign [15]. Yet most of the observations during the experiment were obtained in areas downwind of the source region. This is because retrieving aerosol properties over dust source regions (i.e., arid and semiarid regions) using traditional Advanced Very High Resolution Radiometer (AVHRR) channels in the visible and near-infrared wavelengths is a difficult task because of the bright underlying surfaces over such regions [18]. There have been several approaches developed to retrieve aerosol optical properties over the desert, including contrast reduction (atmospheric blurring) and thermal property techniques [26], [27]. However, since contrast reduction using visible wavelengths depends on the selection of highly contrasted areas as retrieval targets, this approach might not be straightforward for most desert regions. For thermal techniques, the separation of the signal due to mineral aerosols from that due to background temperature and water vapor signals of the terrestrial environment can be complicated and unreliable, particularly over semiarid regions. The latter (i.e., thermal approach), in particular, presents a difficult problem for retrieving aerosol properties in East Asia since the amounts of atmospheric water vapor, aerosol plume height, and surface temperature and emissivity are highly variable and not well known during spring.

In this paper, we present results on retrieved aerosol properties over source regions in East Asia by employing a newly developed aerosol algorithm called "Deep Blue" on satellite radiance measurements taken from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS). The detailed description of the Deep Blue algorithm and its application to derive aerosol properties over the Sahara Desert were previously discussed in [14]. In Section II, we first discuss the results of theoretical simulations performed to examine the advantages and disadvantages of retrieving aerosol properties using different satellite channels from the ultraviolet (UV) to the visible part of spectrum. A brief overview of the Deep Blue algorithm and the derived spectral characteristics of surface reflectance for

Manuscript received March 8, 2006; revised May 25, 2006. This work was supported by the National Aeronautics and Space Administration's EOS program.

The authors are with the Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA (e-mail: christina.hsu@nasa.gov).

Digital Object Identifier 10.1109/TGRS.2006.879540

damping. None of the above processes in early lunar evolution are well explored.

References and Notes

1. P.-S. Laplace, *Traité de Mécanique Céleste* (Paris Duprat, Bachlier 1798-1827), vol. 2, book 5, chap. 2.
2. W. F. Sedgwick, *Messenger Math.* **27**, 171 (1898).
3. H. Jeffreys, *Mem. R. Astron. Soc.* **60**, 187 (1915).
4. H. Jeffreys, *Mon. Not. R. Astron. Soc. Geophys. Suppl.* **4**, 1 (1937).
5. H. Jeffreys, *The Earth* (Cambridge Univ. Press, Cambridge, 1970).
6. A. S. Konopliv *et al.*, *Science* **281**, 1476 (1998).
7. J. G. Williams, D. H. Boggs, C. F. Yoder, J. T. Ratcliff, J. O. Dickey, *J. Geophys. Res.* **106**, 27933 (2001).
8. Z. Kopal, *Proc. R. Soc. London Ser. A* **296**, 254 (1967).
9. P. Goldreich, A. Toomre, *J. Geophys. Res.* **74**, 2555 (1969).
10. M. Lefftz, H. Legros, *Phys. Earth Planet. Inter.* **76**, 317 (1993).
11. K. Lambeck, S. Pullan, *Phys. Earth Planet. Inter.* **22**, 29 (1980).
12. S. K. Runcorn, *Nature* **195**, 1150 (1962).
13. P. Cassen, R. E. Young, G. Schubert, *Geophys. Res. Lett.* **5**, 294 (1978).
14. D. J. Stevenson, *Proc. Lunar Planet. Sci. Conf.* XXXII, abstract 1175 (2001).
15. S. Zhong, M. T. Zuber, *J. Geophys. Res.* **105**, 4153 (2000).
16. G. A. Neumann, M. T. Zuber, D. E. Smith, F. G. Lemoine, *J. Geophys. Res.* **101**, 16841 (1996).
17. T. Kleine, H. Palme, K. Mezger, A. N. Halliday, *Science* **310**, 1671 (2005).
18. C. D. Murray, S. F. Dermott, *Solar System Dynamics* (Cambridge Univ. Press, Cambridge, 1999).
19. J. Touma, J. Wisdom, *Astron. J.* **108**, 1943 (1994).
20. R. D. Ray, R. J. Eanes, F. G. Lemoine, *Geophys. J. Int.* **144**, 471 (2001).
21. The Hansen functions, $X_{l,p,q}$ (e), satisfy $\left(\frac{R}{a}\right)^{l}\cos(pf) = \sum_{q} X_{l,p,q}(e)\cos(q\tilde{M})$ (*32*), where f is the true anomaly and $\tilde{M}$ is the mean anomaly. For our purposes, $l = -3$. The Hansen functions are also called Hansen coefficients, and the expansions in e to fourth order can be found in table 3.2 of (*33*), albeit with a different subscript convention.
22. S. J. Peale, P. Cassen, *Icarus* **36**, 245 (1978).
23. C. F. Yoder, in *Global Earth Physics*, T. J. Ahrens, Ed. (American Geophysical Union, Washington, DC, 1995), p. 1.
24. The simple average of two different sets of parameters β, γ, and C_{20} may take place during the transition from the state of low relaxation time to the state of long relaxation time. During this time, the Moon is plastic enough to accommodate changes in form, yet stiff enough to retain some signature of its state when freeze-in started. Indeed, the Moon is necessarily a sum of different orbits, however close or far apart, if the fossil bulge hypothesis is valid.
25. P. Goldreich, *Mon. Not. R. Astron. Soc.* **126**, 257 (1963).
26. S. J. Peale, *Celest. Mech. Dyn. Astron.* **87**, 129 (2003).
27. J. Touma, J. Wisdom, *Astron. J.* **115**, 1653 (1998).
28. E. Kokubo, S. Ida, J. Makino, *Icarus* **148**, 419 (2000).
29. P. Goldreich, S. J. Peale, *Astron. J.* **71**, 425 (1966).
30. S. J. Peale, in *Satellites*, J. A. Burns, Ed. (Univ. of Arizona Press, Tucson, 1978), p. 87.
31. Mercury's unnormalized coefficients $C_{20} = 6 \times 10^{-5} \pm 2.0$ and $C_{22} = 1 \times 10^{-5} \pm 0.5$ (*34*) are not reproduced by any orbit-spin resonance at Mercury's current semimajor axis.
32. H. C. Plummer, *An Introductory Treatise on Dynamical Astronomy* (Dover, New York, 1960).
33. W. M. Kaula, *Theory of Satellite Geodesy* (Dover, New York, 1966).
34. J. D. Anderson, G. Colombo, P. B. Esposito, E. L. Lau, G. B. Trager, *Icarus* **71**, 337 (1987).
35. We are grateful to B. Hager and B. Weiss for helpful comments. This work was supported by NASA Planetary Geology and Geophysics Program grants (to M.T.Z. and J.W.).

3 April 2006; accepted 8 June 2006
10.1126/science.1128237

Smoke and Pollution Aerosol Effect on Cloud Cover

Yoram J. Kaufman[1] and Ilan Koren[2*]

Pollution and smoke aerosols can increase or decrease the cloud cover. This duality in the effects of aerosols forms one of the largest uncertainties in climate research. Using solar measurements from Aerosol Robotic Network sites around the globe, we show an increase in cloud cover with an increase in the aerosol column concentration and an inverse dependence on the aerosol absorption of sunlight. The emerging rule appears to be independent of geographical location or aerosol type, thus increasing our confidence in the understanding of these aerosol effects on the clouds and climate. Preliminary estimates suggest an increase of 5% in cloud cover.

Aerosol particles originating from urban and industrial pollution or smoke from fires have been shown to affect cloud microphysics, cloud reflection of sunlight to space, and the onset of precipitation (*1*, *2*). Delays in the onset of precipitation can increase the cloud lifetime and thereby increase cloud cover (*3*, *4*). Research on the aerosol effect on clouds and precipitation has been conducted for half a century (*5*). Although we well understand the aerosol effect on cloud droplet size and reflectance, its impacts on cloud dynamics and regional circulation are highly uncertain (*3*, *5–9*) because of limited observational information and complex processes that are hard to simulate in atmospheric models (*10*, *11*). Indeed, global model estimates of the radiative forcing due to the aerosol effect on clouds range from 0 to –5 W/m². The reduction of this uncertainty is a major challenge in improving climate models.

[1]NASA/Goddard Space Flight Center, 613.2, Greenbelt, MD 20771, USA. [2]Department of Environmental Sciences and Energy Research, Weizmann Institute, Rehovot 76100, Israel.

*To whom correspondence should be addressed. E-mail: ilan.koren@weizmann.ac.il

Satellite measurements show strong systematic correlations among aerosol loading, cloud cover (*12*), and cloud height over the Atlantic Ocean (*13*) and Europe (*14*), making the model estimates of aerosol forcing even more uncertain. However, heavy smoke over the Amazon forest (*15*) and pollution over China (*16*) decrease the cloud cover by heating the atmosphere and cooling the surface (*17*) and may balance some of this large negative forcing. Global climate models also show a reduction in cloud cover due to aerosol absorption (τ_{abs}) outside (*18*) and inside the clouds (*19*). In addition, the aerosol effect on slowing down the hydrological cycle by cooling parts of the oceans (*1*) may further reduce cloud formation and the aerosol forcing. Understanding these aerosol effects on clouds and climate requires concentrated efforts of measurement and modeling of the effects.

There are several complications to devising a strategy to measure the aerosol effect on clouds. Although clouds are strongly affected by varying concentrations of aerosol particles, they are driven by atmospheric moisture and stability. Local variations in atmospheric moisture can affect both cloud formation and aerosol humidification, resulting in apparent correlations between aerosol column concentration and cloud cover (*12*, *13*, *20*). In addition, chemical processing of sulfates in clouds can affect the aerosol mass concentration for aerosol dominated by sulfates.

