



Laboratory for Atmospheres 2008 Technical Highlights



COVER PHOTO CAPTIONS

Top Left: California Fire

Sampling California air quality during the ARCTAS-CARB field experiment in summer 2008. The wild fire was encountered and sampled by the DC-8 aircraft. (Photo taken by Mian Chin onboard of DC-8.)

Bottom Left: North Pole Flight-1:

Sampling the Arctic Haze, ozone depletion events, and long-range transport of pollution and smoke. Photo showing the NASA DC-8 doing measurements near the surface during the spring phase ARCTAS field experiment over the Arctic Ocean. (Photo taken by Mian Chin on board of DC-8.)

Top Right: Forecast People

The model forecast and satellite support team in front of the Elvey Building in University of Alaska during the spring phase of the ARCTAS field experiment. Several Lab scientists are in the photo.

Middle Right: North Pole Flight-2

Sampling the Arctic Haze and long-range transport of pollution and smoke during the spring phase of ARCTAS over Alaska. (Photo taken by Mian Chin on board of DC-8.)

Bottom Right: P3B People

Photo showing the P-3B crew, scientists from instrument, model forecast, and satellite support teams in front of the NASA P-3B aircraft during the ARCTAS field experiment in Canada, summer 2008. Several Lab scientists are in the photo.

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Laboratory for Atmospheres 2008 Technical Highlights

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

August 2009

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Dear Reader:

Welcome to the Laboratory for Atmospheres' 2008 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 2008.

The Laboratory's approximately 237 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 Earth's atmosphere.

Satellite missions, and related algorithm development, field campaigns, and related modeling and data analyses, and data set development are important components of the Lab's science activities. These activities are helping us better understand our home planet's environment, and are increasing our knowledge of the complex physics and chemistry of the atmosphere.

The following are some noteworthy events that took place during 2008. Many laboratory scientists participated in the international Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) program to study the impact of boreal wildfire smoke, transported pollution particles, ozone, and other atmospheric gases on the Arctic environment. ARCTAS involves over 300 researchers, and deploys more than 20 instruments on three NASA aircraft, including ground stations, and remote sensing observations from multiple NASA Earth Observing System satellites. Laboratory scientists also played a critical role in the Atmospheric Radiation Measurement (ARM) Ancillary Facility (AAF/SMART¹-COMMIT²) deployment in China during the Asian Monsoon Year (AMY-2008) to acquire comprehensive ground-based observations for aerosol-cloud-water cycle studies. Measurements are being taken in China for dust aerosols originating at the Taklimakan and the great Gobi deserts. These, and other campaigns are described in detail in Section 4 in this report. Others include the development of three instruments funded from NASA's Instrument Incubator Program (IIP) continued, and test flights for two (TWiLiTE³ and HIWRAP⁴) scheduled in 2009; planning of the Global Hawk Pacific Experiment (GloPac), which will be the first science mission flown on the NASA Global Hawk unmanned aircraft system (UAS).

As in previous years, Laboratory scientists garnered many top professional honors. Wei-Kuo Tao (613) received the William Nordberg Award for his outstanding long-term contributions to advancing fundamental understanding of how cloud systems work, his leadership in Earth System modeling and his devotion to nurturing the next generation of Earth scientists. A. Douglass (613.3) was elected by the AMS Council for a three year term. Gerry Heymsfield and Steve Platnick received NASA Honor Awards, Dave Whiteman

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1. SMART: Surface-sensing Measurements for Atmospheric Radiative Transfer
 2. COMMIT: Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere
 3. TWiLiTE: Tropospheric Wind Lidar Technology Experiment
 4. HIWRAP: High-Altitude Imaging Wind and Rain Airborne Profiler

received a Goddard Honor Award and a NASA Group Achievement Award was received for the TC4 mission that took place in Costa Rica in 2007. The year 2008 was also a time to bid farewell to Dick Stewart, Dick Hartle, Jim Spinhirne, Rich Lawrence, Yogesh Sud, and Hans Mayr. Dick Stewart retired after 43 years of service. As the Laboratory Assistant Chief, he edited the last 7 issues of this annual report. Dick Hartle assumed a new role as Chief Scientist in Code 670. Jim Spinhirne retired after 31 years, and returned to research at the University of Texas. Rich Lawrence served 19 years at NASA including managing the budgets for the Precipitation Measurement Missions (PMM) project. Hans Mayr devoted 41 years to NASA and was recently the Project Scientist for the Aeronomy of Ice in the Mesosphere (AIM) mission. Yogesh Sud retired after 29 years in NASA where he worked on improving the physics of general circulation models.

I am pleased to welcome Bill Heaps, Lazaros Oraopoulos, Charles Ichoku, Karen Mohr, Bryant Duncan, and Tom Hanisco to our Laboratory's civil servant staff. Bill Heaps is returning after many years in engineering organizations developing lidar systems. Lazaros Oraopoulos brings years of experience in the areas of cloud-aerosol and radiation interactions, and detection from space of 3D cloud effects through spectral analysis. Charles Ichoku's research is focused on the global occurrence, distribution, radiative properties, and aerosols (particularly fires), and their effects on climate. Karen Mohr is an expert on regional hydroclimate, and precipitation processes. Bryant Duncan works on stratospheric and tropospheric chemistry, and will add strength to our atmospheric chemistry modeling team. Tom Hanisco is one of the best young experimentalists in the atmospheric sciences. He has worked on design, building, and operations of five different *in situ* instruments, and has participated in a number of NASA aircraft field campaigns. The scientific and technical expertise of these new employees will help us continue to advance our science programs.

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

Your comments may be submitted online. Please check out our Web site.



William K.-M. Lau,

Chief, Laboratory for Atmospheres, Code 613

June 2009

TABLE OF CONTENTS

Preface.	vii
1. Introduction.	1
2. Staff, Organization, and Facilities	3
2.1 Staff	3
2.2 Organization	4
2.3 Branch Descriptions	4
2.4 Facilities	6
3. Our Research and Its Place in NASA's Mission	9
4. Major Activities.	11
4.1 Measurements	11
4.2 Field Campaigns	13
4.3 Data Sets	23
4.4 Data Analysis	32
4.5 Modeling	34
4.6 Support for NOAA Operational Satellites	40
4.7 Project Scientists	43
4.8 Interactions with Other Scientific Groups	44
4.9 Commercialization and Technology Transfer	46
5. Highlights of Laboratory Activities in 2006	47
5.1 Mesoscale Atmospheric Processes Branch, Code 613.1	47
5.2 Climate and Radiation Branch, Code 613.2	50
5.3 Atmospheric Chemistry and Dynamics Branch, Code 613.3	52
5.4 Laboratory Research Highlights	59
5.5 Instrument Development.	62
5.6 Awards and Special Recognition.	62
6. Education and Outreach	65
6.1 Introduction	65
6.2 Education.	65
6.3 Summer Programs	67
6.4 University Education.	73
6.5 Open Lecture Series	75
6.6 Public Outreach	76
6.7 Project Outreach	81
7. Acronyms	89
Appendix 1. The Laboratory in the News	95
Appendix 2. Refereed Articles	125
Appendix 3. Highlighted Articles Published in 2008	139

PREFACE

The Technical Highlights for 2008 is the product of the efforts of all the members of the Laboratory for Atmospheres. Their dedication to advancing Earth Science through scientific investigations involving research, developing and running models, designing instruments, managing projects, running field campaigns, publishing results and numerous other activities has produced many significant findings. 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, with Jim Irons, our Associate Chief, checked the report for accuracy, and made suggestions regarding its content. Richard Stewart, editor for several years and now an emeritus member of the Laboratory, made valuable suggestions concerning the organization of this report and its content prior to, and after, his retirement. Members of the administrative staff of the Laboratory and its branches: Lynn Shupp, Cathy Newman, and Pat Lubber are recognized for helping to gather material for the report and for soliciting the contributions of Lab members. Elaine Firestone, of the Technical Information and Management Services Branch (Code 271), performed the final editing, formatting, and typesetting, turning this report into a polished product in a timely manner. Her efforts, as well as those mentioned above, are gratefully acknowledged.

An electronic version of this document is available online at <http://atmospheres.gsfc.nasa.gov>, thanks to the efforts of Paul Przyborski, our Laboratory Web Master.

It is hoped that you will find this document informative and useful.

—Charles E. Cote

**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 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 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 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 2008. 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 co-located (Code 603: Administration and Resources Management Office) resource analysts, with a total staff of 237. The civil service composition of the Laboratory consists of 51 members, of which 48 are scientists, 1 is a technical manager, 1 is administrative support, and 1 is a computer engineer.

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 (GMU), University of Arizona, and Georgia Tech. Of the 74 research associates, 93% hold Ph.D.s. The onsite contractors are a very important component of the staffing of the Laboratory. Out of the total of 98 onsite contractors, 16% hold Ph.D.s. In addition to these members, the Laboratory currently hosts six NASA Postdoctoral Program (NPP) research associates. The makeup of our Laboratory is approximately 23% civil servants, 29% research associates, 45% contractors, and 3% NPP associates. R

The number of refereed publications (from 1993) 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. The reduced number of refereed papers in 2004 and 2005 was 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.

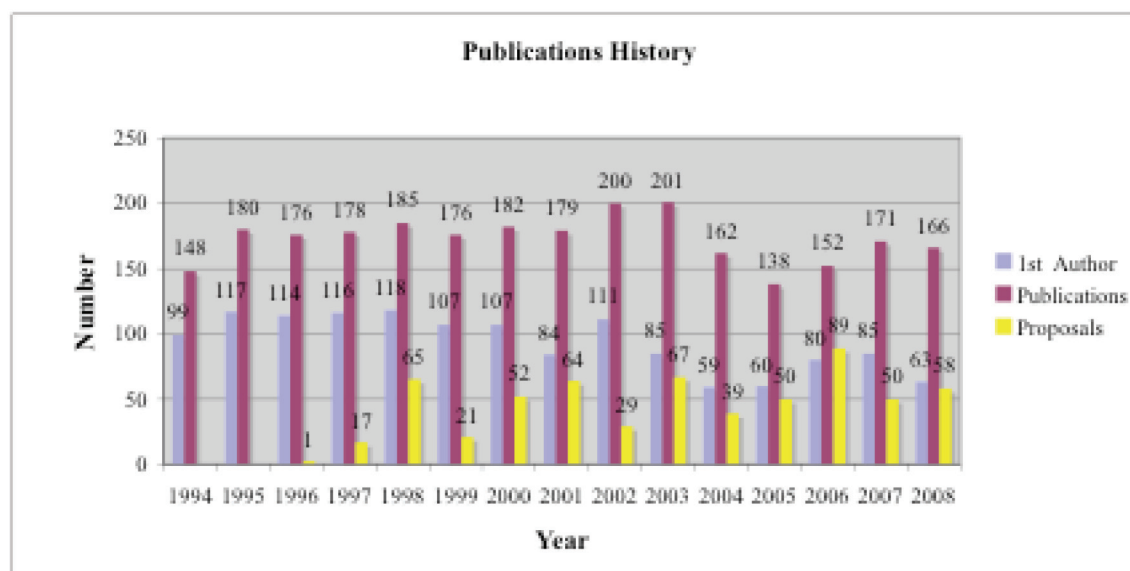


Figure 2.1 Number of proposals and refereed publications by Laboratory for Atmospheres members over the years. The red bar is the total number of publications where a Laboratory member is the first author or co-author, and the blue bar is the number of publications where a Laboratory member is first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

2.2 Organization

The management and branch structure for the Laboratory for Atmospheres at the end of 2007 is shown in Figure 2.2.

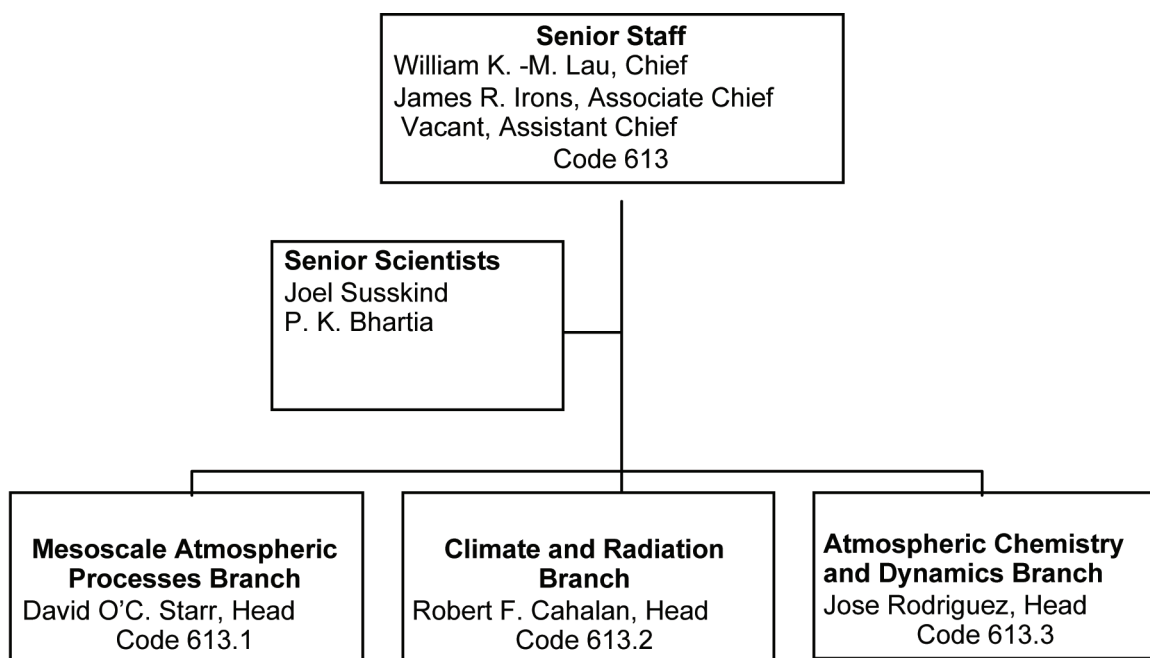


Figure 2.2 Laboratory for Atmospheres organization chart at the end of calendar year 2008.

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.

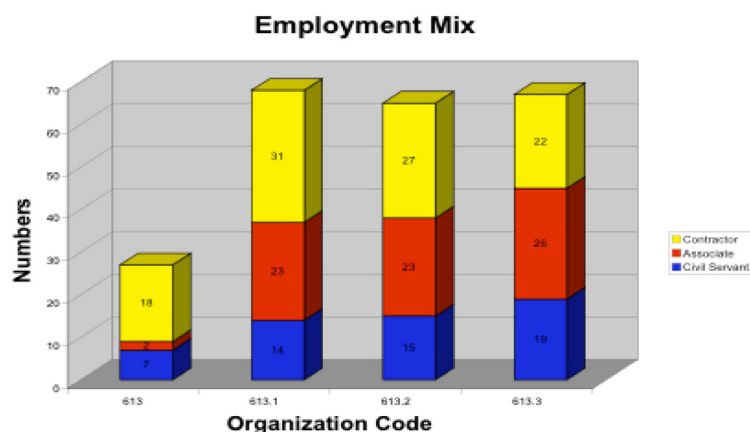


Figure 2.3 Employment composition of the members of the Laboratory for Atmospheres.

A brief description is given below 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.

2.3.1 Mesoscale Atmospheric Processes Branch, Code 613.1

The mission of Mesoscale Atmospheric Processes 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 a central 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, hurricanes, and extratropical cyclones. Characterizing climate impacts at regional and global scales is also a major focus.

Besides developing and using advanced instrumentation and satellite observations, the Branch has vigorous cloud system modeling activities. We have integrated various NASA Goddard physical packages (microphysics, radiation, and land surface models) into the national next-generation weather research and forecasting model (known as WRF), and implemented a mesoscale cloud-resolving model (Goddard Cumulus Ensemble, GCE, Model) into a global model (super-parameterization). Our WRF model is being developed into a unified NASA WRF with coupling to land surface hydrology and chemistry models under NASA's MAP Program. Ultimately, we hope to develop a global cloud-resolving 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 the Tropical Rainfall Measuring Mission (TRMM) and is deeply involved in formulation and development of the Global Precipitation Mission (GPM) scheduled to launch in 2013. We have team members on various other current NASA satellite missions, such as ICESat¹/GLAS², Aqua/AMSR-E³, CloudSat, and CALIPSO⁴.

Similarly, we contribute to mission studies focused on the Decadal Survey Missions (National Academy of Science) for NASA HQ, especially the tier-2 Aerosols-Clouds and Ecology (ACE) Mission involving cloud radar and lidar, and the tier-3 Global Wind Observations Mission (GWOS). While 2008 was a slow year for field missions, we actively participated in such campaigns, such as the NASA African Monsoon Multidisciplinary Analysis (NAMMA), the Costa Rica Aura Validation Experiment (CR-AVE), and the CALIPSO/CloudSat Validation Experiment (CC-VEx) in 2006; and the Tropical Composition, Cloud, and Climate Coupling (TC4) experiment in 2007.

We are currently developing a new generation of active remote sensors (cloud and aerosol lidar, wind lidar, cloud radars) and plan to integrate these on NASA's new Global Hawk high-altitude unmanned vehicle, in addition to more traditional high-altitude, heavy-lift, platforms such as NASA's ER-2 and WB-57F. Further information about Branch activities may be found on the Web at <http://atmospheres.gsfc.nasa.gov/meso/>.

2.3.2 Climate and Radiation Branch, Code 613.2

The Climate and Radiation Branch has a threefold mission:

1. ICESat: Ice, Cloud, and Land Elevation Satellite
2. GLAS: Geoscience Laser Altimeter System
3. AMSR-E: Advanced Microwave Scanning Radiometer—Earth Observing System (EOS)
4. CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

- (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 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/>.

2.3.3 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 Earth Observing System (EOS) Aura satellite, particularly its Ozone Monitoring Instrument (OMI), and works closely with the National Oceanic and Atmospheric Administration (NOAA) on ozone sensors aboard 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 continue to be an important component 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. In addition, Branch members will be involved in scientific and instrument definition for future suborbital and satellite missions studying atmospheric composition. Further information on Branch activities may be found on the Web at <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 analy-

sis and imaging done on single-user personal computers. High-performance computations for high-resolution global and regional models are carried out at the NASA Center for Computational Sciences (NCSS) at GSFC, as well as the Columbia Supercomputer at NASA Ames Research Center.

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 Total Ozone Mapping Spectrometer (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 advanced spaceborne instruments being developed in the Laboratory for Atmospheres for future mission concepts such as the Geostationary Coastal and Air Pollution Events (GEO-CAPE), a National Academy of Sciences (NAS) decadal survey tier-2 mission. In addition, ground-based sky-viewing and aircraft instruments used for research and validation measurements of chemistry missions, such as the Environmental Satellite (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 Research Mission Directorate. These directorates are charged with accomplishing six goals described in the 2006 Strategic Plan. In addition, the Laboratory's research is guided by recommendations made in the decadal survey, "Earth Science and Applications from Space: Imperatives for the Next Decade and Beyond", published by the National Academy of Sciences in 2007 (<http://www.nap.edu/catalog/11820.html>).

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), Astrophysics Science (Code 660), Heliophysics Science (Code 670), and Solar System Exploration (Code 690). The Laboratory for Atmospheres (Code 613) is under the Earth Sciences Division (ESD). Our three branches—Mesoscale Atmospheric Processes (Code 613.1), Climate and Radiation (Code 613.2), and Atmospheric Chemistry and Dynamics (Code 613.3)—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. 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 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	Aerosol
Atmospheric Chemistry	Atmospheric Chemistry and Ozone
Carbon Cycle	Atmospheric Hydrologic Cycle
Climate Change	Carbon Cycle
Global Water and Energy Cycle	Clouds and Radiation
Weather and Short-term Climate Forecasting	Climate Variability and Prediction
	Mesoscale Processes
	Precipitation Systems
	Severe Weather
	Chemistry-Climate Modeling
	Global and Regional Climate Modeling
	Data Assimilation
	Tropospheric Winds
	Solar Variability

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

1. MODIS: Moderate Resolution Imaging Spectroradiometer
2. OMI: Ozone Monitoring Instrument
3. TOVS: TIROS Operational Vertical Sounder
4. TRMM: Tropical Rainfall Measuring Mission
5. UVB: Ultraviolet-B

Classification in the four major activity areas: measurements, data sets, data analysis, and modeling, is somewhat artificial, in that the activities are strongly interlinked and cut across science priorities and the organizational structure of the Laboratory. The grouping corresponds to the natural processes of carrying out scientific research:

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 space-flight missions, and for balloon-, aircraft-, and ground-based observations. Airborne instruments provide critical *in situ* and remote measurements of atmospheric trace gases, aerosol, ozone, and cloud properties. Airborne instruments also serve as stepping-stones in the development of spaceborne instruments, and serve an important role in validating spacecraft instruments.

Table 4.1 shows the space missions that support scientific disciplines in the Laboratory. Satellites are shown in the left-most column. Instruments used by Laboratory scientists are listed in the Table under the supported disciplines in the first row. These instruments are those that were built in the Laboratory, for which a Laboratory scientist had responsibility as Instrument Scientist, for which Laboratory scientists were responsible for algorithm development, calibration and data analysis, or that provided data used by Laboratory scientists for model validation and development.

Table 4.2 lists instruments used in suborbital missions supporting scientific disciplines in the Laboratory. The left-most column indicates each instruments deployment.

Table 4.1: Principal instruments supporting scientific disciplines in the Laboratory for Atmospheres.
(Please refer to Section 7, the Acronym list, for the definitions of acronyms not already defined.)

Satellite	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation
AIM	CIPS	SOFIE	CDE SOFIE
Aqua	AMSU AMSR-E AIRS	AIRS	CERES AMSR-E AIRS MODIS
Aura	MLS	OMI TES MLS HIRDLS	MLS
CALIPSO			CPL
CloudSat			CRS
DSCOVR*	EPIC	EPIC	NISTAR EPIC
GOES	Sounder	SEM	Imager Sounder
Glory			APS TIM
GPM	DPR GMI		DPR GMI
ICESat			GLAS
Landsat			ETM+
NPP*	ATMS CrIS VIIRS	OMPS	VIIRS
POES			AVHRR
SORCE			TIMM SIM SOLTICE XPS
Terra		MOPITT	CERES MISR MODIS
TRMM			TIM SIM
TSIS			GLAS

* Planned mission, not yet launched

Table 4.2: Instruments used in Suborbital Missions that Support Scientific Disciplines in the Laboratory for Atmospheres. (Please refer to Section 7, the Acronym list, for the definitions of acronyms not already defined.)

Instrument Deployment	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation
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 (ATL) Brewer UV Spectrometer KILT Pandora Spectrometers L2-SVIP GeoSpec (IIP)	MPL COVIR SMART COMMIT

In most cases, details concerning the instruments listed in these tables 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/>.

In addition to the above, laboratory scientists are actively involved in the formulation and design of Decadal Survey Mission, particularly for ACE; Climate Absolute Radiance and Reflectivity Observatory (CLARREO); Geo-CAPE; Hyperspectral Infrared Imager (HyspIRI); Active Sensing of CO₂ Emissions over Night, Days, and Seasons (ASCENDS); and 3D-Winds.

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 2008, Laboratory personnel supported six such activities as scientific investigators, or as mission participants, in the planning and coordination phases.

4.2.1 ARCTAS—Spring and Summer 2008

As part of the IGAC¹/POLARCAT² Experiment for the 2008–2009 International Polar Year, the NASA Tropospheric Chemistry and Radiation Science programs sponsored two field deployments to study the impact of boreal wildfire smoke, transported pollution particles, ozone, and other atmospheric gases on the Arctic environment. The Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) program involved three NASA aircraft, the DC-8, P-3B, and B-200, collectively carrying more than 20 instruments, plus ground stations, the NASA EOS satellites, and over 300 researchers, including many from the Laboratory for Atmospheres.

The long-range transport to the Arctic of mid-latitude pollutants was the major focus during the spring deployment, which was based in Fairbanks and Barrow, Alaska during April 2008. Boreal forest fires were targeted during the summer deployment, which was headquartered in Cold Lake, Alberta, Canada from late June through early July. Scientists in the Climate and Radiation Branch, Atmospheric Chemistry and Dynamics Branch, and Global Modeling and Assimilation Office participated in all aspects of the ARCTAS field experiment and continue to contribute to the post-mission data analysis.

During the spring phase of ARCTAS, extensive vertical profile measurements were conducted from the boundary layer to the lower stratosphere, to capture a broad characterization of atmospheric composition and sources of the “Arctic Haze.” The DC-8 also made numerous horizontal leg measurements within the boundary layer to observe halogen chemistry (most active in spring over the Arctic sea ice) and to validate BrO retrievals from OMI. Another major focus of the spring deployment was characterizing the albedo and angular reflectance of snow and ice-covered surfaces. Precise values of these quantities are needed for heat budget calculations, as well as for constraining aerosol retrievals from space-based, passive remote sensing instruments such as the NASA Earth Observing System’s MISR. The Cloud Absorption Radiometer (CAR) instrument aboard the NASA P3 aircraft, led by Charles Gatebe (613.2), played a key role in this experiment, along with coordinated surface and satellite measurements; Dorothy Hall (614.1), Ralph Kahn (613.2), and Alexei Lyapustin (614.4) each contributed to the experiment design and are leading different aspects of the data analysis.

During the summer phase, fresh smoke plumes generated in the Canadian boreal forest, and aged smoke plumes as well as pollution transported from Eurasia, were repeatedly sampled by the aircraft, providing characterization of the trace gases and aerosol properties in these plumes. Just before the summer deployment, the DC-8 and P-3B, with their ARCTAS payloads on board, conducted several flights over California (sponsored by the California Air Resource Board), sampling the intensive wildfires, local pollution, and offshore ship emissions. Eric Wilcox (613.2) worked with the CAR instrument team during this phase of the campaign.

The Goddard Earth Observing System (GEOS)-5 modeling team provided forecasts of CO (a tracer for biomass burning and pollution); aerosols (dust, smoke, pollution); and chlorofluorocarbons (tracer for separating tropospheric and stratospheric air) every day during the field experiment, supporting daily flight planning for both the spring and summer deployments. Figure 4.1 illustrates the GEOS-5 model results for CO and the comparisons with retrieved quantities from AIRS and those measured by the instruments on the DC-8. The modeling forecast group includes scientists from the Atmospheric Chemistry and Dynamics Branch (613.3) and the Global Modeling and Assimilation Office (GMAO): Huisheng Bian, Mian Chin, Peter Colarco, Arlindo da Silva, Bryan Duncan, Qing Liang, and Eric Nielson. Satellite data from MODIS, MISR, AIRS, OMI, TES, and CALIPSO³ were also used to support the ARCTAS field work; scientists providing satellite support include Allen Chu (613.2), Lorraine Remer (613.2), Bill Ridgway (613.2), and Jeffrey Schmaltz (614.5), who all contributed to the MODIS

1. IGAC: International Global Atmospheric Chemistry

2. POLARCAT: POLar study using Aircraft, Remote sensing, surface measurements and modeling of Climate, chemistry, Aerosols, and Transport

3. CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

Rapid Response and analysis effort. In addition, Ralph Kahn (613.2) and Matt Davis (613.2) are contributing MISR wildfire plume heights in the Canadian and Siberian source regions, and aerosol type mapping in the study region, coincident with P3 aircraft observations, for satellite retrieval validation and to provide context for the aircraft observations (Figure 4.2). For further details please contact Ralph Kahn (ralph.a.kahn@nasa.gov) or Mian Chin (Mian.Chin-1@nasa.gov).

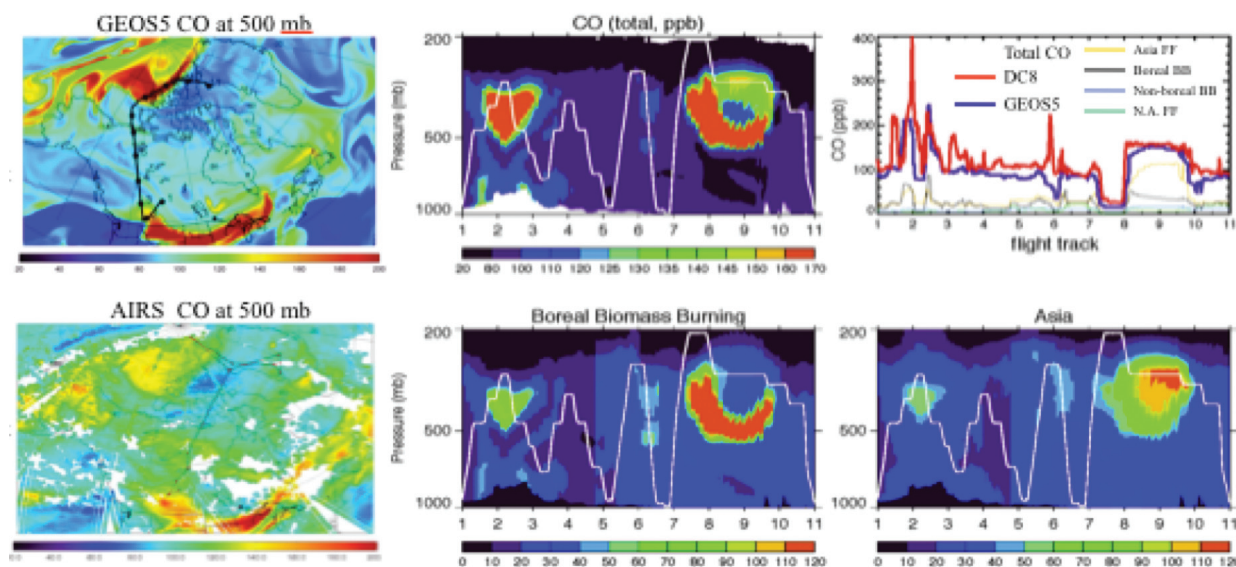


Figure 4.1. Top left and bottom left panels: CO (ppb) at 500 mb simulated with the GEOS-5 model (top left panel) and retrieved from the AIRS instrument (bottom left panel) for July 8, 2008. Top middle, bottom middle, and bottom right panels: Curtain plot of GEOS-5 simulated vertical distributions of total CO, CO from boreal biomass burning, and CO from Asian pollution sources, respectively, along the DC-8 flight track on July 8, 2008 from Cold Lake, Canada to Thule, Greenland. Top right: Comparison of CO simulated by GEOS-5 model (total and source attributions) and measured on the DC-8 on the July 8 flight. Figure credit: Huisheng Bian, Code 613.3; Juying Warner, JCET/UMBC. The DC-8 data are from Glenn Diskin, NASA LaRC.

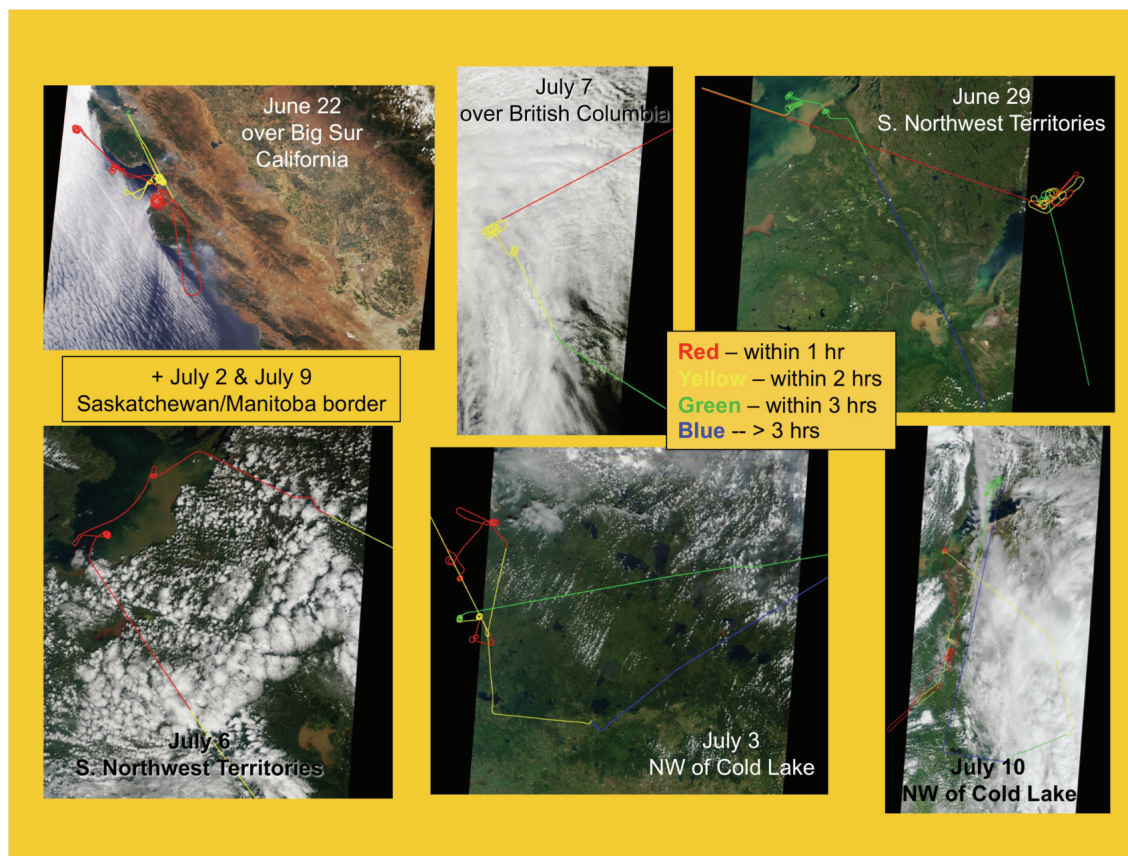


Figure 4.2. MISR/MODIS Terra satellite coincidences with the P3 aircraft during the Summer ARCTAS campaign. These MISR images show six of the eight clear-sky, smoky, and cloudy scenes during which the P3 aircraft flew within the satellite field-of-view. The aircraft ground tracks are superposed, color-coded to indicate the time difference between the aircraft observation and the satellite overflight. These cases are being used for satellite aerosol retrieval validation, and to place the aircraft aerosol observations into a larger context.

4.2.2 The Water Vapor Validation Experiment-Satellite/Sondes 2008 (WAVES_2008)

The WAVES_2008 campaign took place this past winter at the Howard University (HU) Research Campus in Beltsville, Maryland (referred to as HURB). The goals were to provide validation data for A-train satellite overpasses, as well as to support the development of a robust Raman water vapor lidar measurement capability within the NASA-supported Network for the Detection of Atmospheric Composition Change (NDACC). The measurement systems used during WAVES_2008 included: Vaisala RS92 radiosonde, ECC ozonesonde, Cryogenic Frostpoint Hygrometer (provided by the University of Colorado), and the large suite of atmospheric sensing instruments located at the Howard University facility (<http://meiyu.atmphys.howard.edu/beltsville/inde3.html>). Two lidar systems from GSFC were used along with another from Howard University Raman Lidar (HURL). The two NASA GSFC lidar assets that participated were the Code 613.3 AT Raman Lidar system and the Code 613.1 ALVICE. Clear, nighttime conditions were targeted to provide the optimum conditions for lidar profiling of water vapor extending into the lower stratosphere. An example comparison of ALVICE and Vaisala RS92 radiosonde water vapor profiles from the night of March 2 at the Beltsville site is shown in Figure 4.3. The lidar measurements extend to 20 km and indicate lower stratospheric water vapor concentrations between 3–5 ppmv. For further details, please contact Dave Whiteman (David.N.Whiteman@nasa.gov) or Tom McGee (Thomas.J.McGee@nasa.gov).

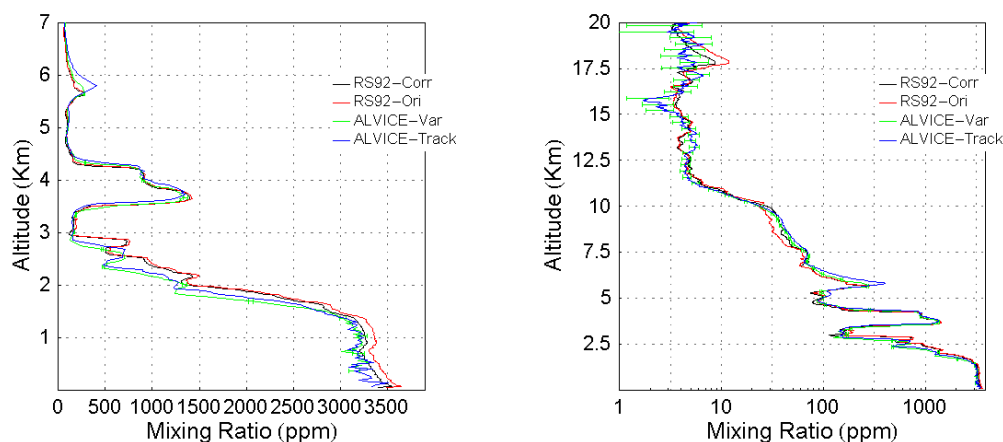


Figure 4.3 Comparison of ALVICE and Vaisala RS92 radiosonde water concentrations.

4.2.3 Pandora Measurement of NO₂, Aerosols, and Other Trace Gases

New, compact, low-cost (~\$10K) solar-viewing spectrometers (Pandora) have been developed at GSFC (Figure 4.4) to measure aerosol optical properties, NO₂, and other trace gases in the atmosphere (H₂O, HCHO, O₃, SO₂). Two versions of the Pandora spectrometers have been developed, one to only make direct sun observations and the other to measure both direct sun and diffuse sky radiances. The goal in developing these new spectrometer instruments was to be able to deploy them at multiple sites for detection of atmospheric pollution and to validate Aura/OMI satellite data. Before deploying large numbers of these systems, two field campaigns at GSFC and the Jet Propulsion Laboratory's (JPL's) Table Mountain Facility (TMF) were designed to validate their performance against a larger more expensive system, MF-DOAS¹, developed by George Mount of Washington State University. In addition to the validation campaigns, a third campaign was conducted in Thessaloniki, Greece.



Figure 4.4: A small inexpensive spectrometer system measuring UV and VIS light from 270–525 nm in 0.5 nm steps. The system consists of an optical head, containing internal filter wheels, mounted on a Sun-sky tracker. The optical head as shown is then mounted on a tripod. The optical head is coupled to the small spectrometer by a 10-m fiber optic cable. The entire spectrometer is maintained at a constant temperature of about 20°C within 1°, using thermoelectric heating and cooling of an insulated waterproof box.

As part of the inversion algorithm, a number of trace gases are obtained at the same time as the primary NO₂ measurement. Figure 4.5 shows the ozone retrieval in two wavelength ranges, 310 and 330 nm, where the retrieved slant column optical depth almost exactly matches the calculated optical depth for each wavelength for a vertical column ozone amount of 325.2 DU. A similar calculation is made for the visible region, which has much less sensitivity. NO₂ can be retrieved in either the UV or visible range, but with the best sensitivity in the visible 400 to 450 nm, where we retrieved 0.92 DU of vertical column NO₂. Formaldehyde, HCHO, is retrieved at 0.57 DU, but with much less sensitivity than NO₂ or ozone (O₃). H₂O is obtained from a weak line feature at

1. MF-DOAS: Multifunction Differential Optical Absorption Spectrometer

442 to 445 nm at 2.04 cm of water vapor, and finally, SO_2 was retrieved simultaneously with O_3 at 1.79 DU. The result shows a fairly polluted atmosphere at GSFC. The retrievals can be obtained once per minute throughout each day when the sun is visible against a blue sky or through thin clouds. Similar measurements can be made at night when the moon is visible. The night measurements in sunrise are invaluable for evaluating model calculations and the validity of their assumed reaction and photolysis rates.

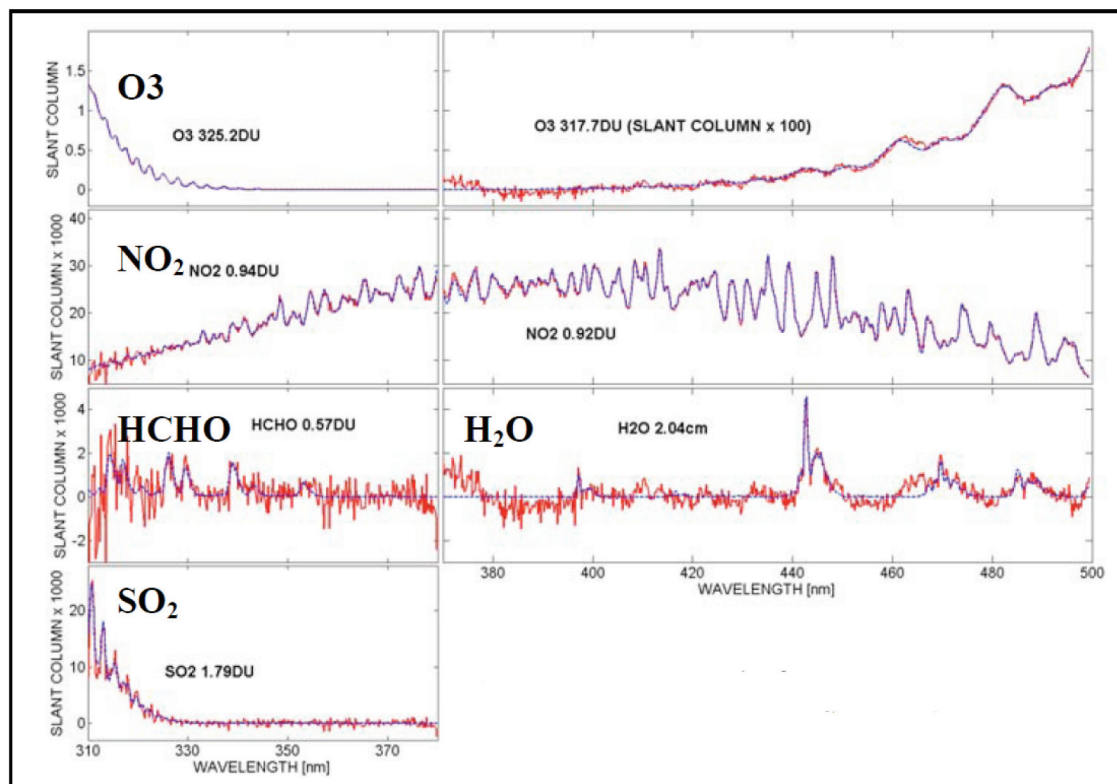


Figure 4.5. Retrieval of vertical column amounts of NO_2 , O_3 , HCHO , H_2O , and SO_2 .

The first set of validation measurements was obtained at GSFC (38.993°N, 76.840°W) during a comparison campaign of Pandora with the University of Washington's MF-DOAS instrument located on the roof of Building 33 about 88 m above sea level with a view of the horizon in most directions. The GSFC location is close to two major highway systems and a busy local road, which are strong sources of NO_2 emissions. When Pandora and MF-DOAS were compared at GFSC, they were found to closely agree, with both instruments having a clear-sky precision of 0.01 DU (1 DU = 2.67×10^{16} molecules/cm²) and a nominal accuracy of 0.1 DU. The high precision is obtained from careful laboratory characterization of the spectrometers (temperature sensitivity, slit function, pixel-to-pixel radiometric calibration, and wavelength calibration) and from sufficient measurement averaging to reduce instrument noise. The accuracy achieved depends on laboratory-measured absorption cross-sections and on spectrometer laboratory and field calibration techniques used at each measurement site. The 0.01 DU precision is sufficient to track minute-by-minute changes in $\text{C}(\text{NO}_2)$ throughout each day with typical daytime values ranging from 0.2–2 DU. The highly variable nature of NO_2 is shown in Figure 4.6.

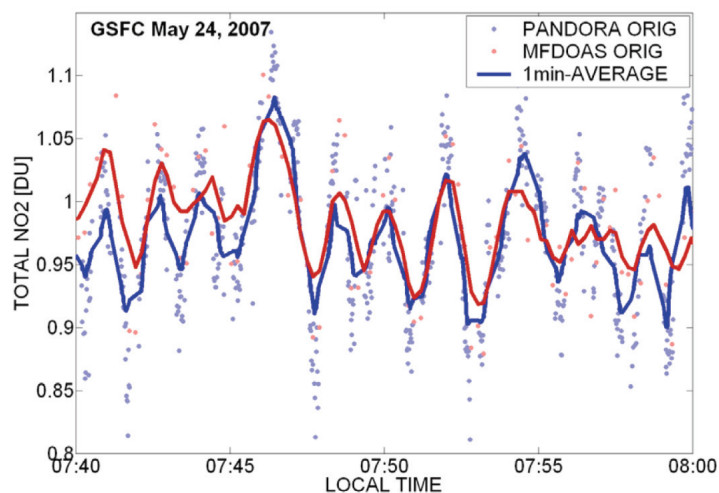


Figure 4.6. High time variability at GSFC observed on May 14, 2007 and May 24, 2007 by Pandora and MFDOAS.

On the morning of May 24, 2007 MF-DOAS sampled every 4 s (light blue dots) and Pandora every 2 s (light red dots). A close look at the Pandora data suggests that the 2-s integration time retrieval detected real changes in $C(\text{NO}_2)$ that were not the result of instrument noise. This can be seen from the systematic distribution of Pandora points relative to the maxima and minima of the 1-min averages in Figure 4.5. The averaged data shows a clear cycle with a rate of change for $C(\text{NO}_2)$ of 0.1 DU/min with a 2-min period. Because two independent instruments, MF-DOAS and Pandora, observed the same variability, the observations are not instrument artifacts. Such rapid change increases the difficulty of interpreting differences with OMI satellite overpass data, which are not precisely co-located and have a much larger field of view (FOV). Pandora and MF-DOAS FOVs are approximately 1.5° , which is only a fraction of a kilometer at the top of the boundary layer at about 3 km. The rapid temporal variability of about $\pm 20\%$ in magnitude over a few minutes suggests the difficulty of accurately modeling the effects of local transport in the boundary layer on the chemistry involved with air quality. A possible, but unproven, source of the short term $C(\text{NO}_2)$ variation is from the operation of a traffic light on a nearby busy four-lane road.

Pandora NO_2 data have also been compared with OMI overpass data and found to agree quite well (Figure 4.7).

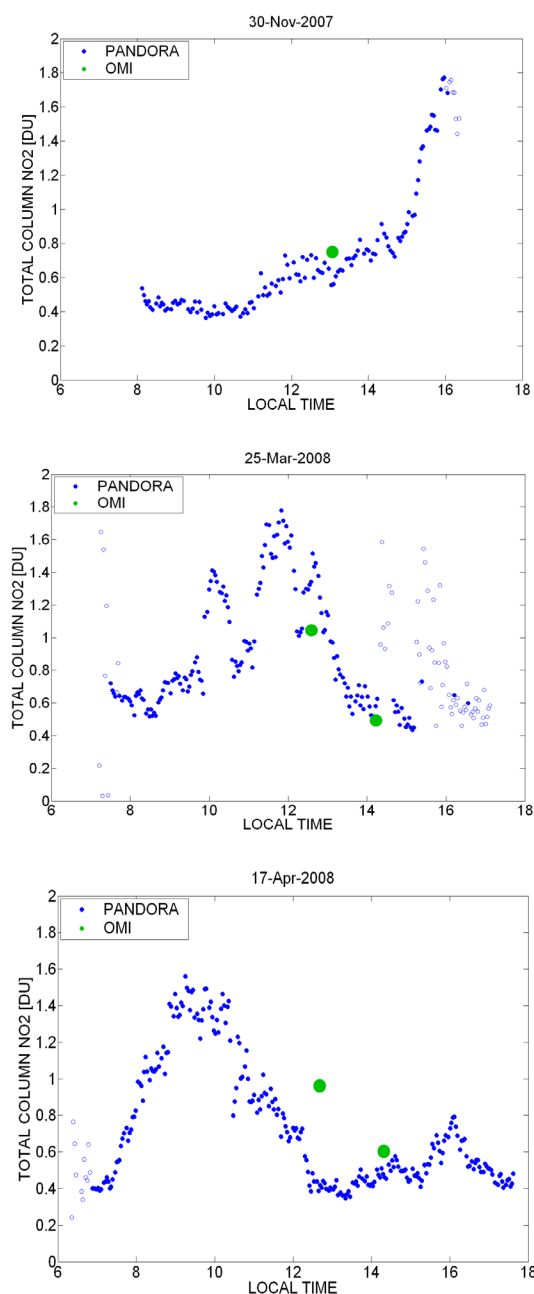


Figure 4.7. Three days of Pandora NO₂ column amount data showing five cases of OMI comparison. On March 25, 2008 and April 17, 2008 there are two cases from successive OMI orbits with different view angles. Light colored dots are when the Pandora field of view contained clouds.

The highly variable daily time dependence of C(NO₂) is illustrated (Figure 4.7) for November 30, 2007, March 25, 2008, and April 17, 2008. In most cases, C(NO₂) has a small value in the morning shortly after sunrise followed by larger values later in the day. Occasionally, this is not true when the local meteorology provides very clean air. For May 21, 2007, there was a coastal storm on Friday and Saturday (May 18 and 19) with a cold front that cleared the area on Sunday and Monday leaving almost cloud-free sunny conditions on Monday with very low pollution levels. On November 30, 2007, the weather was clear after a cold front came through with winds in the morning allowing pollution to build up in the afternoon.

As indicated by the green dot, the agreement with OMI was quite good. On March 25, 2008, the weather was calm, cool, and sunny until the afternoon when clouds appeared. This allowed pollution to build by 10:00 a.m. until noon when the weather started to change. The agreement with OMI was fair for both orbits with OMI tracking the general diurnal change. On April 17, 2008, the weather was sunny, clear and warm with afternoon breezes. The comparison with OMI was poor on both orbits, but with OMI tracking the observed diurnal change. The 13:30 OMI pixel location was not near GSFC ($D_{GO} \gg 20$ km, where D_{GO} is the distance of the center of the OMI pixel from the GSFC observing site—less than 20 km).

Even though the day-to-day $C(\text{NO}_2)$ has high variability, there is a general pattern with respect to seasons and day-of-the-week, as shown in Figure 4.8, where the variation is much larger than the standard error of the mean.

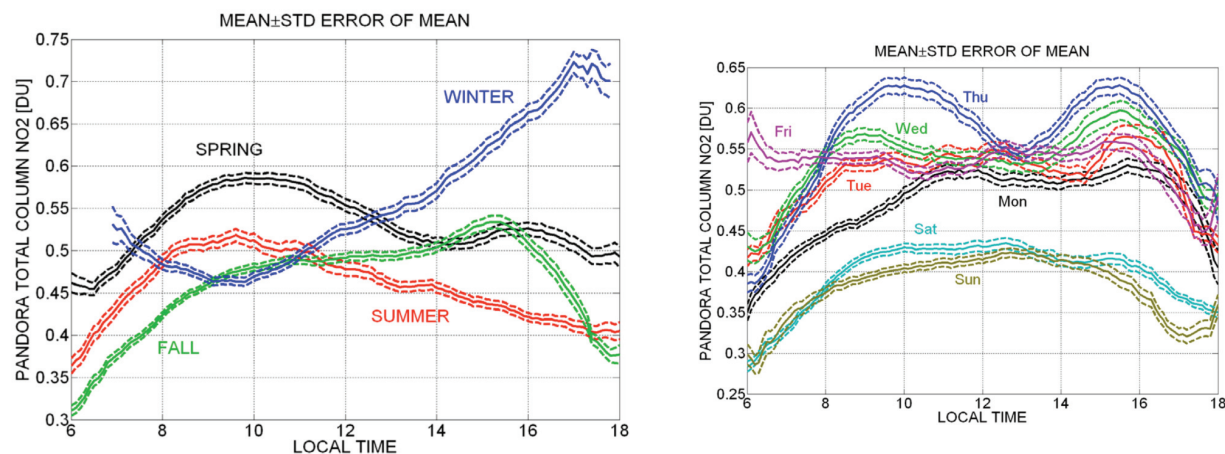


Figure 4.8. Left: Average seasonal time dependence of $C(\text{NO}_2)$ during the day. Right: Annual average for day-of-the-week diurnal behavior of $C(\text{NO}_2)$ at GSFC. Winter (Dec, Jan, Feb); Spring (Mar, Apr, May); Summer (Jun, Jul, Aug); and Fall (Sep, Oct, Nov). The triple lines show the mean value plus-or-minus the standard error of the mean.

4.2.4 Asian Monsoon Year 2008 (AMY 2008)

NASA/GSFC mobile observatories, SMART-COMMIT (<http://smart-commit.gsfc.nasa.gov>), were transferred to the U.S. Department of Energy Atmospheric Radiation Measurements (ARM) program through an interagency agreement and was named the ARM Ancillary Facility (DOE/AAF). Currently, AAF and the ARM Mobile Facility (AMF) are being deployed simultaneously in China during the Asian Monsoon Years (AMY-2008) to acquire comprehensive ground-based observations for aerosol-cloud-water cycle studies. The AAF/SMART-COMMIT measurements are being taken at Zhangye, China, for dust aerosols originating at the Taklimakan and the great Gobi deserts (see Figure 4.9 for instrumental setup). The AAF also closely collaborates with the Lanzhou University, China, which operates a supersite of the Semi-Arid Climate and environment Observatory–Lanzhou (SACOL, <http://climate.lzu.edu.cn>, at an altitude of 1966 m and ~40 km east of Lanzhou city) and a mobile facility of subset SACOL at Jingtai (at an altitude of 1604 m and ~200 km north of Lanzhou city). Thus, analyses of simultaneous measurements from these three sites will provide a better understanding of dust properties near different source regions, as well as properties downwind due to mega-city (Lanzhou) influence.

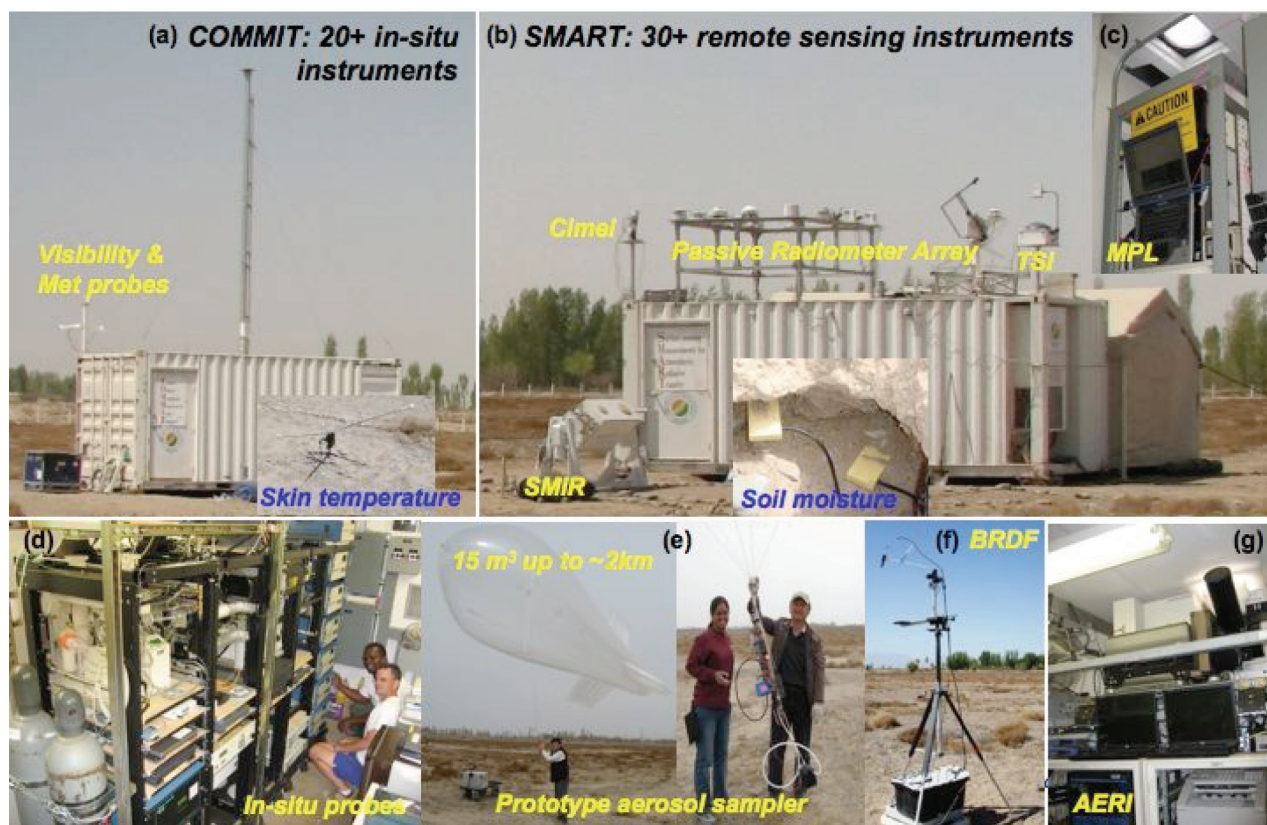


Figure 4.9. (a) COMMIT observatory with skin temperature probe at the foreground, (b) SMART observatory with an array of radiometers on the roof and a scanning microwave radiometer and soil moisture probes at the foreground, (c) a micro-pulse lidar inside SMART, (d) an array of in situ instruments inside COMMIT, (e) in-house built prototype of aerosol sampler, (f) setup for measuring surface bidirectional reflectance, and (g) an atmospheric emitted radiance interferometer.

Periodic dust episodes around the AAF/SMART-COMMIT site have been observed from Earth observing satellites, such as the MODIS sensors aboard EOS/Terra and EOS/Aqua. The color appearance exhibits a bit of brown-yellow for the Gobi/local dust, but pale or beige for the transported dust from the Taklimakan. Using the May 2nd case as an example, Figure 4.10 (left double-panel) shows true-color MODIS images of Terra and Aqua around the AAF site, indicating two dusty areas following respective frontal cloud-bands. Surface observations in the morning started off calm and somewhat hazy. Temperatures warmed until ~2:00 PM when clouds started to roll in and the winds began to pick up from the northwest, with steady winds at ~7 m/s (gusts 10–15 m/s). Local surface dust was being visibly lifted especially in the dry seasonal riverbed. Impressive evolution of the entire day can easily be seen with total-sky imagery, TEOM¹ instantaneous mass, APS coarse-mode concentration, and MPL profiling readings, as well as by other instruments. The air was quite laden with dust (6:00 PM) and visibility dropped to less than 2 miles, as shown in Figure 4.10 (right photo). Preliminary estimates from Aqua images are that the dust aerosols may have come from the Taklimakan deserts, which escaped from the Tarim Basin and were transported quickly over the AAF/SMART-COMMIT site. To fully characterize the properties of airborne dust near desert regions in the field is an important but challenging task.

1. TEOM: Tapered Element Oscillating Microbalance

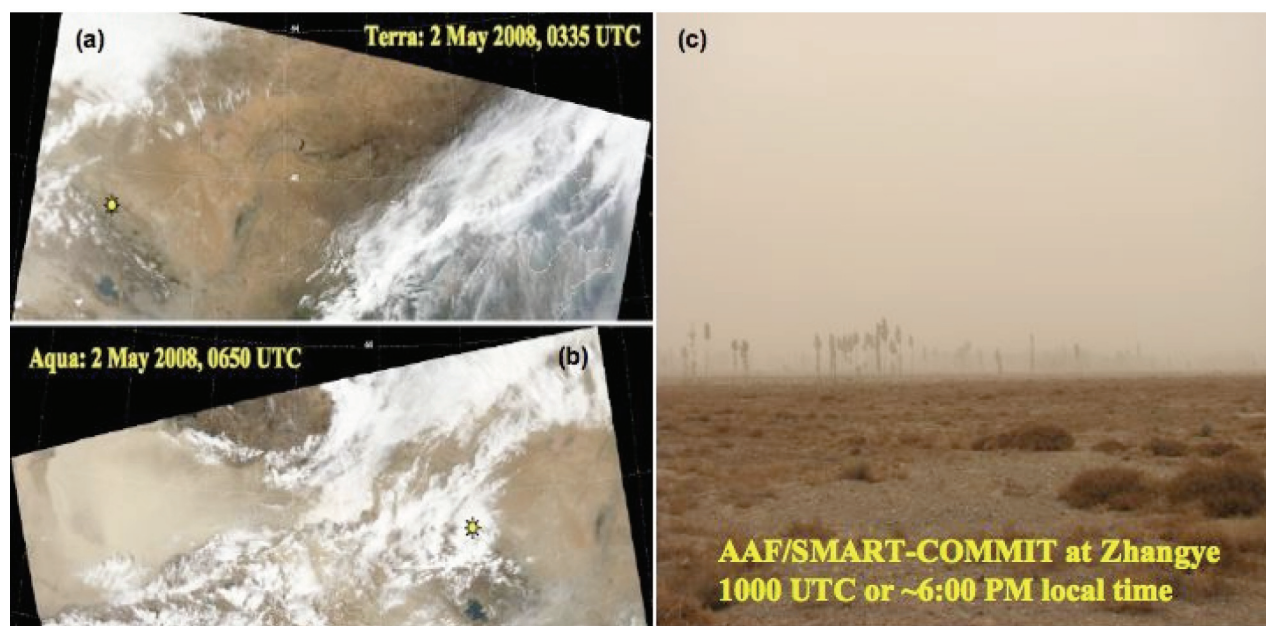


Figure 4.10. (a) Terra/MODIS and (b) Aqua/MODIS images showing airborne dust aerosols associated with frontal cloud system passing over the AAF/SMART-COMMIT site (yellow mark), and (c) photo taken onsite during the dust outbreak.

For further information contact: Si-Chee Tsay (Si-Chee.Tsay-1@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 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 low-Earth orbit satellites, 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 Earth Sciences Data and Information Services Center (GES DISC). 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 11-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 GES DISC 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).

4.3.2 Merged TOMS/SBUV Data Set

We have updated our merged satellite total ozone data set through August of 2008. We have transferred the calibration from the original six satellite instruments to the NOAA-16 and NOAA-17 SBUV/2 instruments. We have further extended this intercalibration to include the OMI instrument on the Aura satellite. In addition, we 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. For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (Stacey.M.Frith@nasa.gov).

4.3.3 Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS operational Atmosphere Team algorithms produce both level-2 pixel-level or swath data) and level-3 (gridded) products for the Terra and Aqua instruments. Over the past year, an updated processing stream (referred to as “Collection 5.1”) was begun for MODIS Aqua. Updated algorithms that are part of this stream include the “deep blue” aerosol algorithm, designed to retrieve aerosols over bright land surfaces, and minor fixes to the level-2 cloud products. While forward processing began in Fall 2008, Aqua reprocessing is expected to be completed in April 2009, followed by Terra reprocessing.

Both Terra and Aqua are now in the extended mission phase with Team Lead and level-1B activities funded through the Senior Review process. All level-2 and higher products are supported through Research Opportunities in Space and Earth Sciences (ROSES) competitions.

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 $1^\circ \times 1^\circ$ global grid and are produced for daily, eight-day, and monthly time periods.

4.3.3.1 Level-2 Products

The Aerosol Product provides aerosol optical thickness over the oceans globally and over a portion of the continents. Furthermore, information regarding the aerosol size distribution is derived over the oceans, while the aerosol type is derived over continents. The new algorithm for bright desert surfaces (referred to as the “Deep Blue” algorithm) is included in the Aqua MODIS collection 5.1 processing. This algorithm provides aerosol optical depth as well as single scattering albedo for dust aerosol. 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 Earth's surface is unobstructed by clouds. The cloud mask also provides additional information about the FOV, including the presence of cirrus clouds, ice and/or 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.

4.3.3.2 Level-3 Products

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

For further information, contact Steven Platnick (Steven.Platnick@nasa.gov) or visit the MODIS Web site at <http://modis-atmos.gsfc.nasa.gov/>.

4.3.4 MPLNET Data Sets

The NASA Micro-Pulse Lidar Network (MPLNET) is a federated network of Micro-Pulse Lidar (MPL) systems designed to measure aerosol and cloud vertical structure continuously, day and night, over long time periods required to contribute to climate change studies and to provide ground validation for models and satellite sensors in the NASA Earth Observing System (EOS). At present, there are 17 permanent sites worldwide, and 2 more are to be completed in 2009 (Figure 4.11). Numerous temporary sites have been deployed in support of various field campaigns since the start of MPLNET in 2000, and two more are planned in 2009. Most MPLNET

sites are co-located with sites in the NASA Aerosol Robotic Network (AERONET) to provide both column and vertically resolved aerosol and cloud data.

In addition to continuation of expansive network growth during the past year, MPLNET has supported several field campaigns during the past year including the International Polar Year (IPY) ICEALOT¹ cruise and aerosol observations in China pre- and post-Olympics as part of the NASA SMART deployment. Another highlight from 2008 is the addition of our newest permanent site on Barbados. The new site is co-located with AERONET, and the University of Miami aerosol monitoring station (30+ year record of dust observations). In addition, surface chemistry measurements from the AGAGE² program and radar profiling from the Barbados Meteorological Service are available for the site, providing a wealth of data on atmospheric structure and composition over the Tropical Atlantic Ocean.

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).

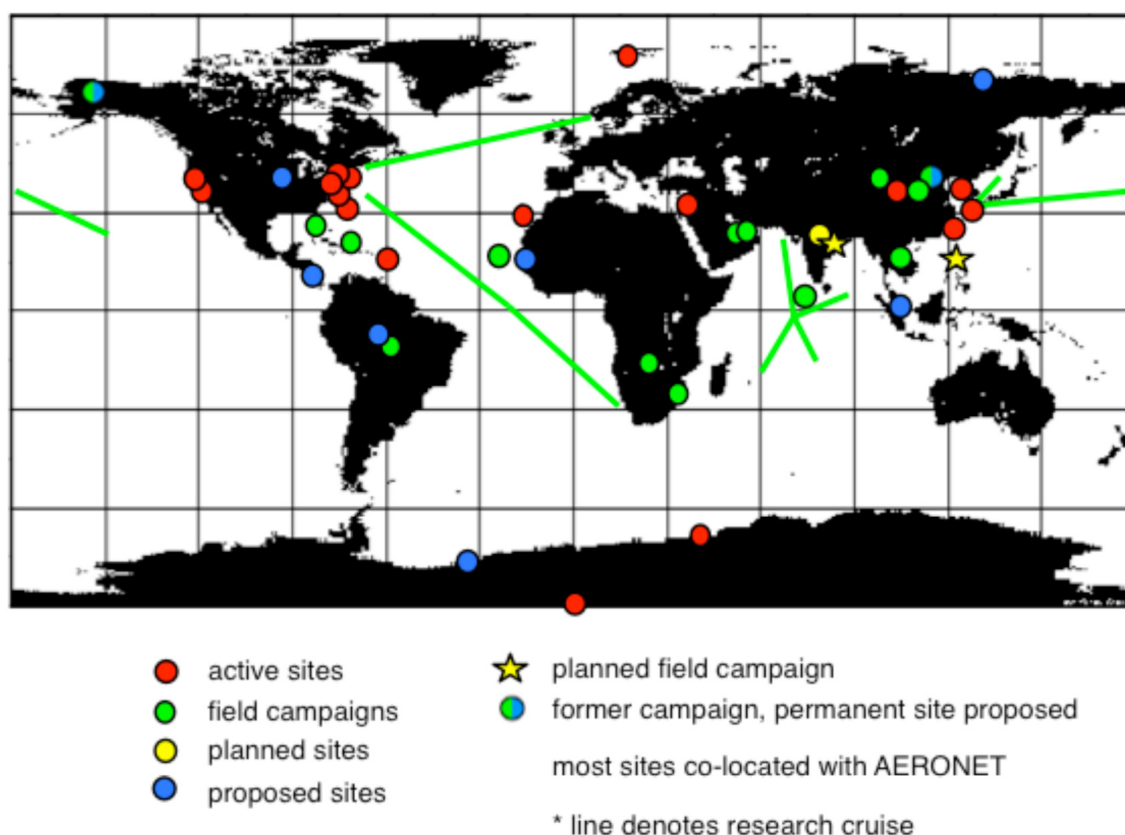


Figure 4.11. MPLNET Sites as of December 2008

4.3.5 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

1. ICEALOT: International Chemistry Experiment in the Arctic LOwer Troposphere

2. AGAGE: Advanced Global Atmospheric Gases Experiment

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 twice daily, five-day mean, and monthly mean 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 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 have been incorporated in the monthly and daily GPCP precipitation data sets. We 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. The AIRS Science Team algorithm Version 5.0, is now operational at the GES DISC. The AIRS Version 5 retrieval algorithm not only produces soundings of greater accuracy than those generated previously, but also contains a significantly improved methodology for Quality Control. The GES DISC has generated spot-by-spot AIRS level-2 soundings beginning September 2002 using Version 5 of the AIRS science team retrieval algorithm, and continues to generate these products on a near real time basis. Version 5 daily mean, eight-day mean, and monthly mean level-3 gridded products are also produced and are up to date. These products are readily available for use in climate studies by the scientific community. 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, now covering the period September 2002–February 2009, can be used to extend the TOVS's 25-year climate data set for longer term climate studies.

In joint work with Oreste Reale, Version 5.0 AIRS Quality Controlled temperature profiles, derived using this improved retrieval algorithm, have been assimilated using the GMAO GEOS-5 forecast analysis system and have been shown to produce a significant improvement in weather prediction skill. Forecast results assimilating Quality Controlled AIRS temperature soundings were shown to be superior to those obtained assimilating AIRS radiances, as done operationally at NCEP¹ and ECMWF² (Joel.Susskind-1@nasa.gov).

4.3.6 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 EP-TOMS (July 1996–December 2005).

TOMS data are given as daily files of ozone, reflectivity, aerosol index, and erythemal UV flux at the ground. The Version 8 algorithm was released in 2004, which addresses errors associated with extreme viewing conditions. The Nimbus-7, Meteor-3, and EP-TOMS data sets were all reprocessed using this algorithm. 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

1. NCEP: National Center for Environmental Prediction

2. ECMWF: European Centre for Medium-Range Weather Forecasts

“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).

4.3.6.1 Sulfur Dioxide, SO₂

Sulfur dioxide (SO₂) is a short-lived atmospheric constituent that is produced primarily by volcanoes, power plants, refinery emissions, and the 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 SO₂ is released in the boundary layer, or with tall smokestacks into the lower troposphere. Where SO₂ remains near Earth’s surface, it has detrimental health and acidifying effects. Emitted SO₂ is soon converted to sulfate aerosol by reaction with OH in the air or by reaction with H₂O₂ 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 SO₂, 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 SO₂ in a major eruption (El Chichón, 1982) was obtained from the six-UV band NASA Nimbus-7 TOMS. All significant eruptions since 1978 have now been measured by the series of TOMS instruments (Nimbus-7, Meteor-3, ADEOS-I¹, Earth Probe (EP): <http://toms.umbc.edu>). The SO₂ 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 SO₂. The OMI SO₂ data set is continuing the TOMS record (e.g., <http://toms.umbc.edu>) 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 (<http://so2.umbc.edu/omi/>). 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>; <http://aura.gsfc.nasa.gov/science/gallery-omi.html>; <http://www.knmi.nl/omi/research/news/>). Using monthly or annual average SO₂ maps, one can detect weaker degassing and pollution, e.g., http://aura.gsfc.nasa.gov/science/top10_smelters.html).

Visualization of daily OMI SO₂ data allows rapid appraisal of the most significant volcanic SO₂ emitters, which in 2007 included Tungurahua and Reventador (Ecuador), Popocatépetl (Mexico), Sheveluch (Shiveluch, Kamchatka, Russia), Piton de la Fournaise, (Réunion) Nyiragongo (Democratic Republic of Congo), Manda Hararo (Afar, Ethiopia), Mt. Etna (Sicily, Italy), and Jebel al-Tair (Yemen). These measurements highlight the deficiencies of previous compilations of volcanic SO₂ emissions, which were biased towards accessible, frequently monitored volcanoes. The eruption of Jebel al-Tair (Yemen) volcano in the Red Sea on October 1, 2007 was the first since 1883 and produced an SO₂ cloud that was carried a long distance by the subtropical jet stream (Figure 4.12).

1. ADEOS: ADvanced Earth Observing System

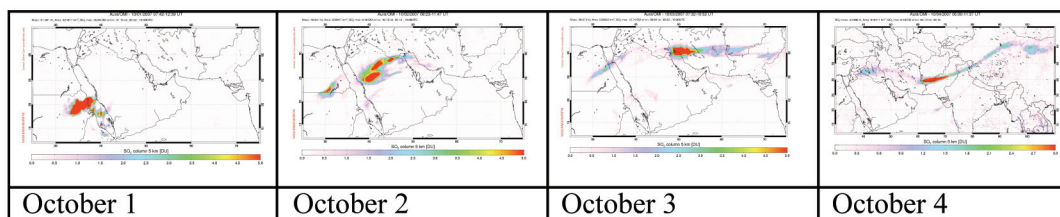


Figure 4.12 Long-range transport of the Jebel al-Tair volcanic SO_2 cloud by the subtropical jet stream observed by Aura/OMI instrument on October 1–11, 2007, <http://so2.umbc.edu/omi/>.

Using OMI data, we 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. An OMI SO_2 validation study was conducted using aircraft *in situ* SO_2 data collected over Shenyang in northeast China as part of the EAST-AIRE¹ field campaign. (Figure 4.13).

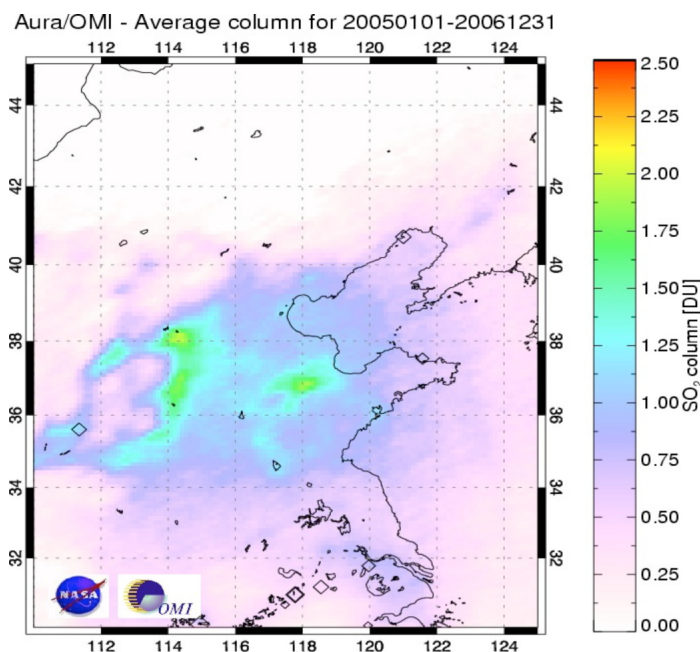


Figure 4.13. A 2-year average OMI SO_2 map over Eastern China in Dobson Units, where $1 \text{ DU} = 2.69 \times 10^{16} \text{ molecules/cm}^2$ showing persistent areas of high SO_2 concentrations in a triangle between Beijing, Shanghai, and the Sichuan basin in agreement with emission inventories. Smaller SO_2 enhancements ($\sim 0.5 \text{ DU}$) over the Shenyang region in North East China (black square) are also significant as compared to the background regions. This was the place of the first OMI SO_2 validation study.

Such measurements are essential given the growing concern over the response of 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

1. EAST-AIRE: East Asian Study of Tropospheric Aerosols: an International Regional Experiment

also amenable to operational SO₂ alarm development, and near-real time application for aviation hazards and volcanic eruption warnings.

For more information contact Nick Krotkov (Nickolay.A.Krotkov@nasa.gov).

4.3.6.2 Cloud

The OMI UV cloud algorithm retrieves an optical centroid cloud pressure 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 rotational Raman scattering as observed from a satellite above; therefore, the higher the cloud, the less filling in that is observed. To validate the cloud pressures, the OMI Raman cloud group assessed potential errors in the algorithm using radiative transfer calculations. They also performed validation of the cloud pressure product using data from the CloudSat cloud profiling radar as shown in Figure 4.14. When there are multiple cloud decks and the upper deck is relatively thin (optical thickness less than ~10), the retrieved optical centroid cloud pressure is close to the top of the lower cloud deck. In contrast, cloud pressures derived from thermal infrared sensors on MODIS are near the top of the upper cloud deck, as seen by CloudSat. In the deep convective areas, clouds are optically thin near the top and there is significant penetration of solar photons into the clouds.

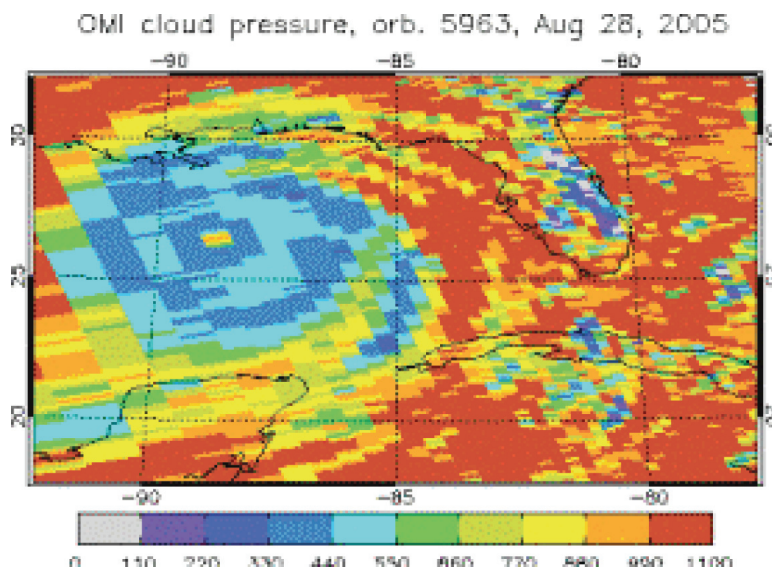


Figure 4.14 Cross section of CloudSat radar reflectivity (colors); Collocated MODIS cloud top pressures are the red boxes along the top; OMI optical centroid cloud pressures are the rust colored triangles; The black diamonds are simulated values of the optical centroid cloud pressure based on CloudSat data.

The OMI Raman cloud pressures have been incorporated into the collection 2 OMI-TOMS total ozone retrievals and subsequent sulfur dioxide retrievals. This significantly improved these products as well as the derived tropospheric ozone. The OMI cloud pressures have also been used in combination with MODIS cloud properties to estimate the radiative forcing due to tropospheric ozone. The OMI Raman cloud group is currently working on an algorithm that combines OMI and MODIS data to detect the presence of multi-layer clouds.

For more information contact Joanna Joiner (Joanna.Joiner@nasa.gov).

4.3.7 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 12 operational sites, including 3 that are north of the equator (Costa Rica, Suriname, and Malaysia). Each station launches weekly or monthly, depending on the resources available. SHADOZ archives ozone and temperature profile data at a user-friendly, open Web site: <http://croc.gsfc.nasa.gov/shadoz>. SHADOZ ozone data are used for a number of purposes:

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

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 4.15. Currently, 12 active sites are participating in SHADOZ. The sites are at Ascension Island; American Samoa; Fiji; Irene, South Africa; Watukosek, Java, Indonesia; Nairobi, Kenya; Alajuela, 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 (Jacquelyn.C.Witte@nasa.gov).

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

4.3.8 Tropospheric O₃ Data

Measurements from OMI and the Microwave Limb Sounder (MLS) onboard the Aura satellite have been used to develop several years of daily and monthly-mean global measurements of tropospheric ozone beginning late August 2004. The tropospheric ozone data are given as both tropospheric column ozone (in Dobson Units) and mean equivalent volume mixing ratio (in ppbv). The data are made available to anyone via the TOMS homepage (<http://toms.gsfc.nasa.gov>). The Web site also provides long time records of both tropospheric and stratospheric ozone in the tropics for the time period January 1979 through December 2005. For more information, please contact Jerry Ziemke (Jerald.R.Ziemke@nasa.gov) the Principal Investigator on the American OMI science team for tropospheric ozone.

4.3.9 Composite Solar Spectral Ultraviolet Irradiance Data Set

A composite solar spectral ultraviolet irradiance data set is now available for general use. The data set consists of daily average spectra covering the wavelength range 120–400 nm in 1-nm bins, and extends from November 8, 1978 to August 1, 2005. It was constructed using data from six different satellite instruments. This data set represents the longest continuous record of solar UV irradiance observations. The composite spectral irradiance data set is available at the LASP Interactive Solar Irradiance Data center (LISIRD) Web site (http://lasp.colorado.edu/lisird/deland_composite.html) in ASCII format and as an IDL save set. A simple description of the contents of the data set is available at the Web site, and a complete discussion of the creation process has been published in the *Journal of Geophysical Research* (DeLand and Cebula, 2008). The LISIRD Web site also contains links to other solar irradiance data sets of interest to solar, atmospheric, climate, and space weather researchers. For more information, please contact Matt DeLand (Matthew_DeLand@ssaihq.com).