We attempt to address these issues by introducing an additional measurement dimension. We stratified the measurements of the aerosol effect on cloud cover as a function of τ_{abs} of sunlight, thus merging in one experiment both the aerosol enhancement and inhibition of cloud cover. Because the concentration of the absorbing component of aerosols is a function of the aerosol chemical composition, rather than aerosol humidification in the vicinity of clouds, this concentration can serve as a signature for the aerosol effect on clouds. A robust correlation of cloud cover with aerosol column concentration and τ_{abs} in different locations around the world can strengthen the quantification of the aerosol effect on cloud cover, though a direct cause-and-effect relationship will await detailed model simulations.

Table 1. Slopes and intercepts of $\Delta f_{ci}/\Delta \ln\tau$ versus τ_{abs} (Fig. 3A) for the complete data set (All data), continental data dominated by air pollution aerosol, coastal stations, and stations dominated by biomass burning. Results are given for (i) absolute change of the independent cloud fraction Δf_{ci} versus the optical depth $\Delta f_{ci}/\Delta \ln\tau$ and for (ii) partial change $\delta f_{ci}/\delta \ln\tau$ from a multiple regression of Δf_{ci} with $\ln\tau$ and total precipitable water vapor.

	Slope versus τ_{abs}		Intercept for $\tau_{abs} = 0$	
	$\Delta f_{ci}/\Delta \ln\tau$	$\delta f_{ci}/\delta \ln\tau$	$\Delta f_{ci}/\Delta \ln\tau$	$\delta f_{ci}/\delta \ln\tau$
All data	–3.5	–2.6	0.17	0.13
Continental	–3.2	–2.6	0.16	0.13
Coastal	–3.4	–1.9	0.17	0.11
Biomass burning	–4.0	–3.5	0.18	0.14

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D09207, doi:10.1029/2005JD006686, 2006

Impact of three-dimensional radiative effects on satellite retrievals of cloud droplet sizes

Alexander Marshak,[1] Steven Platnick,[1] Tamás Várnai,[2] Guoyong Wen,[3] and Robert F. Cahalan[1]

Received 19 September 2005; revised 16 December 2005; accepted 25 January 2006; published 13 May 2006.

[1] There are several dozen papers that study the effects of cloud horizontal inhomogeneity on the retrievals of cloud optical thickness, but only a few of them deal with cloud droplet sizes. This paper is one of the first comprehensive attempts to fill this gap: It takes a close theoretical look at the radiative effects of cloud 3-D structure in retrievals of droplet effective radii. Under some general assumptions, it was found that ignoring subpixel (unresolved) variability produces a negative bias in the retrieved effective radius, while ignoring cloud inhomogeneity at scales larger than a pixel scale (resolved variability), on the contrary, leads to overestimation of the domain average droplet size. The theoretical results are illustrated with examples from Large Eddy Simulations (LES) of cumulus (Cu) and stratocumulus (Sc) cloud fields. The analysis of cloud drop size distributions retrieved from both LES fields confirms that ignoring shadowing in 1-D retrievals results in substantial overestimation of effective radii which is more pronounced for broken Cu than for Sc clouds. Collocated measurements of broken Cu clouds by Moderate Resolution Imaging Spectrometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) are used to check simulations and theory with observations. The analysis of ASTER and MODIS data and associated derived products recommends against blindly using retrieved effective radii for broken cloud fields, especially if one wants to relate aerosol amounts to cloud droplet sizes.

Citation: Marshak, A., S. Platnick, T. Várnai, G. Wen, and R. F. Cahalan (2006), Impact of three-dimensional radiative effects on satellite retrievals of cloud droplet sizes, *J. Geophys. Res.*, *111*, D09207, doi:10.1029/2005JD006686.

1. Introduction

[2] There are several dozen papers that discuss the radiative effects of cloud three-dimensional (3-D) structure on the one-dimensional (1-D) retrievals of cloud optical thickness [e.g., *Marshak et al.*, 1995; *Loeb and Davies*, 1996; *Chambers et al.*, 1997; *Davis et al.*, 1997; *Loeb and Coakley*, 1998; *Zuidema and Evans*, 1998; *Várnai and Marshak*, 2001, 2002a; *Iwabuchi and Hayasaka*, 2002; *Horváth and Davies*, 2004]. Most of these studies assume a "conventional" 10-μm droplet effective radius and variable cloud optical thickness. Though the operational remote sensing of cloud optical properties from multispectral measurements [*Nakajima and King*, 1990; *Platnick et al.*, 2003] typically retrieves cloud optical thickness and effective radius simultaneously, there are only a few papers that, in addition to cloud optical thickness, estimate the effect of cloud inhomogeneity on 1-D retrievals of the droplet effective radius [*Faure et al.*, 2002; *Cornet et al.*, 2004, 2005; *Várnai and Marshak*, 2002b; *Iwabuchi and Hayasaka*, 2003].

[3] Except for Polarization and Directionality of the Earth's Reflectances (POLDER) that retrieves (though not operationally) cloud droplet effective radius from polarization measurements of the reflected light using "cloudbow" (or rainbow) at scattering angles between 150° and 170° [*Deschamps et al.*, 1994; *Bréon and Goloub*, 1998; *Bréon and Doutriaux-Boucher*, 2005], all operational retrievals of cloud droplet size are based on spectral observations [e.g., *Nakajima and King*, 1990]. For the Moderate Resolution Imaging Spectrometer (MODIS), a pair $\{\tau, r_e\}$ that represents cloud optical thickness and droplet effective radius, respectively, is derived for each cloudy 1 km by 1 km pixel from various two band combinations: typically one bulk water-absorption band {1.6, 2.1, or 3.7 μm} and one nonabsorbing (or relatively nonabsorbing) band {0.65, 0.86, or 1.2 μm} [*Platnick et al.*, 2003]. The choice of nonabsorbing band depends on the underlying surface. Since water absorbs differently in the three MODIS absorbing bands, use of the less absorbing 1.6-μm band and the more absorbing 3.7-μm band complement use of the 2.1-μm band for assessing the vertical variation of droplet size in the

[1]NASA Goddard Space Flight Center, Climate and Radiation Branch, Maryland, USA.
[2]Joint Center for Earth System Technology, University of Maryland Baltimore County, Baltimore, Maryland, USA.
[3]Goddard Earth Sciences and Technology Center, University of Maryland Baltimore County, Baltimore, Maryland, USA.

0148-0227/06/2005JD006686$09.00

Atmos. Chem. Phys., 6, 237–253, 2006
www.atmos-chem-phys.org/acp/6/237/
SRef-ID: 1680-7324/acp/2006-6-237
European Geosciences Union

Atmospheric Chemistry and Physics

Aerosol direct radiative effect at the top of the atmosphere over cloud free ocean derived from four years of MODIS data

L. A. Remer and Y. J. Kaufman

Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt MD, USA

Received: 3 May 2005 – Published in Atmos. Chem. Phys. Discuss.: 18 July 2005
Revised: 11 October 2005 – Accepted: 14 December 2005 – Published: 30 January 2006

Abstract. A four year record of MODIS spaceborne data provides a new measurement tool to assess the aerosol direct radiative effect at the top of the atmosphere. MODIS derives the aerosol optical thickness and microphysical properties from the scattered sunlight at 0.55–2.1 μm. The monthly MODIS data used here are accumulated measurements across a wide range of view and scattering angles and represent the aerosol's spectrally resolved angular properties. We use these data consistently to compute with estimated accuracy of $\pm 0.6\,\mathrm{W\,m^{-2}}$ the reflected sunlight by the aerosol over global oceans in cloud free conditions. The MODIS high spatial resolution (0.5 km) allows observation of the aerosol impact between clouds that can be missed by other sensors with larger footprints. We found that over the clear-sky global ocean the aerosol reflected $5.3 \pm 0.6\,\mathrm{Wm^{-2}}$ with an average radiative efficiency of $-49 \pm 2\,\mathrm{Wm^{-2}}$ per unit optical thickness. The seasonal and regional distribution of the aerosol radiative effects are discussed. The analysis adds a new measurement perspective to a climate change problem dominated so far by models.

1 Introduction

Traditionally, chemical transport and general circulation models enjoyed a monopoly on estimating the role of aerosols in the Earth's climate. Model results form the basis of almost every previous estimate of the aerosol effect on climate (IPCC, 2001). Observations of aerosols from ground-based, airborne or satellite instruments are used only to validate these models. The prevailing strategy dictates that measurements improve models, and then models, not measurements, answer climate questions. However, there is a wide range of discrepancy in model results because of the many inherent assumptions involved in modeling the aerosol effect on climate. Models must properly estimate the source terms of the many aerosol species, properly model the aerosol sink terms, and simulate the transport. Even if the model properly simulates the global distribution of aerosol concentration, assumptions have to be made of the aerosol optical properties in order to convert mass concentrations to the radiative fluxes. Because of the complexity of the problem, it is no wonder that the uncertainties in estimating aerosol effects on climate are growing, rather than shrinking.

To narrow the uncertainties associated with estimating aerosol effects on climate, the time has come to include measurement-based estimates of aerosol radiative effects and forcing. With the launch of EOS-Terra carrying the Moderate resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging (MISR) and Clouds and Radiant Energy System (CERES), we are suddenly "data rich". These instruments, along with subsequent instruments on EOS-Aqua, EOS-Aura, ICESat, and Parasol, are designed specifically to observe aerosols and the Earth's radiation budget. They provide global information in a way that previous ground-based or airborne instruments could not, and they provide quantitative information about aerosol that is not only more accurate than our heritage instruments, but also more complete in terms of aerosol characterization. With these increased capabilities, aerosol observations from satellite can provide an independent measure of some key climate parameters in parallel with model predictions.

One key measurement that satellites are able to provide is the direct shortwave radiative effect of aerosols at the top of the atmosphere. By aerosol direct shortwave radiative *effect* we mean the difference in shortwave radiative flux between having aerosols present and having no aerosols at all. This is different from aerosol shortwave direct radiative *forcing*, which is the radiative effect of anthropogenic aerosols only. Analysis suggests that by characterizing aerosol particle size from space, there is information available to the satellites to

Correspondence to: L. A. Remer
(lorraine.a.remer@nasa.gov)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D06201, doi:10.1029/2005JD006246, 2006

Performance of two cloud-radiation parameterization schemes in the finite volume general circulation model for anomalously wet May and June 2003 over the continental United States and Amazonia

Y. C. Sud,[1] David M. Mocko,[1,2] and S. J. Lin[3]

Received 20 May 2005; revised 18 October 2005; accepted 5 December 2005; published 16 March 2006.

[1] An objective assessment of the impact of a new cloud scheme, called Microphysics of Clouds with Relaxed Arakawa-Schubert Scheme (McRAS) (together with its radiation modules), on the finite volume general circulation model (fvGCM) was made with a set of ensemble forecasts that invoke performance evaluation over both weather and climate timescales. The performance of McRAS (and its radiation modules) was compared with that of the National Center for Atmospheric Research Community Climate Model (NCAR CCM3) cloud scheme (with its NCAR physics radiation). We specifically chose the boreal summer months of May and June 2003, which were characterized by an anomalously wet eastern half of the continental United States as well as northern regions of Amazonia. The evaluation employed an ensemble of 70 daily 10-day forecasts covering the 61 days of the study period. Each forecast was started from the analyzed initial state of the atmosphere and spun-up soil moisture from the first-day forecasts with the model. Monthly statistics of these forecasts with up to 10-day lead time provided a robust estimate of the behavior of the simulated monthly rainfall anomalies. Patterns of simulated versus observed rainfall, 500-hPa heights, and top-of-the-atmosphere net radiation were recast into regional anomaly correlations. The correlations were compared among the simulations with each of the schemes. The results show that fvGCM with McRAS and its radiation package performed discernibly better than the original fvGCM with CCM3 cloud physics plus its radiation package. The McRAS cloud scheme also showed a reasonably positive response to the observed sea surface temperature on mean monthly rainfall fields at different time leads. This analysis represents a method for helpful systematic evaluation prior to selection of a new scheme in a global model.

Citation: Sud, Y. C., D. M. Mocko, and S. J. Lin (2006), Performance of two cloud-radiation parameterization schemes in the finite volume general circulation model for anomalously wet May and June 2003 over the continental United States and Amazonia, *J. Geophys. Res.*, *111*, D06201, doi:10.1029/2005JD006246.

1. Introduction

[2] The decision to replace and/or significantly upgrade an existing physical parameterization scheme, such as cloud physics, in a general circulation model (GCM), with that of a new physically more desirable scheme is always a daunting endeavor because the new scheme may not improve all aspects of the model's simulations. Consequently, the performance of the new scheme must be evaluated on a variety of timescales and space scales through extensive intercomparisons with the old. Since model performance can show discernible variances on weather and climate timescales, performance evaluation on both timescales should be invoked. Moreover, it is well known that some areas of the simulations improve while others get worse; consequently, one often waits until the relatively poor aspects of the simulations are better understood and resolved. A central issue is whether the decision to adopt a new scheme should be solely governed by (1) better representation of the relevant physics and its demonstrated superiority in controlled test bed evaluation scores such as Atmospheric Radiation Measurement–Single Column Model (ARM-SCM) evaluations regardless of the impact on GCM simulations or (2) the positive impact on the GCM simulations as the primary determinant of the intrinsic value of the new scheme. The latter can only be ascertained by quantities such as improvement in skill scores on the key timescales. The second approach guarantees continually improving forecast skill, which is also a pragmatic criterion of model performance for weather and/or climate forecasts [*Phillips et al.*, 2004]. On the other hand, if a parameterization is physically more defensible, i.e., it better represents the physical processes of central importance that were either undermined or poorly represented in the old scheme, the most plausible reasons for less than superior performance of

[1]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[2]Also at Science Applications International Corporation, Beltsville, Maryland, USA.
[3]Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA.

0148-0227/06/2005JD006246$09.00

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L21804, doi:10.1029/2006GL027150, 2006

Influence of aerosols on the shortwave cloud radiative forcing from North Pacific oceanic clouds: Results from the Cloud Indirect Forcing Experiment (CIFEX)

Eric M. Wilcox,[1] Greg Roberts,[2] and V. Ramanathan[2]

Received 8 June 2006; revised 24 August 2006; accepted 9 October 2006; published 3 November 2006.

[1] Aerosols over the Northeastern Pacific Ocean enhance the cloud drop number concentration and reduce the drop size for marine stratocumulus and cumulus clouds. These microphysical effects result in brighter clouds, as evidenced by a combination of aircraft and satellite observations. In-situ measurements from the Cloud Indirect Forcing Experiment (CIFEX) indicate that the mean cloud drop number concentration in low clouds over the polluted marine boundary layer is greater by 53 cm^{-3} compared to clean clouds, and the mean cloud drop effective radius is smaller by 4 μm. We link these in-situ measurements of cloud modification by aerosols, for the first time, with collocated satellite broadband radiative flux observations from the Clouds and the Earth's Radiant Energy System to show that these microphysical effects of aerosols enhance the top-of-atmosphere cooling by -9.9 ± 4.3 W m^{-2} for overcast conditions. **Citation:** Wilcox, E. M., G. Roberts, and V. Ramanathan (2006), Influence of aerosols on the shortwave cloud radiative forcing from North Pacific oceanic clouds: Results from the Cloud Indirect Forcing Experiment (CIFEX), *Geophys. Res. Lett.*, *33*, L21804, doi:10.1029/2006GL027150.

1. Introduction

[2] The albedo of low clouds will generally increase as the total liquid water path or geometric thickness of the cloud increases. For clouds of equivalent liquid water amount, however, anthropogenic aerosols acting as additional cloud condensation nuclei (CCN) are known to increase the albedo [*Twomey*, 1977; *Coakley et al.*, 1987]. Furthermore, suppression of drizzle may impact the liquid water path and the cloud fraction [*Albrecht*, 1989; *Ackerman et al.*, 2004]. The net radiative forcing of climate attributable to these indirect aerosol effects has been determined primarily using global atmospheric models, and the magnitude remains highly uncertain [*Lohmann and Feichter*, 2005]. This study reports on the influence of aerosol variations on shortwave cloud radiative forcing over the Northeast Pacific Ocean during April 2004 using observations from the Cloud Indirect Forcing Experiment (CIFEX). In-situ measurements document the aerosol influence on cloud microphysics, and satellite observations determine the resulting influence on cloud radiative forcing.

[1]Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[2]Center for Atmospheric Sciences, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California, USA.

0094-8276/06/2006GL027150$05.00

[3] CIFEX was conducted from April 1 to 21, 2004. During 24 flights in the U. of Wyoming King Air aircraft, a full complement of microphysical measurements were made including aerosol number concentration and size distribution (Particle Cavity Aerosol Spectrometer Probe; PCASP), and cloud drop number concentration and size distribution (Forward Scattering Spectrometer Probe; FSSP). Flights were conducted from Arcata, CA (41.0°N, 124.1°W) to approximately 650 km offshore, alternating between 5–10 min. aerosol sampling below cloud base and 5–10 min. cloud sampling below cloud top. Some clouds were profiled from cloud base to cloud top.

[4] Aerosols sampled during CIFEX have been classified based on the aerosol size distribution and back trajectories [*Roberts et al.*, 2006]. The aerosol types include North American aerosols, marine boundary layer aerosols, recently cloud-processed aerosols, and aerosols linked to Asian outflow. Within the Asian air masses, cases of recent new particle formation were found, as well as cases of aged aerosols. Aerosols linked to Asian outflow were found in layers above the boundary layer. Aerosol samples used in this study are limited to those in the boundary layer (below 1500 m). Most of the boundary layer aerosols encountered during CIFEX were composed of cloud-processed and North American continental aerosols.

[5] Cloud systems observed during CIFEX were predominantly stratocumulus and broken cumulus; some precipitating cumulus and mixed-phase clouds were also encountered. Under pristine conditions, low clouds were frequently observed to be drizzling.

[6] In this study we seek to document the impact of elevated concentrations of aerosol particles coincident with low clouds on the number concentration and size of cloud drops, as well as the resulting impact on shortwave cloud radiative forcing as determined by satellite albedo measurements from broadband radiometer observations. We advance a methodology that provides a quantitative measure of the enhanced shortwave cooling owing to the first aerosol indirect effect (the Twomey effect).