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 (direct effect), modifying cloud microphysics (semi-direct effect), and altering cloud and rainfall patterns (indirect effect). On the other hand, condensation heating from rainfall, and radiative heating from clouds and water vapor associated with fluctuations of the water cycle (feedback processes), 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 analyzing the interrelationships among satellite-derived quantities such as cloud optical thickness and effective radii, aerosol optical thickness and size mode (CALIPSO, CloudSat, MODIS, MISR, OMI, and SeaWiFS), water vapor, non-precipitable cloud liquid/ice water and rainfall (AMSR¹, CloudSat, MODIS, and TRMM), and atmospheric temperatures (MSU and AIRS), 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, including ground-based and airborne operations, for measuring aerosol properties play an important role in this research.

1. AMSR: Advanced Microwave Scanning Radiometer

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 international World Climate Research Programs (WCRP) on aerosols and water-cycle studies. Laboratory scientists have played key roles in major international research projects such as the Joint Aerosol Monsoon Experiment (JAMEX), a core element of the Asian Monsoon Years (2008–2012) under WCRP, involving both field observations, satellite data utilization and modeling effects.

The first AMY/JAMEX campaign has been conducted successfully at northwestern China for characterizing the properties of dust-laden aerosols. Currently, Laboratory scientists are participating in the JAMEX/Radiation, Aerosol Joint Observations-Monsoon Experiment in the Gangetic-Himalayan Area (RAJO-MEGHA); Sanskrit for Dust-Cloud) for studying the climatic impact of elevated aerosols during the pre-monsoon season in South Asia.

For more information, contact William K-M. Lau (William.K.Lau@nasa.gov), N. Christina Hsu (Christina.Hsu@nasa.gov), Mian Chin (Mian.Chin@nasa.gov), Si-Chee Tsay (Si-Chee.Tsay@nasa.gov), Eric Wilcox (Eric.Wilcox@nasa.gov), or Wei-Kuo 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. The possible impact of anthropogenic and natural aerosol on regional and global atmospheric water cycles is also an important component of this research. 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. Laboratory scientists are also engaged in research involving effects of Saharan dust on hurricanes and possible linkage between tropical cyclones and global warming.

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 has recently been extended to combine spaceborne radar data with passive microwave observations for improved estimations.
- An empirical relationship that relates cloud thickness, humidity, and other parameters to rain rates, using TOVS and Aqua–AIRS sounding retrievals.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, 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 climate forcing is one of the largest uncertainties in assessing the global climate change. Aerosol is also a key component determining the surface air quality. Atmospheric models are important tools in incorporating the current knowledge and synthesizing the observed aerosol information in order to project the future change. The aerosol modeling capability at Goddard have branched out from the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model, and now is a part of the GEOS Global Circulation Model and the regional

model Weather Research Forecast–Chemistry (WRF–Chem) model. The modeling activities have always been closely connected to the satellite, ground-based, and aircraft observations. In 2008, research topics involved in aerosol modeling include:

- Support field experiment ARCTAS—also see the field experiment ARCTAS section
- Long-term trends of aerosols and effects on surface radiation
- Relationships between atmospheric aerosol and CO
- Biomass burning aerosol emission, plume height, and transport
- Seasonal and interannual variations of dust sources
- Atmospheric aerosol absorption
- Future satellite mission design

For more information, contact Mian Chin (Mian.Chin@nasa.gov), Huisheng Bian (Huisheng.Bian@nasa.gov), Peter Colarco (Peter.R.Colarco@nasa.gov), Arlindo da Silva (Arlindo.daSilva@nasa.gov), Thomas Diehl (Thomas.Diehl@nasa.gov), Qian Tan (Qian.Tan@nasa.gov), and Hongbin Yu (Hongbin.Yu@nasa.gov).

4.5.2 Chemistry–Climate Modeling (CCM)

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 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 recently ran scenarios that have been defined for the international Chemistry–Climate Model Validation exercise (CCMVal) that will provide input for the next ozone assessment. For this we used Version 2 of our GEOS CCM, which incorporates the same chemistry as Version 1, coupled into a new version of the general circulation model, GEOS-5. We also now have a version 3 in which the GEOS-5 GCM has been coupled to the Combined Stratosphere–Troposphere Model (COMBO) that was developed under the Global Modeling Initiative (GMI). The GEOS-5/COMBO version of the CCM has been run for a 10-year simulation and is being evaluated as a tool for understanding the impact of stratospheric changes on tropospheric chemistry and climate.

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).

4.5.4 Cloud and Mesoscale Modeling (Multi-scale Modeling)

Three different coupled modeling systems were again 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, vegetation and soil) effects on atmospheric convection, cloud–chemistry, cloud–aerosol, and stratospheric–tropospheric interactions. 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 as-

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), for the diurnal variation of precipitation processes, and for flood/drought events during three different years (2005–2007). The new, coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, intraseasonal oscillations, and diurnal variation of precipitation over land, which are very difficult to forecast using even state-of-the-art GCMs. In addition, the fvGCM is being used to conduct very high-resolution simulations (global mesoscale modeling) to model the tropical cyclone formation and the Madden-Julian Oscillation (MJO). Preliminary results for five tropical cyclones indicate that the high-resolution global model is capable of predicting their genesis about two to three days in advance, as well as predicting their subsequent movements.

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, snow events in Canada, severe weather in Taiwan, monsoons in India, and hurricanes in the Atlantic. 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, 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 snow events at higher latitudes, and to improve both precipitation retrievals from NASA satellites and the representation of moist processes in global and climate models.

A cloud library that consists of clouds and cloud systems that developed in different geographic locations is being generated and posted on a Goddard Web site for the public. The cloud data is being used for improving the performance of GPM snow retrievals, for improving the representation of moist processes in large-scale models, and for improving our understanding of precipitation processes associated with impact weather (i.e., hurricane, monsoon, and severe precipitation events). The Web address for the Goddard cloud library is <http://portal.nccs.nasa.gov/cloudlibrary>.

The same microphysical, long- and shortwave radiative transfer, explicit cloud–radiation, and cloud–surface interactive processes are applied in all three modeling systems (called multi-scale modeling system with unified physics). The results from these modeling systems were compared to physical parameters estimated from NASA EOS satellites (i.e., TRMM, CloudSat, Aqua-MODIS, AMSR-E) in terms of surface rainfall and vertical cloud and precipitation structures. In addition, simulated physical parameters (i.e., condensates or hydrometeors, temperature, and humidity profiles) from the Multi-scale Modeling can be used to simulate top-of-atmosphere radiance and backscattering profiles consistent to the NASA EOS satellite measurements through the end-to-end

NASA Goddard Earth Satellite Simulator (see Figure 4.16). This permits a) better evaluation of the Goddard physical packages by comparing model results with direct EOS satellite measurements (i.e., Figure 4.17) and b) support for NASA's satellite missions (i.e., TRMM, the A-Train, GPM, and the ACE mission) by providing virtual satellite measurements as well as simulated atmospheric environments as an *a priori* database of physically-based precipitation retrieval algorithms. The model results were also compared to NASA and non-NASA field campaigns.

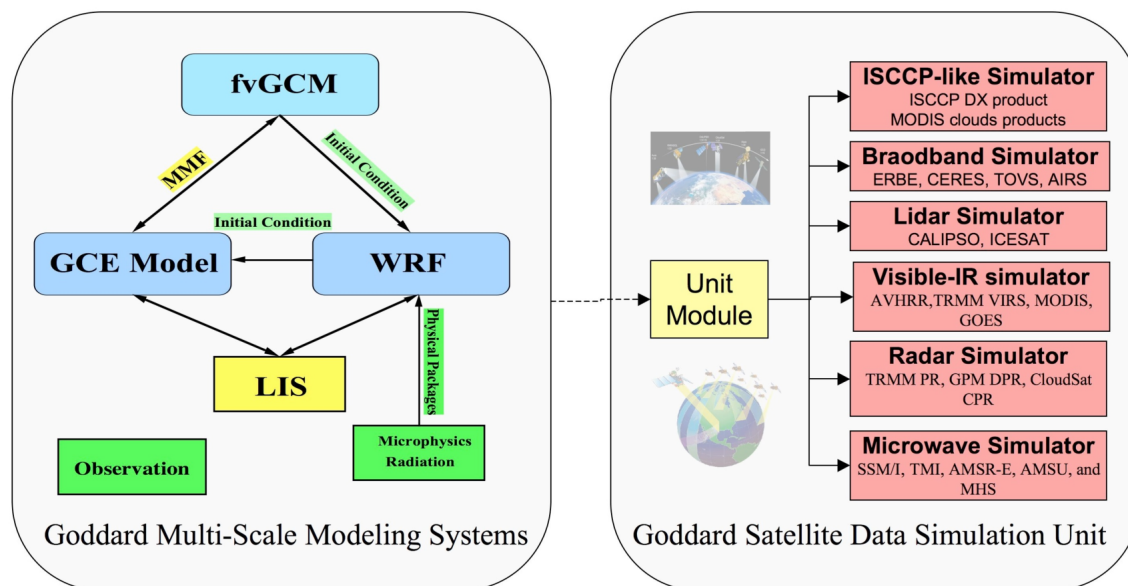


Figure 4.16 Schematic diagram of the Goddard Multi-scale Modeling System with unified physics coupled with the Goddard Satellite Data Simulation Unit (SDSU). The coupling between the fvGCM and GCE is two-way [termed a multi-scale modeling framework (MMF)], while the coupling between the fvGCM and WRF and WRF and the GCE is only one-way. LIS is the Land Information System developed in the Goddard Hydrological Sciences Branch. LIS has been coupled interactively with both WRF and the GCE. Additionally, WRF has been enhanced by the addition of several of the GCE model's physical packages (i.e., microphysical scheme with four different options and short and long-wave radiative transfer processes with explicit cloud-radiation interactive processes). Observations (obtained from satellite and ground-based campaigns) play a very important role in providing data sets for model initialization and validation and consequently, improvements. The Goddard SDSU can convert the simulated cloud and atmospheric quantities into radiance and backscattering signals consistent with those observed from NASA EOS satellites.

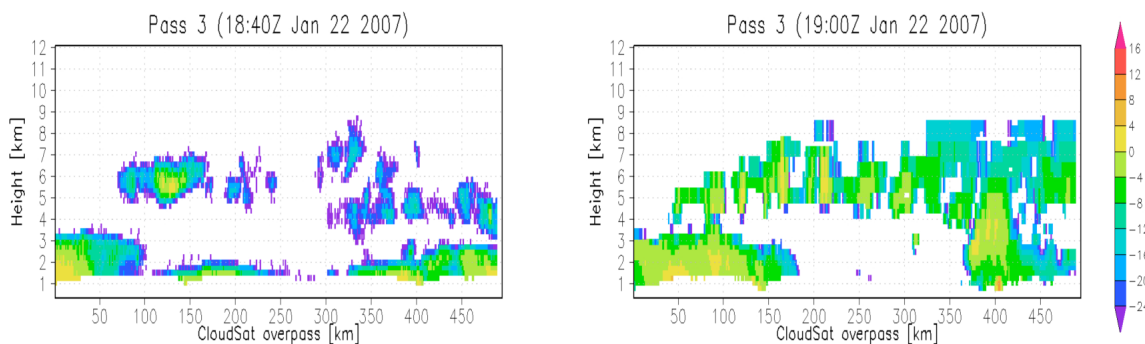


Figure 4.17. Instantaneous cross-sectional snap shot of CloudSAT-observed (left) and WRF-SDSU-simulated (right) Cloud Profiling Radar (CPR, 94 GHz) reflectivities.

The scientific output from the modeling activities was again exceptional in 2008 with more than 15 new papers published, in press or accepted. For more information, contact Wei-Kuo Tao (Wei-Kuo.Tao-1@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 assessing 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 different components of the GMI model 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. Comparison to OMI tropospheric column of NO₂, as well as to surface ozone measurements over Europe also show good agreement. Further testing with satellite data, aircraft, and ground-based measurements are also underway.

The GMI model has participated in the assessment carried out by the Hemispheric Transport of Atmospheric Pollutants (HTAP) international effort. Results of the model have been incorporated in the HTAP interim report, and will contribute to several scientific publications. Model results have also studied the impact of European pollution in the Middle East.

For more information, contact José Rodríguez (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 submodels 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 Laboratory scientists.

The GMAO has the overall responsibility for developing basic state-of-the-art climate models that are bias free; nevertheless, 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. Because 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 Seinfeld aerosol-nucleation scheme for water clouds. 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. We have implemented the Liu and Penner ice nucleation parameterization. The total aerosol–cloud interaction complex, called McRAS-AC, is an upgrade to McRAS. 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 have developed efficient, more accurate, and modular longwave and shortwave radiation codes with parameterized direct effects of man-made and natural aerosols, and clouds that depend on 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 CTMs simulate the evolution of ozone and trace gases that affect ozone. The constituent transport is calculated

using meteorological fields (winds and temperatures) generated by the GMAO or using meteorological fields that are output from a GCM. These calculations are appropriate to simulate variations in ozone and other constituents for time scales ranging from several days or weeks to seasonal, annual, and 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 ongoing 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 general circulation model with coupled chemistry 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 chemistry climate models (CCMs) combine a complete representation of photochemical processes with a general circulation model.

The constituent fields calculated using winds from the GCM, developed jointly by the GMAO and NCAR, exhibit many observed features. We have used output from this GCM in the CTM for multi-decadal simulations. The CCM 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 (GMI), 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. This combined mechanism has been implemented in the CCM for multi-annual simulations, but is presently impractical for multi-decadal simulations because of required computational resources.

The Branch uses trace gas data presently being obtained from sensors on the Earth Observing System–Aura (launched in 2004), as well as data from instruments on the Upper Atmosphere Research Satellite (UARS, 1991–2005), 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), serve on each Source Evaluation Board (SEB) for the engineering formulation of these instruments, and review vendors' progress during construction and testing of the 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 multi-channel 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 Mapping and Profiler Suite (OMPS) and CrIS, which will accompany ATMS and the AMSU crosstrack microwave sounder. Collaboration with the Integrated Program Office (IPO) continues through the Sounder Operational Algorithm Team (SOAT) and the Ozone Operational Algorithm Team (OOAT), which will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. We have conducted numerous 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 CO₂, CO, and CH₄. These studies indicate that total CO₂ can be obtained to 2 ppm (0.5%) from CrIS under clear conditions, total CH₄ 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 ECMWF and NOAA/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. CrIS/ATMS soundings were derived from analysis of the CrIS/ATMS proxy data using an algorithm analogous to that used by the AIRS Science Team to produce soundings using observed AIRS/AMSU data. As with simulated data, the accuracy of soundings derived from proxy CrIS/ATMS data was very similar to that obtained using real AIRS/AMSU data. We are using this proxy CrIS/ATMS data to test the performance of the Northrop Grumman Space Technology (NGST) prototype operational CrIS/ATMS retrieval algorithm and compare it with the results obtained with the government CrIS/ATMS algorithm modeled after the AIRS Science Team retrieval algorithm.

For more information, contact Joel Suskind (Joel.Susskind-1@nasa.gov).

4.6.4 Ozone Mapping and Profiler Suite (OMPS)

OMPS will become the next U.S. operational ozone sounder to fly on NPOESS. The instrument suite has its 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 its 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 will fly on NPP, but probably will not fly on the first NPOESS mission for cost reduction reasons.)

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 Stratospheric Aerosol and Gas Experiment (SAGE) III data when SAGE III operates in a limb scattering mode, which will simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE-1 and SOLSE-2 missions. The advanced ultraviolet and visible radiative transfer models developed in the Laboratory over the last two decades enable this research. The two decades of experience in TOMS and SBUV calibration and validation will also be applied to OMPS. For more information, contact 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. the Earth Science Technology Office (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		Deputy Project Scientists	
Name	Project	Name	Project
Scott Braun	TRMM	Gail Jackson	TRMM
Pawan K. Bhartia	OMI	Joanna Joiner	EOS Aura
Robert Cahalan	EOS SORCE NPOESS/TSIS ¹	Hans Mayr	AIM
Dennis Chesters	GOES	Steve Platnick	EOS Aqua
James Irons	LDCM ²		
James Gleason	NPP	Si-Chee Tsay	EOS Terra
Jay Herman	DSCOVR	Warren Wiscombe	ARM, Chief Scientist
		Christina Hsu	NPP

1. TSIS: Total and Spectral Solar Irradiance Sensor

2. LDCM: Landsat Data Continuity Mission

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

Validation Scientists		Field/Aircraft Campaigns	
Name	Mission	Name	Campaign Leaders
David Starr	EOS	Judd Welton	MPLNET
Ralph Kahn	EOS/MISR		
		Name	Campaign/Instrument
		Tom McGee	WAVES_2008/AT Raman Lidar MOHAVE III/ATL
		Jay Herman	NO ₂ Measurement/Pandora Spectrometer
		David Whiteman	WAVES_2008 MOHAVE
		Eric Wilcox Charles Catebe	ARCTAS/CAR
		Si-Chee Tsay	AMY SMART/COMMIT

4.8 Interactions with Other Scientific Groups

Laboratory staff, at all levels, interact with other labs, branches, and directorates at GSFC, as well as with other scientific groups in the U.S. and worldwide. This section describes some of these interactions.

4.8.1 Contributions to the U.S. Climate Change Science Program's Synthesis and Assessment Products

In the past year, scientists in the Laboratory for Atmospheres contributed to the US Climate Change Science Program (CCSP) Synthesis and Assessment Product (SAP) reports that addressed various aspects of the country's highest-priority climate research, observation and decision-support needs. The NASA-led report in this series, SAP2.3 "Atmospheric Aerosol Properties and Climate Impacts," involved Mian Chin (Code 613.3) as the coordinating lead author; and Ralph Kahn, Lorraine Remer, and Hongbin Yu (all in Code 613.2) as lead authors, as well as seven other scientists from the Goddard Institute for Space Studies (GISS), NOAA, DoE, and NASA HQ. The report provides a comprehensive assessment of current knowledge about aerosol properties and radiative forcing, based on the synthesis of satellite data, *in situ* measurements, and global models. It also recommends the way forward to better understanding the role aerosols play in climate change. The report points out that current uncertainties in total anthropogenic climate forcing estimates (including greenhouse gases and aerosols) are dominated by the uncertainties in the aerosol component. It states that to achieve the goal of reducing uncertainties in aerosol impacts on climate, an advanced, multidisciplinary approach that integrates surface, aircraft, and space-based measurements with models will have to be developed.

Laboratory for Atmospheres scientists, those who participated in writing SAP 2.3, as well as many others, are also leaders in just this sort of work. In addition, Paul Newman, Jay Herman, Anne Douglass, and Richard Stolarski (all in Code 613.3) served as lead authors on a NOAA-led SAP 2.4, "Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure." SAP 2.4 addresses the connections between the emissions, stratospheric ozone trends, and climate change. This report discussed the importance of ozone for screening UV radiation, looked at the compounds that produce ozone destruction (mainly human produced), discussed the ozone depletion (past, present, and future), and covered the science issues behind ozone depletion.

For more information and the entire reports, see <http://www.climatescience.gov/Library/sap/>.

4.8.2 SORCE Mission Extended 2010–2013

Since its launch in January 2003, the Solar Radiation and Climate Experiment (SORCE) has achieved its goal of simultaneously measuring TSI and SSI in the 0.1–27 nm and 115–2400 nm wavelength ranges with unprecedented accuracy and precision. SORCE has successfully completed its 5-year core mission (January 2003 to January 2008) and is in its second year of an extended mission. SORCE has accomplished unique new observations and understanding of solar radiative forcing of Earth's climate and atmosphere during the descending phase of solar activity cycle 23 and has successfully established the first solar reference spectra for cycle minimum conditions, in 2008.

Variations in the Sun's total and spectral irradiance impose key natural forcings of the climate system. Accurate, precise long-term records of TSI and SSI are thus, important components of NASA's Earth Science program. Current TSI and SSI measurements by NASA SORCE, future TSI measurement by NASA Glory, and planned TSI and SSI measurements by NOAA NPOESS TSIS are key climate measurements for our national climate program.

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

4.8.3 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;
- Joint Center for Observation System Science (JCOS), with the Scripps Institution of Oceanography, University of California, San Diego; and
- 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.

4.8.4 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.

4.8.5 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 have included TRMM, with the Japanese National Space Development Agency (NASDA); the TOMS program with NASDA and the Russian Scientific Research Institute of Electromechanics (NIEM); the OMI Program with Netherlands's Agency for Aerospace Programs (NIVR), 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 second SAGE III Ozone Loss and Validation Experiment (SOLVE II) 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-B¹, and MILAGRO² and in 2007 in campaigns such as TC4. 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. Such relationships were developed during the 2008 ARCTAS field campaign in Canada. The program involved three NASA aircraft, the DC-8, P-3B, and B-200, collectively carrying more than 20 instruments, plus ground stations, the NASA EOS satellites, and over 300 researchers, including many from the Laboratory for Atmospheres. These activities are described in detail in Section 4.2.1.

4.9 Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government–Industry partnerships, Small Business Innovation Research (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.

1. INTEX: Intercontinental Chemical Transport Experiment-Part B

2. MILAGRO: Megacity Initiative: Local And Global Research Observations

5. HIGHLIGHTS OF LABORATORY ACTIVITIES IN 2008

This section highlights the Laboratory's accomplishments for 2008. The summaries of Branch activities in sections 5.1, 5.2, and 5.3, expand on the introductory paragraphs in section 2. They 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 2007 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 microscales, with a strong focus on the initiation, development, and effects of cloud systems. A major emphasis is placed on understanding energy exchange and conversion mechanisms, especially cloud microphysical development and latent heat release associated with atmospheric motions. The research is inherently focused on defining the atmospheric component of the global hydrologic cycle, especially precipitation, and its interaction with other components of the Earth system. Branch members participate in satellite missions and develop advanced remote sensing technology with strengths in the active remote sensing of aerosols, water vapor, winds, and convective and cirrus clouds. There are also world-class research activities in cloud system modeling, and in the analysis, application, and visualization of a variety of data.

The MAPB currently consists of 66 onsite personnel. Demographically, there are 13 civil service scientists (12 with Ph.D.s) and one coop Ph.D. student. The Branch maintains Cooperative Agreements with four institutions (UMBC¹/GEST, UMBC/JCET, GMU, and UMCP²/ESSIC), which collectively, comprise 24 scientists and programmers (22 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 24 onsite personnel. Five other support persons are employed by RSIS (now Wyle Information Systems), Stinger Ghaffarian Technologies (SGT), Caelum, and Ecotronics. The GPM Project Scientist (Arthur Hou/GMAO) also resides in the Branch.

The Branch maintains a Web site at <http://atmospheres.gsfc.nasa.gov/meso/>, where current information on 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 high-quality data to the scientific community. For example, in a non-hurricane month (May 2006), the site served 50 GBytes/day to 46,000 distinct hosts at the average rate of 2 requests per second. During a hurricane, the Web server typically hits 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. 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.

1. UMBC: University of Maryland Baltimore County
2. UMCP: University of Maryland College Park

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.

5.1.1 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 overall accuracy of the TRMM algorithms continues to improve. Eleven years of high quality TRMM data are now available through the Goddard Distributed Active Archive Center (DAAC). TRMM, and other precipitation/latent heating data, are used within the Branch for a wide spectrum of studies on precipitating cloud systems, the global water and energy cycles, and precipitation variability. A highlight of the continued algorithm development and improvement activities was the transition toward a greater GPM focus, specifically on snow, e.g., Grecu and Olson (2008). Hou et al. (2008) published a review of advances in the measurement, estimation, and prediction of precipitation and Chandrasekar et al. (2008) published on the potential of using dual polarization radar for validation of satellite measurements. Liao et al. (2008) explored the retrieval of rain and snow from dual band radar. Skofronick-Jackson et al. (2008) worked to improve the accuracy of radiometer retrievals by improving the treatment of the ice phase. The TRMM Ground Validation (GV) team continued to contribute to the improvement in the quality of the TRMM GV data and thus the TRMM rainfall products, e.g., Wolff and Fisher (2008) and Silberstein et al. (2008). Tokay et al. (2008) showed the differences in raindrop size distribution between tropical and extra-tropical cyclones and Yang et al. (2008) documented the occurrence of persistent secondary diurnal modes in oceanic and continental rainfall derived from TRMM observations where each regime exhibited a secondary mode corresponding to the primary mode of the other regime. Hong and Adler (2008) continued their development of a landslide prediction application based on 3-hourly TRMM rainfall observations

Branch scientists also made significant contributions to the development of the Global Precipitation Measurement (GPM) mission in a wide range of areas including the following:

1. definition of mission requirements and de-scoping options;
2. GPM participation in the highly successfully Canadian CloudSat/CALIPSO Validation Program (C3VP) field campaigns in the winter of 2006–07 and subsequent analysis;
3. establishing joint ground validation plans with Finland, Canada, and France;
4. working with the international community to develop a common reference standard for intercalibrations of GPM constellation radiometers, which is key to providing the next-generation global precipitation products for research and applications; and
5. successful completion of the GPM Preliminary Design Review (PDR).

5.1.2 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 structure and optical depth of clouds (CPL), atmospheric aerosols (MPLNET, CPL), water vapor and aerosols (ALVICE, RASL), and winds (GLOW) at fine temporal and/or spatial resolution from ground-based (MPLNET, ALVICE, GLOW) or airborne platforms (CPL, RASL). Our airborne Cloud Radar System (CRS), a millimeter-wavelength radar for profiling cloud systems, is an instrument simulator for CloudSat, and together with our CPL CALIPSO simulator, provides a powerful and unique airborne measurement synergy within the Branch. For example, in July–August 2007, both CPL and

CRS were flown on the Earth Resources-2 (ER-2) satellite as a critical component of the TC4 mission, providing a mobile and directable CloudSat–CALIPSO capability for observing tropical cloud systems and aerosol fields as they evolved.

Development of three instruments funded from NASA's Instrument Incubator Program (IIP) continued. Our airborne Raman lidar (RASL) was completed and successfully flown in the WAVES-07 field campaign. TWiLiTE is an airborne direct detection Doppler lidar to measure wind profiles through the troposphere (0–17 km) using the laser signal backscattered from molecules. HIWRAP is 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. Both TWiLiTE and HIWRAP are on schedule for engineering test flights in 2009 on NASA's ER-2 and WB-57 high-altitude aircraft, respectively. We also plan to proceed with the integration of HIWRAP on NASA's new Global Hawk high-altitude unmanned vehicle in 2009. In addition, a new CPL was completed (UAV-CPL) and will be flown on the first science mission of NASA's Global Hawk in spring 2009 for Aura validation.

The NASA MPLNET is a federated network of Micro-Pulse Lidar (MPL) systems designed to measure aerosol and cloud vertical structure continuously—day and night—over long time periods required to contribute to climate change studies and provide ground validation for models and satellite sensors in NASA EOS. At present, there are 17 permanent sites worldwide, with 2 more to be completed in 2009. Numerous temporary sites have been deployed in support of various field campaigns since the start of MPLNET in 2000, and two more are planned in 2008. Most sites are co-located with sites in the NASA Aerosol Robotic Network (AERONET) to provide both column and vertically resolved aerosol and cloud data. Further information on the MPLNET project, and access to data, may be found at <http://mplnet.gsfc.nasa.gov>.

Our Raman lidar activity is now contributing to the Network for the Detection of Atmospheric Composition Change (NDACC). There is also a substantial effort and collaboration with Howard University (HU), including a series of field campaigns (WAVES), focused on Aura validation, at the HU Beltsville campus. The goals of these campaigns were to bring together a diverse set of instrumentation for validation of satellite water vapor, ozone, and clouds. WAVES-07 included the first flights of RASL, which flew in support of the Aura and CALIPSO missions, as well as for mesoscale studies and instrument comparisons. About 20 undergraduate and graduate students and many scientists from Howard University, GSFC, Penn State, Univ. of Virginia, Univ. of Colorado, the National Center for Atmospheric Research (NCAR), Maryland Department of Environment, United States Department of Agriculture (USDA), the National Weather Service (NWS), and scientists from Italy, Bolivia, and Brazil have participated in the WAVES experiments. Details of the WAVES experiments, including links to activities, goals, pictures, and more can be found at <http://ecotronics.com/lidar-misc/WAVES.htm>.

5.1.3 Numerical Modeling

The Branch is active in the development, improvement and application of atmospheric modeling systems. Three major development efforts continued to progress. The finite volume General Circulation Model (fvGCM), a global model, is coupled with the Goddard Cumulus Ensemble (GCE) model, a mesoscale cloud-resolving model, in a multi-scale modeling approach. A 2-D version of GCE is implemented within each fvGCM grid volume. The provides global coverage with explicit simulation of cloud processes and their interactions with radiation and surface processes, in contrast with conventional, more highly parametric, approaches. This modeling system has been applied and its performance tested for two different climate scenarios (El Niño /La Niña), for the diurnal variation of precipitation processes, and for flood/drought events. The new, coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, intraseasonal oscillations (Madden-Julian Oscillation, MJO), and diurnal variation of precipitation over land, which have proven very difficult to forecast using state-of-the-art GCMs. In addition, the fvGCM is being used to conduct very high-resolution simulations (global mesoscale modeling). Preliminary results for five tropical cyclones indicate that the high-resolution global

model is capable of predicting tropical cyclone genesis about two to three days in advance, as well as predicting the subsequent cyclone movement.

Various NASA Goddard physical packages (microphysics, radiation, and land surface models) have been integrated into the next-generation national weather research and forecast model (WRF), Kumar et al. (2008). The new, coupled modeling system allows better forecasting (or simulation) of convective systems and tropical cyclones. The GCE model was 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 better understand cloud and precipitation processes in the tropics, as well as snow events at higher latitudes and to improve both precipitation retrievals from NASA satellites and the representation of moist processes in global and climate models.

All three modeling systems now incorporate the same microphysical, radiative, and cloud–surface interactive processes (multi-scale modeling system with unified physics). The results from these modeling systems were compared to physical parameters estimated from NASA EOS satellites (i.e., TRMM, CloudSat, Aqua-MODIS, AMSR-E) in terms of surface rainfall and vertical cloud and precipitation structures. In addition, simulated physical parameters (i.e., **condensates or hydrometeors, temperature, and humidity profiles**) can be used to calculate top-of-atmosphere (TOA) radiance (L1) and backscattering profiles consistent with NASA EOS satellite measurements through our newly developed end-to-end NASA Goddard Earth Satellite Simulator. This permits better evaluation of the Goddard physical packages by comparing model results with direct/fundamental EOS satellite measurements, including CloudSat and CALIPSO (absent the complication of the application and uncertainty of the geophysical satellite retrieval algorithms). It also provides an *a priori* database for physically-based precipitation retrieval algorithm development over a wide range of simulated atmospheric environments.

Branch scientists continue active research in the areas of hurricane formation, structure, and precipitation processes. We also use models and TRMM satellite data to study the organization of precipitation in winter storms and the mechanisms responsible for that organization. Our increasing attention to the role of cloud microphysics in cloud system studies is highlighted in Zeng et al. (2008). We are increasingly addressing the issue of aerosol–cloud interactions and the possible effects in climate change.

A cirrus cloud model has been used in conjunction with Raman lidar observations to demonstrate the potential of Raman lidar to observe profiles of microphysical information, including number concentration and a quantitative measure of crystal habits (Reichart et al., 2008). This model was also used with time series of sophisticated lidar and Doppler cloud radar observations from the ARM Southern Great Plains site to examine details of cirrus cloud microphysical development and its relationship to estimated mesoscale vertical motion forcing (Comstock et al., 2008)

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.

The MISR aerosol product is also being maintained and improved in the branch, and provides a significant compliment to the MODIS aerosol product. The availability of MODIS and MISR cloud and aerosol products is opening new pathways of research in climate modeling and data assimilation in the Laboratory. MODIS and MISR data analysis efforts include the role of 3-D radiative effects on aerosol retrievals and a number of studies of 3-D 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 $-5.3 \pm 0.6 \text{ Wm}^{-2}$. 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 11 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. For the eleventh summer in a row, afternoon rainfall in summer over the continental U.S., as estimated by satellite, tends to be larger Tuesday to Friday than on weekends. 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 show a positive correlation, in agreement with previous satellite studies. Efforts to improve cloud-aerosol radiation interactions in large-scale models are being led by Lazaros Oreopoulos, through two Modeling and Analysis Program (MAP) projects involving collaboration with the GMAO, and the Atmospheric Chemistry Branch, to test alternate radiation codes, and to improve treatments of aerosol and cloud optical properties, subgrid-scale clouds, and cloud vertical correlations. Closely related efforts include the Continuous Intercomparison of Radiation Codes (CIRC), based on observationally-tested benchmarks, a working group chaired by Dr. Oreopoulos, and co-sponsored by the GEWEX Radiation Panel, and by the International Radiation Commission (IRC).

In the applications area, high-resolution MODIS Aerosol Optical Depth (AOD) products (1, 2, and 5 km) were evaluated as part of an ongoing 3-D air quality monitoring system project over the U.S. This 3-year effort (2006–2008) was funded by the NASA Application Program (Code YO), with a strong partnership with the U.S. Environmental Protection Agency (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), studied air quality in the San Joaquin Valley, California. This project was in support of the Global Earth Observation System of Systems (GEOSS) and funded by the EPA Pilot Program using high-resolution MODIS AOD products. Both projects incorporated CALIPSO, airborne, and ground-based lidar measurements to study the vertical distribution of aerosol. These two projects provided insights into the relationship of satellite-derived AOD and *in situ* PM_{2.5} mass concentration (for particles sizes less than 2.5 μm).

Branch members continued participating in NASA-sponsored field campaigns, including ARCTAS (June 2008), the NAMMA Special Observing Period (SOP)-3 study of African easterly waves (August 2008), and the U.S. DOE Atmospheric Radiation Measurements (ARM) Mobile Facility (AMF) and ARM Ancillary Facility (AAF/SMART-COMMIT) simultaneous deployment in China during the Asian Monsoon Year (AMY-2008) to acquire comprehensive ground-based observations for aerosol-cloud-water cycle studies.

The branch continues to serve in key leadership positions on international programs, panels, and committees. Robert Cahalan was elected President of the IRC, for the term 2008–2012, succeeding Teriyuki Nakajima of University of Tokyo. Alexander Marshak chairs the IRC's 3-D Radiative Transfer working group, and also leads the International Intercomparison of 3-D Radiation Codes, or I3RC. Lazaros Oraopoulos chairs the IRC's CIRC working group. Warren Wiscombe continues his tenure as the DOE ARM Chief Scientist, which 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 SORCE, launched on January 25, 2003. SORCE is measuring both Total Solar Irradiance (TSI) and Spectral Solar Ir-

radiance (SSI) with unprecedented accuracy and spectral coverage and has continued beyond its initial 5-year nominal mission lifetime. Dr. Cahalan also serves as project scientist of the SORCE follow-on mission, namely the Total and Spectral solar Irradiance System (TSIS), due to be launched on NPOESS C1, and expected to become, along with CERES, one of the first two climate missions to become operational. Deputy project scientists in the branch include Si-Chee Tsay (Terra), Steven Platnick (Aqua), and Christina Hsu (NPOESS Preparatory Project). Steven Platnick is serving as Acting EOS Senior project scientist, following retirement of Michael King, who in 2008 moved to University of Colorado's LASP.

We continue to make strides in many areas of science leadership, education, and outreach. Thanks to initial organizational efforts of the late Yoram Kaufman and involvement of Lorraine Remer, Charles Ichoku (ESSIC/613.2), and other Branch members, the popular AeroCenter seminar series has continued into year eight. 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 encourages 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, some of whose members (including manager Rebecca Lindsay, SSAI¹) 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. Another educational resource is PUMAS—Practical Uses of Math and Science—led by Ralph Kahn, and on the Web at <http://pumas.nasa.gov>. Developed to support high school teachers, PUMAS is keyed to teachers' specific needs in mathematics and science education. The branch also supports for the GLOBE² Student Research Campaign on Climate, which will occur over a 2-year period, beginning in January 2009, with an effort led by Charles Ichoku, and supported by Charles Gatebe and Robert Cahalan (see <http://globe.gov>).

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 conducts research including both the gas-phase and aerosol composition of the atmosphere. Both areas of research involve extensive measurements from space to assess the current composition and to validate the parameterized processes that are used in chemical and climate prediction models. The area of chemical research dates back to the first satellite ozone missions and the Division has had a strong satellite instrument, aircraft instrument, and modeling presence in the community. Both the EOS Aura satellite and the OMI instrument U.S. Science team come from this group. Atmospheric aerosols are an area of research in which the Division is responsible for aerosol retrievals from the Advanced Very High Resolution

1. SSAI: Science Systems and Applications, Inc.

2. GLOBE: Global Learning and Observations to Benefit the Environment

Radiometer (AVHRR) on POES, MODIS on EOS Terra and Aqua, and the Aerosol Polarimetric Sensor (APS) on Glory, as well as from modeling.

5.3.1 Satellite Data Analysis and Records

Branch scientists have been active participants in satellite research projects. In the late 1960s, our scientists pioneered development of the Backscatter 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 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. We have updated our merged satellite total ozone data set through September of 2008. We have transferred the calibration from the original six satellite instruments to the NOAA-16 and NOAA-17 Solar Backscatter Ultraviolet/Version 2 (SBUV/2) instruments, and we have further extended this intercalibration to include the OMI instrument on the Aura satellite. 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, ozone assessments, and for scientific studies in general.

For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (Stacey.M.Frith@nasa.gov).

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 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, NO₂, SO₂, and O₃ data.

The above instruments also provide information about light penetration inside clouds. The launch of CloudSat into the A-train with Aura has demonstrated that the cloud pressures provided by UV/VIS¹ measurements (referred to as optical centroid cloud pressures) are distinct from the physical cloud top and more appropriate for use in UV/VIS trace-gas retrievals. In the future, TOMS ozone data will be reprocessed with a cloud climatology based on OMI data. Branch scientists are also involved in satellite constituent retrievals from thermal infrared instruments such as the Aqua AIRS.

During the next four years, the reflectivity data from TOMS, SBUV-2, OMI, and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) will be combined to create a climate data record stretching back to 1979. This data record will be extended using GOME and the future NPP and NPOESS satellite instruments. Based on the first year's work, we will be able to determine whether there has been any long-term change in cloud cover over the land and oceans in response to global warming. Preliminary results indicate that there has been a small increase in cloud cover that is consistent with the independently developed data indicating global dimming (less light

1. VIS: Visible

reaching Earth's surface). In addition, we have found local areas of decreasing cloud cover over parts of Europe and the U.S. leading to increased amounts of UV exposure.

Our analysis of OMI data has also produced global maps of pollutants such as NO₂ and SO₂. In particular, these measurements are consistent with changes in the emissions of these species. A striking example is the diminution of observed NO₂ and SO₂ in the areas near Beijing due to stricter emission controls during the time of the Beijing Olympics.

5.3.2 Modeling Activities

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.

The development of our chemical modeling capability is one part of the overall Earth Science Directorate (ESD) goals to develop comprehensive Earth-system models. There are a number of efforts in chemical modeling that contribute to this goal, including the following:

1. Goddard Earth Observing System Chemistry Climate Model (GEOS CCM);
2. Global Modeling Initiative (GMI);
3. Stratospheric Chemistry and Transport model (CTM) in both two and three dimensions;
4. Global Ozone Chemistry Aerosol Radiation Transport Model (GOCART), described in the aerosol section;
5. aerosol microphysics and composition modeling (also described in the aerosol section); and
6. mesoscale modeling.

These efforts are used in different applications, but have strong common elements, the use of constituent observations to evaluate and improve the representation of processes in the models to provide better potential for reliable future predictions. These efforts are closely coupled to the development of the underlying general circulation model(s) and are part of the development process for including improved representations of processes in the model and pushing it forward towards the goal of a comprehensive Earth-system model.