[7] Measurements of cloud drop number concentration (N_d), effective radius (r_{eff}) and albedo (α) are sorted according to the number concentration of aerosol particles (N_a) in the 0.1–3.0 μm diameter range as determined from the PCASP instrument, and evaluated as a function of cloud liquid water path (*LWP*) from the AMSR-E microwave radiometer on the Aqua satellite (F. Wentz and T. Meissner, AMSR-E/Aqua L2B Global Swath Ocean Products derived from Wentz Algorithm V001, March to June 2004, http://nsidc.org/data/ae_ocean.html). Albedo is observed from the Clouds and the Earth's Radiant Energy System (CERES) instrument [*Wielicki et al.*, 1996], which is also mounted on

Tellus (2006), 58B, 463–475
Printed in Singapore. All rights reserved

TELLUS

A test of sensitivity to convective transport in a global atmospheric CO_2 simulation

By H. BIAN[1]*, S. R. KAWA[2], M. CHIN[2], S. PAWSON[2], Z. ZHU[2], P. RASCH[3] and S. WU[4],
[1]*UMBC Goddard Earth Science and Technology Center, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA;* [2]*NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA;* [3]*National Center for Atmospheric Research, Boulder, CO 80307, USA;* [4]*Harvard University, Cambridge, MA 02138, USA*

(Manuscript received 9 January 2006; in final form 3 July 2006)

ABSTRACT

Two approximations to convective transport have been implemented in an offline chemistry transport model (CTM) to explore the impact on calculated atmospheric CO_2 distributions. Global CO_2 in the year 2000 is simulated using the CTM driven by assimilated meteorological fields from the NASA's Goddard Earth Observation System Data Assimilation System, Version 4 (GEOS-4). The model simulates atmospheric CO_2 by adopting the same CO_2 emission inventory and dynamical modules as described in Kawa et al. (convective transport scheme denoted as Conv1). Conv1 approximates the convective transport by using the bulk convective mass fluxes to redistribute trace gases. The alternate approximation, Conv2, partitions fluxes into updraft and downdraft, as well as into entrainment and detrainment, and has potential to yield a more realistic simulation of vertical redistribution through deep convection. Replacing Conv1 by Conv2 results in an overestimate of CO_2 over biospheric sink regions. The largest discrepancies result in a CO_2 difference of about 7.8 ppm in the July NH boreal forest, which is about 30% of the CO_2 seasonality for that area. These differences are compared to those produced by emission scenario variations constrained by the framework of Intergovernmental Panel on Climate Change (IPCC) to account for possible land use change and residual terrestrial CO_2 sink. It is shown that the overestimated CO_2 driven by Conv2 can be offset by introducing these supplemental emissions.

1. Introduction

The importance of characterizing transport error in forward models has been widely recognized, and substantial effort has been devoted to quantifying such error (e.g. Denning et al., 1999; Engelen et al., 2002; Palmer et al., 2003). Tropospheric constituent transport occurs by advective, diffusive and convective processes and inadequacies in any of these mechanisms will lead to error in simulated trace gas concentrations. The primary goal of this study is to explore the extent to which the treatment of convective transport impacts the atmospheric CO_2 distribution. The study uses a chemistry transport model (CTM) with specified surface flux distributions and perturbs the representation of convective transport in this system, while all other processes are held fixed. The two approximations to convective transport are referred to as Conv1 and Conv2. Following Kawa et al. (2004), Conv1 uses a constraint of the total convective mass flux (CMF), in which air parcels entrained at cloud base are transported upwards, detraining at a rate proportional to the convergence of CMF. Conv2 is a potentially more accurate approximation, using information on updraft and downdraft, as well as entrainment and detrainment rates; this allows for air parcels to be ventilated within the entire cloud ensemble and also to enter or leave the cloud environment at any altitude, subject to the same constraints on total CMF. All fields used were archived as 3 h averages from the Goddard Earth Observation System Version 4 (GEOS-4) data assimilation system (Bloom et al., 2005). Hence, the two algorithms represent cloud convective transport from a very simple to a relatively complex form. The uncertainty induced by them will represent one term in the potential cloud convection error. We will further identify regions where mixing ratios are sensitive to atmospheric convection, with an overall goal to assist regional carbon cycle simulation. This study complements a number of other approaches to quantifying transport uncertainty, in at least two ways.

First, several studies have attempted to quantify the differences between atmospheric transport using different algorithms of atmospheric convection. Mahowald et al. (1995) used a column model to quantify transport differences among seven different cumulus convection parameterizations, illustrating vastly different results that are sensitive to aspects of 'closure' (the criteria used to determine onset of convection, dependent on some

*Corresponding author.
e-mail: Bian@code916.gsfc.nasa.gov
DOI: 10.1111/j.1600-0889.2006.00212.x

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 44, NO. 5, MAY 2006 1245

Algorithm for NO_2 Vertical Column Retrieval From the Ozone Monitoring Instrument

Eric J. Bucsela, Edward A. Celarier, Mark O. Wenig, James F. Gleason, J. Pepijn Veefkind, K. Folkert Boersma, and Ellen J. Brinksma

***Abstract*—We describe the operational algorithm for the retrieval of stratospheric, tropospheric, and total column densities of nitrogen dioxide (NO_2) from earthshine radiances measured by the Ozone Monitoring Instrument (OMI), aboard the EOS-Aura satellite. The algorithm uses the DOAS method for the retrieval of slant column NO_2 densities. Air mass factors (AMFs) calculated from a stratospheric NO_2 profile are used to make initial estimates of the vertical column density. Using data collected over a 24-h period, a smooth estimate of the global stratospheric field is constructed. Where the initial vertical column densities exceed the estimated stratospheric field, we infer the presence of tropospheric NO_2, and recalculate the vertical column density (VCD) using an AMF calculated from an assumed tropospheric NO_2 profile. The parameters that control the operational algorithm were selected with the aid of a set of data assembled from stratospheric and tropospheric chemical transport models. We apply the optimized algorithm to OMI data and present global maps of NO_2 VCDs for the first time.**

***Index Terms*—Algorithm, nitrogen dioxide (NO_2), Ozone Monitoring Instrument (OMI), troposphere.**

I. INTRODUCTION

MEASUREMENTS of nitrogen dioxide (NO_2) are important to the understanding of tropospheric and stratospheric chemistry, particularly in relation to ozone production and loss. NO_2 takes part in catalytic destruction of ozone in the stratosphere [1], and anthropogenic NO_2 emissions are precursors for tropospheric ozone production, largely through reactions with hydrocarbons, e.g., [2]. Brewer *et al.* [3] made the first ground-based measurements of stratospheric NO_2, and extensive analysis of stratospheric NO_2 behavior and distribution was undertaken by Noxon [4]–[6], [45] and Solomon and Garcia [7]. Data from the Global Ozone Monitoring Experiment (GOME), deployed in 1995, have been used to retrieve global NO_2 column amounts, which have been used to study the behavior of stratospheric NO_2 [8]. Early results from GOME, showing enhanced NO_2 over the populated areas of the Eastern United States and Europe, were presented by Burrows *et al.* [9], who attributed the enhancements to urban tropospheric pollution. Leue *et al.* [10] and Richter and Burrows [11] attempted to quantify the tropospheric amounts. Comparisons between GOME tropospheric NO_2 and models have been carried out by Velders *et al.* [12], Martin *et al.* [13], Lauer *et al.* [14], and Heland *et al.* [15] made the first comparisons with *in situ* aircraft measurements. A new generation of satellite instruments now provides measurements of trace gases, including NO_2, at spatial resolutions that exceed GOME resolutions by factors of seven or more. One of these is the Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) [16]. Martin *et al.* [17] have recently analyzed SCIAMACHY NO_2 data along with aircraft measurements to constrain NO_x emission inventories. The Ozone Monitoring Instrument (OMI), on the Earth Observing System (EOS) Aura satellite, has better spatial and temporal resolution than SCIAMACHY and is the subject of the current study.

Satellite-based Earth radiance measurements yield trace gas slant column densities (SCDs), which depend on not only the density of the gas, but on numerous other measurement parameters. Since the quantity of interest is the vertical column density (VCD), one must convert the SCD into the VCD by dividing the SCD by the *air mass factor* (AMF). The AMFs are calculated using radiative transfer models that account for optical geometry, surface reflectivity, cloud and aerosol properties, and the vertical distribution of the absorbing trace gas. For optically thin trace gases in the stratosphere and upper troposphere, the AMF depends almost entirely on the geometry alone. In the case of NO_2, which is a weak absorber and not widely distributed in the troposphere, a stratospheric AMF can be used to obtain a first-order approximation of the VCD. However, although this method is valid over much of the Earth, it underestimates total column densities in areas with significant boundary layer NO_2. Thus, more accurate analyzes of satellite NO_2 data require subtraction of the estimated stratospheric NO_2 before evaluation of the tropospheric component. Variations on this general approach have been used effectively with GOME data [10]–[13]. The correction procedures consist of two steps: 1) recognition of geographic regions that contain significant tropospheric pollution and 2) accurate evaluation of the AMF in these polluted regions. We present the considerations involved in both of these steps.

Algorithms to identify polluted regions have relied on the fact that most tropospheric NO_2 enhancements occur over land and industrially developed regions and that geographic variation in the tropospheric NO_2 occurs on smaller distance scales than that of stratospheric NO_2. Many investigators [11], [13], [14] use the *reference sector method*, in which the stratospheric component of the NO_2 column in any latitude band is approximated by the total NO_2 column value at the corresponding latitude in

Manuscript received April 29, 2005; revised October 27, 2005.

E. J. Bucsela, E. A. Celarier, M. O. Wenig, and J. F. Gleason are with the NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA (e-mail: eric.bucsela@gsfc.nasa.gov).

J. P. Veefkind, K. F. Boersma, and E. J. Brinksma are with the Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands (e-mail: veefkind@knmi.nl).

Digital Object Identifier 10.1109/TGRS.2005.863715

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D05304, doi:10.1029/2005JD006585, 2006

Measurements of nitrogen dioxide total column amounts using a Brewer double spectrophotometer in direct Sun mode

Alexander Cede,[1,2] Jay Herman,[2] Andreas Richter,[3] Nickolay Krotkov,[2,4] and John Burrows[3]

Received 12 August 2005; revised 1 November 2005; accepted 23 November 2005; published 2 March 2006.

[1] NO_2 column amounts were measured for the past 2 years at Goddard Space Flight Center, Greenbelt, Maryland, using a Brewer spectrometer in direct Sun mode. A new "bootstrap" method to calibrate the instrument is introduced and described. This technique selects the cleanest days from the database to obtain the solar reference spectrum. The main advantage for direct Sun measurements is that the conversion uncertainty from slant column to vertical column is negligible compared to the standard scattered light observations where it is typically on the order of 100% (2σ) at polluted sites. The total 2σ errors of the direct Sun retrieved column amounts decrease with solar zenith angle and are estimated at 0.2 to 0.6 Dobson units (DU, 1 DU $\approx 2.7 \times 10^{16}$ molecules cm^{-2}), which is more accurate than scattered light measurements for high NO_2 amounts. Measured NO_2 column amounts, ranging from 0 to 3 DU with a mean of 0.7 DU, show a pronounced daily course and a strong variability from day to day. The NO_2 concentration typically increases from sunrise to noon. In the afternoon it decreases in summer and stays constant in winter. As expected from the anthropogenic nature of its source, NO_2 amounts on weekends are significantly reduced. The measurements were compared to satellite retrievals from Scanning Image Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY). Satellite data give the same average NO_2 column and show a seasonal cycle that is similar to the ground data in the afternoon. We show that NO_2 must be considered when retrieving aerosol absorption properties, especially for situations with low aerosol optical depth.

Citation: Cede, A., J. Herman, A. Richter, N. Krotkov, and J. Burrows (2006), Measurements of nitrogen dioxide total column amounts using a Brewer double spectrophotometer in direct Sun mode, *J. Geophys. Res.*, *111*, D05304, doi:10.1029/2005JD006585.

1. Introduction

[2] Nitrogen dioxide (NO_2) is a key species in the chemistry of both the stratosphere and troposphere. It is one of the most important ozone precursors in the troposphere and locally also contributes to radiative forcing [*Solomon et al.*, 1999]. In addition, it is known to cause human respiratory problems [e.g., *Environmental Protection Agency*, 1998]. The majority of atmospheric NO_2 is produced by anthropogenic sources. Industry and traffic produce about 50%, and biomass burning is estimated to contribute about 20%. Other important sources are lightning (~10%) and emissions from soil (~15%) [*Lee et al.*, 1997]. Stratospheric NO_2 shows a diurnal cycle with maximum concentrations around sunset and a seasonal cycle with maxima in summer and larger abundance at midlatitudes and high latitudes than in the tropics [*Noxon*, 1979; *Van Roozendael et al.*, 1997; *Liley et al.*, 2000]. In midlatitudes the stratospheric column of NO_2 varies roughly between 0.05 and 0.25 Dobson units (DU); 1 DU corresponds to a column density of $\sim 2.7 \times 10^{16}$ cm^{-2}. Quantity and temporal behavior of tropospheric NO_2 are less known. Column amounts of tropospheric NO_2 between 0 and more than 2 DU have been estimated from ground-based column measurements [*Brewer et al.*, 1973], from satellite retrievals [*Richter and Burrows*, 2002], and from in situ measurements converted into column amounts by means of chemical transport models [*Petritoli et al.*, 2004; *Ordóñez et al.*, 2006]. Satellite data, in situ measurements, and calculations with chemical transport models show seasonal cycles of tropospheric NO_2 with maximum amounts in winter [*Velders et al.*, 2001; *Petritoli et al.*, 2004; *Ordóñez et al.*, 2006].

[3] Remote sensing measurements of atmospheric NO_2 from the ground are usually performed using differential optical absorption spectroscopy (DOAS) [*Platt*, 1994] of scattered sunlight. In this technique the spectral sky radiance is measured, and the slant column density of the

[1]Science Systems and Applications Incorporated, Lanham, Maryland, USA.
[2]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[3]Institute of Environmental Physics, University of Bremen, Bremen, Germany.
[4]Goddard Earth Science and Technology Center, University of Maryland Baltimore County, Catonsville, Maryland, USA.

0148-0227/06/2005JD006585$09.00

ELSEVIER

Journal of Atmospheric and Solar-Terrestrial Physics 68 (2006) 65–77

Journal of ATMOSPHERIC AND SOLAR-TERRESTRIAL PHYSICS

www.elsevier.com/locate/jastp

Spectral measurements of PMCs from SBUV/2 instruments

Matthew T. DeLand[a,*], Eric P. Shettle[b], Gary E. Thomas[c], John J. Olivero[d]

[a]Science Systems and Applications, Inc. (SSAI), 10210 Greenbelt Rd., Suite 400, Lanham, MD 20706, USA
[b]Code 7227, Remote Sensing Division, Naval Research Laboratory, Washington DC 20375-5051, USA
[c]LASP, University of Colorado, Boulder, CO 80309-0392, USA
[d]Department of Physical Sciences, Embry-Riddle Aeronautical University, Daytona Beach, FL 32114, USA

Available online 5 October 2005

Abstract

The SBUV/2 (Solar Backscattered Ultraviolet, model 2) instrument is designed to monitor ozone stratospheric profile and total column ozone using measurements of the Earth's backscattered ultraviolet albedo. We have previously demonstrated that the normal radiance measurements from SBUV/2 instruments, which sample 12 discrete wavelengths between 252 and 340 nm during each scan, can be used to identify polar mesospheric clouds (PMCs). Some SBUV/2 instruments also periodically view the earth in continuous scan mode, covering the wavelength range 160–400 nm with 0.15 nm sampling. Analysis of these data show PMC occurrence rates similar to the normal discrete scan results, although the observation technique reduces the number of daily measurements by a factor of six. PMC observed by SBUV/2 instruments show a monotonic variation in the residual spectral albedo over the wavelength range 250–300 nm, with maximum enhancements of 10–15% at 250 nm. This result is consistent with microphysical model predictions from Jensen [1989.A numerical model of polar mesospheric cloud formation and evolution, Ph. D. Thesis, University of Colorado]. We find no evidence for a systematic localized increase in PMC residual albedo for wavelengths near 260 nm, in contrast to the recently reported results from the MSX UVISI instrument [Carbary J.F., et al., 2004. Evidence for bimodal particle distribution from the spectra of polar mesospheric clouds. Geophysics Research. Letters 31, L13108]. This result is observed for three different SBUV/2 instruments in both Northern and Southern Hemisphere data over a 13-year span. Our Mie scattering calculations show that the location and magnitude of the 260 nm "hump" feature is dependent upon the specific scattering angles appropriate to the MSX measurements. Although it explains the MSX spectrum, the bimodal size distribution proposed by Carbary et al. (2004), cannot explain the lack of scattering angle dependence of the SBUV/2 spectral shapes. The spectral signature of the SBUV/2 continuous scan PMC data is thus inconsistent with the bimodal particle size distribution suggested by Carbary et al. (2004).

Keywords: Polar mesospheric cloud; PMC; Noctilucent cloud; Remote sensing; Scattering

1. Introduction

Polar mesospheric clouds (PMCs), also known as noctilucent clouds, are optically thin clouds that are formed at extremely high altitudes (80–85 km). PMCs are normally observed only at high latitudes (> 55°) in each hemisphere, during a limited season

*Corresponding author. Tel.: +1 301 867 2164; fax: +1 301 867 2151.
E-mail address: matthew_deland@ssaihq.com (M.T. DeLand).

1364-6826/$ - see front matter
doi:10.1016/j.jastp.2005.08.006

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L17809, doi:10.1029/2006GL026492, 2006

Sensitivity of Arctic ozone loss to polar stratospheric cloud volume and chlorine and bromine loading in a chemistry and transport model

A. R. Douglass,[1] R. S. Stolarski,[1] S. E. Strahan,[2] and B. C. Polansky[3]

Received 4 April 2006; revised 6 July 2006; accepted 1 August 2006; published 9 September 2006.

[1] The sensitivity of Arctic ozone loss to polar stratospheric cloud volume (V_{PSC}) and chlorine and bromine loading is explored using chemistry and transport models (CTMs). One simulation uses multi-decadal winds and temperatures from a general circulation model (GCM). Winter polar ozone loss depends on both equivalent effective stratospheric chlorine (EESC) and polar vortex characteristics (temperatures, descent, isolation, polar stratospheric cloud amount). The simulation reproduces a linear relationship between ozone loss and V_{PSC} in agreement with that derived from observations for 1992–2003. The relationship holds for EESC within ~85% of its maximum (~1990–2020). For lower EESC the ozone loss varies linearly with EESC unless $V_{PSC} \sim 0$. A second simulation recycles a single year's winds and temperatures from the GCM so that polar ozone loss depends only on changes in EESC. This simulation shows that ozone loss varies linearly with EESC for the entire EESC range for constant, high V_{PSC}. **Citation:** Douglass, A. R., R. S. Stolarski, S. E. Strahan, and B. C. Polansky (2006), Sensitivity of Arctic ozone loss to polar stratospheric cloud volume and chlorine and bromine loading in a chemistry and transport model, *Geophys. Res. Lett.*, *33*, L17809, doi:10.1029/2006GL026492.

1. Introduction

[2] *Rex et al.* [2004] (hereinafter referred to as R2004) report a linear relationship between winter-spring loss of Arctic ozone and the volume of polar stratospheric clouds (PSCs). R2004 used data for 10 winters between 1992 and 2003, a period when inorganic chlorine in the upper stratosphere was close to its maximum. R2004 suggest this relationship as an element of Chemistry Climate Model (CCM) evaluation and point out that additional stratospheric cooling could lead to more PSCs and additional polar ozone loss. Chemistry and transport models (CTMs) are driven by input meteorological fields and ignore feedback processes that are included in CCMs, but still should reproduce this relationship. R2004 show that the sensitivity of polar ozone loss to the volume of PSCs (V_{PSC}) in a version of the SLIMCAT CTM, driven by meteorological fields from the United Kingdom Meteorological Office UKMO, is less than that derived from observations. *Chipperfield et al.* [2005] show that a modified version of SLIMCAT reproduces the observed relationship.