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

5.3.2.1 Chemical Transport Model and the Global Modeling Initiative

GMI is a broad community effort funded by NASA HQ that is managed by the Atmospheric Chemistry and Dynamics Branch. 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. The GMI CTM includes both tropospheric and stratospheric chemistry and is being used to fully realize the benefits of the trace gas measurements in the lower stratosphere and troposphere, which are being made by instruments on Aura. Such applications are a prerequisite to interpretation of simulations using the fully coupled version of GEOS-5 (see below). In addition, the CTM also includes aerosol modules such as GOCART, as well as microphysical modules. The GMI chemistry has been incorporated into the GEOS-5 framework to allow for future coupled chemistry-climate simulations encompassing both the troposphere and the stratosphere. Current efforts are targeting the full incorporation of the GMI model into the GEOS-5 framework, allowing for a CTM capability within the same computational framework.

The GMI model continues to be compared to different observations, particularly near the tropopause (Considine et al., 2008). It has participated in the assessment carried out by the Hemispheric Transport of Atmospheric Pollutants (HTAP) international effort. Results from GMI simulations have been incorporated in the HTAP interim report, and will contribute to several scientific publications. GMI results have also investigated the impact of European pollution on the Middle East (Duncan et al., 2008), and the subgrid impact of relative humidity on aerosol optical depths (Bian et al., 2008).

A particular focus of GMI is to reduce the uncertainty in assessment by making it possible to determine the sensitivity of results to various model components. GMI will be mainly used for producing hindcasts, forecasts, and for sensitivity studies. GMI will be the comprehensive tool used by NASA for World Meteorological Organization (WMO)/United Nations Environment Programme (UNEP) and Intergovernmental Panel on Climate Change (IPCC) assessments.

5.3.3 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, deserts, oceans, vegetation, and volcanoes. In addition to the original offline version of the model which is driven by the GEOS-DAS¹ assimilated meteorological fields from GMAO, the GOCART modules have been implemented into the online GEOS-GCM model, as well as the GMI modeling framework in the past year by the Branch scientists to further enhance the modeling capability. The GOCART model and GEOS-5 were used to provide on-site forecasts of CO and aerosols during the ARCTAS mission. Recently, collaborating with NOAA scientists, the GOCART model is being implemented into the regional model WRF-Chem and the NOAA Global Forecasting System (GFS) to expand its applications and serve the larger scientific community

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, MISR, and CALIPSO, 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 SO₂ and absorbing aerosols are being tested to facilitate OMI retrievals. The model has been a part of the international project AEROCOM² and has been used in the new international activities of HTAP and the Atmospheric Chemistry and Climate initiatives. Results from GOCART simulations have been used to determine the contribution to polluted aerosol environments from both local sources and long-range transport.

5.3.3.1 Chemistry-Climate Model (CCM)

The chemistry-climate model is now in its third year of development. This effort is a collaboration between the Atmospheric Chemistry and Dynamics Branch (ACDB, Code 613.3) and GMAO (Code 610.1). It combines the CTMs developed in ACDB with the GEOS GCMs developed in GMAO. The first version of this effort coupled the 3-D stratospheric CTM developed over the past two decades in ACDB with the GEOS-4 atmospheric GCM. The goals of this effort were to better understand how the recovery of the ozone layer would take place as the underlying climate changed and how the ozone depletion and recovery might affect the climate. This version of the model was used as part of the 2006 WMO/UNEP Ozone Assessment and has been part of an international

1. DAS: Data Assimilation System

2. AEROCOM: AEROSol Comparisons between Observations and Models

intercomparison of chemistry-climate models (CCMVal). An updated version of the model now couples the stratospheric chemistry to the GEOS-5 atmospheric GCM. This version will be used for the upcoming 2010 WMO/UNEP Ozone Assessment. A third version that uses the combined stratosphere-troposphere chemistry (Combo) developed by GMI is now being tested and evaluated. This version will have seamless prediction of ozone in both the troposphere and stratosphere for better evaluation of its impact on climate change. The future for the chemistry-climate modeling effort includes both improvement in the underlying model through extensive data comparisons, and extension of the coupling in the model to include the aerosol-chemistry processes and the ocean-atmosphere GCM.

In the near term, we are focusing on the questions of how ozone will recover in a changing climate and how that recovery will affect the climate. With the version of the CCM including the combined stratosphere-troposphere chemistry we will begin to ask questions about how stratospheric ozone recovery affects tropospheric chemistry, and possibly air pollution. Simulations with our first version of the CCM have shown how stratospheric ozone and circulation are expected to respond to climate change driven by greenhouse gases (GHG). Simulations from 1950 to 2100 have shown that, as ozone-depleting substances (ODS) are removed from the stratosphere, ozone does not recover to the same distribution as existed before ODS were introduced. This is because of stratospheric cooling due to GHG and a possible change in the circulation of the stratosphere. We will do several simulations with the combined stratosphere-troposphere chemistry to separately evaluate the response of tropospheric chemistry to changes in both ODS and GHG. Longer term plans for this version of the model will include biogeochemical processes at the surface that can respond to changes in climate, thus providing variable input of chemicals to the atmospheric system. This advanced version of the model will be used for assessing the interaction of GHG and ODS with natural biological processes.

One of the results from our present studies is a better understanding of the role of sea-surface temperatures (SSTs) in the circulation and composition of the stratosphere. The atmospheric GCM uses SSTs specified from either observations or from simulations by coupled ocean-atmosphere models. The sensitivity of many of our results to SST assumptions highlights the importance of moving the CCM toward the use of a coupled ocean-atmosphere GCM. The development of such a model in GMAO provides us with an opportunity to further extend the coupled CCM in this direction.

Co-Principal Investigators (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).

5.3.3.2 Mesoscale Chemical Modeling

Global scale models are currently too computationally costly to reasonably resolve urban scale (<10 km) chemical composition. For the urban scale chemical composition, mesoscale models have been developed that include large-scale boundary input from global scale models. The mesoscale modeling effort currently being developed to support satellite and field missions, sensitivity studies, and satellite mission development. We are currently using and refining the Weather Research and Forecasting (WRF) regional model to include aerosols and chemistry in a way that is:

1. flexible in terms of spatial resolution (from sub-100 km to a few kilometers) and geographic location, and is ready to run in forecast, analysis, and testing modes; and
2. can be nested within the global model to study the regional-global interactions. This model is also a component of the definition studies for future missions.

5.3.4 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 CO₂ transport, has incorporated a land-biosphere emissions model and satellite data-constrained biomass burning emissions to produce CO₂ 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 CO₂ observations, such as the Orbiting Carbon Observatory.

We continue collaborating with the GMAO in a new effort to develop a carbon cycle data assimilation system. We are also in a collaborative effort with the Solar System Exploration Division to develop an airborne CO₂ 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 CO₂ profiler, is also being developed in the Laboratory for Atmospheres. The laser profiler has recently achieved CO₂ 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 CO₂ within the planetary boundary layer. The real-time CO₂ observations will be compared with modeled distributions to improve our knowledge of the coupling between carbon cycle processes and climate change.

5.3.5 Solar Proton Events

Charles Jackman is using the Whole Atmosphere Community Climate Model (WACCM) to study the influence of solar proton events (SPEs) on the middle atmosphere (stratosphere and mesosphere). He is working on this endeavor with staff at NCAR, where WACCM was developed. This work has focused on the very largest SPEs in the past 45 years. Comparisons between WACCM predictions and observations are generally reasonable for the SPE-caused production of polar NO_x (NO + NO₂) and the associated decrease in ozone during these very large solar events. He plans to continue this work and concentrate next on dynamically induced changes caused by the SPEs.

5.3.6 Instrumentation

Over the next five years, ground and aircraft observations will be focused on continued support for satellite measurements including those from Aura and Aqua; the Network for the Detection of Atmospheric Chemical Change (NDACC) ground-based network, and the Southern Hemisphere Additional Ozonesondes (SHADOZ) balloon network. In particular the NDACC will be supported by the Stratospheric Ozone Lidar Trailer Experiment (STROZ-LITE) measuring ozone aerosol, temperature and water vapor profiles; and by the Aerosol and Temperature Lidar (ATL) measuring aerosol scattering, extinction, and depolarization, stratospheric and tropospheric temperature, and water vapor. In the near future, a tropospheric ozone lidar capability will be added to the ATL, to provide observations for OMI comparisons. All data from these lidar instruments are also used in support of Aura measurements. Global Hawk Pacific Experiment (GloPac), and the Pacific Atmospheric Composition, Cloud and Climate Experiment (PAC3E). GloPac will be the first science mission flown on the Global Hawk UAS. Work continues on the development of a ground-based CO₂ lidar to make routine, highly accurate profile measurements for monitoring and field mission support. ESD scientists are collaborating with scientists from Langley Research Center to develop downward looking, ozone lidar instruments for the Global Hawk and ER-2 aircraft for future missions.

During the past two years, new accurate ground-based low cost instruments (Pandora and Cleo costing less than \$12,000) have been developed to measure trace gas amounts and aerosol properties to validate satellite measurements (OMI, GOME, and future NPP and NPOES instruments); explore the details of tropospheric chemistry;

and to determine air quality at multiple sites. Extending the three Pandora spectrometers currently operating, a network of these (20 instruments) will be deployed during the next two years at various sites throughout the world. The Pandora systems are capable of measuring O₃, SO₂, HCHO, NO₂, and H₂O column amounts with good accuracy (1%) and very high precision (0.1%). Uniquely, the Pandora system can determine ozone profiles from the ground to 50 km every 15 minutes throughout the day, which is especially important for satellite validation and air quality measurements. In addition, the Pandora spectrometers have the capability of making aerosol optical property and particle size measurements as a function of wavelength from 300 to 520 nm in 0.5 nm steps. The importance of the new aerosol measurement has been established by recent shadowband data, which show that the absorption properties of aerosols in the UV are different than those based on extrapolations of AERONET data. The absorption properties in the UV permit the determination of the type of aerosol and are required for improved model estimates of tropospheric chemistry. The Cleo spectrometer systems are an advanced version of the shadowband instruments, but are capable of measuring aerosol properties from 300 to 800 nm in 1 nm steps and O₃, SO₂, and H₂O column amounts. Unlike the original shadowband, the Cleo version can be field calibrated without an expensive laboratory setup. This makes them ideal for a widely distributed network of low maintenance instruments.

The Branch has also hired an experimental scientist to spearhead the development of a capability for *in situ* measurements aboard aircraft and balloons. The measurements, based on the Laser Induced Fluorescence technique, are expected to prove useful in developing new capabilities for validation of satellite data of species such as formaldehyde. ESD scientists are collaborating with NASA HQ in feasibility studies of the satellite missions detailed in the National Research Council (NRC) Decadal Survey.

Development of future satellite observations depends on the lessons-learned from ongoing efforts with currently flying satellite instrumentation: Aura's OMI instrument, TOMS, SBUV-2, and the European instruments Global Ozone Monitoring Experiment (GOME) and SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY). Studies are currently under way to refine scientific goals and measurement requirements for the GEO-CAPE mission. In addition, the Airborne Compact Atmospheric Mapper (ACAM), a UV/VIS high resolution instrument developed under an IIP project, has flown aboard the WB-57 in the TC-4 and NOVICE¹ campaigns, and may provide a prototype for an instrument to be flown in the GEO-CAPE mission. A concept for a Venture-type mission for stratospheric measurements, Chemical and Aerosol satellite Sounding System (CASS), is also under study. All these activities may be hampered by the retirement of experimental scientists in UV detection and calibration, and new hires are needed to continue this activity and maintain our world leadership. Code 613.3 scientists are participating in the support, execution, and development of aircraft field missions. ESD scientists provided onsite support in chemical forecast of CO and aerosols for the Arctic Research of the Composition of the Troposphere from Aircraft and Satellite (ARCTAS), during both the spring 2008 and summer 2008 deployments. Support of ARCTAS will continue through post-mission analysis of aircraft and satellite data. GloPac will be the first science mission flown on the Global Hawk unmanned aircraft system (UAS). GloPac will fly a mix of *in situ* and remote sensing instruments for supporting Aura validation, and exploring issues related to stratospheric ozone depletion, aerosol transport, and global pollution. Code 613.3 is contributing to GloPac with project science leadership, flight planning, and the ACAM UV/Vis instrument. The Pacific, Atmospheric Composition, Cloud and Climate Experiment (PAC3E). PAC3E is a multi-Agency, NASA multi-program, field mission to investigate the structure, properties, and processes in the tropopause transition layer (TTL), and the chemistry of the lower troposphere over the tropical Western Pacific. The PAC3E mission is currently in the development stage, but is tentatively planned for January and February of 2011.

In addition to GloPac and PAC3E, Code 613.3 scientists are beginning work on a number of missions that will be proposed under the Venture class. The first Venture class NASA Research Announcement (NRA) will be released in 2010, with funding for 2011. We are working on two missions in collaboration with NASA Ames

1. NOVICE: Newly-Operating and Validated Instruments Comparison Experiment

Research Center: the Hurricane and Severe Storm Sentinel Mission (HS3), and a missions flying a UV/Vis spectrometer in support of the GEO-CAPE Decadal Survey Tier II mission.

5.4 Laboratory Research Highlights

5.4.1 Global Modeling

One of the strengths of Atmospheric Chemistry and Dynamics Branch (613.3) is that results from models and from various data sources can be used to address an issue. Douglass et al. (2008) used output from the CGCM, the GMI CTM, the 2-D CTM, and a trajectory model to understand why *in situ* measurements from the ER-2 in the middle- and high- latitude lower stratosphere show that photolysis has broken apart significant fractions of the long-lived chlorofluorocarbons (CFCs) such as CF₂Cl₂ and CFC13, even though the rate of destruction at the altitude of the measurement is insignificant. There is an observed compact relationship between the mean age of a parcel and the parcel fractional release, i.e., the amount of CFC that has been destroyed relative to the amount in the parcel when it crossed the tropical tropopause. This relationship is reproduced by simulations that produce realistic distributions for the mean age, but not by simulations that produce young age distributions as was common for both 2-D and 3-D models during the 1990s. The modern models that reproduce the observed relationships also produce longer lifetimes than the models that produce young ages, e.g., the lifetime for CFC13 that is consistent with the ER-2 observations for mean age and fractional release is about 56 years, significantly longer than the 45 years deduced from ground-based measurements and a simple model. This is important because the 45-year lifetime is used to produce the boundary conditions for assessment calculations or for projections of the recovery of the ozone hole.

The above example illustrates an important aspect of the atmospheric chemistry modeling research within the Atmospheric Chemistry and Dynamics Branch; the importance of keeping modeling activity firmly grounded in data such as that obtained by satellite instruments, aircraft missions, and ground-based instruments. For further information contact Rich Stolarski (richard.s.stolarski@nasa.gov).

5.4.2 Reversal of Trend of Biomass burning in the Amazon

5.4.3. Global Increase in UV (280–325 nm) Irradiance During 1979–2008

Ultraviolet irradiance (from 290 nm to 325 nm) reaching Earth's surface has significantly increased since 1979 at all latitudes except the equatorial zone. The annual average increase was caused by a corresponding decrease in ozone amount. In the Southern Hemisphere, the increase is partially offset by a decrease in cloud and aerosol transmission through the lower troposphere, but not in the Northern Hemisphere. The ozone changes have been obtained from a multiple satellite time series starting with Nimbus-7 TOMS in 1979 and continuing to the end of 2008 with the SBUV-2 series, Earth-Probe TOMS (EP-TOMS), and OMI. The changes in cloud cover have been obtained from the 340 nm reflectivity data from the same series of satellite instruments, except for EP-TOMS. The reflectivity data set was generated in response to the MEaSUREs¹ program to produce climate data records.

1. MEaSUREs: Making Earth Science Data Records for Use in Research Environments

Table 5.1 Satellite Instruments for ozone and reflectivity.

1979–1992	Nimbus-7/TOMS (N7)	Full global coverage every day. Only a few missing days from 1980 to 1992. Ozone plus reflectivity. Near noon orbit
1985–2008	SBUV-2 Series (N-9, N-11, N-16, N-17, N-18)	Nadir viewing only. Only a few missing days. Ozone plus reflectivity. N-9 and N-11 have a drifting orbit.
1996–2006	EP-TOMS (EP)	Full global coverage every day. Only a few missing days in 10 years. The calibration precision was improved by using N-16 as a reference. Not used for cloud plus aerosol reflectivity. Near noon orbit.
1997–2008	SeaWiFS (SW)	The 412 nm reflectivity has been produced using the TOMS production algorithm. Does not measure ozone. Noon orbit.
2004–2008	OMI	Full global coverage every day with few missing days. OMI produces both ozone and reflectivity values. 1:30 PM orbit.

The ozone data are obtained from NASA Goddard Space Flight Center's Web site (http://hyperion.gsfc.nasa.gov/Data_services/merged/index.html) for monthly and 5° zonal average band values.

The irradiance change estimates are based on a new derivation of an apparently empirical Power Law method, which is commonly used for modeling changes in action spectrum weighted irradiance functions encompassing a wide range of wavelengths with changes in ozone amount. The Power Law form empirically matches broadband irradiance data (e.g., erythral irradiance) quite well. The derived changes in ozone amount and cloud-plus-aerosol transmission are shown in Figure 5.1.

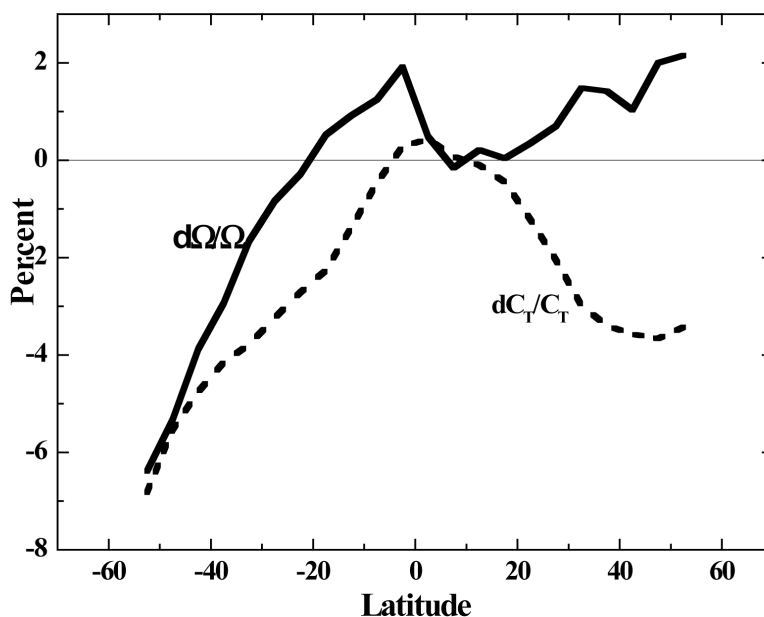


Figure 5.1. The 30-year percent change in zonal average annual ozone amount Ω and cloud transmission C_T as a function of latitude.

Based on Figure 5.1, the estimated changes in irradiances caused by ozone changes are given for six wavelengths (Figures 5.2 and 5.3). The wavelength range from 305–325 nm encompasses the region where the DNA damage,

Vitamin-D, and erythema action spectra have their maximum effect. All of the UVB wavelengths show a strong dependence on ozone change, which also carries over to some of the UVA wavelengths (320–325 nm).

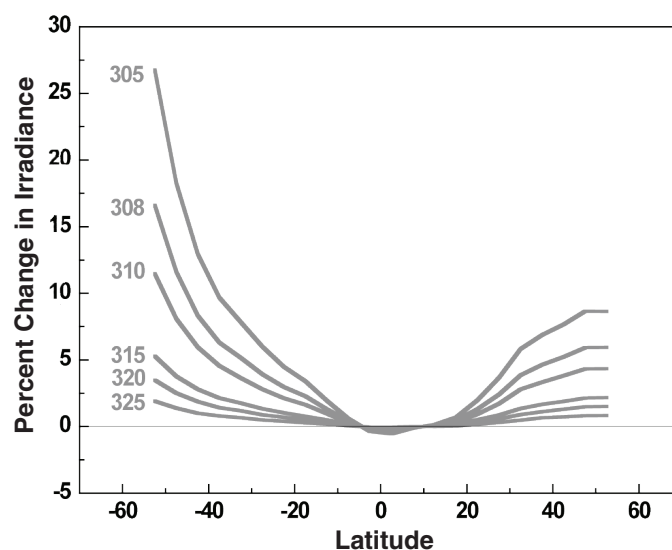


Figure 5.2. Percent annual changes in zonal average 305 to 325 nm and erythema irradiances from changes in ozone amount for 30 years (1979–2008).

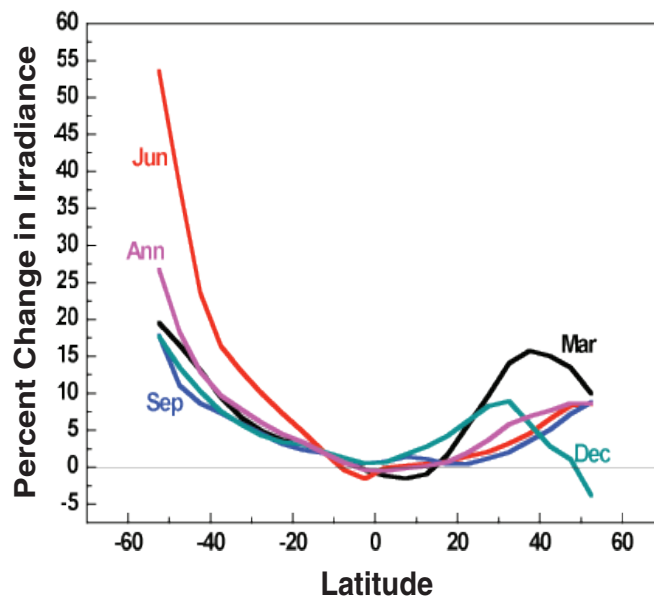


Figure 5.3. Monthly and annual (Ann) percent changes in zonal average 305 nm Irradiance from changes in ozone amount for 30 years (1979–2008).

For further information contact: Jay Herman (jay.r.herman@nasa.gov)

5.5 Instrument Development

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. Because 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 dual-beam, dual-wavelength conical scan radar that uses new technologies, which utilize solid state rather than tube-based transmitters (Figure 5.4). Although primarily intended for atmospheric (precipitation) measurements, HIWRAP can serve as a QuikScat simulator with its Ku-band frequency and can provide measurements for GPM algorithm development because it has similar Ku- and Ka-band frequencies. HIWRAP is currently being integrated and tested. The prototype sensor will be completed and tested on the high-altitude WB-57 aircraft in Fall 2009 to demonstrate the system level performance of the instrument. For further information contact Gerry Heymsfield (Gerald.M.Heymsfield@nasa.gov).

5.5.2 Cloud Physics Lidar

During 2008, Dr. Matthew McGill received support from Goddard's Internal Research and Development (IRAD) funding to complete assembly of the new Cloud Physics Lidar (CPL) for the Global Hawk. The CPL will be one of the first instruments integrated to NASA's new Global Hawk aircraft in 2009. Similar in form and function to the highly successful version of CPL flown on the ER-2 aircraft, the new version will be capable of extended duration (up to 36 hours) flights on the Global Hawk. The first science mission for the Global Hawk will be the GloPac campaign to be flown in spring 2009 with the primary goal of Aura and A-Train validation.

For further information contact Matt McGill (Matthew.J.McGill@nasa.gov).

5.6 Awards and Special Recognition

Wei-Kuo Tao (613) received the William Nordberg award at the Goddard Science Colloquium on November 7, 2008. The William Nordberg Memorial Award for Earth Science is presented annually to a Goddard employee "who best exhibits qualities of broad scientific perspective, enthusiastic programmatic and technical leadership on the national and international levels, wide recognition by peers, and substantial research accomplishments in understanding Earth science processes." This award recognizes Dr. Tao's outstanding long-term contributions to advancing fundamental understanding of how cloud systems work, his leadership in Earth system modeling and his devotion to nurturing the next generation of Earth scientists. His important contributions to the highly successful TRMM effort helped ensure the quality of its rainfall and latent heating products.

Gerald Heymsfield (613.1) was awarded the NASA Exceptional Scientific Achievement Medal on May 13, 2008, for his innovative development and application of airborne radars to advance knowledge of atmospheric storm systems, especially in support of the TRMM.

Steve Platnick (613.2) was awarded the NASA Exceptional Scientific Achievement Medal on May 13, 2008,

Si-Chee Tsay (613.2) was awarded the NASA Outstanding Leadership Medal on May 13, 2008:

Citation: “For outstanding leadership on the SMART-COMMIT (BASE-ASIA, NAMMA, and Cape Verde) Field Deployments.”

A. Douglass (613.3) was selected as a member of the American Meteorological Society (AMS) council.

5.6.1 Goddard Honor Awards

David Whiteman (613.1) was awarded the Robert H. Goddard Award for Exceptional Science Achievement on September 8, 2008, for his contributions to the advancement and application of Raman lidar measurements, especially for validation of tropospheric water vapor measurements by NASA satellites.

5.6.2 Group Achievement Awards

On May 8, 2008, a NASA Group Achievement Award for Outstanding achievements in atmospheric science during the Tropical Composition, Cloud and Climate Coupling (TC4) Mission in Costa Rica and Panama in 2007 was awarded to a large group of scientists in 613.

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. However, in recent years, undergraduate and graduate enrollment and the number of doctorates awarded in science and engineering have been declining. 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

6.2.1 PUMAS—Practical Uses of Math And Science



Pumas is an online journal, a Web-based collection of brief examples aimed at giving K-12 teachers insights into how the math and science they teach are actually used in everyday life. This site was founded and is edited by **Ralph Kahn** (613.2), who joined the Laboratory in September 2007, coming from JPL. The examples are written primarily by scientists and engineers, and are available to teachers, students, and other interested parties via the PUMAS Web site (<http://pumas.nasa.gov/>). Scientists contribute their expertise by writing the examples, which may be activities, anecdotes, descriptions of “neat ideas,” formal exercises, puzzles, or demonstrations. These examples are widely used by pre-college teachers around the world to enrich their presentation of topics in math and science. PUMAS offers researchers a way to make a substantial contribution to precollege education with a relatively small investment of time and effort, and at the same time, to get a peer-reviewed science education journal article published on the Web. For further information contact Ralph Kahn (Ralph.Kahn@nasa.gov).

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

6.2.2.1 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 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 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 have contributed 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.

Recently, HU was awarded a NASA University Research Center grant that establishes the Howard University Beltsville Center for Climate System Observation. This grant is administered by the GSFC education office and involves several GSFC personnel from Code 610 including David Whiteman, Alexander Marshak, Warren Wiscombe, Gerry Heymsfield, Christina Hsu, and Bruce Gentry in joint areas of Climate System Research. In addition, a Space Act Agreement between the Laboratory for Atmospheres and HU was put in place specifically to foster collaboration at the Beltsville facility and at GSFC in the atmospheric sciences with special emphasis on laser remote sensing.

6.2.2.2 Participation with HU on the Beltsville Campus Research Site:

For several years, HU has been in the process of building a multi-agency, multi-university field observation research station at the Howard University Research site at Beltsville (HURB). This research facility is part of the NOAA-Howard University Center for Atmospheric Science (NCAS) and the recently established NASA University Research Center for Climate System Observation. David Whiteman (613.1), Bruce Gentry (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.

Four intensive field operations periods have now been hosted at the Beltsville site for the purposes of Aura/Aqua satellite validation and Raman lidar evaluation and calibration. These experiments have been referred to as WAter Vapor Validation Experiments Satellite and Sondes (WAVES) experiments and have occurred in the summers of 2006 and 2007 and the winter of 2008. These experiments have brought together a large number of researchers from a diverse set of institutions including NASA/GSFC, NOAA/Boulder, NWS/Sterling, and with many universities: University of Maryland, both at College Park (UMCP) and Baltimore county (UMBC); Penn State; Bowie State; Trinity University in DC; University of Virginia, Charlottesville, VA; Smith College, in New Hampshire; University of Wisconsin; and universities from Brazil, Italy, and Bolivia.



Figure 6.1. A NASA civil servant and Dr. Joseph of Howard University (second from left) training students from Howard University, Trinity University, Smith College, Univ. of Wisconsin, and UMPC on the details of multiple radio sounding launches on a single balloon.

Previous satellite validation activities have been hosted at sites such as the Department of Energy ARM sites, which offer pristine measurement conditions not influenced by pollution sources and away from high population pressure. The Howard University Research Campus is in Beltsville, MD, a suburb of Washington, DC, and can be subject to periods of high pollution during the summer. This fact coupled with the heterogeneous terrain and the high population density makes satellite retrievals of such quantities as water vapor, ozone, and temperature more difficult. Because of the large affected population and the proximity to the Nation's capital, it is very important that satellite retrievals work well in such areas. The WAVES_2006 and WAVES_2007 field campaigns were held in July–August, 2006 and 2007 to provide a high-quality set of ground-based and balloon borne measurements to assess the quality of the retrievals from the Aura and Aqua sensors under the “difficult” retrieval conditions that exist in the mid-Atlantic region of the US during the summer. The WAVES_2008 campaign focussed on clear, pristine conditions during the winter to permit Raman lidar measurements extending into the lower stratosphere to be characterized.

The WAVES activities have been funded by the Atmospheric Composition Program of NASA HQ. For further information, contact David Whiteman (David.N.Whiteman@nasa.gov).

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 9 to August 15, 2008. 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. The Laboratory for Atmospheres' scientists participating in the institute, students, and research topics are shown in Table 6.1.

Table 6.1. Laboratory Scientists Mentoring Students in the 2008 Summer Institute

Table 6.1. Laboratory Scientists Mentoring Students in the 2008 Summer Institute		
Mentor, Code	Student, University	Topic
Stephen Palm/ 613.1	Aaron Ferrel Texas A & M	A Study of Comparison of Reflectivity Using WSR-88D and Disdrometers
Stephen Palm/ 613.1	Eric Holt University of Missouri	Cloud Cover Extent Statistics Using both ICESat and CALIPSO Measurements
Santiago Gasso/613.2	Jeff Ceratto Valparaiso University	Case Studies of Patagonian Dust Transport to Antarctica
Santiago Gasso/613.2	Aaron Johnson Valparaiso University	Boreal Biomass Burning and Climate Change from MODIS Aerosol Optical Depth: Variability and Correlation to Climate Cycles

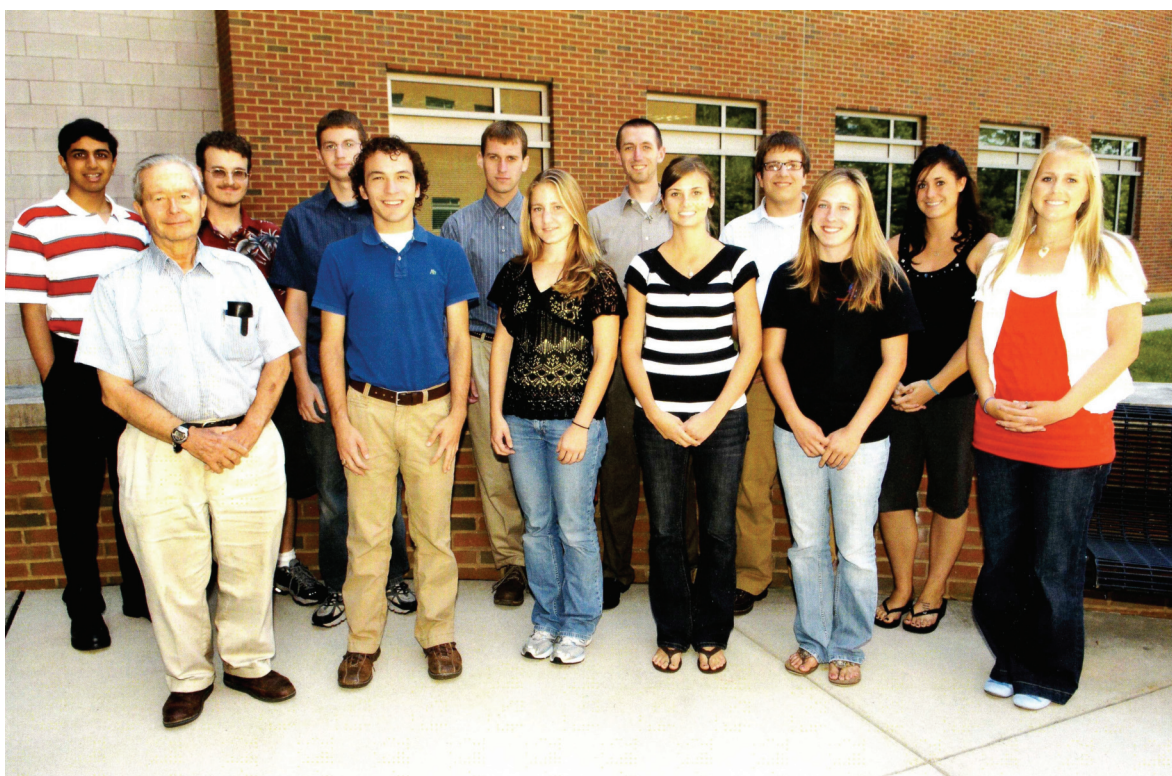


Figure 6.2. Participants in the 2008 Summer Institute. Per Gloersen is second from the left.

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 are eligible to receive a two-year fellowship for graduate study at the University of New Hampshire.

During summer 2008, José Rodríguez, of the Atmospheric Chemistry and Dynamics Branch, was an advisor for Jordan Goodrich; and Judd Welton, of the Mesoscale Atmospheric Processes Branch, was an advisor for Virginia Sawyer. On August 6, these students gave the presentations “Assessing the Uncertainty in the Global Distribution of Atmospheric CH₄ using AQUA/AIRS and GMI CTM” (Jordan Goodrich), and “Preliminary Micro-pulse Lidar Observations During ICEALOT, March–April 2008” (Virginia Sawyer).

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 its Graduate Student Summer Program (GSSP). This prestigious program is in its eighth 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 and 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 2008, Laboratory personnel acted as mentors for four GEST students. The mentors, students, and their research topics are given in Table 6.2.

Table 6.2. Laboratory Scientists Mentoring Students in the 2008 GEST-GSSP Program

Mentor, Code	Student, University	Report
Oreste Reale, 613/GEST	Josh Hatzis	
Allen Chu, 613.2/GEST	Aaron Johnson Valparaiso University	A study of interannual variability of boreal biomass burning and its relationship with climate cycles
Eric Wilcox, 612.2 and Charles Gatebe 613.2/GEST	Miguel Roman Boston University	The MODIS BRDF ¹ /Albedo Product: Assessment of Pixel-Specific Accuracy through Synergistic use of <i>In-Situ</i> and Remote Sensing Data
George Huffman, 613.1/SSAI	Ali Behrangi	Multispectral Precipitation Estimation

1. BRDF: Bidirectional Reflectance Distribution Function

Graduate Student Summer Program (GSSP)**Final Report Presentations**

Building 33, Room A128

Aug. 8, 2008, 9:00–11:30

Presentations are 20 minutes long including questions.

1. A Dimensional Case Study of Wind Profile Effects on a Florida Cirrus Anvil (Nicole Hastings)
2. Analyzing an Artificial Neural Network Clustering Approach for Precipitation Estimation: The Self Organizing Feature Map (Ali Behrangi)
3. Jamaica's Mid-Summer Dry Spell (Teddy Allen)
4. Using MODIS Observations to Study Cloud Glaciation Level (Amalia Anderson)

Break

5. The Inter-annual Variability of Biomass Burning in North America: MODIS Observation and Meteorological Impacts (David Peterson)
6. Water Sources for the June 2008 Midwest Floods (Josh Hatzis)
7. Effects of Aerosol Mixing State on Black Carbon Concentrations in GISS ModelE (Jessica Sagona)

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; the student 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 six-week program ran from June 23 to August 1. Eric Wilcox mentored Ryan Smith from Southern High School. His project, “Aerosol radiative forcing at the surface in the Amazon and links to the regional hydrological cycle” was presented by Dr. Wilcox at the 2008 Fall Meeting of the AGU.

6.3.5 AMS Fellowship Winners' Visit

On June 4, 2008 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 6.3.

Table 6.3. 2008 AMS Fellowship Winners Visiting GSFC

Student	University	Research Interest
Holly Anderson	Florida State University	Improve lightning-cessation forecasts
James Belanger*	SUNY-Albany	Tropical cyclone research
David Bodine	University of Oklahoma	Mesoscale meteorology
Christina Crowe*	University of Alabama	Tornado research
Stephan Holcomb	Colorado State University	Aerosol measurement techniques
Eric Meyers*	University of Illinois-Urbana	Micrometeorology
Amber Ortega	Pennsylvania State University	Atmospheric chemistry
Leigh Patterson	Colorado State University	Pollution measurement
Owen Shieh	University of Oklahoma	Tornado research

* Indicates NASA-Sponsored Fellowship

During the morning seminar, presentations were given by scientists from the Laboratory for Atmospheres (Code 613), the Hydrospheric and Biospheric Sciences Laboratory (Code 614), and the Global Modeling and Assimilation Office (GMAO, Code 610.1). In the afternoon, the students toured the *Hubble Space Telescope* clean room in Building 29, as well as several other facilities located in that building. The agenda was the following:

AMS Fellowship Winners GSFC Visit

June 4, 2008

9:30–9:45: Franco Einaudi, Director, Earth Sciences Division (610)

Welcome and opening remarks.

9:45–10:15: Claire Parkinson, Cryospheric Sciences Branch (614.1).

“Sea Ice: A hot topic in climate change research”

10:15–10:45: Steven Pawson, Global Modeling and Assimilation Office (610.1)

“Studying the links between ozone and climate using complex computer models”

10:45–11:00: Break

11:00–11:30: Matt McGill, Mesoscale Atmospheric Processes Branch (613.1)

“Recent results from airborne cloud/aerosol lidar”

11:30–11:50 Break and travel to Royal Jade Restaurant

11:50–12:50 Lunch, Royal Jade Restaurant

12:50–1:00 Return to GSFC

1:00–2:00 Afternoon Tour, Bldg. 29 Clean Room.



Figure 6.3. Franco Einaudi, ESD Director, discusses research opportunities in NASA with the AMS fellowship students.

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



Figure 6.4. Barbara Lambert, right foreground, has students try out the gloves that astronauts wear to perform many complex tasks during space walks.

6.4 University Education

Laboratory members are active in supporting university education through teaching courses and advising graduate students. Table 6.4 lists the instructors and the courses taught.

Table 6.4. Courses Taught in 2008

University	Course	Instructor, Code
UMBC	Physics 622: Atmospheric Physics	Tamas Varnai, 613.2/UMBC
Johns Hopkins Univ.	Physics 615.415.31: Statistical Mechanics and Thermodynamics	Prasun Kundu, 613.2

Table 6.5 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 6.5. Graduate Student Advising by Laboratory for Atmospheres Members

Member, Code	Student	Degree	Institution	Thesis Topic or Area
William Lau, 613	Massimo Bollas-inna	Ph.D.	UMCP	Effects of aerosols on the hydro-climate of Asian monsoon
William Lau, 613	Owen Doherty	Ph.D.	State Univ. of New York (SUNY), Stony Brook	Saharan dust transport and its effects on climate
Jim Irons/613	Gynesh Chander	Ph.D.	South Dakota State University	Cross correlation of remote sensing instruments
Oreste Reale 613/UMBC	Marangelly Fuentes	Ph.D.	Howard University	Comparison of tropical cyclogenetic processes in current global models
David Starr, 613.1	Tamara Singleton	Ph.D.	UMCP	Influence of gravity waves on cirrus clouds
Eyal Amitai, 613.1/Chapman Univ.	Xavier Llorc	Ph.D.	UPC ¹ , Barcelona	Radar meteorology
Gerald Heymsfield 613.1	Steven Guimond	Ph.D.	Florida State University	Hurricane hot towers with aircraft and satellite observations
David Whiteman, 613.1	Rasheen Connell	Ph.D.	Howard University	A numerical model characterizing the performance of the Howard University Raman Lidar system
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
Ralph Kahn, 613.2	Wei-Ting Chen	Ph.D.	Caltech	Global modeling and observations of atmospheric aerosols
Steven Platnick, 613.2	Brent Maddox	Ph.D.	Univ. of Wisconsin, Madison	Analysis of MODIS gridded cloud products

Charles Gatebe, 613.2	Juliao J. Cumbane, Summer 2009	Ph.D.	Univ. of Johannesburg, South Africa	Investigations of clean air slots over Southern Africa/multian-gular measurements
Christina Hsu, 613.2	Ritash Gautam	Ph.D.	GMU	Aerosol radiative effect and im-pact on Indian monsoon water cycle
Hongbin Yu, 613.2, UMBC	Yan Zhang July 28, 2008	Ph.D.	Georgia Institute of Technology	The radiative effect of aerosols from biomass burning on the transition from dry to wet season over the Amazon as tested by a regional climate model
David Whiteman, 613.2	Scott Rabenhorst	Ph.D.	UMCP	Assimilation of water vapor lidar data for improvement of short term numerical weather forecast
Nick Krotkov 613.3/ GEST	Can Li	Ph.D.	UMCP	Emissions, transport, and evolu-tion of atmospheric pollutants from China: An observational study
Randy Kawa, 613.3	Nicholas Parazoo	Ph.D.	Colorado State Univ.	Carbon cycle processes in nu-merical models
Kenneth Pickering, 613.3	Amanda Hansen	Ph.D.	Florida State Univ.	Development of a lightning NOx parameterization for the WRF-Chem model

1. UPC: Universitat Politècnica de Catalunya (Technical University of Catalonia; Barcelona, Spain)

Laboratory members participate with faculty at several joint centers identifying students whose research inter-ests are shared by a faculty member and a Laboratory scientist. Students are encouraged to visit Goddard and it is anticipated that the Laboratory member will serve on the student's thesis committee. Table 6.6 lists students currently supported.