[3] Here we focus on simulations using the GSFC CTM driven by meteorological output from a General Circulation Model (GCM). *Stolarski et al.* [2006] show that simulated mean total ozone for 60°S–60°N reproduces many aspects of Total Ozone Mapping Spectrometer observations. Here we show the realism of the simulated polar vortex by comparing N_2O and its horizontal gradients with N_2O observed by the Microwave Limb Sounder (MLS) on NASA's Aura satellite [*Waters et al.*, 2006]. We show that the sensitivity of simulated winter chemical loss of ozone to V_{PSC} follows the R2004 relationship for 1990–2020, years when the equivalent effective stratospheric chlorine (EESC), i.e., chlorine and bromine available in the stratosphere to destroy ozone, is within 85% of its maximum. This simulation used standard photochemical input data and a standard scenario for chlorine and bromine source gases. We also investigate the dependence of polar ozone loss on EESC for fixed V_{PSC}.

[4] Simulations use the GSFC CTM and the Global Modeling Initiative (GMI) CTM [*Douglass et al.*, 2004], described in Section 2. Section 3 shows comparisons with N_2O to support the realism of the simulated polar vortex and verifies the method used to account for the ozone increase due to transport. Results are presented in section 4 followed by discussion and conclusions.

2. Chemistry and Transport Models

[5] *Stolarski et al.* [2006] describe the GSFC CTM and the primary simulation used here. Meteorological fields from a 50-year integration of the GEOS-4 GCM (Goddard Earth Observing System, Version 4, General Circulation Model) are input to the CTM. The GCM and its implementation are described elsewhere [*Stolarski et al.*, 2006, and references therein]. Aspects of the CTM important to this analysis follow. Rate constant data and cross sections are taken from JPL Evaluation 14 [*Sander et al.*, 2003] (hereinafter referred to as JPL2003). The polar stratospheric cloud parameterization follows *Considine et al.* [2000] and accounts for denitrification through PSC sedimentation. The *Lin and Rood* [1996] constituent transport scheme is used. The horizontal grid is 2.5° longitude and 2° latitude. The 28 vertical levels between the surface and 0.4 hPa use a terrain following coordinate in the troposphere and pressure above the interface at 247 hPa. Vertical spacing is about 1 km near the tropopause and increases to 4 km near the upper boundary. Surface boundary conditions for source gases including CFCs, halons, methane and nitrous oxide are specified from Scenario A2 in Appendix 4B of the Scientific Assessment of Ozone Depletion: 2002 [*World Meteorological Organization*, 2003].

[6] A second simulation investigates the dependence of ozone loss on EESC for fixed V_{PSC}. The Global Modeling

[1]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[2]Goddard Earth Science and Technology Center, University of Maryland Baltimore County, Baltimore, Maryland, USA.
[3]Science Systems and Applications, Inc., Lanham, Maryland, USA.

0094-8276/06/2006GL026492$05.00

1272 IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 44, NO. 5, MAY 2006

First Results From the OMI Rotational Raman Scattering Cloud Pressure Algorithm

Joanna Joiner and Alexander P. Vasilkov

***Abstract*—We have developed an algorithm to retrieve scattering cloud pressures and other cloud properties with the Aura Ozone Monitoring Instrument (OMI). The scattering cloud pressure is retrieved using the effects of rotational Raman scattering (RRS). It is defined as the pressure of a Lambertian surface that would produce the observed amount of RRS consistent with the derived reflectivity of that surface. The independent pixel approximation is used in conjunction with the Lambertian-equivalent reflectivity model to provide an effective radiative cloud fraction and scattering pressure in the presence of broken or thin cloud. The derived cloud pressures will enable accurate retrievals of trace gas mixing ratios, including ozone, in the troposphere within and above clouds. We describe details of the algorithm that will be used for the first release of these products. We compare our scattering cloud pressures with cloud-top pressures and other cloud properties from the Aqua Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument. OMI and MODIS are part of the so-called A-train satellites flying in formation within 30 min of each other. Differences between OMI and MODIS are expected because the MODIS observations in the thermal infrared are more sensitive to the cloud top whereas the backscattered photons in the ultraviolet can penetrate deeper into clouds. Radiative transfer calculations are consistent with the observed differences. The OMI cloud pressures are shown to be correlated with the cirrus reflectance. This relationship indicates that OMI can probe through thin or moderately thick cirrus to lower lying water clouds.**

***Index Terms*—Cloud, Raman, retrieval, scattering.**

I. INTRODUCTION

PART OF THE mission of the Ozone Monitoring Instrument (OMI) [1] on NASA's Earth Observing System (EOS) Aura satellite is to continue the 25-year record of high-quality total column ozone retrievals from the total ozone mapping spectrometer (TOMS). The higher spectral and spatial resolution, coverage, and sampling of OMI, as compared with TOMS will allow for improved ozone retrievals, including estimates of tropospheric ozone as well as retrievals of other trace gases such as SO_2, NO_2, BrO, and HCHO [2].

The retrieval of tropospheric ozone has been accomplished with TOMS using cloud-slicing techniques [3], [4]. These methods have been previously implemented using cloud-top pressures derived from thermal infrared (IR) measurements or other assumptions about clouds, e.g., that some highly reflecting clouds either reach close to the tropopause or contain very little tropospheric ozone within and above them. A similar approach [5] has been used with data from the Global Ozone Monitoring Experiment (GOME) [6] aboard the European Space Agency's (ESA) Second European Remote Sensing Satellite (ERS-2). In that work, cloud pressures were derived simultaneously with GOME using measurements in the oxygen A-band [7], and it was shown that most convective cloud pressures were between 300 and 500 hPa and do not extend to the tropical tropopause.

Using cloud pressures derived from simultaneous ultraviolet (UV) observations in place of climatological IR cloud-top pressures improves estimates of the above-cloud column ozone [8]. Therefore, it is reasonable to assume that estimates of tropospheric ozone from cloud-slicing will also be improved by using simultaneous measurements in the UV.

Cloud pressures can be retrieved with OMI using either atmospheric rotational Raman scattering (RRS) in the UV [9] or O_2-O_2 absorption near 477 nm [10]. Both techniques are based on the fact that clouds screen the atmosphere below them from satellite observations. Therefore, clouds reduce the amount of RRS or O_2-O_2 absorption seen by satellite-borne instruments. Both approaches are being pursued with OMI data. Here, we focus on the RRS retrieval algorithm.

RRS is an inelastic component of molecular scattering in the atmosphere that produces photons that differ in frequency from the incident light. The frequency difference is related to rotational properties of O_2 and N_2 molecules. Approximately 4% of total scattered energy is contained in the RRS lines. The RRS energy is transferred to both longer wavelengths (Stokes lines) and shorter wavelengths (anti-Stokes lines). The RRS wavelength shifts in the UV are of the order of 2 nm.

RRS produces filling-in (depletion) of solar Fraunhofer lines cores (wings). This filling-in, also known as the Ring effect, was first observed in ground-based measurements [11] and later in satellite backscatter observations (e.g., [12]). The Ring effect is present throughout the ultraviolet.

The concept of retrieving cloud pressure using properties of RRS was first demonstrated in [13] using a Lambertian-equivalent reflectivity (LER) cloud model. Later, de Beek *et al.* [14] showed that holding all else constant, the amount of filling-in decreases with increasing cloud optical thickness (τ) for $\tau <\sim 50$ and saturates for $\tau > 50$. The filling-in computed using their Mie scattering radiative transfer model compared well with ground-based measurements and satellite-based observations from GOME.

Joiner *et al.* [9] refined the approach of retrieving a scattering cloud pressure using the LER model with a spectral fitting algorithm and high-spectral resolution GOME measurements.

Manuscript received January 20, 2005; revised November 18, 2005. This work was supported by NASA through funding for the EOS Aura OMI science team.

J. Joiner is with the National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, MD 20771 USA (e-mail: joanna.joiner@nasa.gov).

A. P. Vasilkov is with Science Systems and Applications, Inc., Lanham, MD 20706 USA.

Digital Object Identifier 10.1109/TGRS.2005.861385

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L05812, doi:10.1029/2005GL025650, 2006

QBO as potential amplifier of solar cycle influence

Hans G. Mayr,[1] John G. Mengel,[2] Charles L. Wolff,[1] and Hayden S. Porter[3]

Received 29 December 2005; accepted 17 January 2006; published 10 March 2006.

[1] The solar cycle (SC) effect in the lower atmosphere has been linked observationally to the quasi-biennial oscillation (QBO) of the zonal circulation. Salby and Callaghan (2000) in particular analyzed the QBO covering more than 40 years and found that it contains a large SC signature at 20 km. We discuss a 3D study in which we simulate the QBO under the influence of the SC. For a SC period of 10 years, the relative amplitude of radiative forcing is taken to vary with height: 0.2% (surface), 2% (50 km), 20% (100 km and above). This model produces in the lower stratosphere a relatively large modulation of the QBO, which appears to come from the SC and qualitatively agrees with the observations. The modulation of the QBO, with constant phase relative to the SC, is shown to persist at least for 50 years, and it is induced by a SC modulated annual oscillation that is hemispherically symmetric and confined to low latitudes (Mayr et al., 2005). **Citation:** Mayr, H. G., J. G. Mengel, C. L. Wolff, and H. S. Porter (2006), QBO as potential amplifier of solar cycle influence, *Geophys. Res. Lett.*, *33*, L05812, doi:10.1029/2005GL025650.

1. Introduction

[2] *Labitzke* [1982, 1987] and *Labitzke and Van Loon* [1988, 1992] discovered that the temperatures at northern polar latitudes in winter are positively and negatively correlated with the solar cycle (SC) when the quasi-biennial oscillation (QBO) of the zonal circulation is in its negative and positive phase respectively. At mid-latitudes they observed opposite correlations. *Dunkerton and Baldwin* [1992] and *Baldwin and Dunkerton* [1998] found evidence of a quasi-decadal oscillation correlated with the QBO and SC.

[3] *Salby and Callaghan* [2000] analyzed the 40-year record of the observed QBO zonal winds at about 20 km altitude. The power spectrum in their Figure 1 shows a sharp peak at 0.41 cycles per year (cpy), corresponding to a QBO period of about 29 months. Smaller neighboring maxima in the spectrum at 0.5 and 0.59 cpy reveal difference frequencies that represent the 11-year SC modulation of the QBO and its second harmonic of 5.5 years. To isolate the SC signature, Salby and Callaghan synthesized the QBO with its spectral side-lobes. It shows that, correlated with the SC, the wind power at 20 km varies from about 150 to 400 m^2/s^2, corresponding to a large variation in the winds from about 12 to 20 m/s. Analyzing 50 years of wind observations, *Hamilton* [2002] confirmed the quasi-decadal modulation inferred by Salby and Callaghan but concluded that the connection to the SC is not as clear in the extended data record.

[4] The observations by *Salby and Callaghan* [2000] were the stimulus for the 3D modeling study discussed here, in which we simulate the SC modulation of the QBO.

2. Wave Driven Quasi-Biennial Oscillation (QBO)

[5] The QBO, with periods between 22 and 34 months and reviewed by *Baldwin et al.* [2001], is confined to low latitudes where it dominates the zonal circulation of the lower stratosphere. Associated with the QBO is the semi-annual oscillation (SAO), which dominates the equatorial circulation of the upper stratosphere and mesosphere [*Hirota*, 1980]. It was demonstrated by *Lindzen and Holton* [1968], *Holton and Lindzen* [1972], and others [e.g., *Plumb*, 1977; *Dunkerton*, 1985] for the QBO, and by *Dunkerton* [1979] and *Hamilton* [1986] for the SAO, that these equatorial oscillations can be driven by planetary waves. More recently, modeling studies with observed planetary waves have led to the conclusion that small-scale gravity waves (GW) appear to be more important [e.g., *Hitchman and Leovy*, 1988]. Except for a few attempts at simulating the QBO with resolved GWs [e.g., *Takahashi*, 1999], these waves need to be parameterized for global-scale models [e.g., *Giorgetta et al.*, 2002]. Applying the GW parameterization of *Hines* [1997a, 1997b], we were among the first to reproduce with our Numerical Spectral Model (NSM) the QBO and SAO [e.g., *Mengel et al.*, 1995; *Mayr et al.*, 1997]. In agreement with our model results, the analysis of *Haynes* [1998] showed how a globally uniform wave source can generate the zonal circulation of the QBO confined to low latitudes as observed.

[6] The QBO amplitude and its period are strongly influenced by external time dependent forcing. In the seminal theory for the QBO by *Lindzen and Holton* [1968], the seasonal cycle and resulting SAO were invoked to seed, and thereby influence the QBO. This influence was confirmed with a 2D study [*Mayr et al.*, 1998], where QBO like oscillations were generated, (a) for perpetual equinox and (b) with the seasonal cycle of solar heating. The seasonal cycle lengthened the period of the QBO from 17 to 21 months and more than doubled its amplitude in the lower stratosphere.

[7] Driven by waves, but strongly influenced by the seasonal variations, the QBO then could be affected significantly also by the SC whose signature then would extend to lower altitudes. Two factors are important for this. First, at equatorial latitudes where the Coriolis force vanishes, the wave source accelerates primarily the zonal winds without

[1]Atmospheric Chemistry and Dynamics Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[2]Science Systems & Applications, Inc., Lanham, Maryland, USA.
[3]Department of Computer Science, Furman University, Greenville, South Carolina, USA.

0094-8276/06/2005GL025650$05.00

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L12814, doi:10.1029/2005GL025232, 2006

When will the Antarctic ozone hole recover?

Paul A. Newman,[1] Eric R. Nash,[2] S. Randolph Kawa,[1] Stephen A. Montzka,[3] and Sue M. Schauffler[4]

Received 20 December 2005; revised 9 May 2006; accepted 22 May 2006; published 30 June 2006.

[1] The Antarctic ozone hole demonstrates large-scale, man-made affects on our atmosphere. Surface observations now show that human produced ozone-depleting substances (ODSs) are declining. The ozone hole should soon start to diminish because of this decline. We demonstrate a parametric model of ozone hole area that is based upon a new algorithm for estimating chlorine and bromine levels over Antarctica and late spring Antarctic stratospheric temperatures. This model explains 95% of the ozone hole area's variance. We then use future ODS levels to predict ozone hole recovery. Full recovery to 1980 levels will occur around 2068 and the area will very slowly decline between 2001 and 2017. Detection of a statistically significant decrease of area will not occur until about 2024. We further show that nominal Antarctic stratospheric greenhouse gas forced temperature change should have a small impact on the ozone hole. **Citation:** Newman, P. A., E. R. Nash, S. R. Kawa, S. A. Montzka, and S. M. Schauffler (2006), When will the Antarctic ozone hole recover?, *Geophys. Res. Lett.*, *33*, L12814, doi:10.1029/2005GL025232.

1. Introduction

[2] As ozone-depleting substances (ODSs) decline, full ozone hole recovery over Antarctica is expected about 2050 [*Hofmann et al.*, 1997; *World Meteorological Organization* (*WMO*), 2003]. *Hofmann et al.* [1997] fit ozone with ODS amounts over 12–20 km to estimate the recovery date. *WMO* [2003] estimated recovery based upon an ensemble of three-dimensional (3-D) models. Ozone recovery is expected in three phases: 1) a cessation of ozone decline, 2) a turnaround where ozone begins to increase, and 3) full recovery to 1980 levels. We define, for the ozone hole, phase 1 as a cessation of the growth of the ozone hole area, phase 2 as the year of peak area, and phase 3 as the date when the ozone hole has zero area.

[3] Recent analyses have shown that the ozone hole has entered this first phase of recovery because it is no longer growing [*Newman et al.*, 2004; *Huck et al.*, 2005; *Yang et al.*, 2005]. These analyses are based upon empirical fits of ozone hole diagnostics to effective equivalent stratospheric chlorine (EESC) and stratospheric temperatures. EESC is a convenient measure of ozone depleting stratospheric chlorine (Cl) and bromine (Br) levels that is estimated from ground-based measurements of halocarbons with assumptions about transit times into the stratosphere and rates at which halocarbons become destroyed in the stratosphere [*Prather and Watson*, 1990; *Daniel et al.*, 1995; *Montzka et al.*, 1999; *World Meteorological Organization* (*WMO*), 1999].

[4] This paper describes an estimate of the ozone hole's future based upon a parametric fit of the ozone hole's area to Cl and Br abundances and stratospheric temperature during the past 25 years.

2. Ozone Hole Area

[5] The ozone hole over Antarctica expanded rapidly in the 1980s, but that expansion slowed in the early 1990s, and appears to have stopped in the last few years. Figure 1 shows Total Ozone Mapping Spectrometer (TOMS) observed average ozone hole area (gray line). The area is determined from version 8 TOMS data for 21–30 September 1979–2004 (TOMS was not operational in 1995) and Ozone Monitoring Instrument data in 2005. The area is contained by the 220-DU contour in the Antarctic region. Values below this represent anthropogenic ozone losses over Antarctica [*Newman et al.*, 2004]. The ozone hole peak occurs during 21–30 September, prior to the late spring breakup when Antarctica is fully illuminated. Large area variations result from variations of stratospheric dynamics.

[6] While vortex collar ozone losses are driven primarily by the abundance of reactive Cl and Br species derived from ODSs [*Anderson et al.*, 1991], the temperature of the polar vortex collar region has a secondary impact on ozone-hole area [*Newman et al.*, 2004]. While Antarctic meteorological analyses are observationally derived, multidecadal observations of ODSs, and inorganic Cl and Br levels over Antarctica are unavailable. Therefore, it is necessary to estimate Cl and Br inside the stratospheric polar vortex from trace-gas measurements at Earth's surface and consideration of atmospheric mixing. *Newman et al.* [2004] fit ozone-hole area using polar vortex collar temperature and an estimate of EESC with a 6-year lag to account for the delay of ODSs and their products to arrive over Antarctica. They showed that the ozone hole is decreasing quite slowly because of the slow decrease of ODSs.

3. Estimates of Inorganic Chlorine and Bromine Abundances in the Stratosphere

[7] The gases that cause ozone loss (e.g., chlorofluorocarbons or CFCs and other gases) are released at Earth's surface, and are then carried from the troposphere into the stratosphere in the tropics. The Brewer-Dobson circulation transports these chemicals upward through the stratosphere and mesosphere in the tropics and subtropics and then

[1]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[2]Science Systems and Applications, Inc., Lanham, Maryland, USA.
[3]NOAA Climate Monitoring and Diagnostics Laboratory, Boulder, Colorado, USA.
[4]National Center for Atmospheric Research, Boulder, Colorado, USA.

0094-8276/06/2005GL025232$05.00

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L21805, doi:10.1029/2006GL026820, 2006

An ozone increase in the Antarctic summer stratosphere: A dynamical response to the ozone hole

R. S. Stolarski,[1] A. R. Douglass,[1] M. Gupta,[1,2] P. A. Newman,[1] S. Pawson,[3]
M. R. Schoeberl,[4] and J. E. Nielsen[5]

Received 5 May 2006; revised 31 August 2006; accepted 19 September 2006; published 7 November 2006.