Table 6.6. Graduate Students Supported at the Joint Centers

Student	University	Topic	Advisor and/or Sponsor
Oleg Aulov	UMBC	Enabling Model Interac-tions in Sensor Webs	David Lary 613.3/UMBC
Andrew Rickert	UMBC	Enabling Model Interac-tions in Sensor Webs	David Lary 613.3/UMBC
Tabitha Huntemann	UMCP	Cloud-model Simulations of NOx from Lightning	Kenneth Pickering 613.3
James Cipriani	UMCP	WRF-Chem simulations of Convective Transport and Lightning NOx Pro-duction in the NASA TC4 Experiment	Kenneth Pickering 613.3

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 2008.

January 17, 2008

Wei-Kuo Tao

NASA GSFC

"A Multi-scale Modeling System with Unified Physics"

February 21, 2008

Joel Susskind

NASA GSFC Laboratory for Atmospheres Sounder Research Team

"Weather and Climate Applications of AIRS/AMSU Sounding Data"

March 13, 2008

Mark Schoeberl

NASA GSFC Laboratory for Atmospheres

"The EOS-Aura Mission"

April 17, 2008

Richard Stolarski

NASA GSFC Laboratory for Atmospheres

"CFCs, Ozone Change, and the Montreal Protocol"

May 15, 2008

Matthew McGill

NASA GSFC Laboratory for Atmospheres.

"Recent Results from Airborne Cloud/Aerosol Lidar"

July 17, 2008

Shaun Lovejoy

McGill University

"The Space-Time Cascade Structure of Satellite Radiances and Numerical Models of the Atmosphere"

September 18, 2008

Witold Krajewski

University of Iowa

"A Hydrologic Framework for Studying Scale-Dependent Utility of GPM Rainfall for Flood Forecasting"

October 2, 2008

Garcia Rolando

National Center for Atmospheric Research, Boulder, CO, USA

"Mechanisms for the Acceleration of the Brewer-Dobson Circulation in a Climate Change Scenario"

October 16, 2008

Gerald R. North

Texas A & M University

“Climate Change over the Last Thousand Years—and the Next Hundred”

November 12, 2008

Lelieveld Jos

Max-Planck-Institute for Chemistry

“Stratospheric Dryness: Model Calculations and Satellite Observations”

December 4, 2008

Scott Braun

NASA Code 613.1

“Improving Our Understanding of Atlantic Hurricanes Through Knowledge of the Saharan Air Layer: Hope or Hype?”

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. (Bold type indicates names of Laboratory staff members.)

Oreste Reale (613.0, UMBC-GEST) hosted a Maryland Public School teacher during the “teacher shadow” segment of the NASA/GSFC Maryland Public School Summer Science Academy on July 17, 2008.

The following scientists gave lectures at the Science and Technology Lecture Series at Riderwood Village, a senior community of 2800 residents in Silver Spring, MD. Many residents have science and engineering backgrounds and come from academic, Government, and private R&D organizations. On April 3, **Michael King** (610.0 Emeritus) gave a lecture entitled “Our Changing Planet”; and on April 15, **David Atlas** (613.0) gave a lecture entitled “Stormy Weather: A Medley of Serendipitous Discovery.”

Sebastian Stewart (613.1, SSAI) mentored high school student Alex Levin on a senior science project during the 2007–2008 school year. The project was to measure the speed of light using a modulated laser. The results were presented at a student poster presentation. Mr. Levin is now at the University of Delaware.

Hongbin Yu (613.2/GEST) provided information about using satellites to track pollution to Meaghan Schumm and Elyse Katz for their science fair project. They are two 8th grade students from New York taking an Earth Science Regents course.

Eyal Amitai (613.1, GMU) gave a departmental seminar on “Utilizing UND Research Facilities for a Breakthrough in Radar Hydrology” at the Department of Atmospheric Sciences, University of North Dakota, Grand Forks, North Dakota on February 21.

David Starr (613.1) served as a science fair judge at Rockledge Elementary, and **David Whiteman** (613.1) served as a science fair judge at both the Greenbelt Elementary School and Robert Goddard French Immersion School. All three schools are in Prince George’s County, Maryland.

On March 7, **Tom Bell** (613.2) gave an invited seminar at UMCP Dept. of Atmospheric and Oceanic Science Atmospheric Chemistry Brown Bag Talks entitled “Midweek increase in U.S. summer rain and storm heights suggests air pollution invigorates rainstorms.”

Ali Tokay (613.1/JCET) attended a master's degree defense at the University of Louisiana-Lafayette as a committee member on Thursday, April 3.

Steven Platnick (613.2) was an invited speaker at the University of Virginia, Dept. of Environmental Sciences Seminar Series, April 7–9, 2008, Charlottesville, VA.

George Huffman (613.1/SSAI) gave a presentation on hurricanes to the weekly breakfast meeting of the Greenbelt, MD Rotary Club.

A Space Act Agreement between NASA/GSFC and Howard University has recently been completed. The intent of the agreement is to formalize the ongoing relationship between NASA/GSFC's Laboratory for Atmospheres and the Howard University Research Campus in Beltsville, MD. The goals of the agreement are to foster joint research and student training both at the Beltsville Research Campus and in Code 610 laboratory space. The technical points of contact on the agreement are **David Whiteman** (613.1) and Gregory Jenkins/Chair, Department of Physics and Astronomy.

Richard Kleidman (613.2/SSAI), **Robert Levy** (613.2/SSAI), and **Lorraine Remer** (613.2) were instructors at an ISRO¹-NASA MODIS Workshop, in Dehradun India, May 12–15, 2008. The purpose of this workshop was to instruct graduate students and researchers in how to understand, obtain, and use MODIS atmosphere and other related Earth Science data and products.

David Whiteman (613.1) participated in commencement exercises at the University of Maryland, Baltimore County on May 21. Dr. Whiteman was the research advisor for Felicita Russo who received her Ph.D. degree in Atmospheric Physics for research into techniques for studying the aerosol indirect effect using Raman lidar. Dr. Whiteman jointly hooded Ms. Russo with Dr. Ray Hoff, her faculty sponsor at UMBC.

Students from all over the world gathered to participate in the Odyssey of the Mind's 29th World Finals, a creative problem-solving competition, at UMCP, May 31 through June 3. These students advanced from competitions held earlier in the year at the local, regional, state, or country levels and will now compete for the Odyssey's top awards. Outreach participation from Climate and Radiation Branch members include **Steven Platnick** (613.2) and **Rob Simmon** (613.2/SSAI).

On May 25, 2008, **Robert Cahalan** (613.2) spoke to a group of 30 journalists from major print media, at the "University of Maryland Knight Center for Specialized Journalism, on the topic "Climate Change: What Science Tells Us." The journalists also visited GSFC, and heard **David Adamec** (614.2) speak on "Oceanography and Climate," and Waleed Abdalati (614.1) speak on "Polar Ice and Sea Level."

On June 4, 2008, **Robert Cahalan** (613.2) spoke on the topic "Earth's Changing Climate: What's been happening in recent decades? What might we do about it?" to the IEEE² Washington/Northern Virginia Chapter of the Geoscience and Remote Sensing Society (W/NV GRSS). The talk was given at the Goddard Visitor's Center.

On June 4, **Matthew McGill** (613.1) gave a presentation to the visiting AMS Fellowship Winners about cloud/aerosol lidar work at Goddard.

Judd Welton (613.1) and **Sebastian Stewart** (613.1/SSAI) attended the Smithsonian Folklife Festival on July 3, and presented the work of NASA's Micro-Pulse Lidar Network (MPLNET) together with representatives from the Aerosol Robotic Network (AERONET). They brought a display model of a micro-pulse lidar and were available to speak with festival attendees throughout the day.

1. ISRO: Indian Space Research Organization

2. IEEE: Institute of Electrical and Electronics Engineers, Inc.

Eric Nelkin (613.1/SSAI) hosted a pair of Dorchester County Public School teachers during the “teacher shadow” segment of the NASA/GSFC Maryland Public School Summer Science Academy on July 17, 2008.

Robert Cahalan (613.2), **Steven Platnick** (613.2) and **Rob Simmon** (613.2/SSAI) participated in the 2008 Smithsonian Folklife Festival on the National Mall, July 2–6, 2008.

Richard Kleidman (613.2/SSAI) was the instructor at a workshop: “Understanding, accessing, and using MODIS atmosphere and other remote sensing products,” held at the University of São Paulo, Brazil, July 29–31, 2008.

Howard University was awarded a 5-year NASA University Research Center grant entitled “Howard University Beltsville Center for Climate System Observation.” Several NASA employees were named collaborators on this proposal including **Wei-Kuo Tao** (613.1), **Bruce Gentry** (613.1), **Gerry Heymsfield** (613.1), **Ali Tokay** (613.1/UMBC), **David Whiteman** (613.1), **Warren Wiscombe** (613.2), and **Alexander Marshak** (613.2).

George J. Huffman (613.1/SSAI) served as a LaunchFest Expert for Building 32. This was an important activity that contributed to the success of LaunchFest because guests needed a great deal of guidance in knowing where they were, what the Building 32 and 33 exhibits were, and particularly what buses to use to exit the Center.

George J. Huffman (613.1/SSAI) participated in a workshop to start developing Citizen Scientist informal education materials for EOS/Terra, August 12–13, 2008, Greenbelt, MD. Writing teams will return draft activity pages in the first quarter of 2009.

Ralph Kahn (613.2) developed a Science on a Sphere presentation titled: “What satellites can tell us about Global Climate Change,” and presented it several times during the GSFC Launchfest, as well as to Cub Scout Troop 60 in November 2008. He also gave an interview for Earth and Sky Radio in June on “Will pollution increase?” and a WebCast presentation to the Challenger Schools consortium in May giving guidelines for their “Changing Earth Imaging from Space” project.

Several members of the Atmospheric Chemistry and Dynamics Branch (613.3), **Bryan Duncan**, **Ken Pickering**, **Joanna Joiner**, **Paul Newman**, **Richard Stolarski**, **Charles Jackman**, and **Nick Krotkov** participated in LaunchFest. Using displays in the lobby of Building 33, they explained how instruments on the Aura satellite monitor air pollution, the ozone hole, volcanic eruptions, etc., and they showed plots and animations to illustrate the data. They also explained basic concepts about visible and ultraviolet radiation with the aid of prisms and UV-sensitive frisbees, which were popular with the kids.

Jim Irons (613) had a poster in the lobby of Building 33 that explained the history and current measurements made by Landsat.

On July 2, **Charles Jackman** (613.3) gave a presentation entitled “Has the Ozone Layer Changed?” to the Scientific and Engineering Student Internship Program at Goddard.

Robert Cahalan (613.2) and **Charles Gatebe** (613.2/GEST) attended the Twenty-Second Greater Horn of Africa Climate Outlook Forum (GHACOF 22) Intergovernmental Authority on Development (IGAD) in Nairobi, Kenya from August 28–29, 2008. In addition, they held meetings with high level government officials in Kenya and Tanzania and visited several high schools in both countries and interacted with staff and students.

Toshihisa Matsui (613.1/GEST) gave a invited seminar at the University of Alabama/NASA Marshall Space Flight Center (MSFC) on September 10, 2008. The seminar title was “On the Development of Multi-Scale Cumulus Ensemble Models with Satellite Radiance Observations and Multi-Frequency Satellite Simulations.” Dr. Matsui also held a short tutorial training course on the Goddard Satellite Data Simulation Unit at NASA MSFC Short-term Prediction Research and Transition (SPoRT) Center.

Peter Colarco (613.3) was invited to give the Stout Lecture in the Department of Geosciences at the University of Nebraska, Lincoln. He presented a lecture entitled “A View of Earth’s Aerosol System from Space and Your Office Chair,” on September 12, 2008. He presented the same lecture to the Creighton University (Omaha, NE) Physics Department a day earlier.

Santiago Gassó (613.2/GEST/UMBC) visited the city of Cordoba in Argentina. Under a program to improve collaborations with the international research community sponsored by CONICET¹ (the Argentine NSF), Prof. Diego Gaiero of the University of Cordoba invited Dr. Gassó to teach an introductory course on MODIS data and its applications.

Scott Braun (613.1) presented the talk entitled “Improving our understanding of Atlantic hurricanes through knowledge of the Saharan Air Layer: Hope or Hype?” at the Dept. of Atmospheric and Oceanic Science at the University of Maryland, College Park, on October 9 as part of their weekly seminar series.

Eric Wilcox (613.2) spoke at the California Institute of Technology (October 7), NASA Jet Propulsion Laboratory (October 8), and at UCLA (October 10) on “Satellite observations of deep cumulus convection and GCM simulations of extreme rain events.”

Robert Cahalan (613.2) gave a talk at Ewha Women’s University in Seoul, entitled “Earth Observations of Climate Change.” He was hosted there by Professor Jung Moon Yoo, a frequent visitor to Goddard. Dr. Cahalan also presented a report on activities of the International Radiation Commission (IRC) at the GEWEX Radiation Panel (GRP) meeting, and led a discussion on the “Future of Radiation Research.”

David (Tai) Zheng from the Montgomery Blair High School, who worked as summer intern in Code 613.3 (mentor: **Mian Chin** (613.3)), has been designated one of three Regional Finalists from Maryland in the prestigious Siemens/Westinghouse Science Competition. The region includes Maryland, Virginia, Pennsylvania, New York, Massachusetts, and the rest of New England. David’s research paper, entitled “Determining Dust Sources through the Normalized Difference Vegetation Index,” is the result of his summer intern project. David will be competing for the Regional Winner.

Charles Ichoku (613.2) undertook a two-week trip to West Africa from October 25 to November 8, 2008. During the first week of the trip, he attended the 7th International Conference of the African Association for Remote Sensing of the Environment (AARSE)-2008 held in Accra, Ghana, at which he delivered an oral presentation entitled “Satellite-based assessment of fire impacts on ecosystem changes in West Africa.” The conference, whose theme was “Earth Observation and Geo-information for Governance in Africa,” was attended by over 550 delegates. During the second week of the trip, Dr. Ichoku visited the remote sensing centers of two prominent Nigerian universities and delivered public lectures to various audiences. He was invited to the Department of Geoinformatics and Surveying at the University of Nigeria, Enugu Campus, and was invited to present a lecture entitled “The Importance of Satellite Remote Sensing For Environmental Planning and Monitoring in West Africa.” This lecture was attended, not only by the faculty and students of the department, but also those of the entire faculty of environmental studies of that university and other universities within 100 miles of the campus, as well as, environmental professionals from government and private agencies in the area. Dr. Ichoku was also invited to visit and lecture at the regional Center of Excellence on Environmental Information Management System (EIMS) located at the University of Lagos. In addition, he visited two Nigerian high schools, where he gave a talk entitled “Our environment and our future.” During the talk, he encouraged active participation in the NASA-sponsored Global Learning and Observations to Benefit the Environment (GLOBE) program (<http://www.globe.gov>) and the reinforcement of climate-change related environmental observations in the schools’ curricula.

1. CONICET: Consejo Nacional de Investigaciones Científicas Y Técnicas (National Council for Science and Technology, Argentina)

Charles Ichoku was invited to speak at the Harvard University School of Engineering and Applied Sciences (Atmospheric Sciences) Fall 2008 Seminar Series in Cambridge, Massachusetts, on December 5, 2008, where he delivered a lecture entitled “Measurement of Fire Radiative Energy from space and implications for fire-disaster monitoring and smoke emissions modeling.”

From November 3–7, **Richard Kleidman** (613.2/SSAI) and **Steve Platnick** (613.2) conducted a workshop on MODIS atmosphere and land products at the Ben Gurion University Sede Boker campus in the Negev Desert in Israel. The workshop focused on data acquisition, visualization and analysis in addition to algorithms and their scientific uses. On November 9, Kleidman and Platnick gave a workshop with a similar focus on NASA A-Train instruments for use in aerosol and cloud studies at the Weizmann Institute of Science in Rehovot, Israel. Participants at both workshops included graduate students as well as researchers. The workshops were sponsored by Ilan Koren of the Weizmann Institute’s Department of Environmental Sciences (and previous Climate and Radiation branch member) and Arnon Karnieli of Ben Gurion University’s Remote Sensing Laboratory.

From November 3–7, **Robert Levy** (613.2/SSAI) visited Colorado State University (CSU) and presented a special seminar to the Department of Atmospheric Science entitled “The challenges of deriving ‘climate data quality’ global aerosol properties from MODIS.” He also visited Michael King and other faculty at Colorado University–Boulder. (November 17)

Hongbin Yu (613.2/GEST) gave an invited talk entitled “Satellite-based studies of aerosol impacts on climate,” at the Key Laboratory of Regional Climate–Environment Research for Temperate East Asia (RCE-TEA), Institute of Atmospheric Physics, Chinese Academy of Science, Beijing, China, on November 12, 2008.

Hongbin Yu (613.2/GEST) was asked to review an article entitled “What Weather Satellites Are Telling Us about Global Pollution.” The article will be published in the April 2009 issue of *ChemMatters*, a magazine for high school students published by the American Chemical Society. He was also asked to provide some images that could go with the article.

The Discovery Channel visited Goddard on November 24 and 25 to do some filming for a new special on hurricanes. **Scott Braun** (613.1) was filmed at several locations: at his desk, talking about currently available satellite data and how it is used to study hurricanes; in instrument labs with **Gerry Heymsfield** (613.1) to talk about development of new radar technologies; in another instrument lab with **Matt McGill** (613.1) to talk about lidar technologies; at the Visitor Center to talk in front of the Science on a Sphere about hurricanes; and in a clean room where a satellite is being built to talk about the deployment of new technologies on space-borne platforms.

Michael Reilly, of *Discovery Channel News*, published a news item on November 26 based on an interview with Laboratory member **Tom Bell** (613.2) about recent research results showing a pronounced increase in summertime lightning activity in the southeast U.S. during the middle of the work week. The results support satellite observations showing similar midweek increases in storms in the region. Bell’s research with Danny Rosenfeld of Hebrew University will be reported at the American Geophysical Union meeting next month.

David Whiteman (613.1) organized a Science Fair mentoring day at Greenbelt Middle School involving Aijun Chen (610.2), Erin Smith (665.0), Inge Loes Ten Kate (699/UMBC), **Kevin Vermeesch** (613.1), Kumar Hemant (698), Stephen Holland (660.1), and Trena Ferrell (130.0). The GSFC scientists spent the day meeting with students and discussing ideas and approaches for their science fair projects. The group will return to their school to participate in the judging the Science Fair in February.

Nader Abuhassan (613.3/GEST) participated on the NSF-RISE¹ external advisory board meeting at Morgan State University, Baltimore, MD. December 17. Morgan State University is requesting funds to support research

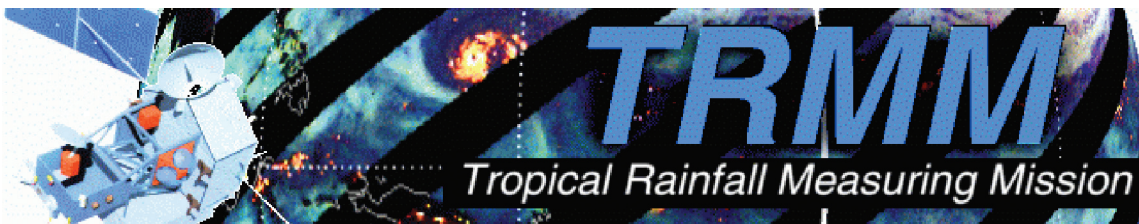
1. RISE: Research Infrastructure for Science and Engineering

that will advance the fundamental scientific and technological knowledge necessary for the development of new biological and chemical sensors for use in bioenvironmental research. This research is essential to the long-term success of Morgan's Ph.D.s in Bioenvironmental Sciences and Doctor of Engineering programs.

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.

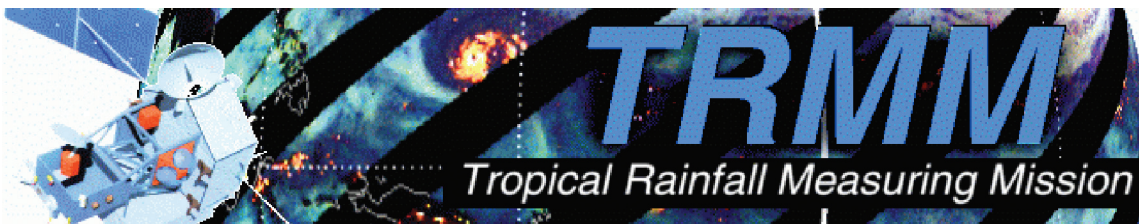
TERRA



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, 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 Scout Braun (Code 613), and TRMM Education and Outreach Scientist Jeffrey Halverson (613.1/UMBC). TRMM has also included the development of broadcast visuals and educational curriculum in its outreach activities. The Educational Resources link on the TRMM home page leads to five problem-based classroom modules in PDF format. These manuals are titled "Investigating the Climate System" and consist

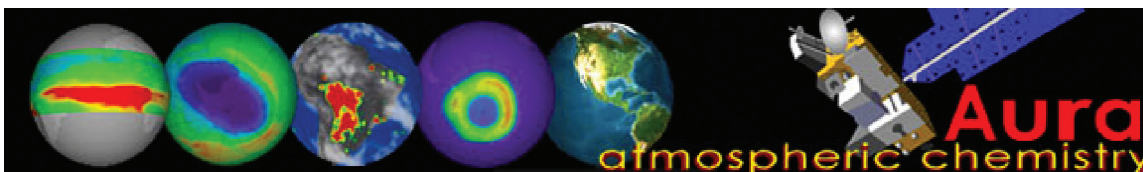
of tutorials on clouds, winds, precipitation, weather, and energy. The first four are appropriate for students in grades 5–8, the last is directed at students in grades 9–12. These packages are available on the TRMM Web site (<http://trmm.gsfc.nasa.gov/>) and have been reviewed as a part of the Earth Science Enterprise (ESE) Education product review. There are also 11 educational videos that give brief tutorials on various aspects of the TRMM project and on the atmosphere's water and energy cycles.

Global Precipitation Measurement (GPM)



The GPM is a follow-on, and expanded, mission of the current ongoing TRMM. GPM is one of the Earth Observing System 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 features' section on either page has links to numerous 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 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, PA) ground-based instruments will measure ultraviolet-A (UV-A) radiation and aerosols to support measurements taken from the Aura spacecraft. A tropospheric ozone measurement developed by Langley Research Center is also a GLOBE protocol.

Aura's Education and Project Outreach program will also be present at science and environmental fairs and science and technology conferences to demonstrate how Aura fits 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. This textbook was designed as an educational resource for the general public, as well as for students and educators. It contains 12 chapters covering all aspects of the science of stratospheric ozone. Each chapter has numerous low- and high-resolution figures, and ends with a set of review questions.

7. ACRONYMS

Acronyms defined and used only once in the text may not be included in this list. Two acronyms, NPP and GMI, have dual definitions. The meaning will be clear from context in this report.

AAD	ARM Ancillary Facility
AARSE	African Association for Remote Sensing of the Environment
ACAM	Airborne Compact Atmospheric Mapper
ACDB	Atmospheric Chemistry and Dynamics Branch
ACE	Aerosol–Clouds and Ecology
ACRM	ARM Climate Research Facility
ACS	American Chemical Society
ADEOS	ADvanced Earth Observing Satellite
AEROCOM	AEROSol Comparisons between Observations and Models
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
ALVICE	Atmospheric Lidar for Validation, Interagency Collaboration and Education
AMF	ARM Mobile Facility
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	AMSR Earth Observing System (EOS)
AMSU	Advanced Microwave Sounding Unit
AMY	Asian Monsoon Year
AOD	Aerosol Optical Depth
APS	Aerosol Polarimetric Sensor
APSATS	Asia Pacific Satellite Training Seminar
ARC	Ames Research Center
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
ARM	Atmospheric Radiation Measurement (Program)
ARM CART	ARM Cloud and Radiation Test Bed
AROTAL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ASCENDS	Active Sensing of CO ₂ Emissions over Night, Days, and Seasons
ASP/DoE	Atmospheric Sciences Program/Department of Energy
ATL	Aerosol and Temperature Lidar
ATMS	Advanced Technology Microwave Sounder
AVE	Aura Validation Experiment
AVHRR	Advanced Very High Resolution Radiometer
BASE-ASIA	Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment
BRDF	Bidirectional Reflectance Distribution Function
BUV	Backscatter Ultraviolet

ACRONYMS

C3VP	Canadian CloudSat/CALIPSO Validation Program
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	Convection And Moisture EXperiment
CAR	Cloud Absorption Radiometer
CCM	Chemistry Climate Model
CCMVal	Chemistry–Climate Model Validation exercise
CCN	Cloud Condensation Nuclei
CCSP	Climate Change Science Program
CC-VEx	CALIPSO-CloudSat Validation Experiment
CDE	Cosmic Dust Experiment
CERES	Clouds and the Earth’s Radiant Energy System
CFCs	Chlorofluorocarbons
CGCM	Chemistry and General Circulation Model
CHAPS	Cumulus Humilis Aerosol Processing Study
CIMSS	Cooperative Institute of Meteorological Satellite Studies
CIPS	Cloud Imaging and Particle Size experiment
CIRC	Continuous Intercomparison of Radiation Codes
CLARREO	Climate Absolute Radiance and Reflectivity
CLASIC	Cloud and Land Surface Interaction Campaign
CLIVAR	Climate Variability and Predictability Programme
CMOS	Complementary metal–oxide–semiconductor
COMBO	Combined Stratospheric-Tropospheric Model
COMMIT	Chemical, Optical, and Microphysical Measurements of <i>In situ</i> Troposphere
CONICET	Consejo Nacional de Investigaciones Científicas Y Técnicas (National Council for Science and Technology, Argentina)
CoSSIR	Compact Scanning Submillimeterwave Imaging Radiometer
COVIR	Compact Visible and Infrared Radiometer
CP	Convective Parameterization
CPL	Cloud Physics Lidar
CPR	Cloud Profiling Radar
CR-AVE	Costa Rica-Aura Validation Experiment
CrIS	Crosstrack Infrared Sounder
CRS	Cloud Radar System
CSTEa	Center for the Study of Terrestrial and Extraterrestrial Atmospheres
CSU	Colorado State University
CTM	Chemical Transport Model
DAAC	Distributed Active Archive Center
DAS	Data Assimilation System
DFRC	Dryden Flight Research Center
DOAS	Differential Optical Absorption Spectroscopy
DoE	Department of Energy
DPR	Dual-frequency Precipitation Radar
DSCOVR	Deep Space Climate Observatory (formerly Triana)
DU	Dobson Unit
EAST-AIRE	East Asian Study of Tropospheric Aerosols: an International Regional Experiment
ECC	Electrochemical Concentration Cell
ECMWF	European Centre for Medium-Range Weather Forecasts

EDOP	ER-2 Doppler Radar
EIMS	Environmental Information Management System
ELF	Elastic Lidar Facility
EnviSat	Environmental Satellite
ENSO	El Niño Southern Oscillation
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPIC	Earth Polychromatic Imaging Camera
EP-TOMS	Earth Probe TOMS
ER-2	Earth Resources-2 (satellite)
ERBE	Earth Radiation Budget Experiment
ESD	Earth Sciences Division
ESE	Earth Science Enterprise
ESMF	Earth System Modeling Framework
ESRL	Earth System Research Laboratory (NOAA)
ESSIC	Earth System Science Interdisciplinary Center
ESTO	Earth Science Technology Office
ETM+	Enhanced Thematic Mapper-Plus
EU	European Union
FMI-ARC	Finnish Meteorological Institute—Arctic Research Center
FOV	Field of View
fvGCM	Finite volume General Circulation Model
GAW	Global Atmospheric Watch
GCE	Goddard Cumulus Ensemble model
GCM	General Circulation Model
GEO-CAPE	Geostationary Coastal and Air Pollution Events
GEOS	Goddard Earth Observing System
GeoSpec	Geostationary Spectrograph
GEOSS	Global Earth Observation System of Systems
GES DISC	Goddard Earth Sciences Data and Information Services Center
GEST	Goddard Earth Sciences and Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecasting System
GHACOF	Greater Horn of Africa Climate Outlook Forum
GHG	Greenhouse Gases
GISS	Goddard Institute for Space Studies
GLAS	Geoscience Laser Altimeter System
GLOBE	Global Learning and Observations to Benefit the Environment
GloPac	Global Hawk Pacific Experiment
GLOW	Goddard Lidar Observatory for Winds
GMAO	Global Modeling and Assimilation Office
GMI	GPM Microwave Imager
GMI	Global Modeling Initiative
GMT	Greenwich Mean Time
GMU	George Mason University
GOCART	Global Ozone Chemistry Aerosol Radiation Transport

ACRONYMS

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
GRP	GEWEX Radiation Panel
GRSS	Geoscience and Remote Sensing Society
GSFC	Goddard Space Flight Center
GSSP	Graduate Student Summer Program
GSWP	Global Soil Wetness Project
GV	Ground Validation
GVP	Ground Validation Program
GWOS	Global Wind Observations Mission
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
HS3	Hurricane and Severe Storm Sentinel mission
HSB	Humidity Sounder Brazil
HTAP	Hemispheric Transport of Atmospheric Pollutants
HU	Howard University
HUPAS	Howard University Program in Atmospheric Sciences
HURB	Howard University Research site at Beltsville
HURL	Howard University Raman Lidar
HypIRI	Hyperspectral Infrared Imager
HY-SiB	Hydrology and Simple Biosphere
I3RC	International Intercomparison of 3-Dimensional Radiation Codes
ICESat	Ice, Cloud, and Land Elevation Satellite
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IGAD	Intergovernmental Authority on Development
IIP	Instrument Incubator Program
INTEX-B	Intercontinental Chemical Transport Experiment—Part B
IORD	Integrated Operational Requirements Document
IPCC	Intergovernmental Panel on Climate Change
IPO	Integrated Program Office
IPY	International Polar Year
IRAD	Internal Research and Development
IRC	International Radiation Committee
IRIS	Interdisciplinary Remote Imaging and Sensing
ISAS	Institute of Space and Aeronautical Science (Japan)
ISCCP	International Satellite Cloud Climatology Project
ISRO	Indian Space Research Organization
JAXA	Japan Aerospace Exploration Agency

JAMEX	Joint Aerosol Monsoon Experiment
JCET	Joint Center for Earth Systems Technology
JCOSS	Joint Center for Observation System Science
JCSDA	Joint Center for Satellite Data Assimilation
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
LASP	Laboratory for Atmospheric and Space Physics
LDCM	Landsat Data Continuity Mission
LIDAR	Light Detection and Ranging
LIS	Land Information System
LRR	Lightweight Rainfall Radiometer
LRR-X	LRR-X band
MAP	Modeling and Analysis Program
MAPB	Mesoscale Atmospheric Processes Branch
MAS	MODIS Airborne Simulator
MAXDOAS	Multi-Axis Differential Optical Absorption Spectroscopy
McRAS	Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme
McRAS-AC	The total aerosol–cloud interaction complex (an upgrade to McRAS)
MDE	Maryland Department of the Environment
MEaSUREs	Making Earth Science Data Records for Use in Research Environments
MF-DOAS	Multi-Function Differential Optical Absorption Spectrometer
MFRSR	Multi-filter Rotating Shadowband Radiometer
MILAGRO	Megacity Initiative: Local And Global Research Observations
MISR	Multi-Angle Imaging Spectroradiometer
MIT	Massachusetts Institute of Technology
MJO	Madden-Julien Oscillation
MLS	Microwave Limb Sounder
MM5	Mesoscale Model 5
MMF	Multi-Model Framework
MMF	Multi-Scale Modeling Framework
MODIS	Moderate Resolution Imaging Spectroradiometer
MOHAVE	Measurements Of Humidity in the Atmosphere and Validation Experiment
MOPITT	Measurement of Pollution in the Troposphere
MPL	Micro-Pulse Lidar
MPLNET	Micro-Pulse Lidar Network
MSFC	Marshall Space Flight Center
MSL	Mean Sea Level
MSU	Microwave Sounding Unit
NAMMA	NASA African Monsoon Multidisciplinary Analysis
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)

ACRONYMS

NATIVE	Nittany Atmospheric Trailer and Integrated Validation Experiment
NCAR	National Center for Atmospheric Research
NCAS	NOAA (Howard University) Center for Atmospheric Science
NCEP	National Center for Environmental Prediction
NCSS	NASA Center for Computational Sciences
NDACC	NASA-supported Network for the Detection of Atmospheric Composition Change
NEO	NASA Earth Observations
NESDIS	National Environmental Satellite Data and Information Service
NGST	Northrop Grumman Space Technology
NICT	National Institute of Information and Communications Technology
NIEM	Russian Scientific Research Institute of Electromechanics
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NISTAR	National Institute of Standards and Technology Advanced Radiometer
NIVR	Netherlands's Agency for Aerospace Programs
NMNH	National Museum of Natural History
NMS	Neutral Mass Spectrometer
NOAA	National Oceanic and Atmospheric Administration
NOVICE	Newly-Operating and Validated Instruments Comparison Experiment
NPOESS	National Polar Orbiting Environmental Satellite System
NPP	NASA Postdoctoral Program
NPP	NPOESS Preparatory Project
NRA	NASA Research Announcement
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NWS	National Weather Service
ODS	Ozone Depleting Substances
OGO	Orbiting Geophysical Observatory
OLR	Outgoing Longwave Radiation
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
OOAT	Ozone Operational Algorithm Team
ORAU	Oak Ridge Associated Universities
PAC3E	Pacific Atmospheric Composition, Cloud, and Climate Experiment
PAVE	Polar Aura Validation Experiment
PBL	Planetary Boundary Layer
PDF	Portable Document Format
PDR	Preliminary Design Review
PI	Principal Investigator
PM2.5	Particulate Matter, diameter < 2.5 μm
PMC	Polar Mesospheric Clouds
PMM	Precipitation Measurement Missions
POES	Polar Orbiting Environmental Satellite
PR	Precipitation Radar

PUMAS	Practical Uses of Math and Science
QuikSCAT	(NASA's) Quick Scatterometer satellite
RAJO-MEGHA	Radiation, Aerosol Joint Observations-Monsoon Experiment in the Gangetic-Himalayan Area
RASL	Raman Airborne Spectroscopic Lidar
RCDF	Radiometric Calibration and Development Facility
RCE-TEA	Regional Climate-Environment Research for Temperate East Asia
RFP	Request for Proposal
RMS	Root Mean Squared
RRS	Radiosonde Replacement System
SACOL	Semi-Arid Climate and environment Observatory–Lanzhou
SAGE	Stratospheric Aerosol and Gas Experiment
SAIC	Science Applications International Corporation
SAP	Synthesis and Assessment Product
SAL	Saharan Air Layer
SAOZ	Système d'Analyse parObservation Zénithal
SAP	Scientific Assessment Panel
SAUNA	Sodankylä Total Column Ozone Intercomparison
SBIR	Small Business Innovative Research
SBUV	Solar Backscatter Ultraviolet
SBUV/2	Solar Backscatter Ultraviolet/version 2
SCIAMACHY	Scanning Imaging Absorption SpectroMeter for Atmospheric CHartography
SDS	Scientific Data Set
SDSU	Satellite Data Simulation Unit
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEB	Source Evaluation Board
SEM	Solar Emission Monitor
SESI	Scientific and Engineering Student Internship program
SGP	Southern Great Plains
SGT	Stinger Ghaffarian Technologies
ShADOE	Shared Aperture Diffractive Optical Element (telescope)
SHADOZ	Southern Hemisphere ADditional OZonesondes
SIVO	Software Integration and Visualization Office
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMD	Science Mission Directorate
SOAT	Sounder Operational Algorithm Team
SOFIE	Solar Occultation for Ice Experiment
SOLSE/LORE	Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment
SOLVE	SAGE III Ozone Loss and Validation Experiment
SOP	Special Observing Period
SORCE	Solar Radiation and Climate Experiment
SPE	Solar Proton Event
SPoRT	Short-term Prediction Research and Transition (Center)
SRL	Scanning Raman Lidar
SSAI	Science Systems and Applications, Inc.
SSI	Spectral Solar Irradiance

ACRONYMS

SSM/I	Special Sensor Microwave Imager
SST	Sea-Surface Temperature
SSU	Spectral Sensor Unit
STEM	Science, Technology, Engineering, and Mathematics
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
STS	Space Transportation System
SUNY	State University of New York
SVIP	Solar Viewing Interferometer Prototype
TC4	Tropical Composition, Cloud, and Climate Coupling
TCSP	Tropical Cloud Systems and Processes
TEOM	Tapered Element Oscillating Microbalance
TES	Tropospheric Emission Spectrometer
THOR	cloud THickness from Offbeam Returns
TIROS	Television Infrared Observation Satellite
TMF	Table Mountain Facility
TMI	TRMM Microwave Imager
TMPA	TRMM Multi-satellite Precipitation Analysis
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
TSI	Total Solar Irradiance
TSIS	Total and Spectral Solar Irradiance Sensor
TTL	Tropopause Transition Layer
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
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UMBC	University of Maryland, Baltimore County
UMCP	University of Maryland, College Park
UNEP	United Nations Environment Programme
UNH	University of New Hampshire
UPC	Universitat Politècnica de Catalunya (Technical University of Catalonia; Barcelona, Spain)
URAD	UAV Radar
USDA	United States Department of Agriculture
UTC	Universal Coordinated Time
UV	Ultraviolet
UV-A	Ultraviolet-A radiation
UV-B	Ultraviolet-B radiation
UV-MFRSR	Ultraviolet Multifilter Rotating Shadowband Radiometer
VIIRS	Visible/Infrared Imager/Radiometer Suite
VINTERSOL	Validation of International Satellites and study of Ozone Loss
VIS	Visible

WACCM	Whole Atmosphere Community Climate Model
WAVES	Water Vapor Validation Experiment – Satellite and Sondes
WCRP	World Climate Research Program
WMI	Weather Modification Inc.
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WRF-Chem	Weather Research and Forecasting—Chemistry

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 2007.


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Feature

NASA Data Link Pollution to Rainy Summer Days in the Southeast

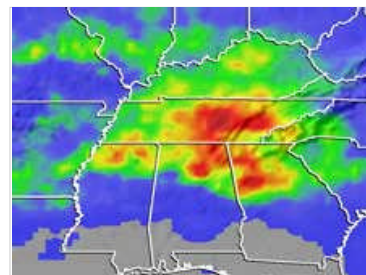
02.01.08

Rainfall data from a NASA satellite show that summertime storms in the southeastern United States shed more rainfall midweek than on weekends. Scientists say air pollution from humans is likely driving that trend.

The link between rainfall and the day of the week is evident in data from NASA's Tropical Rainfall Measuring Mission satellite, known as TRMM. Midweek storms tend to be stronger, drop more rain and span a larger area across the Southeast compared to calmer and drier weekends. The findings are from a study led by Thomas Bell, an atmospheric scientist at NASA's Goddard Space Flight Center, Greenbelt, Md. Bell said the trend could be attributed to atmospheric pollution from humans, which also peaks midweek.