[1] Profiles of ozone concentration retrieved from the SBUV series of satellites show an increase between 1979 and 1997 in the summertime Antarctic middle stratosphere (~25–10 hPa). Data over the South Pole from ozone sondes confirm the increase. A similar ozone increase is produced in a chemistry climate model that allows feedback between constituent changes and the stratospheric circulation through radiative heating. A simulation that excludes the radiative coupling between predicted ozone and the circulation does not capture this ozone increase. We show that the ozone increase in our model simulations is caused by a dynamical feedback in response to the changes in the stratospheric wind fields forced by the radiative perturbation associated with the Antarctic ozone hole. **Citation:** Stolarski, R. S., A. R. Douglass, M. Gupta, P. A. Newman, S. Pawson, M. R. Schoeberl, and J. E. Nielsen (2006), An ozone increase in the Antarctic summer stratosphere: A dynamical response to the ozone hole, *Geophys. Res. Lett.*, *33*, L21805, doi:10.1029/2006GL026820.

1. Introduction

[2] The ozone loss leading to the Antarctic ozone hole has been observed to occur during springtime, in the lower stratosphere, between altitudes of about 12 and 22 kilometers (~150–25 hPa) [*Hofmann et al.*, 1997]. This paper examines the seasonal variation of ozone trends in the 25–10 hPa layer using data from the Solar Backscatter Ultraviolet (SBUV) series of instruments and from ozone sondes launched from the South Pole station. Time series analysis of this data indicates small negative trends in ozone concentration, except during the summer months when trends are positive.

[3] Chemistry/transport models (CTMs) reproduce many observed behaviors of stratospheric ozone and other minor constituents [e.g., *Douglass et al.*, 2004; *Stolarski et al.*, 2006]. CTMs do not have the feedback processes between trace gases and the radiation field that provide a mechanism for changes in trace gases to affect the circulation of the stratosphere and modify the trace-gas response to forcing. The importance of these feedbacks can be estimated with a model that allows interactions among its radiative, chemical, and dynamical components. Chemistry/climate models (CCMs) combine a general circulation model (GCM) with a representation of photochemistry developed for CTMs [e.g. *Austin et al.*, 2003; *Eyring et al.*, 2006]. We combined the GEOS-4 GCM (Goddard Earth Observing System, Version 4, General Circulation Model) with the photochemistry from our stratospheric CTM to produce the GEOS CCM.

[4] Prior studies have examined changes associated with the Antarctic ozone hole, but have neither focused on the region of ozone increase that overlies the region of depletion nor isolated the signature of ozone increase in observations. The ozone increase is surprising and is not a direct effect of the increase in chlorine or bromine, which are expected to increase the loss of ozone throughout the stratosphere. Several CCMs have calculated a warmer layer in the Antarctic spring above the cooled region of the ozone hole [e.g., *Kiehl et al.*, 1988; *Mahlman et al.*, 1994]. Similar ozone changes to those reported here are evident in prior CCM studies [e.g., *Austin*, 2002; *Langematz et al.*, 2003; *Manzini et al.*, 2003] but the cause of the increase has not been discussed in detail.

[5] In the following section we describe the ozone increase as seen in ground- and space-based observations. The GEOS CCM and the simulations used here are described in Section 3, and are used to explain the formation and generation of the observed ozone enhancement in Section 4.

2. Observed Trends in the Antarctic Summer Ozone Profile

[6] A series of SBUV instruments yields stratospheric ozone profiles between 50 and 1 hPa. The Version 8 (V8) processing algorithm derives profiles with information on vertical scales of about 5 km [*Bhartia et al.*, 1996; *DeLand et al.*, 2004; *Bhartia et al.*, 2004; *Taylor et al.*, 2003]. The V8 processing algorithm homogenizes the data record through re-calibration of each SBUV instrument. Use of a time-independent *a priori* in the retrievals and the calibration of each SBUV instrument to the same scale prevents artificial trends in the data set.

[7] Following *Stolarski et al.* [2006], statistical analysis of the time series of SBUV retrievals between 1979 and 2003 was performed for months that are sunlit at high southern latitudes (October–April). Explanatory variables in the statistical model include seasonal cycle, equivalent effective stratospheric chlorine (EESC), the quasi-biennial oscillation, volcanic aerosols and the solar cycle. The ozone trend for 1979–1997 is the projection on to EESC term, which increases linearly in this period, before leveling off.

[1]Atmospheric Chemistry and Dynamics Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[2]Office of Environment and Energy, Federal Aviation Administration, Washington, DC, USA.
[3]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[4]Earth Science Directorate, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[5]Science Systems and Applications, Inc., Lanham, Maryland, USA.

0094-8276/06/2006GL026820$05.00

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D19303, doi:10.1029/2006JD007089, 2006

Tropospheric ozone determined from Aura OMI and MLS: Evaluation of measurements and comparison with the Global Modeling Initiative's Chemical Transport Model

J. R. Ziemke,[1,2] S. Chandra,[1,2] B. N. Duncan,[1,2] L. Froidevaux,[3] P. K. Bhartia,[4]
P. F. Levelt,[5] and J. W. Waters[3]

Received 19 January 2006; revised 20 April 2006; accepted 14 June 2006; published 5 October 2006.

[1] Ozone measurements from the OMI and MLS instruments on board the Aura satellite are used for deriving global distributions of tropospheric column ozone (TCO). TCO is determined using the tropospheric ozone residual method which involves subtracting measurements of MLS stratospheric column ozone (SCO) from OMI total column ozone after adjusting for intercalibration differences of the two instruments using the convective-cloud differential method. The derived TCO field, which covers one complete year of mostly continuous daily measurements from late August 2004 through August 2005, is used for studying the regional and global pollution on a timescale of a few days to months. The seasonal and zonal characteristics of the observed TCO fields are also compared with TCO fields derived from the Global Modeling Initiative's Chemical Transport Model. The model and observations show interesting similarities with respect to zonal and seasonal variations. However, there are notable differences, particularly over the vast region of the Saharan desert.

Citation: Ziemke, J. R., S. Chandra, B. N. Duncan, L. Froidevaux, P. K. Bhartia, P. F. Levelt, and J. W. Waters (2006), Tropospheric ozone determined from Aura OMI and MLS: Evaluation of measurements and comparison with the Global Modeling Initiative's Chemical Transport Model, *J. Geophys. Res.*, *111*, D19303, doi:10.1029/2006JD007089.

1. Introduction

[2] Many of the current techniques for deriving tropospheric ozone are based on the tropospheric ozone residual (TOR) method, which derives tropospheric column ozone (TCO) by subtracting concurrent measurements of stratospheric column ozone (SCO) from total column ozone measured by the Total Ozone Mapping Spectrometer (TOMS) instrument [*Fishman and Larsen*, 1987; *Fishman et al.*, 1990]. The TOR concept, which has recently been used by *Fishman et al.* [2003] using the TOMS and Solar Backscatter Ultraviolet (SBUV) combination, and by *Chandra et al.* [2003] using the TOMS and Upper Atmosphere Research Satellite (UARS) Microwave Limb Sounder (MLS) combination, has been implemented to derive TCO and SCO fields from the Aura satellite where total column ozone is measured by the Dutch-Finnish Ozone Monitoring Instrument (OMI) [*Levelt et al.*, 2006a], and SCO is measured by the MLS instrument [*Waters et al.*, 2006]. The use of MLS on board Aura for measuring SCO is a significant improvement in alleviating some of the problems associated with the use of SBUV or UARS MLS. The SBUV measurements have difficulty in retrieving ozone in the lower stratosphere below the ozone number density peak (~25 km altitude), and while UARS MLS may be extended down to 100 hPa in ozone profile measurements, this limits maps of SCO to mostly tropical and subtropical latitudes. An important issue for the TOR method involving independent satellite instruments is interinstrument calibration which may seriously impact an accurate determination of TCO. Such calibration [*Chandra et al.*, 2003] can be obtained at locations where OMI can directly measure SCO using the Convective Cloud Differential (CCD) method [*Ziemke et al.*, 1998]. A main advantage of the new Aura MLS and OMI measurements is that near-global maps of calibrated TCO can be obtained on a daily basis which was not possible with previous satellite measurements.

[3] The OMI and MLS instruments on board the Aura spacecraft platform [*Schoeberl et al.*, 2004] have been providing global measurements of total and stratospheric column ozone soon after the launch of Aura on 15 July 2004 (Aura webpage: http://aura.gsfc.nasa.gov/). This has enabled near global measurements of TCO on almost a day-to-day basis from late August 2004 to present. The continuous global nature of the measurements allow the data to be compared with global models of tropospheric ozone in more detail than in previous studies. The previous studies were generally limited to tropical and subtropical latitudes [*Martin et al.*, 2000, 2002; *Peters et al.*, 2002; *Chandra et al.*, 2002;

[1]Goddard Earth Sciences and Technology, University of Maryland Baltimore County, Baltimore, Maryland, USA.
[2]Also at NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[3]NASA Jet Propulsion Laboratory, Pasadena, California, USA.
[4]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[5]Royal Netherlands Meteorological Institute, De Bilt, Netherlands.

0148-0227/06/2006JD007089$09.00

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
15-04-2007	Technical Memorandum	

4. TITLE AND SUBTITLE
Laboratory for Atmospheres 2006 Technical Highlights

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Laboratory for Atmospheres

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Goddard Space Flight Center
Greenbelt, MD 20771

8. PERFORMING ORGANIZATION REPORT NUMBER
2007-00557-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING REPORT NUMBER
TM-2007-214150

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited, Subject Category: 42, 47, 48
Report available from the NASA Center for Aerospace Information, 7115 Standard Drive, Hanover, MD 21076. (301)621-0390

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The 2006 Technical Highlights describes the efforts of all 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, are highlighted in this report.

15. SUBJECT TERMS
Technical Highlights, Laboratory for Atmospheres, Atmospheric Research

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19b. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified	Unclassified	147	Richard W. Stewart / (301) 614-6045