"It's eerie to think that we're affecting the weather," said Bell, lead author of the study published online this week in the American Geophysical Union's Journal of Geophysical Research. "It appears that we're making storms more violent."

Rainfall measurements collected from ground-based gauges can vary from one gauge site to the next because of fickle weather patterns. So, to identify any kind of significant weekly rainfall trend, Bell and colleagues looked at the big picture from Earth's orbit. The team collected data from instruments on the TRMM satellite, which they used to estimate daily summertime rainfall averages from 1998 to 2005 across the entire Southeast.



Torrential rainfall from a 2003 storm in the Southeast resulted in massive accumulations of rain (red). Similar data from NASA's TRMM satellite has revealed that more rain falls midweek. Credit: NASA
[> Larger image](#)

NASA - NASA Data Link Pollution to Rainy Summer Days in the Southeast

The team found that, on average, it rained more between Tuesday and Thursday than from Saturday through Monday. Newly analyzed satellite data show that summer 2007 echoed the midweek trend with peak rainfall occurring late on Thursdays. However, midweek increases in rainfall were more significant in the afternoon, when the conditions for summertime storms are in place. Based on satellite data, afternoon rainfall peaked on Tuesdays, with 1.8 times more rainfall than on Saturdays, which experienced the least amount of afternoon rain.

The team used ground-based data from gauges, along with vertical wind speed and cloud height measurements, to help confirm the weekly trend in rainfall observed from space.

To find out if pollution from humans indeed could be responsible for the midweek boost in rainfall, the team analyzed particulate matter, the concentrations of airborne particles associated with pollution, across the U.S. from 1998 to 2005. The data, obtained from the Environmental Protection Agency, showed that pollution tended to peak midweek, mirroring the trend observed in the rainfall data.

"If two things happen at the same time, it doesn't mean one caused the other," Bell said. "But it's well known that particulate matter has the potential to affect how clouds behave, and this kind of evidence makes the argument stronger for a link between pollution and heavier rainfall."

Scientists long have questioned the effect of workweek pollution, such as emissions from traffic, businesses and factories, on weekly weather patterns. Researchers know clouds are "seeded" by particulate matter. Water and ice in clouds grab hold around the particles, forming additional water droplets. Some researchers think increased pollution thwarts rainfall by dispersing the same amount of water over more seeds, preventing them from growing large enough to fall as rain. Still, other studies suggest some factors can override this dispersion effect.

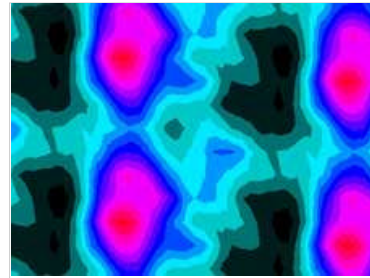
In the Southeast, summertime conditions for large, frequent storms are already in place, a factor that overrides the rain-thwarting dispersion effect. When conditions are poised to form big storms, updrafts carry the smaller, pollution-seeded raindrops high into the atmosphere where they condense and freeze.

"It's the freezing process that gives the storm an extra kick, causing it to grow larger and climb higher into the atmosphere," Bell said. He and his colleagues found that the radar on the TRMM satellite showed that storms climb to high altitudes more often during the middle of the week than on weekends. These invigorated midweek storms, fueled by workweek pollution, could drop measurably more rainfall.

The trend doesn't mean it will always rain on weekday afternoons during summertime in the Southeast. Rather, "it's a tendency," according to Bell. But with the help of satellites, new insights into pollution's effect on weather one day could help improve the accuracy of rainfall forecasts, which Bell said, "probably under-predict rain during the week and over-predict rain on weekends."

Kathryn Hansen
Goddard Space Flight Center

Find this article at:



Tracking upward, this chart shows Southeast summer rain cycles of less rain (black) to more rain (red) over the period of a week, averaged from satellite data collected from 1998 to 2005. Credit: NASA
[> Larger image](#)



Rainy Days and Weekdays

When rain ruins weekend plans, it seems like Mother Nature can be a real drip. But weather researchers have found evidence that rain storms tend to take it easy on the weekend. The extra weekday rain might be caused by the pollution we generate by commuting to work.

Cloudbursts on the Calendar

Rain clouds don't care whether you've got baseball tickets or picnic plans — humans are usually victims of the weather's whims. But now, a new study of satellite data suggests that the weather somehow follows our work schedule. The finding: rain falls more on weekdays than on weekends, at least in certain areas of the country.

There's no way that weather knows whether it's Sunday or Wednesday. Certainly not over the course of years, and we see this effect year in and year out," says researcher **Tom Bell** of NASA's Goddard Space Flight Center.

Yet, at least in the Southeastern United States in the summertime, he "saw clear evidence that there was a change in the rainfall with the day of the week." As Bell and colleagues wrote in the *Journal of Geophysical Research*, heavier rain during weekdays may be caused by air pollution, which is worse during weekdays than on weekends.

"It has to be due to something that human beings are doing," Bell says. "And one thing we do know that humans are doing is that they're polluting the atmosphere more — at least in urban areas, for certain — in the middle of the week" than on weekends.

The study also showed that rainstorms were more severe in the middle of the week. "Not only is there more rain, but the storms are more violent, and lots of things besides just rain could be affected by the increased violence of the storms," Bell explains. "You're going to have higher winds, it's possible you would have more hail, more lightening...so the effects of pollution are not just on rainfall. It's also an effect on the severity of storms. and all the effects that storms have on people."

The satellite Bell's group used for its research — NASA's Tropical Rainfall Measuring Mission (TRMM) satellite — is special because it tracks not only rainfall, but also storm severity over the globe's midriff rather than the less populated poles. The satellite approach, says Bell, also works better than methods "based on little buckets that are put around in various places." With satellites, researchers can track big swaths of land, but the study was limited by TRMM's orbit.

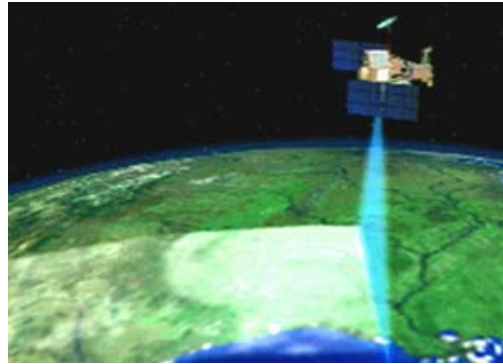


image courtesy NASA

"This satellite is in what is called a low-inclination orbit, meaning that the tilt of the orbit with respect to the equator of the earth is not nearly as big as it is for the satellites that go over the poles. This satellite only is able to see around 40 degrees of latitude," he says, "Which is roughly my latitude near Washington, DC. And the satellite is unable to see beyond that because the orbit never takes it north of that latitude or south of -40 degrees."

Bell says he got interested in weekly rain patterns because of the established fact that pollution levels change with the day of the week. "I live in an urban area and I can see with my eyes that there's more pollution in the middle of the week than on weekends," he explains.

But he says more research is needed to figure out exactly how pollution could be causing this weekend effect. It's "hard to doubt that the weather is changing with the day of the week. The only question is why is it changing," he explains.

For now, the chief suspect is aerosol pollution, rather than carbon dioxide or other greenhouse gases. Aerosol pollution is the particulate matter — "the brown trail of stuff coming out of the smoke stack," Bell says — that is known to affect the weather.

Unlike greenhouse gases, which cause the planet to heat up, aerosol pollution can have a cooling effect because the particles act like little miniature window shades, blocking out the sun. They may also make storms more severe by preventing water droplets from becoming too big. The diminutive droplets then travel higher up into the atmosphere, where they freeze and therefore have more energy to release when they travel back to earth.

"The storms just grow more vigorously, because they're more in a rising motion. The storm sucks more moist air...into the storm, and that extra moist air is, in a sense, a fuel" for the storm, explains Bell.

But if aerosol pollution can have a cooling effect, could it be useful in these warming times? Bell says no. "I still don't like it. But it makes me appreciate how pervasive its influence is on the atmosphere," he explains. "It still surprises me that we can change the kinds of storms we see depending on the day of the week, and just because of the fact that we drove more, or our trucks drove more in the middle of the week than on weekends."

Bell says the findings could improve weather forecasts, which, without pollution information would tend to underestimate rainstorms during the week and overestimate them on the weekends. "If the weather forecast models don't know about this, at their present stage of development, when they make a forecast they won't be able to tell, 'Oh, this is a day with a high level of pollution, the storms might be particularly bad on this day,'" he says.

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NEWS

NASA NEWS ARCHIVE

February 2, 2008

2007 HURRICANE SEASON STARTS EARLY, ENDS LATE

The Atlantic Hurricane Season began early in 2007, and by mid-December it was still going. The season officially begins June 1 and ends Nov. 30. That means that for the most part, storms have formed and fizzled between those dates, or they used to.

NASA satellites were watching and providing data from the beginning when Andrea kicked off the season on May 9 when she formed 150 miles northeast of Daytona Beach, Florida. On Dec. 10, 2007, Sub-Tropical Storm Olga formed to the east of Hispaniola.

The hurricane season produced 2 tropical depressions and 15 tropical storms, six of which became hurricanes. That's a little more than average. The storms that became hurricanes were: Dean, Felix, Humberto, Karen, Lorenzo and Noel.

Double Trouble With Category 5 Storms

Of special note, there were two Category 5 hurricanes which led to a "first." It was the first time two Category 5's made landfall in one season. Both storms, Dean and Felix, made landfall in Central America. Hurricane Dean made landfall near Costa Maya on the Yucatan Peninsula on Aug. 21, packing sustained winds near 165 mph. Dean then moved into the Gulf of Campeche to make a second landfall near Tecolutla, with 100 mph winds as a Category 2 storm.

Twelve days after Dean's first landfall, Hurricane Felix made landfall near Punta Gorda, Nicaragua on Sept. 2 with sustained winds of 160 mph. Dean was also noteworthy for another reason, it was the first Category 5 hurricane to make an Atlantic Ocean basin landfall since 1992, when Andrew hit south Florida.

Which Ones Affected the Mainland U.S.?

The mainland U.S. was hit by five storms during the 2007 Atlantic Hurricane Season. There was one hurricane, three tropical storms and one tropical depression that affected the U.S. Hurricane Humberto made landfall along the upper Texas coast on Sept. 13. Tropical storms that hit the U.S. were Barry, Erin and Gabrielle.

Barry came ashore on June 2 near Tampa Bay, Florida. A weak Tropical Storm Erin hit southeast Texas on August 16. Tropical Storm Gabrielle made landfall along the Cape Lookout, North Carolina National Seashore on Sept. 9. Tropical Depression Ten made landfall near Fort Walton Beach, Florida late on Sept. 21.

Erin is noteworthy because of the massive flooding that it produced in Oklahoma and Texas. Erin's highest rainfall totals through August 20 occurred well inland and were between 200 to 250 millimeters, or approximately 8 to 10 inches over central Oklahoma. The central Texas Gulf Coast also received a substantial amount of rain, between 100 to 200 millimeters or between 4 to 8 inches, where Erin made landfall.

Humberto Was the Season's Fastest Grower It only took Humberto 24 hours to go from a tropical depression with sustained winds of 35 mph to a hurricane with sustained winds of 85 mph. There were only three other storms in recorded history that strengthened from a depression to a hurricane in 24 hours: Celia in 1970, and Arlene and Flora 1963. Other storms have intensified faster if one considers the net intensity change over 24 hours. For example, Wilma in 2005 went from a tropical storm to a Category 5 storm in less than 24 hours. That may be the most rapid rate of intensification ever, but starting from tropical storm stage rather than tropical depression stage.

Noel Was Deadliest

Hurricane Noel was the deadliest storm of the 2007 season, as it killed 122 people in the Dominican Republic and Haiti when it passed through there as a tropical storm in late October. News reports indicated 664 homes were destroyed and an additional 15,600 were damaged in the Dominican Republic, while Haiti reported 4,850 houses damaged, 1,075 completely destroyed, and crop losses from floods and mudslides.

Oceanographer Bill Patzert from NASA's Jet Propulsion Laboratory, Pasadena, Calif. said "In May, NOAA's Climate Prediction Center and other long-range hurricane forecasters predicted an above normal Atlantic hurricane season (13-17 named storms and 7-10 hurricanes) based on ocean and atmospheric conditions, like a building La Nina. At season's end, 15 named storms and 6 hurricanes were generated leaving many forecasters scratching their heads. The good news was that U.S. Gulf and East Coast communities were cut a break in 2007 and avoided major hurricane damage this year. The bad news, with no rainfall relief from tropical storms or hurricanes, the record-breaking Southeast drought continued and deepened."

A Deadly Season in the Western Pacific and Indian Oceans Other parts of the world weren't quite as fortunate as the U.S. this hurricane season. In the western Pacific and Indian Ocean regions, cyclones were very active.

The north Indian Ocean experienced a damaging and deadly 2007 hurricane

(cyclone) season. In June, Category 5 Cyclone Gonu surged out of the Arabian Sea and struck Oman and Iran - nations that almost never experience cyclones - causing almost \$4 billion in damage. In mid-November, Cyclone Sidr was spawned in the Bay of Bengal, grew to Category 5 intensity, and devastated Bangladesh. More than 4,000 died and tens of thousands of homes were leveled. Both of these Category 5 cyclones caused immense property damage and had crippling impacts in these emerging nations.

In the northwest Pacific, twenty-four named tropical storms developed during 2007. Usually the busiest region for hurricanes (typhoons), this relatively large number of tropical storms was below the annual average of 27. Of the twenty-four named tropical storms, fourteen storms were classified as typhoons, equaling the annual average. Although an "average" season, northwest Pacific tropical typhoons affected millions in southeast Asia, with typhoons Pabuk, Krosa, Lekima and tropical storms like Peipah among the most severe. Flooding, crop loss and wide spread property damage were experienced during this "normal" northwest Pacific hurricane season.

First Cyclone of Season Forms Near Western Australia The end of December also marked the formation of the first cyclone near western Australia. Tropical cyclone Melanie developed at sea on Dec. 28, about 600 miles northwest of the coastal community of Broome, Australia. The season in that region normally runs from November to April.

NASA Satellites Provided Valuable Information in 2007 NASA satellites provided NASA and university scientists with innovative new views of hurricanes in both hemispheres and during all seasons. Using simultaneous, accurate measurements of cloud-top temperatures from the Moderate Resolution Imaging Spectroradiometer on NASA's Aqua satellite, and cloud-top height and cloud profiling information from NASA's CloudSat satellite, NASA and university scientists announced they developed a promising new technique for estimating the intensity of tropical cyclones from space. The method could one day supplement existing techniques, assist in designing future tropical cyclone satellite observing systems, and improve disaster preparedness and recovery efforts. This new technique was developed by scientists at NASA's Jet Propulsion Laboratory, Pasadena, Calif.; Colorado State University, Fort Collins, Colo.; and the Massachusetts Institute of Technology (MIT), Cambridge, Mass. The framework used by the team to estimate tropical cyclone intensity was developed by co-author Kerry Emanuel of MIT and his colleague Valerie Wong.

While several factors likely contributed to the sharp decrease in the number of hurricanes during 2007, research by **William Lau**, Chief of the Laboratory for Atmospheres at NASA's Goddard Space Flight Center, Greenbelt, Md. showed that Saharan dust may have a major effect on seasonal hurricane activity. Lau and his colleagues used data from the Moderate Resolution Imaging Spectroradiometer on NASA's Terra and Aqua spacecrafts to better understand the role of African dust

storms in hurricane activity. Lau noted that Saharan dust through its radiative properties, spatial and temporal coverage and concentrations may play as big a role as other atmosphere-ocean conditions, like El Niño, and offer some predictive value, so they should be closely monitored to improve hurricane forecasts.

NASA's QuikSCAT provided information on surface wind direction and speed in storms and was useful for identifying when various storms first developed a surface circulation. In general, hurricane forecasters at the National Oceanic and Atmospheric Administration's (NOAA) National Hurricane Center used these data, experimentally, to improve forecasts of hurricane intensity and direction. One of their goals is too more precisely forecast hurricane landfalls and lessen the financial impacts of unnecessary evacuations.

Scott Braun, Meteorologist at NASA Goddard said, "The Tropical Rainfall Measuring Mission (TRMM) satellite and NASA's Aqua satellite's Advanced Microwave Scanning Radiometer (AMSR) data provided information on precipitation structure, changes in which can often reflect changes in intensity, as well as helped to provide more accurate locations on the centers of storms such as powerful storms like Dean and Felix, as well as all other storms."

"Further, QuikSCAT winds, TRMM and AMSR precipitation, and radiances from the Atmospheric Infrared Sounder (AIRS) on NASA's Aqua satellite were used as input into NOAA's operational forecast models," Braun said. "The TRMM multi-satellite precipitation analysis was used to monitor heavy rainfalls associated with Hurricane Noel and Tropical Storm Olga in the Dominican Republic and Haiti, where these storms did a great deal of damage and killed many people."

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News

NASA NEWS ARCHIVE

March 17, 2008

NASA SATELLITE MEASURES POLLUTION FROM EAST ASIA TO NORTH AMERICA

In a new NASA study, researchers taking advantage of improvements in satellite sensor capabilities offer the first measurement-based estimate of the amount of pollution from East Asian forest fires, urban exhaust, and industrial production that makes its way to western North America.

China, the world's most populated country, has experienced rapid industrial growth, massive human migrations to urban areas, and considerable expansion in automobile use over the last two decades. As a result, the country has doubled its emissions of man-made pollutants to become the world's largest emitter of tiny particles called pollution aerosols that are transported across the Pacific Ocean by rapid airstreams emanating from East Asia.

Hongbin Yu, an associate research scientist of the University of Maryland Baltimore County working at NASA's Goddard Space Flight Center in Greenbelt, Md., grew up in China and taught there as a university professor, where he witnessed first-hand and studied how pollution from nearby power plants in China affected the local environment. Early this decade, scientists began using emerging high-accuracy satellite data to answer key questions about the role tiny particles play in the atmosphere, and eventually expanded their research to include continent-to-continent pollution transport. So Yu teamed with other researchers to take advantage of the innovations in satellite technology and has now made the first-ever satellite-based estimate of pollution aerosols transported from East Asia to North America.

The new measurements from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Terra satellite substantiate the results of previous model-based studies, and are the most extensive to date. The new study will be published this spring in the American Geophysical Union's Journal of Geophysical Research-Atmospheres.

"We used the latest satellite capabilities to distinguish industrial pollution and smoke from dust transported to the western regions of North America from East Asia. Looking at four years of data from 2002 to 2005 we estimated the amount of

pollution arriving in North America to be equivalent to about 15 percent of local emissions of the U.S. and Canada," Yu said. "This is a significant percentage at a time when the U.S. is trying to decrease pollution emissions to boost overall air quality. This means that any reduction in our emissions may be offset by the pollution aerosols coming from East Asia and other regions."

Yu and his colleagues measured the trans-Pacific flow of pollution in teragrams, a unit of measurement of the mass of pollution aerosol (1 teragram is about 2.2 billion pounds). Satellite data confirmed 18 teragrams – almost 40 billion pounds – of pollution aerosol was exported to the northwestern Pacific Ocean and 4.5 teragrams – nearly 10 billion pounds – reached North America annually from East Asia over the study period.

Yu points out, however, that the matter of pollution transport is a global one. "Our study focused on East Asian pollution transport, but pollution also flows from Europe, North America, the broader Asian region and elsewhere, across bodies of water and land, to neighboring areas and beyond," he said. "So we should not simply blame East Asia for this amount of pollution flowing into North America." In fact, in a model study published last November in the *Journal of Atmospheric Chemistry and Physics*, **Mian Chin**, also a co-author of this study and an atmospheric scientist at NASA Goddard, suggests that European pollution also makes a significant contribution to the pollution inflow to North America.

"Satellite instruments give us the ability to capture more accurate measurements, on a nearly daily basis across a broader geographic region and across a longer time frame so that the overall result is a better estimate than any other measurement method we've had in the past," said study co-author **Lorraine Remer**, a physical scientist and member of the MODIS science team at NASA Goddard. The MODIS instrument can distinguish between broad categories of particles in the air, and observes Earth's entire surface every one to two days, enabling it to monitor movement of the East Asian pollution aerosols as they rise into the lower troposphere, the area of the atmosphere where we live and breathe, and make their way across the Pacific and up into the middle and upper regions of the troposphere.

Remer added that the research team also found that pollution movements fluctuate during the year, with the East Asian airstream carrying its largest "load" in spring and smallest in summer. The most extensive East Asian export of pollution across the Pacific took place in 2003, triggered by record-breaking wildfires across vast forests of East Asia and Russia. Notably, the pollution aerosols also travel quickly. They cross the ocean and journey into the atmosphere above North America in as little as one week.

"Using this imaging instrument, we cannot determine at what level of elevation in the atmosphere pollution travels. So, we do not have a way in this study to assess the degree of impact the pollution aerosols from China have on air quality here once they cross over to North America. We need improved technology to make that

determination," said Remer. "Nevertheless, we realize there is indeed impact. For example, particles like these have been linked to regional weather and climate effects through interactions between pollution aerosols and the Sun's heat energy. Since pollution transport is such a broad global issue, it is important moving forward to extend this kind of study to other regions, to see how much pollution is migrating from its source regions to others, when, and how fast," said Remer.



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Mission News

Solar Variability: Striking a Balance with Climate Change

05.07.08

The sun has powered almost everything on Earth since life began, including its climate. The sun also delivers an annual and seasonal impact, changing the character of each hemisphere as Earth's orientation shifts through the year. Since the Industrial Revolution, however, new forces have begun to exert significant influence on Earth's climate.

"For the last 20 to 30 years, we believe greenhouse gases have been the dominant influence on recent climate change," said Robert Cahalan, climatologist at NASA's Goddard Space Flight Center in Greenbelt, Md.

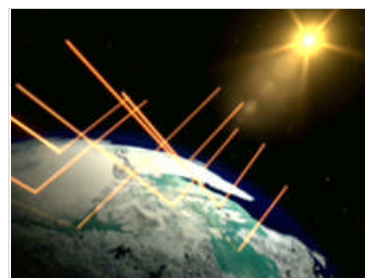
For the past three decades NASA scientists have investigated the unique relationship between the sun and Earth. Using space-based tools, like the Solar Radiation and Climate Experiment (SORCE), they have studied how much solar energy illuminates Earth, and explored what happens to that energy once it penetrates the atmosphere. The amount of energy that reaches Earth's outer atmosphere is called the total solar irradiance. Total solar irradiance is variable over many different timescales, ranging from seconds to centuries due to changes in solar activity.

The sun goes through roughly an 11-year cycle of activity, from stormy to quiet and back again. Solar activity often occurs near sunspots, dark regions on the sun caused by concentrated magnetic fields. The solar irradiance measurement is much higher during solar maximum, when sunspot cycle and solar activity is high, versus solar minimum, when the sun is quiet and there are usually no sunspots.

"The fluctuations in the solar cycle impacts Earth's global temperature by about 0.1 degree Celsius, slightly hotter during solar maximum and cooler during solar minimum," said Thomas Woods, solar scientist at the University of Colorado in Boulder. "The sun is currently at its minimum, and the next solar maximum is expected in 2012."

Using SORCE, scientists have learned that about 1,361 watts per square meter of solar energy reaches Earth's outermost atmosphere during the sun's quietest period. But when the sun is active, 1.3 watts per square meter (0.1 percent) more energy reaches Earth. "This TSI measurement is very important to climate models that are trying to assess Earth-based forces on climate change," said Cahalan.

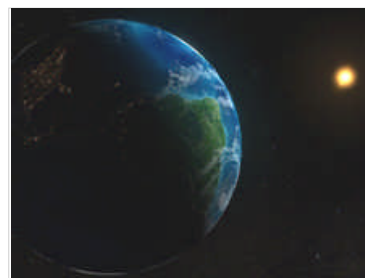
Over the past century, Earth's average temperature has increased by approximately 0.6 degrees Celsius (1.1 degrees Fahrenheit). Solar heating accounts for about 0.15 C, or 25 percent, of this change, according to computer modeling results published by NASA Goddard Institute for Space



[> View the solar balance Web video](#)

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Credit: NASA Goddard Space Flight Center



The sun radiates huge amounts of electromagnetic energy in all directions. Earth is only one small recipient of the sun's energy; the sun's rays extend far out into the solar system, illuminating all the other planets. **Credit:** NASA

NASA - Solar Variability: Striking a Balance with Climate Change

Studies researcher David Rind in 2004. Earth's climate depends on the delicate balance between incoming solar radiation, outgoing thermal radiation and the composition of Earth's atmosphere. Even small changes in these parameters can affect climate. Around 30 percent of the solar energy that strikes Earth is reflected back into space. Clouds, atmospheric aerosols, snow, ice, sand, ocean surface and even rooftops play a role in deflecting the incoming rays. The remaining 70 percent of solar energy is absorbed by land, ocean, and atmosphere.

[> Larger image](#)

"Greenhouse gases block about 40 percent of outgoing thermal radiation that emanates from Earth," Woods said. The resulting imbalance between incoming solar radiation and outgoing thermal radiation will likely cause Earth to heat up over the next century, accelerating the melting polar ice caps, causing sea levels to rise and increasing the probability of more violent global weather patterns.

Non-Human Influences on Climate Change

Before the Industrial Age, the sun and volcanic eruptions were the major influences on Earth's climate change. Earth warmed and cooled in cycles. Major cool periods were ice ages, with the most recent ending about 11,000 years ago.

"Right now, we are in between major ice ages, in a period that has been called the Holocene," said Cahalan. "Over recent decades, however, we have moved into a human-dominated climate that some have termed the Anthropocene. The major change in Earth's climate is now really dominated by human activity, which has never happened before."

The sun is relatively calm compared to other stars. "We don't know what the sun is going to do a hundred years from now," said Doug Rabin, a solar physicist at Goddard. "It could be considerably more active and therefore have more influence on Earth's climate."

Or, it could be calmer, creating a cooler climate on Earth similar to what happened in the late 17th century. Almost no sunspots were observed on the sun's surface during the period from 1650 to 1715. This extended absence of solar activity may have been partly responsible for the Little Ice Age in Europe and may reflect cyclic or irregular changes in the sun's output over hundreds of years. During this period, winters in Europe were longer and colder by about 1 C than they are today.

Since then, there seems to have been on average a slow increase in solar activity. Unless we find a way to reduce the amount of greenhouse gases we put into the atmosphere, such as carbon dioxide from fossil fuel burning, the solar influence is not expected to dominate climate change. But the solar variations are expected to continue to modulate both warming and cooling trends at the level of 0.1 to 0.2 degrees Celsius (0.18 to 0.26 Fahrenheit) over many years.

Future Measurements of Solar Variability

For three decades, a suite of NASA and European Space Agency satellites have provided scientists with critical measurements of total solar irradiance. The Total Irradiance Monitor, also known as the TIM instrument, was launched in 2003 as part of the NASA's SORCE mission, and provides irradiance measurements with state-of-the-art accuracy. TIM has been rebuilt as part of the Glory mission, scheduled to launch in 2009. Glory's TIM instrument will continue an uninterrupted 30-year record of solar irradiance measurements and will help researchers better understand the sun's direct and indirect effects on climate. Glory will also collect data on aerosols, one of the least understood pieces of the climate puzzle.

Related links:

- [> More on SORCE from NASA's Earth Observatory](#)
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Feature

Satellites Illuminate Pollution's Influence On Clouds

05.27.08

Clouds have typically posed a problem to scientists using satellites to observe the lowest part of the atmosphere, where humans live and breathe, because they block the satellite's ability to capture a clear, unobstructed view of Earth's surface. It turns out, however, that these "obstructions" are worth a closer look, as clouds and their characteristics actually serve a valuable role in Earth's climate. That closer look is now available by satellites comprising the Afternoon Constellation, or A-Train.

"The A-Train is providing a new way to examine cloud types," said Mark Schoeberl, A-Train project scientist at NASA's Goddard Space Flight Center, Greenbelt, Md.

Using data from instruments in a constellation of NASA satellites, scientists have discovered that they can see deep inside of clouds. The satellites are taking first-of-a-kind measurements, shedding new light on the link between clouds, pollution and rainfall.

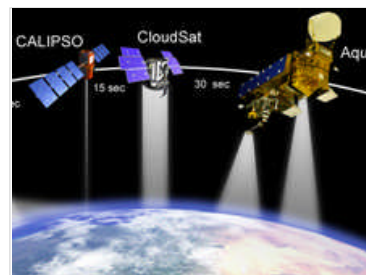
Jonathan Jiang of NASA's Jet Propulsion Laboratory, Pasadena, Calif., and colleagues used these A-Train sensors to find that South American clouds infused with airborne pollution – classified as "polluted clouds" – tend to produce less rain than their "clean" counterparts during the region's dry season. Details of the findings will be presented today at the American Geophysical Union's 2008 Joint Assembly in Fort Lauderdale, Fla.

Discovery of the link between rain and pollution was possible due to near-simultaneous measurements from multiple satellites making up the string of satellites in the Afternoon Constellation, more commonly called the A-Train. "Typically, it is very hard to get a sense of how important the effect of pollution on clouds is," said Anne Douglass, deputy project scientist at Goddard for NASA's Aura satellite. "With the A-Train, we can see the clouds every day and we're getting confirmation on a global scale that we have an issue here."

Jiang's team used the Microwave Limb Sounder on the A-Train's Aura satellite to measure the level of carbon monoxide in clouds. The presence of carbon monoxide implies the presence of smoke and other aerosols, which usually come from the same emission source, such as a power plant or agricultural fire.

With the ability to distinguish between polluted and clean clouds, the team next used Aqua's Moderate Resolution Imaging Spectroradiometer to study how ice particle sizes change when aerosol pollution is present in the clouds. The team also used NASA's Tropical Rainfall Measuring Mission satellite to measure the amount of precipitation falling from the polluted and clean clouds. All three measurements together show the relationship between pollution, clouds and precipitation.

The team found that polluted clouds suppressed rainfall during the June-to-October dry season in South America, which is also a period of increased



This artist's concept shows how the satellites composing the A-Train fly in formation to make near-simultaneous observations of Earth. **Credit: NASA**
[> Full image](#)

NASA - Satellites Illuminate Pollution's Influence On Clouds

agricultural burning. During that period it was more difficult for the measurably smaller ice particles in aerosol polluted clouds to grow large enough to fall as rain.

This trend turned up seasonal and regional differences, however, and aerosol pollution was found, on average, to be less of a factor during the wet monsoon seasons in South America and in South Asia. Other physical effects, such as large-scale dynamics and rainy conditions that clear the air of aerosol particles, might also be at play, the researchers suggest.

"The complexity of interactions between aerosols and clouds pose difficult problems that no one satellite instrument can solve," said Jiang. "But when you put parameters from multiple satellites all together, you will find much more information than from a single instrument alone."

The five satellites – NASA's Aqua, Aura, CloudSat and CALIPSO and the French Space Agency's PARASOL – of the A-Train orbit only eight minutes apart and can be thought of as an extended satellite observatory, providing unprecedented information about clouds, aerosols and atmospheric composition.

[+ Click here for more information](#)

Kathryn Hansen
NASA's Goddard Space Flight Center

Find this article at:

http://www.nasa.gov/topics/earth/features/atrain_climate.html



Pollution has long been observed to coexist with clouds, as seen here, but a group of NASA satellites are now revealing more about the complex relationship.

Credit: Mark Schoeberl

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Feature

Text Size

For Hurricanes, Storms, Raindrop Size Makes All the Difference

06.09.08

When Tropical Storm Gaston hit Richmond, Va., in August 2004, its notable abundance of small and mid-sized raindrops created torrential rains that led to unexpected flash flooding throughout the city and its suburbs. New research from NASA has concluded that tropical cyclones like Gaston produce rain differently than another class of storms called "extra-tropical" cyclones. According to the study, making a proper distinction between these systems by looking at both raindrop size and abundance may be a key to assisting weather forecasters in estimating rainfall intensity. By doing so, forecasters can reduce the surprise factor of flash flooding and the unfortunate loss of property and life.

Ali Tokay, a research scientist from the Joint Center for Earth Systems Technology (JCET) at the University of Maryland Baltimore County, Baltimore, and NASA's Goddard Space Flight Center, Greenbelt, Md., compared the rain measurements collected in tropical storms and hurricanes during the past three Atlantic hurricane seasons with measurements after these storms transitioned to being extra-tropical. Tokay's study appeared in the May issue of the American Meteorological Society's Monthly Weather Review.


When a tropical cyclone -- the generic name for tropical depressions, tropical storms and hurricanes -- merges with a mid-latitude frontal storm system, measurable changes to the raindrop size and abundance occur as the system transitions to become extra-tropical. Extra-tropical cyclones also form outside the tropics without being part of a tropical system, and tend to form over land rather than over the open ocean. This category of storm can produce anything from a cloudy sky to a thunderstorm as it develops between weather fronts, the boundaries separating air masses of different densities.

Tokay looked at raindrop size, rain intensity, and the area in which rain falls in both tropical cyclones and extra-tropical cyclones using ground-based rain-measuring instruments called disdrometers. These instruments measure the range of raindrop sizes in a storm and the intensity of the rainfall. The disdrometer is an important part of the ground-based rain measuring instruments that are used to validate rainfall seen from satellites including the Tropical Rainfall Measuring Mission (TRMM), a joint mission with NASA and the Japanese Space Agency. He concluded that tropical cyclones that form over water tend to rain harder and have a greater amount of smaller drops before they transition to being extra-tropical with raindrops of larger size and mass.


"Torrents of rainfall from tropical storms are not surprising since the systems are large and move slowly. It is also true that slow moving frontal systems associated with an extra-tropical cyclone can result in abundant rainfall at a site," said Tokay. "What is less known is that the distribution of raindrops within a volume of air between the two systems differs substantially even though weather radar may measure the same returned power which is known as reflectivity." This is why disdrometer measurements of raindrop size are needed.

"Both rain intensity and reflectivity are integral products of raindrop size distribution, but they are mathematically related to different powers of the drop size," said Tokay. Weather radars cannot measure the range of raindrop sizes. As a result, rainfall estimates from weather radars must employ the use of equations that make assumptions about raindrop size. These assumptions can result in underestimation of rain intensity, and the possibility of deadly flooding.

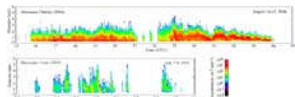
In the study, Tokay uses disdrometer data from various sites around the U.S. and abroad. Most of the data were collected at NASA's Wallops Flight Facility, Wallops Island, Va., where Paul Bashor of Computer Sciences Corporation, Wallops Island, Va. maintains several types of disdrometers. The data from two tropical storms were collected at Orlando, Fla., and Lafayette, La. through collaborative efforts with Takis Kasparis at the University of Central Florida's Orlando campus, and Emad Habib of the University of Louisiana at Lafayette.



Tropical Storm Gaston moved ashore over the coast of McClellanville, South Carolina on August 29, 2005 as captured by the MODIS instrument aboard NASA's Terra satellite. At the time this image was taken, Gaston poured large amounts of small and mid-sized raindrops across several states, including the city of Richmond, Va. Credit: NASA



Disdrometers like this one measure rainfall rates and size distribution. Credit: NASA



Hurricane Cindy (2005) was observed after it became an extratropical cyclone indicated by larger raindrops that are

From: owner-spa@igpp.ucla.edu on behalf of AGU newsletter editor
Sent: Thursday, August 07, 2008 4:57 PM
Subject: SPAM-LOW-SPA SECTION NEWSLETTER, Volume XV, Issue 52

AMERICAN GEOPHYSICAL UNION SPA SECTION NEWSLETTER . . .
Volume 15, Issue 52, August 7, 2008 . . .
Editor: Peter Chi .
Email: editor at igpp.ucla.edu
SPA Web Site: <http://spc.igpp.ucla.edu/spa/>

Composite Solar Spectral Ultraviolet Irradiance Data Set Available

From: **Matthew DeLand** <matthew_deland@ssaihq.com>

A composite solar spectral ultraviolet irradiance data set is now available for general use. The data set consists of daily average spectra covering the wavelength range 120 nm to 400 nm in 1 nm bins, and extends from November 8, 1978 to August 1, 2005. It has been constructed using data from six different satellite instruments. This data set represents the longest continuous record of solar UV irradiance observations.

The composite spectral irradiance data set is available at the LASP Interactive Solar Irradiance Datacenter (LISIRD) web site (http://lasp.colorado.edu/lisird/deland_composite.html) in ASCII format and as an IDL save set. A simple description of the contents of the data set and a more detailed discussion of the creation process can also be found there. The LISIRD web site also contains links to other solar irradiance data sets of interest to solar, atmospheric, climate, and space weather researchers.

For more information, please contact Matt DeLand.

environmentalresearchweb

RESEARCH HIGHLIGHTS

Aug 13, 2008

How real clouds respond to aerosols

Aerosols have been increasing in the atmosphere since the industrial revolution. One of their indirect effects, called the cloud albedo effect, is to increase the amount of solar radiation reflected back to space by clouds. Now, using detailed satellite observations, NASA scientists have examined the susceptibility of real clouds to this effect globally, for the first time. Their results help to validate predictions of the cloud albedo effect in climate models.

Aerosols – suspended particles of soot and other pollutants – affect the climate both directly and indirectly. They directly reflect or absorb solar radiation themselves. But their indirect effects on cloud properties may have a greater impact on global climate.

One indirect aerosol effect, called the cloud albedo effect or the Twomey effect after the scientist who first described it, increases the amount of solar energy reflected from a cloud. It happens because aerosols act as cloud condensation nuclei, so clouds with added aerosols develop a greater number of smaller water droplets. Increasing the albedo (or diffuse reflectivity) of clouds in this way causes a cooling effect, or in other words, a negative radiative forcing.

While the cloud albedo effect is characterised in many global climate models, it is very challenging to measure directly. The physical properties of clouds are complex and constantly changing. Different types of cloud respond differently to aerosols and it is extremely hard to be sure whether an observed difference in albedo is caused by aerosols, by other factors such as temperature and humidity change, or by different initial cloud properties.

Now, atmospheric physicists Lazaros Oreopoulos and Steve Platnick from the NASA Goddard Space Flight Centre, US, have taken a new approach to finding out how the albedo of the world's clouds can be expected to respond to added aerosols. They used cloud observations taken by MODIS (Moderate Resolution Imaging Spectroradiometer), an imaging system aboard two NASA Earth Observation satellites launched at the start of this century.

Data from MODIS provided global maps of actual cloud albedo for four months in 2005, calculated from measurements of each cloud's opacity (known as optical thickness) and water droplet distribution. Oreopoulos and Platnick then superimposed a uniform change in the concentration of water droplets onto all the clouds and re-calculated their albedo. "Essentially, we mimic the effect of adding more aerosols," says Oreopoulos.

Their results showed two general patterns. First, clouds over oceans are more sensitive to aerosol addition, increasing their reflectance more than those over land. "This is partly because of the properties of marine clouds before they were perturbed, and partly because they are sitting over a dark surface – the ocean," says Oreopoulos. The other pattern is that clouds at high latitudes are less sensitive to aerosols than those nearer the equator.

The study found that if you increase the number of water droplets in the clouds by 10%, it leads to a global change in radiative forcing of 1–2 Wm⁻². Happily, this is similar to the numbers emerging from climate models that have not incorporated observational cloud data.

The team now plans to collaborate with climate modellers and predict the effect of a more realistic, variable distribution of aerosols on their cloud data. They are also starting to investigate the potential effect of aerosols on ice clouds, which are far less well understood. "The data coming out of MODIS are relatively new, and there

9/19/2008 1

is still a lot of science we can do with them," says Platnick.

This study was published in the **Journal of Geophysical Research**.

About the author

Lynn Dicks is a contributing editor to **environmentalresearchweb**.


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Feature

2007 Hurricane Forecasts Took Blow from Winds and Saharan Dry, Dusty Air

08.18.08

A new analysis of environmental conditions over the Atlantic Ocean shows that hot, dry air associated with dust outbreaks from the Sahara desert was a likely contributor to the quieter-than-expected 2007 hurricane season.

Factors known to influence the number and intensity of hurricanes in a season, including El Niño, sea surface temperatures, wind, and sea level pressure, led to NOAA forecasts for an above-average 2007 hurricane season. However, the season, which runs from June through November, turned up six hurricanes – a near normal number, but less than the 10 expected and far fewer than the record-breaking 15 hurricanes in 2005.

The difference between the 2007 and 2005 seasons could be due in part to the westward reach of Saharan dry air and dust over the North Atlantic, according to researchers, including Bill Lau of NASA's Goddard Spaceflight Center in Greenbelt, Md., and co-author of a study on this finding published Aug. 14 in the American Geophysical Union's *Geophysical Research Letters*. The study also confirms the possible role of Saharan dust in shattering predictions for the 2006 hurricane season, and has implications for more accurate predictions for future hurricane seasons.

Lau and colleagues previously reported that the presence of dust could have contributed to a weaker 2006 hurricane season than forecasters expected. Dust over the North Atlantic blocked some sunlight from reaching the ocean, accounting for 30 to 40 percent of the drop in sea surface temperatures measured between June 2005 and June 2006. The cooler sea surface increases atmospheric stability and also reduces the transfer of heat from ocean to atmosphere – a major source of fuel that drives hurricanes.

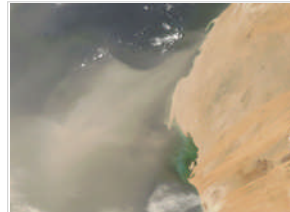
Now, the team found that hurricane formation in 2007 was also hampered by Saharan dry air. They go further, however, to describe the extent to which the dry air and associated dust spread across the tropical North Atlantic, as seen by instruments aboard NASA satellites such as the Moderate Resolution Imaging Spectroradiometer. They created a "wind-stretch index," based on the east-west difference in wind speed over the tropical Atlantic. The index is connected to relative humidity over the tropical western Atlantic, and is a perfect measure of how far west dry air and dust from Africa extends over the North Atlantic.

The team found that instances of Saharan dry air and dust extending far west over the Caribbean were in sync with conditions that contributed to fewer hurricanes in both 2007 and 2006, including lower sea surface temperatures. They also found that the far-reaching western extent of dust in 2006 and 2007 was associated with less-than-normal humidity over the western North Atlantic.

"This index hasn't been looked at before," said Lau. "We introduce a way to relate wind stretch to dry air and dust, which correlate very well with humidity in the western tropical Atlantic."

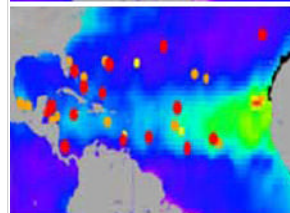
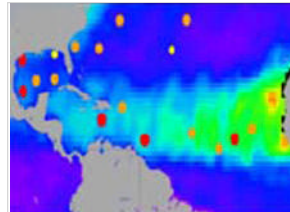
The link between dust and humidity, the researchers say, could aid future forecasts. As dust outbreaks occur most often in early summer prior to peak hurricane season, researchers could use a measure of humidity in the western tropical Atlantic to gauge the extent of dust transport, possibly providing an additional parameter to estimate the following month's hurricane activity.

"The index we proposed may provide practical implications for the prediction of Atlantic hurricane activities," says Donglian Sun of George Mason University in Fairfax Va., and lead author of the study. "Further studies are needed to discern the general prediction capability of our results."



A dust plume from Northern Africa moves over the Atlantic on July 20, 2007. The westward extent of such dust could have contributed to the relatively quiet 2007 hurricane season.

Credit: NASA
[> Larger image](#)



Dots mark the locations of tropical depressions, tropical storms and hurricanes during the hurricane seasons of 2007 (above) and 2008 (below). Green indicates the westward extent of dust.
 Credit: NASA

If the index is on target, the team believes it could also describe dust's role in past hurricane seasons. Records of historical wind data from ground stations could be applied to the index to infer the westward extent of dry air and dust long before satellites existed to "see" dust from above.

Related Links:

[Saharan Dust Has Chilling Effect on North Atlantic](#)

[Did Dust Bust the 2006 Hurricane Season Forecasts?](#)

Kathryn Hansen

NASA's Goddard Space Flight Center

Find this article at:

http://www.nasa.gov/centers/goddard/news/topstory/2008/hurricane_forecasts.html

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NEWS

NASA NEWS ARCHIVE

September 4, 2008

2008 HURRICANE SEASON KICKS INTO HIGH GEAR

For the first time in the 2008 hurricane season, there are four tropical cyclones active in the Atlantic Ocean basin on one day (Sept. 2). September is considered the peak of the Atlantic Ocean hurricane season, and in the first week of September there were four tropical cyclones that forecasters were watching.

Why is September the peak month for hurricanes? NASA oceanographer, Bill Patzert at the Jet Propulsion Laboratory, Pasadena, Calif., provided the answer: "Hurricanes are fueled by warm ocean temperatures and September is the end of the Northern Hemisphere ocean warming season. The 2008 Atlantic hurricane season started early with the formation of Tropical Storm Arthur on May 30, from the remnants of the eastern Pacific Ocean's first storm, Alma, which crossed Central America and reformed in the Gulf of Mexico. It took one month and four days for the next storm to form, Bertha. Now, the action is definitely picking up. The tropical Atlantic is warm, but not unusually so. In the tropical Atlantic, Caribbean and Gulf of Mexico, temperatures are certainly well above the 80 degree Fahrenheit threshold, so conditions are ripe for generating and sustaining major tropical storms and hurricanes."

Once a powerful Category 3 hurricane, now a tropical depression, Gustav moved from northwest Louisiana into northeastern Texas and into Arkansas by Sept. 3. Like Tropical Storm Fay in August, Gustav's legacy will lie in large rainfall totals. According to the National Hurricane Center's discussion on Sept. 2, "Storm total rainfalls are expected to be five to ten Inches with isolated maximums of 15 inches over portions of Louisiana, Arkansas and Mississippi. Rainfall amounts of 4-8 inches have been already reported in parts of Alabama, Mississippi and Louisiana."

Meanwhile, Tropical Storm Hanna formed near the Leeward Islands from the eighth tropical depression. Observed by the Tropical Rainfall Measuring Mission (TRMM) satellite to contain a deep and intense thunderstorm tower on Sept. 1 (often a precursor to intensification), it subsequently strengthened briefly into a hurricane before weakening under the influence of vertical wind shear (winds that can weaken or tear a tropical cyclone apart). On Sept. 3 and 4 Hanna was pounding the

Bahamas with heavy rains and tropical storm force winds, according to the National Hurricane Center.

The ninth tropical depression of the year formed some 1,200 miles east of the Leeward Islands and has blown up into Tropical Storm Ike. On Sept. 4, Ike strengthened into a major hurricane, Category 4 on the Saffir-Simpson Scale, with maximum sustained winds near 145 mph. Ike is forecast to head west and may also affect the Bahamas.

Behind Ike, on Sept. 2, the tenth tropical depression in the Atlantic Ocean basin was born. Tropical Depression 10 formed west of the African coast, so it has a long way to go before it has any impact on the U.S. or the Caribbean. By the late morning, that tropical cyclone became Tropical Storm Josephine.

In August, Fay's ten-day romp from the U.S. Southeast northward up the Appalachian Mountains seemed like a harbinger for September's storms. Fay took her time going northward and dumped tremendous amounts of rain along the way. Melbourne Beach, Fla., received as much as 25.28 inches of rain. Other cities in various states reported high totals: Thomasville, Ga., reported 17.43 inches; Camden, Ala., received 6.85 inches; Beaufort, S.C., received 6.11 inches; Carthage, Tenn., reported 5.30 inches, and Charlotte, N.C., reported 5.90 inches. Fay was a perfect example of how weaker tropical storms can cause flooding inland.

"Our findings [in a recent journal article] indicate that weak tropical systems could significantly contribute to rainfall totals," said Marshall Shepherd, lead author of a NASA-funded study that appeared in a December 2007 issue of the American Geophysical Union's Geophysical Research Letters. "These types of storms are significant rain producers. The larger hurricanes aren't frequent enough to produce most of the actual rain during the season and therefore are not the primary storm type that relieves drought in the region."

Conditions in the Atlantic this year are favorable for an active season because of warm sea surface temperatures and low wind shear (winds that tear a tropical cyclone apart). "Although La Nina conditions in the equatorial Pacific Ocean have subsided, the atmospheric jet stream over North American and the North Atlantic are still retaining some characteristics of the faded La Nina," Patzert said. "The upper atmospheric winds that could shear the tops off tropical storms are staying north, allowing tropical storms to develop and grow into hurricanes."

Compared to the long-term historical record, the first half of the 2008 hurricane season has been busier than usual. According to meteorologist Scott Braun at NASA's Goddard Space Flight Center, Greenbelt, Md.: "Looking back to 1995 and earlier, most seasons have had only 5-7 storms by Sept. 2, whereas this year has had 10. 2008 is surpassed only by 1995 (13), 2003 (11), and 2005 (14) and matched by 2004 (10). Prior to 1995, the last time there were 10 storms by Sept. 2 was 1936

(11).”

As Gustav has shown, a powerful, land-falling storm can impact millions of people and do billions of dollars of damage. As we approach the mid-September peak in hurricane activity, hurricane experts are on high alert and the residents of the Caribbean Islands, Central America, and the American Gulf and East coasts should be prepared for additional hurricane activity.

Related link:

[> Smaller Storms Drop Larger Overall Rainfall in Hurricane Season](#)

Rob Gutro, Bill Patzert and Scott Braun
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##

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http://www.nasa.gov/mission_pages/hurricanes/archives/2008/active_season08.html

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Pollution Causes Most Lightning Strikes at Midweek

Michael Reilly, Discovery News

Nov. 26, 2008 -- As if getting through "hump day" could get any tougher, new research shows that the middle of the week is the worst time for lightning.

There are 10-20 percent more strikes on Wednesdays and Thursdays than there are on the weekends. The weekly spike in dangerous weather appears to occur in the summer in the southeastern part of the United States as a result of air pollution.

"The one thing that seems to change most during the week is heavy truck traffic,"

Thomas Bell of NASA's Goddard Space Flight Center in Maryland said. "It starts rising on Monday, then peaks around Wednesday or Thursday. We don't know why that would be, but it's a pretty dramatic pattern."

In previous research, Bell found that summer precipitation in the southeastern United States follows a similar pattern. He suspects that microscopic particles spewed from trucks' diesel engines act as seeds for forming water droplets in clouds. With more seeds in the air more droplets form, but they are smaller.

Rising bubbles of warm air can easily loft small droplets high into the atmosphere, forming huge, towering thunderheads. And if the droplets get high enough, they freeze.

"The thinking is that ice crystals colliding with one another plays a big role in the charge separation that causes lightning," Bell said, though he added that the exact mechanism is still a bit of a mystery.

Using data from the National Lightning Detection Network, Bell compiled lightning strike information from 1998 to 2006 over the continental United States. He found that in several regions -- and especially the southeastern United States -- summer lightning strikes went up significantly during the middle of the week.

The study is due to be presented next month at the American Geophysical Union meeting in San Francisco.

"People have been debating about the effects of aerosols on weather for the last five years or so," Dong Wu of the California Institute of Technology said. "We know there is a relationship between aerosol loading in the atmosphere and rainfall; it's one way humans seem to be influencing the climate."

A series of studies over the past few years have shown that surface temperature, cloud formation, and precipitation all appear to follow a weekly cycle that could be linked to human activity. "Earth's climate is going to warm significantly in the next 50 to 100 years," Wu said. "We want to know what role aerosols play in this; is it a warming

effect, cooling, or neutral? It's a hard problem, untangling anthropogenic influence on weather from what is just natural variability. Looking at the effects of aerosol pollution is one way we can do that."



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News

New Satellite Data Reveal Impact of Olympic Pollution Controls

12.16.08

Chinese government regulators had clearer skies and easier breathing in mind in the summer of 2008 when they temporarily shuttered some factories and banished many cars in a pre-Olympic sprint to clean up Beijing's air. And that's what they got.

They were not necessarily planning for something else: an unprecedented experiment using satellites to measure the impact of air pollution controls. Taking advantage of the opportunity, NASA researchers have since analyzed data from NASA's Aura and Terra satellites that show how key pollutants responded to the Olympic restrictions.

According to atmospheric scientist Jacquelyn Witte and colleagues from NASA's Goddard Space Flight Center in Greenbelt, Md., the emission restrictions had an unmistakable impact. During the two months when restrictions were in place, the levels of nitrogen dioxide (NO₂) -- a noxious gas resulting from fossil fuel combustion (primarily in cars, trucks, and power plants) -- plunged nearly 50 percent. Likewise, levels of carbon monoxide (CO) fell about 20 percent.

Witte presented the results on behalf of the team on Dec. 16 at the fall meeting of the American Geophysical Union in San Francisco.

Some scientists have questioned whether Beijing's highly publicized air quality restrictions actually had an impact. This new data shows clearly that they did. "After the authorities lifted the traffic restrictions, the levels of these pollutants shot right back up," Witte noted.

The steep decline in certain pollutants surprised the researchers. In a preliminary analysis of the data, the effect seemed to be minimal, explained Mark Schoeberl, project scientist for the Aura mission and a contributor to the study. The reductions only became noticeable when the investigators focused tightly on the Beijing area.

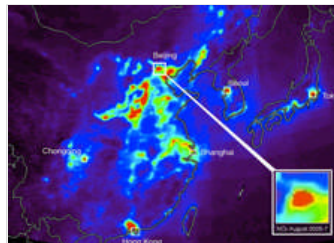
"If you take a wide view, you start to pick up long distance transport of pollutants," Schoeberl said. That seemed to be the case with sulfur dioxide (SO₂), which has a longer lifetime in the atmosphere. Although satellites detected reductions in levels of SO₂ -- a major byproduct of coal-fired power plants and a key ingredient of acid rain -- the decline was more widespread due to a larger effort to reduce SO₂ emissions across China, explained Kenneth Pickering, another Goddard scientist involved in the research.

Witte and colleagues presume that winds carried SO₂ in from the heavily industrialized provinces to the south of Beijing. However, she cautions that it is difficult to capture accurate readings of sulfur dioxide from the satellites due to difficulties detecting the gas low to the ground, where it is most abundant. It's best to consider the SO₂ measurements a work in progress, emphasized Pickering.

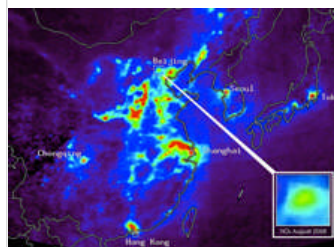
Ultimately, researchers aim to use satellite data to evaluate and refine local and regional models to predict how pollution levels respond to changes in emissions. Such models are important for understanding the integrated Earth system and aiding policymakers considering ways to reduce pollution.

Until recently, it's been difficult to improve atmospheric composition and chemistry models because scientists have had difficulty correlating "bottom up" estimates of total emissions -- tallies of likely pollution sources, such as the number of cars on the road or the amount of coal burned -- with "top down" observations from instruments on satellites. According to Pickering, data from the Netherlands-supplied Ozone Monitoring Instrument (OMI) on Aura and the Measurement of Pollution in the Troposphere (MOPITT) instrument on Terra help significantly.

Still, it will take a few years for the research team -- which includes investigators from the University of Iowa and Argonne National Laboratory in Illinois -- to perfect and finalize the models.



This map, an average of August 2005-07 nitrogen dioxide (NO₂) levels, shows high levels of pollution in Beijing and other areas of eastern China. **Credit: NASA**
[> Larger image](#)



In contrast, levels of nitrogen dioxide (NO₂) plunged nearly 50 percent in and around Beijing in August 2008 after officials instituted strict traffic restrictions in preparation for the Olympic Games. **Credit: NASA**
[> Larger image](#)

The team is sharing its findings with colleagues from Tsinghua University in China. "They are very interested in what we're finding," says Pickering, noting that the data from Aura and Terra are unique and will help scientists devise more accurate ways to quantify and evaluate ongoing efforts to reduce emissions.

China is currently in the midst of a sustained effort to reduce sulfur dioxide, according to the Xinhua News Agency. Officials recently decided to reinstitute a less stringent version of the Olympic driving restrictions, requiring most cars to stay off the road at least one day each week, the agency reported in October.

Sorting out what's happening over Beijing is just the beginning, says Greg Carmichael, a professor of chemical and biochemical engineering at the University of Iowa. The procedures demonstrated here, he said, offer the capability to detect emission changes and improve models the world over.

Related Links:

> [Aura Web site](#)

> [NASA Embarks on International Study of Air Pollution Flowing into U.S. from Abroad](#)

Adam Voiland

NASA's Goddard Space Flight Center

Find this article at:

http://www.nasa.gov/topics/earth/features/olympic_pollution.html

APPENDIX 2. REFEREED ARTICLES

Asterisks indicate articles highlighted in Appendix 3.

Laboratory members' names are in boldface.

Code 613 Refereed Publications

Bollasina, M., S. Nigam, and **K.M. Lau**, 2008: Absorbing aerosols and summer monsoon evolution over South Asia: An observational portrayal. *J. Climate.*, **21**, 3221–3239, Doi:10.1175/2007JCLI2094.1

Lau, K.M., V. Ramanathan, G-X. Wu, Z. Li, **S.C. Tsay**, **C. Hsu**, R. Siika, B. Holben, D. Lu, G. Tartari, **M. Chin**, P. Koudelova, H. Chen, Y. Ma, J. Huang, K. Taniguchi, and R. Zhang., 2008: The Joint Aerosol-Monsoon Experiment: A New Challenge in Monsoon Climate Research. *Bull. Am. Meteor. Soc.*, **89**, 369–383, Doi:10.1175/BAMS-89-3-369.

Reale, O., **J. Susskind**, R. Rosenberg, E. Brin, E. Liu, L.P. Riishojgaard, J. Terry, and **J.C. Jusem**, 2008: Improving forecast skill by assimilation of quality-controlled AIRS temperature retrievals under partially cloudy conditions. *Geophys. Res. Lett.*, **35**, L08809, doi:10.1029/2007GL033002.

Sui, C.H., X. Li, C.H. Ho, and **K.M. Lau**, 2008: Effects of radiative cooling on the tropical convective response to sea surface temperature: 2-D large domain cumulus ensemble simulations. *J. Geophys. Res.*, **113**, Doi:10.1029/2007JD008557.

Sun, D., **K.M. Lau**, and M. Kafatos. 2008: Contrasting the 2007 and 2005 hurricane seasons: Evidence of possible impacts of Saharan dry air and dust on tropical cyclone activity in the Atlantic basin. *Geophys. Res. Lett.*, **35**, L15405, doi:10.1029/2008GL034529.

Code 613 NASA Technical Reports, and Other Publications

Molnar, G., and **J. Susskind**, “Atmospheric Parameter Climatologies from AIRS: Monitoring Short-, and Longer-Term Climate Variabilities and Trends,” *Proc. SPIE*, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIII, Orlando, Florida, March 16–20, 2008.

Susskind, J., “Data Assimilation Experiments Using Quality Controlled AIRS Version 5 Temperature Soundings,” *Proc. Amer. Meteor. Soc. Conf.*, New Orleans, LA, January 20–24, 2008.

Susskind, J., and **J. Blaisdell**, “Improved Surface Parameter Retrievals using AIRS/AMSU Data,” *Proc. SPIE*, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIII, Orlando, Florida, March 16–20, 2008.

Susskind, J., and **G. Molnar**, “Spatial and Temporal Inter-Relationships Between Anomalies of Temperature, Moisture, Cloud Cover, and OLR as Observed by AIRS/AMSU on Aqua,” *Geosci. Remote Sens. Symp.*, IGARSS July 7–11, 2008. IEEE International, Vol. **5**, V-1–V-4, 10.1109/IGARSS.2008.4780012.

Susskind, J., and **O. Reale**, “Data Assimilation Experiments Using Quality Controlled AIRS Version 5 Temperature Soundings,” *Geosci. Remote Sens. Symp.*, IGARSS July 7–11, 2008. IEEE International, Vol. **2**, II-359–II-362, 10.1109/IGARSS.2008.4779002.

613.1 Refereed Publications

- Chandrasekar, V., E. Gorgucci, **E.A. Smith**, **G. Skofronick-Jackson**, S.A. Rutledge, V.N. Bringi, W.A. Petersen, and **A. Hou**, 2008: Potential role of dual polarization radar in the validation of satellite precipitation measurements: rationale and opportunities. *Bull. Amer. Meteor. Soc.*, **89**, 1127–1145.
- Chiu, J., **J. Welton**, S. Valencia, W. Wiscombe, and A. Marshak, 2008: Cloud optical depth retrievals from solar background “signal” of micropulse lidars, *IEEE Geosci. Remote Sens.*, **4**, 456–460.
- Comstock, J.M., **D. O’C. Starr**, P. Yang, and R. Lin, 2008: Understanding ice supersaturation, particle growth, and number concentration in cirrus clouds, *J. Geophys. Res.*, **113**(23), Doi:10.1029/2008JD010332, D23211.
- Fan, J., K. Mohr, **W.-K. Tao**, and R. Zhang, 2008: Aerosol radiative effects on deep convective clouds and associated radiative forcing, *J. Geophys. Res.*, **113**, Doi:10.1029/2007JD009257, D08209.
- Feidas, H., **A. Negri**, **M. Manyin**, N. Chrysoulakis, Y. Kamarianakis, and G. Kokolatos, 2008: Validation of an infrared-based satellite algorithm to estimate accumulated rainfall over the Mediterranean basin, *Theo. Appl. Clim.*, DOI 10.1007/s00704-007-0360.
- Hong, Y., **G. Huffman**, and R. Adler, 2008: Satellite Remote Sensing for Landslide Monitoring on a Global Basis, *EOS*, **88**(37), 357–358.
- Hong, Y., and **R. Adler**, 2008: Estimation of global SCS curve numbers using satellite remote sensing and geo-spatial data. *Intl. J. Remote. Sens.*, **29**:2(471–477), DOI 10.1080/01431160701264292.
- Hou, A.Y., C. Kummerow, J.M. Shepherd, and **G. Skofronick-Jackson**, 2008: Global Precipitation Measurement, Chapter 6 in *Precipitation: Advances in Measurement, Estimation and Prediction*, Springer-Verlag, Silas Michaelides, Eds., 540.
- Hossain, F., and **G. Huffman**, 2008: Investigating error metrics for satellite rainfall data at hydrologically relevant scales. *J. Hydrometeor.*, **9**(3), 563–575.
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APPENDIX 3. HIGHLIGHTED ARTICLES PUBLISHED IN 2008

613.1 Highlighted Articles



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, D23211, doi:10.1029/2008JD010332, 2008

Understanding ice supersaturation, particle growth, and number concentration in cirrus clouds

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[1] Many factors control the ice supersaturation and microphysical properties in cirrus clouds. We explore the effects of dynamic forcing, ice nucleation mechanisms, and ice crystal growth rate on the evolution and distribution of water vapor and cloud properties in nighttime cirrus clouds using a one-dimensional cloud model with bin microphysics and remote sensing measurements obtained at the Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility located near Lamont, OK. We forced the model using both large-scale vertical ascent and, for the first time, mean mesoscale velocity derived from radar Doppler velocity measurements. Both heterogeneous and homogeneous nucleation processes are explored, where a classical theory heterogeneous scheme is compared with empirical representations. We evaluated model simulations by examining both bulk cloud properties and distributions of measured radar reflectivity, lidar extinction, and water vapor profiles, as well as retrieved cloud microphysical properties. Our results suggest that mesoscale variability is the primary mechanism needed to reproduce observed quantities. Model sensitivity to the ice growth rate is also investigated. The most realistic simulations as compared with observations are forced using mesoscale waves, include fast ice crystal growth, and initiate ice by either homogeneous or heterogeneous nucleation. Simulated ice crystal number concentrations (tens to hundreds particles per liter) are typically two orders of magnitude smaller than previously published results based on aircraft measurements in cirrus clouds, although higher concentrations are possible in isolated pockets within the nucleation zone.

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1. Introduction

[2] The interaction between ice clouds and water vapor in the upper troposphere is critical for properly simulating current and future climates. Cirrus clouds may regulate upper tropospheric humidity and likely play a role in dehydration and transport of water vapor into the stratosphere [Corti *et al.*, 2006; Immler *et al.*, 2007]. Ice supersaturated regions are prevalent both in and outside cirrus clouds [Jensen *et al.*, 2001; Spichtinger *et al.*, 2004; Comstock *et al.*, 2004; Gettelman *et al.*, 2006]. Ice supersaturation is required for ice formation in cirrus clouds, yet most global models do not allow ice supersaturation. A recent study shows that incorporating ice supersaturation into a global model tends to decrease the occurrence of thick cirrus and anvils, and increase strato-

spheric water vapor [Gettelman and Kinnison, 2007]. Only the most recently developed ice nucleation parameterizations for global models require ice supersaturation [Kärcher and Lohmann, 2002, 2003; Liu and Penner, 2005; Tompkins *et al.*, 2007] and have been demonstrated in global simulations [Lohmann *et al.*, 2004; Liu *et al.*, 2007].

[3] The mechanisms that control ice supersaturation in cirrus clouds are not well understood. One mechanism that could explain large supersaturation (>130%) in cold clouds (colder than -70°C) involves the presence of nitric acid on the surface of ice crystals, which could inhibit the uptake of water vapor by the ice [Gao *et al.*, 2004]. Another possible mechanism is the formation of cubic ice, which occurs at temperatures colder than $\sim -80^{\circ}\text{C}$, grows to very small particle sizes, and subsequently increases the water vapor pressure in cold clouds [Murphy, 2003; Murray *et al.*, 2005; Shilling *et al.*, 2006]. However, these mechanisms will only contribute to a small fraction of midlatitude cirrus clouds that occur at such cold temperatures.

[4] Ice nucleation mechanism also influences the relative humidity with respect to ice (RHI) in cirrus. Cirrus clouds that form via homogeneous nucleation will have a much higher threshold RHI than those that form via heterogeneous nucleation on insoluble ice nuclei [i.e., Haag *et al.*, 2003; Koop *et al.*, 2000]. It is generally assumed that homogeneous nucleation is the primary mechanism for ice

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Precipitating Snow Retrievals from Combined Airborne Cloud Radar and Millimeter-Wave Radiometer Observations

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ABSTRACT

An algorithm for retrieving snow over oceans from combined cloud radar and millimeter-wave radiometer observations is developed. The algorithm involves the use of physical models to simulate cloud radar and millimeter-wave radiometer observations from basic atmospheric variables such as hydrometeor content, temperature, and relative humidity profiles and is based on an optimal estimation technique to retrieve these variables from actual observations. A high-resolution simulation of a lake-effect snowstorm by a cloud-resolving model is used to test the algorithm. That is, synthetic observations are generated from the output of the cloud numerical model, and the retrieval algorithm is applied to the synthetic data. The algorithm performance is assessed by comparing the retrievals with the reference variables used in synthesizing the observations. The synthetic observation experiment indicates good performance of the retrieval algorithm. The algorithm is also applied to real observations from the Wakasa Bay field experiment that took place over the Sea of Japan in January and February 2003. The application of the retrieval algorithm to data from the field experiment yields snow estimates that are consistent with both the cloud radar and radiometer observations.

1. Introduction

Snow is an important component of the earth's hydrological cycle. Over land, in some regions and seasons, snow may be the only form of precipitation, and therefore it is very important for water resources management and planning. Also, over land, snow may be associated with severe weather that impacts human lives. Over land or oceans, snow is important because it influences the atmosphere's thermal structure through release of latent heating and radiative cooling. For these reasons, snow has been systematically studied from hydrologic, severe-weather, and climate standpoints.

The advent of spaceborne radars provides new opportunities for studying snow. Although spaceborne

precipitation radars have difficulties detecting snow because of sensitivity limitations, spaceborne cloud radars operating at the W band are instruments that can provide unprecedented insight into various aspects of snow formation, global distribution, and interaction with other atmospheric or land processes. Such an instrument is the 94-GHz cloud-profiling radar (CPR) aboard the Cloud Satellite Mission (CloudSat). Although the CloudSat CPR itself can provide valuable information, it is expected that in conjunction with observations from other instruments (such as microwave radiometers) better interpretations of the CPR observations can be achieved.

Radar observations cannot be uniquely converted into snow contents because the size distribution of particles in the radar's observing volumes cannot be expressed as functions of single variables and usually at least two variables are necessary to describe the size distributions of snow particles. This makes the relationships of reflectivity versus snow content variable in time

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Optical-microphysical cirrus model

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[1] A model is presented that permits the simulation of the optical properties of cirrus clouds as measured with depolarization Raman lidars. It comprises a one-dimensional cirrus model with explicit microphysics and an optical module that transforms the microphysical model output to cloud and particle optical properties. The optical model takes into account scattering by randomly oriented or horizontally aligned planar and columnar monocrystals and polycrystals. Key cloud properties such as the fraction of plate-like particles and the number of basic crystals per polycrystal are parameterized in terms of the ambient temperature, the nucleation temperature, or the mass of the particles. The optical-microphysical model is used to simulate the lidar measurement of a synoptically forced cirrostratus in a first case study. It turns out that a cirrus cloud consisting of only monocrystals in random orientation is too simple a model scenario to explain the observations. However, good agreement between simulation and observation is reached when the formation of polycrystals or the horizontal alignment of monocrystals is permitted. Moreover, the model results show that plate fraction and morphological complexity are best parameterized in terms of particle mass, or ambient temperature which indicates that the ambient conditions affect cirrus optical properties more than those during particle formation. Furthermore, the modeled profiles of particle shape and size are in excellent agreement with in situ and laboratory studies, i.e., (partly oriented) polycrystalline particles with mainly planar basic crystals in the cloud bottom layer, and monocrystals above, with the fraction of columns increasing and the shape and size of the particles changing from large thin plates and long columns to small, more isometric crystals from cloud center to top. The findings of this case study corroborate the microphysical interpretation of cirrus measurements with lidar as suggested previously.

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1. Introduction

[2] Extraction of microphysical information from lidar observations of cirrus clouds is a challenging scientific objective because for an ensemble of ice particles no straightforward relationship exists between the optical properties at the relevant backscattering direction and the microphysical properties. Recently, *Reichardt et al.* [2002c]

reported lidar measurements of Arctic cirrus clouds which showed that (1) the particle optical properties, specifically depolarization ratio δ_{par} and extinction-to-backscatter ratio, or lidar ratio, S_{par} , were strongly correlated; (2) over the length of each cirrus measurement, the particle properties varied systematically; and (3) the particle optical properties depended on the ambient temperature. On the basis of theoretical particle optical data, these measurements were explained in terms of size, shape and growth of the cirrus particles. According to the interpretation of *Reichardt et al.* [2002c], light scattering by small hexagonal columns with aspect ratios close to one was dominant near the cloud top in the early stage of the cirrus development. Over time, as the cloud base extended to lower altitudes with warmer temperatures, the ice particles grew larger and became morphologically diverse: the optical lidar signature was indicative of a mixture of column- and plate-like particles (particles that have the scattering properties of hexagonal columns or plates, respectively). Toward the cloud base, light scattering was predominantly by plate-like ice particles. The proposed interpretation would hold out the prospect of model-supported retrieval of cirrus particle size, morphology (shape), and ice water content if it were

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Retrieval of Snow and Rain From Combined X- and W-Band Airborne Radar Measurements

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Abstract—Two independent airborne dual-wavelength techniques, based on nadir measurements of radar reflectivity factors and Doppler velocities, respectively, are investigated with respect to their capability of estimating microphysical properties of hydrometeors. The data used to investigate the methods are taken from the ER-2 Doppler radar (X-band) and Cloud Radar System (W-band) airborne Doppler radars during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment campaign in 2002. Validity is assessed by the degree to which the methods produce consistent retrievals of the microphysics. For deriving snow parameters, the reflectivity-based technique has a clear advantage over the Doppler-velocity-based approach because of the large dynamic range in the dual-frequency ratio (DFR) with respect to the median diameter D_0 and the fact that the difference in mean Doppler velocity at the two frequencies, i.e., the differential Doppler velocity (DDV), in snow is small relative to the measurement errors and is often not uniquely related to D_0 . The DFR and DDV can also be used to independently derive D_0 in rain. At W-band, the DFR-based algorithms are highly sensitive to attenuation from rain, cloud water, and water vapor. Thus, the retrieval algorithms depend on various assumptions regarding these components, whereas the DDV-based approach is unaffected by attenuation. In view of the difficulties and ambiguities associated with the attenuation correction at W-band, the DDV approach in rain is more straightforward and potentially more accurate than the DFR method.

Index Terms—Airborne radar, attenuation, particle size distribution, radar retrieval, rain, snow.

I. INTRODUCTION

DUAL-WAVELENGTH radar has shown promise in accurately inferring microphysical properties of hydrometeors if one of the wavelengths is operating in the region of non-Rayleigh scattering. Studies show that the median volume diameter D_0 of snow can be reasonably well derived from dual-wavelength measurements, and the estimates are nearly independent of the snow density if the snow density is constant and the shape parameter of the size distribution is fixed

[1]–[4]. The Global Precipitation Measurement Dual-frequency Precipitation Radar (DPR) has been proposed to globally map precipitation in conjunction with its onboard passive microwave sensors [5]. The DPR, with frequencies of 13.6 GHz (Ku-band) and 35.5 GHz (Ka-band), is expected to provide more accurate estimates of rain rates over a broader dynamic range than the Tropical Rainfall Measuring Mission Precipitation Radar (PR) that operates at a single frequency of 13.8 GHz [6], [7]. In addition, with its matched beams, the DPR should provide information on the drop size distribution (DSD) for both snow and rain. However, attenuation of the DPR signals while propagating through the rain, cloud, and mixed-phase precipitation not only complicates retrievals of rain and microphysical properties of hydrometeors, but also affects the accuracy of the algorithms because of uncertainties involved in the procedures for attenuation correction. Examination of the dual-wavelength techniques for the retrieval of the characteristic parameters of the DSD is critical in determining their accuracy in estimating rain and snow rates.

During the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE) field campaign in South Florida in 2002, the ER-2 Doppler radar (EDOP) X-band (9.6 GHz) and Cloud Radar System (CRS) W-band (94 GHz) radars aboard the ER-2 high-altitude aircraft acquired Doppler and reflectivity factor data along nadir. With the Doppler capabilities of EDOP and CRS radars, the measured mean Doppler velocities at two wavelengths can be used to derive particle size information [8]–[10], which can be used to compare with the results of algorithms based on radar reflectivities. An advantage of the use of Doppler velocity is its independence of attenuation. This implies that retrievals of particle size information can be carried out at each radar range without the influence of neighboring range gates. This gate-to-gate independence makes the retrieval much more straightforward than the reflectivity-based dual-wavelength radar techniques, where the retrieval at one gate depends on parameter estimates at other gates. Despite this advantage, the Doppler-based estimates have several drawbacks. For example, in snow, the difference in the mean Doppler velocities at the two wavelengths that is used to estimate D_0 has a small dynamic range relative to the measurement errors. Moreover, the accuracy of the measured Doppler velocities is affected by aircraft motion and pointing-angle errors.

In this paper, dual-wavelength algorithms that use measurements of radar reflectivity factors and mean Doppler velocities at X- and W-bands are analyzed for estimates of snow and rain size distribution parameters. The particle size parameters estimated from the Doppler velocities are checked for

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Nonspherical and spherical characterization of ice in Hurricane Erin for wideband passive microwave comparisons

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[1] In order to better understand the characteristics and physical-to-radiative relationships of frozen hydrometeors in hurricane systems, computed brightness temperatures (T_B) from 10.7 to 183 ± 10 GHz were compared with radiometric observations of Hurricane Erin (2001) from the NASA ER-2 aircraft. The focus was on the high frequencies (≥ 85 GHz) that are particularly sensitive to frozen hydrometeors. In order to initialize the cloud profiles used in the radiative transfer calculations, data from airborne radars, dropsondes, and cloud models were used. Three different ice habit and size parameterizations were used with these cloud profiles to obtain the particle radiative signatures including (1) spherical particles with size distributions derived from in situ observations, (2) spherical “fluffy” snow and graupel particles with modified Marshall-Palmer size distributions, and (3) a non-spherical bullet rosette habit where the radiation attributes (scattering, absorption, and asymmetry properties) were computed using the Discrete Dipole Approximation. In addition, three different reflectivity to ice water content (Z-IWC) relationships were used with the three habit and size parameterizations to provide a measure of the sensitivity of the Z-IWC relationship. This work showed that both the scattering and asymmetry coefficients, along with the ice water content in each layer, play an important role in determining the resultant high frequency brightness temperatures. All low frequency (<40 GHz) calculations matched the observations with correlation coefficients greater than 0.9. At higher frequencies (> 90 GHz), correlation coefficients ranged from 0.7 to 0.92. Comparing between the three ice habit and size parameterizations showed less than a 0.2 difference in correlation coefficient, while the comparisons between the three Z-IWC relationships caused changes of up to 0.15 in the correlation coefficients, but they had a significant effect on the mean differences between the observations and the calculations.

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1. Introduction

[2] The development and strength of tropical cyclones is highly influenced by frozen hydrometeors in hurricane rainbands and convection [e.g., *McFarquhar et al.*, 2006; *Heymsfield et al.*, 2006; *Willoughby*, 1998]. In fact “hot towers” associated with increasing hurricane intensity contain a significant amount of frozen hydrometeors. They are called hot towers because their column of air is slightly warmer than the surrounding air temperature, but above the melting layer at about 4–6 km to the tops of the towers at

15–19 km, the cloud hydrometeors are frozen. However, little information is known about frozen hydrometeor characteristics in hurricane and other clouds. While cloud resolving models do incorporate frozen hydrometeors [e.g., *Wu et al.*, 2006; *Tao et al.*, 2007], in general these modeled particles are only validated with extremely sparse in situ measurements or through comparisons between forward radiative transfer calculations using the model data and radiometer observations at frequencies up to 85 GHz. Unfortunately, the brightness temperature sensitivity to ice hydrometeors in clouds is limited by the physical and dielectric characteristics of ice for frequencies below 85 GHz. The sensitivity of higher frequency channels ($\sim > 85$ GHz) to frozen hydrometeors has been proven [e.g., *Skofronick-Jackson et al.*, 2004; *Bennartz and Bauer*, 2003]. With these higher frequencies the relationships between wide-band radiometer observations and the physical and electromagnetic properties of frozen hydrometeors can be studied. Understanding these physical-radiative rela-

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Raindrop Size Distribution Measurements in Tropical Cyclones

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ABSTRACT

Characteristics of the raindrop size distribution in seven tropical cyclones have been studied through impact-type disdrometer measurements at three different sites during the 2004–06 Atlantic hurricane seasons. One of the cyclones has been observed at two different sites. High concentrations of small and/or midsize drops were observed in the presence or absence of large drops. Even in the presence of large drops, the maximum drop diameter rarely exceeded 4 mm. These characteristics of raindrop size distribution were observed in all stages of tropical cyclones, unless the storm was in the extratropical stage where the tropical cyclone and a midlatitude frontal system had merged. The presence of relatively high concentrations of large drops in extratropical cyclones resembled the size distribution in continental thunderstorms. The integral rain parameters of drop concentration, liquid water content, and rain rate at fixed reflectivity were therefore lower in extratropical cyclones than in tropical cyclones. In tropical cyclones, at a disdrometer-calculated reflectivity of 40 dBZ, the number concentration was $700 \pm 100 \text{ drops m}^{-3}$, while the liquid water content and rain rate were $0.90 \pm 0.05 \text{ g m}^{-3}$ and $18.5 \pm 0.5 \text{ mm h}^{-1}$, respectively. The mean mass diameter, on the other hand, was $1.67 \pm 0.3 \text{ mm}$. The comparison of raindrop size distributions between Atlantic tropical cyclones and storms that occurred in the central tropical Pacific island of Roi-Namur revealed that the number density is slightly shifted toward smaller drops, resulting in higher-integral rain parameters and lower mean mass and maximum drop diameters at the latter site. Considering parameterization of the raindrop size distribution in tropical cyclones, characteristics of the normalized gamma distribution parameters were examined with respect to reflectivity. The mean mass diameter increased rapidly with reflectivity, while the normalized intercept parameter had an increasing trend with reflectivity. The shape parameter, on the other hand, decreased in a reflectivity range from 10 to 20 dBZ and remained steady at higher reflectivities. Considering the repeatability of the characteristics of the raindrop size distribution, a second impact disdrometer that was located 5.3 km away from the primary site in Wallops Island, Virginia, had similar size spectra in selected tropical cyclones.

1. Introduction

Flooding rainfall generated by tropical cyclones is generally attributed to the presence of abundant small

and midsize drops. This conclusion is mainly driven through postanalysis of coincident radar and rain gauge observations where different forms of the radar reflectivity Z and rain rate R relations were applied to the radar measurement. The agreement between radar-estimated and gauge-measured rainfall is highly dependent on the coefficient and exponent of the Z – R relation (Vieux and Bedient 1998; Petersen et al. 1999). For

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Comparisons of Instantaneous TRMM Ground Validation and Satellite Rain-Rate Estimates at Different Spatial Scales

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(Manuscript received 14 September 2007, in final form 3 January 2008)

ABSTRACT

This study provides a comprehensive intercomparison of instantaneous rain rates observed by the two rain sensors aboard the Tropical Rainfall Measuring Mission (TRMM) satellite with ground data from two regional sites established for long-term ground validation: Kwajalein Atoll and Melbourne, Florida. The satellite rain algorithms utilize remote observations of precipitation collected by the TRMM Microwave Imager (TMI) and the Precipitation Radar (PR) aboard the TRMM satellite. Three standard level II rain products are generated from operational applications of the TMI, PR, and combined (COM) rain algorithms using rain information collected from the TMI and the PR along the orbital track of the TRMM satellite. In the first part of the study, $0.5^\circ \times 0.5^\circ$ instantaneous rain rates obtained from the TRMM 3G68 product were analyzed and compared to instantaneous Ground Validation (GV) program rain rates gridded at a scale of $0.5^\circ \times 0.5^\circ$. In the second part of the study, TMI, PR, COM, and GV rain rates were spatiotemporally matched and averaged at the scale of the TMI footprint ($\sim 150 \text{ km}^2$). This study covered a 6-yr period (1999–2004) and consisted of over 50 000 footprints for each GV site. In the first analysis, the results showed that all of the respective rain-rate estimates agree well, with some exceptions. The more salient differences were associated with heavy rain events in which one or more of the algorithms failed to properly retrieve these extreme events. Also, it appears that there is a preferred mode of precipitation for TMI rain rates at or near 2 mm h^{-1} over the ocean. This mode was noted over ocean areas of Kwajalein and Melbourne and has been observed in TRMM tropical–global ocean areas as well.

1. Introduction

The Tropical Rainfall Measuring Mission's (TRMM) Ground Validation (GV) program was established early in the prelaunch phase of the mission with the principal long-term goals of determining the accuracy of the satellite rainfall measurements and the systematic biases stemming from application of the rainfall algorithms. More specifically, the GV program was structured around two validation strategies: 1) determining the quantitative accuracy of the integrated monthly rainfall products at GV regional sites over large areas of about 500 km^2 using integrated ground measurements and 2) intercomparing–validating instantaneous satellite and GV rain-rate statistics at spatiotemporal scales optimized to the various resolutions of the satellite and GV sensors (Simpson et al. 1988; Thiele 1988). This study will address both parts of the

validation problem, but will primarily be concerned with validating the instantaneous satellite rain products.

The GV program was originally designed around validating the TRMM Microwave Imager (TMI), Precipitation Radar (PR), and Combined (COM) standard rain products on monthly scales over the regional GV sites. Prior to launch, instantaneous validation was still considered somewhat intractable because of statistical uncertainties stemming from the spatiotemporal measuring characteristics of the satellite and GV observations. Direct instantaneous comparisons between coincident measurements are difficult to achieve without a sufficient number of regional overpasses. But empirically verifying the accuracy on monthly time scales using independent datasets at the surface has also posed logistical challenges due to the existence of temporal sampling errors in the integrated rain estimates.

The TRMM satellite retrieves rain information between roughly 35°N and 35°S while orbiting over the surface of the earth. The satellite collects between one and three estimates per day over any given location

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Persistent Nature of Secondary Diurnal Modes of Precipitation over Oceanic and Continental Regimes

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ABSTRACT

This investigation seeks a better understanding of the assorted mechanisms controlling the global distribution of diurnal precipitation variability based on the use of the Tropical Rainfall Measuring Mission (TRMM) microwave radiometer and radar data. The horizontal distributions of precipitation's diurnal cycle are derived from 8 yr of TRMM Microwave Imager (TMI) and Precipitation Radar (PR) measurements involving three TRMM standard rain retrieval algorithms; the resultant distributions are analyzed at various spatiotemporal scales. The results reveal both the prominent and expected late-evening (LE) to early-morning (EM) precipitation maxima over oceans and the counterpart prominent and expected mid- to late-afternoon (MLA) maxima over continents. Moreover, and not generally recognized, the results reveal a widespread distribution of secondary maxima, which generally mirror their counterpart regime's behavior, occurring over both oceans and continents. That is, many ocean regions exhibit clear-cut secondary MLA precipitation maxima, while many continental regions exhibit just as evident secondary LE-EM maxima. This investigation is the first comprehensive study of these globally prevalent secondary maxima and their widespread nature, a type of study only made possible when the analysis procedure is applied to a high-quality global-scale precipitation dataset.

The characteristics of the secondary maxima are mapped and described on global grids using an innovative clock-face format, while a current study that is to be published at a later date provides physically based explanations of the seasonal regional distributions of the secondary maxima. In addition to a primary "explicit" maxima identification scheme, a secondary "Fourier decomposition" maxima identification scheme is used as a cross-check to examine the amplitude and phase properties of the multimodal maxima. Accordingly, the advantages and ambiguities resulting from the use of a Fourier harmonic analysis are investigated.

1. Introduction

Studies of atmospheric diurnal processes that are influenced by the regulated daily cycle of incoming solar

radiation at the top of the atmosphere (TOA) have been taking place for over 100 yr. The seminal study of Hann (1901) was the first to address precipitation's diurnal cycle. Observational and modeling analyses have demonstrated that diurnal processes are evident in many atmospheric quantities. These include precipitation (e.g., Hong et al. 2005; Yang and Smith 2006), surface temperature (e.g., Smith 1986), surface winds (e.g., Deser and Smith 1998), surface pressure (e.g., Pertenko and Argentini 2002), vertical motion (e.g., Krishnamurti and Kishtawal 2000), cloudiness (e.g., Wylie and Woolf 2002), and surface and TOA radiation fluxes

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On the Sensitivity of Atmospheric Ensembles to Cloud Microphysics in Long-Term Cloud-Resolving Model Simulations

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Abstract

Month-long large-scale forcing data from two field campaigns are used to drive a cloud-resolving model (CRM) and produce ensemble simulations of clouds and precipitation. Observational data are then used to evaluate the model results. To improve the model results, a new parameterization of the Bergeron process is proposed that incorporates the number concentration of ice nuclei (IN). Numerical simulations reveal that atmospheric ensembles are sensitive to IN concentration and ice crystal multiplication.

Two- (2D) and three-dimensional (3D) simulations are carried out to address the sensitivity of atmospheric ensembles to model dimensionality. It is found that the ensembles with high IN concentration are more sensitive to dimensionality than those with low IN concentration. Both the analytic solutions of linear dry models and the CRM output show that there are more convective cores with stronger updrafts in 3D simulations than in 2D, which explains the differing sensitivity of the ensembles to dimensionality at different IN concentrations.

613.2 Highlighted Articles

Outbreaks of Asian Dust Storms: An Overview from Satellite and Surface Perspectives

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ABSTRACT

TAIWAN, located downwind of dust storm outbreaks from China, at the sink region of biomass-burning aerosols from Southeast Asia, and at the outflow of urban-industrial pollutants from the Pearl and Yangtze River Delta, is exposed to a seasonal milieu of natural and anthropogenic aerosols in the atmosphere. In the springtime, outbreaks of Asian dust storms occur frequently in the arid and semi-arid areas of northwestern China –about 1.6×10^6 square kilometers including the Gobi and Taklimakan deserts– with continuous expanding of spatial coverage. These airborne dust particles, originating in desert areas far from polluted regions, interact with anthropogenic sulfate and soot aerosols emitted from Chinese mega-cities during their transport over the mainland. Adding the intricate effects of clouds and marine aerosols, dust particles reaching the marine environment can have drastically different properties than those from their sources.

Together with anthropogenic pollutants, airborne dust particles may alter regional hydrological cycles by aerosol direct/indirect radiative forcing, influence fisheries by causing nutrient deposition anomalies, and increase adverse health effects to humans by trace metal enrichment. In addition to their local-to-regional impact, these dust aerosols can transport swiftly across the Pacific Ocean to reach North America in less than a week, resulting in an even larger scale effect. Asian dust aerosols can be distinctly detected by their colored appearance on modern Earth-observing satellites (e.g., MODerate-resolution Imaging Spectroradiometer, MODIS; Total Ozone Mapping Spectrometer, TOMS; Sea-viewing Wide Field-of-view Sensor, SeaWiFS; Geostationary Meteorological Satellites, GMS), and its evolution monitored by satellites and surface networks (e.g., Aerosol Robotic Network, AERONET; Micro-Pulse Lidar Network, MPLNET). However, these essential observations are incomplete due to the unique properties of the data constituted unilaterally on either the spatial (snapshot global coverage) or temporal (long-term point sites) dimension. Comprehensive modeling is required to bridge these spatial and temporal observations, and to serve as an integrator for our understanding of the effects of dust's physical, optical, and radiative properties on various forcing, response, and feedback processes occurring in the Earth-atmosphere system.

Many recent field experiments (e.g., international ACE-Asia and regional follow-on campaigns) are conducted to shed light on characterizing the compelling variability of dust aerosols in spatial and temporal scales, especially near the source and downwind regions. As a result of synergizing satellite, aircraft and surface observations, our understanding of the distributions and properties of airborne dust aerosols has advanced significantly. It is our goal/hope to continue combining observational and theoretical studies to investigate in-depth the changes of regional climate, hydrological budget, tropospheric chemistry, wind erosion, and dust properties in Asia. These regional changes (e.g., aerosol loading, cloud amount, precipitation rate) constitute a vital part of global change, and our success or failure in developing reliable predictions of, as well as adequate responses to, this change will determine the prospective course for sustainable civilization. Consequently, the lessons learned will help strengthen our ability to issue early warnings of Asian dust storms and minimize further desertification in the future.



Midweek increase in U.S. summer rain and storm heights suggests air pollution invigorates rainstorms

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[1] Tropical Rainfall Measuring Mission (TRMM) satellite estimates of summertime rainfall over the southeast U.S. are found on average to be significantly higher during the middle of the work week than on weekends, attributable to a midweek intensification of afternoon storms and an increase in area with detectable rain. TRMM radar data show a significant midweek increase in the echo-top heights reached by afternoon storms. Weekly variations in model-reanalysis wind patterns over the region are consistent with changes in convection implied by the satellite data. Weekly variations in rain gauge averages are also consistent with the satellite estimates, though possibly smaller in amplitude. A midweek decrease of rainfall over the nearby Atlantic is also seen. EPA measurements of surface particulate concentrations show a midweek peak over much of the U.S. These observations are consistent with the theory that anthropogenic air pollution suppresses cloud-drop coalescence and early rainout during the growth of thunderstorms over land, allowing more water to be carried above the 0°C isotherm, where freezing yields additional latent heat, invigorating the storms and producing large ice hydrometeors. The enhanced convection induces regional convergence, uplifting and an overall increase of rainfall. Compensating downward air motion suppresses convection over the adjacent ocean areas. Pre-TRMM-era data suggest that the weekly cycle only became strong enough to be detectable beginning in the 1980's. Rain-gauge data also suggest that a weekly cycle may have been detectable in the 1940's, but with peak rainfall on Sunday or Monday, possibly explained by the difference in composition of aerosol pollution at that time. This "weekend effect" may thus offer climate researchers an opportunity to study the regional climate-scale impact of aerosols on storm development and monsoon-like circulation.

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1. Introduction

[2] The effect of pollution on rainfall has been observed to depend both on the type of pollution and the precipitating environment [Rosenfeld, 1999, 2000; Phillips *et al.*, 2002; Jacobson and Kaufman, 2006]. Pollution aerosols have been documented to suppress precipitation from shallow

clouds (cloud heights below about the -10°C [Albrecht, 1989; Rosenfeld, 1999, 2000; Rosenfeld, 2002]. When polluted clouds develop to great heights, as often happens in the summertime, Rosenfeld suggested [Williams *et al.*, 2002; Andriantiatsaholainaina *et al.*, 2004] that suppressed rainout enables unprecipitated droplets to reach greater heights where they can release additional latent heat and further invigorate cloud updrafts. This might in turn delay the onset of precipitation and the development of downdrafts, prolong the growth of the convective cloud, allow water vapor to be ingested and further invigorate [Rosenfeld, 2006]. Some recent cloud simulation studies [Wang *et al.*, 2005], [Seifert and Beheng, 2005], [Wang *et al.*, 2005], and [Teller and Levin, 2006] suggest the possibility that in a moist, unstable atmosphere the effect prevails during the summer in the southeast

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Effects of doubled CO₂ on tropical sea surface temperatures (SSTs) for onset of deep convection and maximum SST: Simulations based inferences

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[1] A primary concern of CO₂-induced warming is the associated rise of tropical (10S-10N) sea-surface temperatures (SSTs). GISS Model-E was used to produce two sets of simulations—one with the present-day and one with doubled CO₂ in the atmosphere. The intrinsic usefulness of model guidance in the tropics was confirmed when the model simulated realistic convective coupling between SSTs and atmospheric soundings and that the simulated-data correlations between SSTs and 300 hPa moist-static energies were similar to the observed. Model predicted SST limits for (i) the onset of deep convection and (ii) maximum SST, increased in the doubled CO₂ environment. Changes in cloud heights, cloud frequencies, and cloud mass-fractions showed that convective-cloud changes increased the SSTs, while warmer mixed-layer of the doubled CO₂ contained ~10% more water vapor; clearly that would be conducive to more intense storms and hurricanes. **Citation:** Sud, Y. C., G. K. Walker, Y. P. Zhou, G. A. Schmidt, K.-M. Lau, and R. F. Cahalan (2008), Effects of doubled CO₂ on tropical sea surface temperatures (SSTs) for onset of deep convection and maximum SST: Simulations based inferences, *Geophys. Res. Lett.*, 35, L12707, doi:10.1029/2008GL033872.

1. Introduction

[2] Two features of present-day tropical SSTs are well-established. First, the highest observed SST does not exceed 30–31°C [e.g., Waliser and Graham, 1993] and second, towering cumulus clouds emerge suddenly at around 28°C SST [Gadgil *et al.*, 1984; Graham and Barnett, 1987; Zhang, 1993]. Some highly cited explanations for the upper limit of the SST are as follows. Newell [1979] suggested evaporative cooling that increases with the SST also limits it. Ramanathan and Collins [1991] suggested that clouds following onset of deep convection reduce the solar irradiation into the ocean to provide a thermostat-like control. Several scientists [e.g., Wallace, 1992; Fu *et al.*, 1992; Lau *et al.*, 1994; Clement *et al.*, 1996] argued that the R-C explanation was

simplistic and many other contributory processes ignored. Using the TOGA-COARE data, Sud *et al.* [1999] identified “downdraft cooling” to be the key missing of the thermostat regulation, as well as provided a basis for the onset of deep convection at 28°C.

[3] Singer and Avery [2006] referred to the [1999] and argued that tropical SSTs can not warm 30–31°C, even for doubled CO₂ (hereafter 2xCO₂) sphere. However, Sud *et al.* [1999] did not imply 28°C for the onset of deep convection and the 30°C limiting SST are rigid constraints. On the other hand, Sud *et al.* had argued that outside of tropics, deep convection occurs at temperatures far below 28°C. In their data Kleypas *et al.* [2008] found relatively small SST in the tropics and attributed it to cooling by thermostat to it as a “mysterious thermostat”. We submit, to evaluate these inferences without examining the key processes that influence tropical SSTs and above two SST limits adjust to a 2xCO₂ environment how dire can be its consequences. The coupling saturation moist static energy (SMSE) at convective level h_t ($h_t = c_p T + gz + Lq^*$, where standard for enthalpy $c_p T$, potential energy gz , and latent energy Lq^* are employed) and cloud base MSE h_b help to establish cloud-buoyancy energy that a cloud in ascent conserves for its reduction by entrainment/detrainment of ambient cloud air. In addition, such an analysis also identifies maximum attainable SSTs [Sud *et al.*, 1999]. In this paper we describe a) the model and simulations in Section 2, b) the key results with verification in Section 3, and c) a brief discussion of several final resulting consequences in Section 4.

2. GISS Model-E simulations

[4] GISS Model-E (GISS-E) was chosen for the investigation. It employs 4° lat. x 5° long. x 20-sig in the vertical. GISS-E [Schmidt *et al.*, 2006] includes interactive land, a multilayer ocean, and dynamical sphere with parameterized physics. Its current cloud is from Del Genio *et al.* [1996]. The code and forcing datasets can be downloaded from website: <http://www.giss.nasa.gov/tools/modelE>. It was run at GISS for 380-years till its land, ocean, and atmosphere attained quasi-equilibrium with pre-industrial CO₂. This was reconfirmed by running the mode

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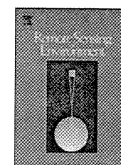
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Global characterization of biomass-burning patterns using satellite measurements of fire radiative energy

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ABSTRACT

Remote sensing is the most practical means of measuring energy release from large open-air biomass burning. Satellite measurement of fire radiative energy (FRE) release rate or power (FRP) enables distinction between fires of different strengths. Based on a 1-km resolution fire data acquired globally by the MODerate-resolution Imaging Spectro-radiometer (MODIS) sensor aboard the Terra and Aqua satellites from 2000 to 2006, instantaneous FRP values ranged between 0.02 MW and 1866 MW, with global daily means ranging between 20 and 40 MW. Regionally, at the Aqua-MODIS afternoon overpass, the mean FRP values for Alaska, Western US, Western Australia, Quebec and the rest of Canada are significantly higher than these global means, with Quebec having the overall highest value of 85 MW. Analysis of regional mean FRP per unit area of land (FRP flux) shows that at peak fire season in certain regions, fires can be responsible for up to 0.2 W/m² at peak time of day. Zambia has the highest regional monthly mean FRP flux of ~ 0.045 W/m² at peak time of day and season, while the Middle East has the lowest value of ~ 0.0005 W/m². A simple scheme based on FRP has been devised to classify fires into five categories, to facilitate fire rating by strength, similar to earthquakes and hurricanes. The scheme uses MODIS measurements of FRP at 1-km resolution as follows: category 1 (< 100 MW), category 2 (100 to < 500 MW), category 3 (500 to < 1000 MW), category 4 (1000 to < 1500 MW), category 5 (≥ 1500 MW). In most regions of the world, over 90% of fires fall into category 1, while only less than 1% fall into each of categories 3 to 5, although these proportions may differ significantly from day to day and by season. The frequency of occurrence of the larger fires is region specific, and could not be explained by ecosystem type alone. Time-series analysis of the proportions of higher category fires based on MODIS-measured FRP from 2002 to 2006 does not show any noticeable trend because of the short time period.

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1. Introduction

Fires burn extensive areas in different vegetated landscapes across the globe, and constitute a major disturbance to land-based ecosystems, such as forests and savannas. For instance, the total global burned area has been estimated at 3.5 million km² in year 2000 alone (Tansey et al., 2004), and 2.97–3.74 million km²/year in 2001–2004 (Giglio et al., 2006b). By voraciously consuming biomass, releasing intense heat energy, and emitting thick plumes of smoke into the atmosphere, such large-scale fires exert several adverse effects on life, property, the environment, weather, and climate both directly and indirectly.

Correct assessment of fire impacts requires accurate documentation of where and when the fires occur, their size and/or strength, the amount of biomass burned, and the quantity of particulate and

gaseous matter emitted in the smoke. Unlike most other physical objects and phenomena, because of the exothermic, aggressive, and erratic nature of large fires, their characteristics cannot be measured quantitatively in situ or even at close range. As such, alternative means of fire characterization includes judging its strength from measurements of the radiative component of its heat energy release, which can be sensed from a great distance.

Measures of Fire Radiative Energy (FRE) are currently being provided with specialized satellite-borne sensors, such as the MODerate-resolution Imaging Spectroradiometer (MODIS) aboard the Earth Observing System (EOS) Terra and Aqua polar-orbiting satellites (Kaufman et al., 1998) and the Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard the Meteosat-8 (formerly Meteosat Second Generation) geostationary satellite (Roberts et al., 2005). However, since every observation by these sensors lasts only an instant, what they actually measure is the rate of release of FRE per unit time (R_{fire}) or Fire Radiative Power (FRP) in MW (Kaufman et al., 1998; Wooster et al., 2003; Giglio et al., 2006a). A number of recent studies using small experimental fires have demonstrated that the total FRE

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REPORTS

Table 1. Atomic positions and occupations from GIXRD analysis. Au1 to Au6 are the Au atoms in the first Au surface layer, a1 and a2 are the Au adatoms, and m1 and m2 are the S atoms.

	Occupancy (± 0.05)	x/a	y/b (± 0.008)	z/c
Au1	0	—	—	—
Au2	1	−0.011	0.624	−0.045
Au3	1	−0.010	0.283	−0.025
Au4	0.6 (± 0.1)	0.493	0.985	−0.022
Au5	1	0.527	0.697	+0.025
Au6	1	0.530	0.351	+0.033
a1	0.6 (± 0.1)	0.678	0.610	0.294
a2	0.6 (± 0.1)	—	a1 − b/2	—
m1	—	0.113	0.193	0.265
m2	—	0.523	0.396	0.365

As a consequence of these findings, studies regarding the formation, growth, diffusion, and mechanical properties of these films may need to be revisited in order to properly account for the influence of Au-S interactions and the presence of the RS-Au-SR structural motifs. From a theoretical perspective, this gives paramount importance

to the development of empirical potential models that include not only molecule-molecule interactions but explicitly the Au-SR interactions, which are often neglected. In addition, our findings indicate that the adatom structures will alter the local density of states at the Fermi energy (I_8) and will affect the interpretation of electronic and magnetic properties of these materials.

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Smoke Invigoration Versus Inhibition of Clouds over the Amazon

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The effect of anthropogenic aerosols on clouds is one of the most important and least understood aspects of human-induced climate change. Small changes in the amount of cloud coverage can produce a climate forcing equivalent in magnitude and opposite in sign to that caused by anthropogenic greenhouse gases, and changes in cloud height can shift the effect of clouds from cooling to warming. Focusing on the Amazon, we show a smooth transition between two opposing effects of aerosols on clouds: the microphysical and the radiative. We show how a feedback between the optical properties of aerosols and the cloud fraction can modify the aerosol forcing, changing the total radiative energy and redistributing it over the atmospheric column.

The effect of aerosols on clouds and precipitation contributes the largest uncertainty to the estimation of the anthropogenic contribution to climate change. There are two main pathways by which aerosols can change cloud properties: microphysical and radiative processes (1, 2). Changes in aerosol particle concentration produce changes in the size distribution of the cloud droplets (because aerosols function as cloud condensation nuclei) and therefore affect condensation and evaporation rates, latent heat release, collision coalescence efficiency, and related cloud properties such as reflectance, lifetime, phase, size, and precipitation (3–5).

Additionally, the absorption of aerosols can change the atmospheric stability profile by heating the aerosol layer and cooling the layers below. This may stabilize shallow layers and reduce their relative humidity, suppress moisture and heat fluxes from the surface, and suppress shallow cloud formation inside or below the aerosol layer (6, 7), while destabilizing the profile above the aerosol layer.

The microphysical and the radiative pathways of interaction initiate many feedbacks that add complexity to the system and have different sensitivities to the aerosol loading. Clouds are sensitive to the initial concentration and size distribution of the potential cloud condensation nuclei (CCN). For a given aerosol type (size distribution and chemistry), clouds have a logarithmic sensitivity to the amount of potential CCN (8–10). Small changes in the aerosol loading in clean environments (a low CCN concentration of ~100

CCN/cm³) will potentially change the cloud properties (fraction, optical depth, and droplet size distribution) much more than similar changes when the cloud is polluted (a CCN concentration of ~1000 CCN/cm³) and the effect approaches saturation. In contrast, the absorption of electromagnetic energy (mostly in the visible and near-infrared range) by aerosols has a completely different sensitivity to aerosol loading. The overall absorption of energy increases steadily with the aerosol loading, and the increasing rate depends on the diurnal cycle of solar flux (geometry), aerosol optical properties, surface albedo, and the depths of the aerosol layer (11).

In this paper, we develop a theoretical basis that ties together the two pathways and explores the relationships of cloud amount and vertical development to aerosol optical thickness (τ), a proxy for CCN and for the potential to absorb solar energy. We find a smooth transition between these two pathways in an observational data set obtained over the Amazon.

The (aerosol) absorption (cloud) fraction feedback (AFF) can be described as follows: Aerosol absorption of solar radiation heats the aerosol layer and cools the surface, stabilizing the temperature profile and reducing relative humidity and surface moisture fluxes (evapotranspiration). This effect reduces cloudiness. Reduced cloud coverage exposes greater areas of the aerosol layer to direct fluxes from the Sun and therefore produces more intense heating of the aerosol layer, further reducing cloudiness. This positive feedback will be balanced once the extra heating of the surface raises the surface temperature sufficiently to destabilize the profile again and to transfer the humidity concentrated

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A simple model for the cloud adjacency effect and the apparent bluing of aerosols near clouds

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[1] In determining aerosol-cloud interactions, the properties of aerosols must be characterized in the vicinity of clouds. Numerous studies based on satellite observations have reported that aerosol optical depths increase with increasing cloud cover. Part of the increase comes from the humidification and consequent growth of aerosol particles in the moist cloud environment, but part comes from 3-D cloud-radiative transfer effects on the retrieved aerosol properties. Often, discerning whether the observed increases in aerosol optical depths are artifacts or real proves difficult. The paper only addresses the cloud-clear sky radiative transfer interaction part. It provides a simple model that quantifies the enhanced illumination of cloud-free columns in the vicinity of clouds that are used in the aerosol retrievals. This model is based on the assumption that the enhancement in the cloud-free column radiance comes from enhanced Rayleigh scattering that results from the presence of the nearby clouds. This assumption leads to a larger increase of AOT for shorter wavelengths, or to a “bluing” of aerosols near clouds. The assumption that contribution from molecular scattering dominates over aerosol scattering and surface reflection is justified for the case of shorter wavelengths, dark surfaces, and an aerosol layer below the cloud tops. The enhancement in Rayleigh scattering is estimated using a stochastic cloud model to obtain the radiative flux reflected by broken clouds and comparing this flux with that obtained with the molecules in the atmosphere causing extinction, but no scattering.

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1. Introduction

[2] Numerous studies based on satellite observations have reported a positive correlation between cloud amount and aerosol optical thickness (AOT) [e.g., *Sekiguchi et al.*, 2003; *Loeb and Manalo-Smith*, 2005; *Ignatov et al.*, 2005; *Zhang et al.*, 2005; *Kaufman et al.*, 2005a; *Matheson et al.*, 2005]. Recently, *Koren et al.* [2007], using MODIS data, showed that the average reflectance for cloud-free ocean scenes far away from clouds were up to 30% lower than those near cloud edges. The higher reflectances lead to higher AOTs retrieved in the vicinity of clouds. This positive correlation can be explained as a result of physical phenomena such as the humidification of aerosols in the relatively moist cloud environment or a transition between aerosol and clouds where the cloud signature is weak

(evaporation and/or activation of cloud drops) and the distinction between cloudy and cloud-free air becomes problematic. The term “twilight zone” was coined by *Koren et al.* [2007] to describe the regions around clouds which are neither precisely cloud-free nor precisely cloudy. On the other hand, part of the correlation can result from remote sensing artifacts such as cloud contamination of the cloud-free fields of view used in the aerosol retrievals. *Kaufman and Koren* [2006] noted that any “satellite analysis may be affected by potential cloud artifacts.”

[3] There are two ways that clouds affect the retrievals of aerosols: (1) the existence of small amounts of subpixel sized clouds in pixels identified as being cloud-free and (2) an enhancement in the illumination of the cloud-free column through the reflection of sunlight by nearby clouds. When the pixels are relatively large (e.g., TOMS ~ 40 km, OMI ~ 15 km), only the first type (unresolved variability), cloud contamination is considered [e.g., *Torres et al.*, 2002; *Sinyuk et al.*, 2003]. The second type (resolved variability), also called the “cloud adjacency effect,” is more pronounced when satellite pixels are relatively small (e.g., MODIS and MISR ~ 0.5 km). *Kobayashi et al.* [2000], *Cahalan et al.* [2001], *Podgorny* [2003], *Wen et al.* [2001, 2006, 2007], and *Nikolaeva et al.* [2005] studied the cloud adjacency effect when cloud-free pixels are brightened (or shadowed) by

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Radiative susceptibility of cloudy atmospheres to droplet number perturbations:

1. Theoretical analysis and examples from MODIS

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[1] Theoretical and satellite-based assessments of the sensitivity of broadband shortwave radiative fluxes in cloudy atmospheres to small perturbations in the cloud droplet number concentration (N) of liquid water clouds under constant water conditions are performed. Two approaches to study this sensitivity are adopted: absolute increases in N , for which the radiative response is referred to as “absolute cloud susceptibility,” and relative increases in N or “relative cloud susceptibility.” Estimating the former is more challenging as it requires an assumed value for either cloud liquid water content or geometrical thickness; both susceptibilities require an assumed relationship between the droplet volume and effective radius. Expanding upon previous susceptibility studies, present radiative calculations include the effect of ΔN perturbations on droplet asymmetry parameter and single-scattering albedo, in addition to extinction. Absolute cloud susceptibility has a strong nonlinear dependence on the droplet effective radius as expected, while relative cloud susceptibility is primarily dependent on optical thickness. Molecular absorption and reflecting surfaces both reduce the relative contribution of the cloud to the top-of-atmosphere (TOA) flux and therefore also reduce the TOA albedo susceptibility. Transmittance susceptibilities are negative with absolute values similar to albedo susceptibility, while atmospheric absorptance susceptibilities are about an order of magnitude smaller than albedo susceptibilities and can be either positive or negative. Observation-based susceptibility calculations are derived from MODIS pixel-level retrievals of liquid water cloud optical thickness, effective radius, and cloud top temperature; two data granule examples are shown. Susceptibility quantifies the aerosol indirect effect sensitivity in a way that can be easily computed from model fields. As such, susceptibilities derived from MODIS observations provide a higher-order test of model cloud properties used for indirect effect studies. MODIS-derived global distributions of cloud susceptibility and radiative forcing calculations are presented in a companion paper.

Citation: Platnick, S., and L. Oreopoulos (2008), Radiative susceptibility of cloudy atmospheres to droplet number perturbations: 1. Theoretical analysis and examples from MODIS, *J. Geophys. Res.*, **113**, D14S20, doi:10.1029/2007JD009654.

1. Introduction

[2] The global aerosol burden has substantially increased since the beginning of the industrialized era [*Intergovernmental Panel on Climate Change*, 2007]. Aerosol particles affect solar radiation by direct scattering and absorption, but can also change cloud properties through the subset of particles that act as cloud condensation nuclei (CCN) and ice nuclei (IN), a pathway referred to as the “indirect aerosol effect” (IAE). While the IAE is a continuum of effects and consequences, it is often considered the manifestation of two

primarily different aerosol-cloud interaction mechanisms. One mechanism is the radiative effect due to cloud microphysical changes only (no change in cloud water or other properties). Here, the greater availability of CCN or IN yields clouds with more numerous but smaller cloud particles and therefore larger optical thicknesses (commonly referred to as the “Twomey effect” [Twomey, 1974] or 1st IAE). A second mechanism encompasses the effect of aerosols on cloud water, e.g., a decrease in cloud particle size decreasing precipitation efficiency and thereby increasing cloud lifetime, fraction [Albrecht, 1989], and/or physical thickness [Pincus and Baker, 1994]. This 2nd IAE can modify both cloud radiative and macrophysical properties. Clearly, the two mechanisms are coupled, but the separate partitioning is useful in understanding the relative role of each process for different cloud types and scenarios. Other microphysical consequences have been invoked for

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Radiative susceptibility of cloudy atmospheres to droplet number perturbations:

2. Global analysis from MODIS

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[1] Global distributions of albedo susceptibility for areas covered by liquid clouds are presented for 4 months in 2005. The susceptibility estimates are based on expanded definitions presented in a companion paper and include relative cloud droplet number concentration (CDNC) changes, perturbations in cloud droplet asymmetry parameter and single-scattering albedo, atmospheric/surface effects, and incorporation of the full solar spectrum. The cloud properties (optical thickness and effective radius) used as input in the susceptibility calculations come from MODIS Terra and Aqua Collection 5 gridded data. Geographical distributions of susceptibility corresponding to absolute (“absolute cloud susceptibility”) and relative (“relative cloud susceptibility”) CDNC changes are markedly different indicating that the detailed nature of the cloud microphysical perturbation is important for determining the radiative forcing associated with the first indirect aerosol effect. However, both types of susceptibility exhibit common characteristics such as significant reductions when perturbations in single-scattering properties are omitted, significant increases when atmospheric absorption and surface albedo effects are ignored, and the tendency to decrease with latitude, to be higher over ocean than over land, and to be statistically similar between the morning and afternoon MODIS overpasses. The satellite-based susceptibility analysis helps elucidate the role of present-day cloud and land surface properties in indirect aerosol forcing responses. Our realistic yet moderate CDNC perturbations yield forcings on the order of $1\text{--}2\text{ W m}^{-2}$ for cloud optical property distributions and land surface spectral albedos observed by MODIS. Since susceptibilities can potentially be computed from model fields, these results have practical application in assessing the reasonableness of model-generated estimates of the aerosol indirect radiative forcing.

Citation: Oreopoulos, L., and S. Platnick (2008), Radiative susceptibility of cloudy atmospheres to droplet number perturbations: 2. Global analysis from MODIS, *J. Geophys. Res.*, *113*, D14S21, doi:10.1029/2007JD009655.

1. Introduction

[2] Studies investigating the modification of cloud microphysical and optical properties by anthropogenic aerosol, commonly referred to as the Indirect Aerosol Effect (IAE) have become more numerous in recent years, in no small part because of the availability of new ground-based observational systems like the Aerosol Robotic Network (AERONET) [Holben *et al.*, 1998], as well as the development of models that attempt to account for aerosol sources and transport [e.g., Chin *et al.*, 2007]. Satellite observations have also been used to study the IAE [e.g., Bréon *et al.*, 2002; Coakley and Walsh, 2002; Sekiguchi *et al.*, 2003; Kaufman *et al.*, 2005; Koren *et al.*, 2005]. However, there are many chal-

lenges in isolating cloud changes due to aerosol effects alone, while all relevant dynamic/thermodynamic quantities remain fixed. These challenges include the need to identify and then quantify the background (premodified) state of the cloud, the relationship between column aerosol optical thickness and CCN concentrations at cloud level, and cloud-dependent dynamic/thermodynamic changes that correlate with changes in aerosol amounts. Rather than confronting the formidable task of assessing the partial derivative of cloud properties in a particular place and time, we have adopted an alternative approach where satellite retrievals are used to estimate the radiative response or sensitivity to some specified change in cloud droplet number concentration (CDNC) under constant liquid water content and water path conditions. While these CDNC perturbations can be due to a variety of underlying causes, our intention is to contribute to the understanding of the 1st IAE or “Twomey effect” (the albedo increase of constant liquid water path clouds as they become optically thicker because of more numerous, but smaller, droplets). In essence, our method is therefore an attempt to quantify the

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Retrievals of Thick Cloud Optical Depth from the Geoscience Laser Altimeter System (GLAS) by Calibration of Solar Background Signal

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ABSTRACT

Laser beams emitted from the Geoscience Laser Altimeter System (GLAS), as well as other spaceborne laser instruments, can only penetrate clouds to a limit of a few optical depths. As a result, only optical depths of thinner clouds (< 3 for GLAS) are retrieved from the reflected lidar signal. This paper presents a comprehensive study of possible retrievals of optical depth of thick clouds using solar background light and treating GLAS as a solar radiometer. To do so one must first calibrate the reflected solar radiation received by the photon-counting detectors of the GLAS 532-nm channel, the primary channel for atmospheric products. Solar background radiation is regarded as a noise to be subtracted in the retrieval process of the lidar products. However, once calibrated, it becomes a signal that can be used in studying the properties of optically thick clouds. In this paper, three calibration methods are presented: (i) calibration with coincident airborne and GLAS observations, (ii) calibration with coincident Geostationary Operational Environmental Satellite (GOES) and GLAS observations of deep convective clouds, and (iii) calibration from first principles using optical depth of thin water clouds over ocean retrieved by GLAS active remote sensing. Results from the three methods agree well with each other. Cloud optical depth (COD) is retrieved from the calibrated solar background signal using a one-channel retrieval. Comparison with COD retrieved from GOES during GLAS overpasses shows that the average difference between the two retrievals is 24%. As an example, the COD values retrieved from GLAS solar background are illustrated for a marine stratocumulus cloud field that is too thick to be penetrated by the GLAS laser. Based on this study, optical depths for thick clouds will be provided as a supplementary product to the existing operational GLAS cloud products in future GLAS data releases.

1. Introduction

The Geoscience Laser Altimeter System (GLAS) was launched on board the Ice, Cloud, and Land Elevation Satellite (ICESat) in January 2003 as part of the NASA Earth Observing System project (Spinhirne et al. 2005a). GLAS observes the earth at two wavelengths: the 532-nm channel, which uses photon-counting detectors, and the 1064-nm channel, which uses analog detection. More sensitive to atmospheric

signals, the 532-nm channel is used as the primary channel for atmospheric products (Palm et al. 2002). Since its launch, GLAS has been providing data that contribute significantly to studying cloud and aerosol properties (e.g., Hart et al. 2005; Hlavka et al. 2005; Spinhirne et al. 2005b). However, the retrieved optical depths are limited to the relatively thin clouds that can be penetrated by the laser beam (< 3).

Prior to the lidar retrieval process, the reflected solar energy has to be subtracted as noise from the signals received by the photon detectors. However, Platt et al. (1998, 2006) suggested that, if calibrated, the solar background can be viewed as a signal and used to retrieve cloud optical depths of dense clouds, thus com-

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A satellite-based assessment of transpacific transport of pollution aerosol

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[1] It has been well documented that pollution and dust from east Asia can be transported across the North Pacific basin, reaching North America and beyond. In this study, we assess the transpacific transport of “pollution aerosol” (defined as a mixture of aerosols from urban/industrial pollution and biomass burning) by taking advantage of the much improved measurement accuracy and enhanced new capabilities of satellite sensors in recent years. A 4-year (2002 to 2005) climatology of optical depth for pollution aerosol was generated from Moderate Resolution Imaging Spectroradiometer (MODIS) observations of fine- and coarse-mode aerosol optical depths. The pollution aerosol mass loading and fluxes were then calculated using measurements of the dependence of aerosol mass extinction efficiency on relative humidity and of aerosol vertical distributions from field campaigns and available satellite observations in the region. We estimated that about 18 Tg/a pollution aerosol is exported from east Asia to the northwestern Pacific Ocean, of which about 25% reaches the west coast of North America. The imported flux of 4.4 Tg/a to North America is equivalent to about 15% of local emissions from the United States and Canada. The pollution fluxes are largest in spring and smallest in summer. For the period we have examined the strongest export and import of pollution particulates occurred in 2003, largely because of record intense Eurasia boreal forest fires in spring and summer. The overall uncertainty of pollution fluxes is estimated at a factor of 2. Simulations by the Goddard Chemistry Aerosol Radiation and Transport (GOCART) and Global Modeling Initiative (GMI) models agree quite well with the satellite-based estimates of annual and latitude-integrated fluxes, with larger model-satellite differences in latitudinal and seasonal variations of fluxes.

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1. Introduction

1.1. Asian Pollution and Intercontinental Transport

[2] East Asia is an important source region of a variety of natural and anthropogenic aerosols, also called particulate matter (PM). China, the world's most populous country has been undergoing persistent rapid industrialization and urbanization and the burgeoning expansion of automobile usage over the last two decades. As a result, China has more than doubled its emissions in recent decades to quickly become one of the largest emitters of aerosols and aerosol precursors in the world [Bond *et al.*, 2004; Richter *et al.*, 2005; Wang *et al.*, 2006; Akimoto *et al.*, 2006]. The large emissions of aerosols in east Asia may have brought about substantial impacts to climate [Huang *et al.*, 2006], hydro-

logical cycle [Menon *et al.*, 2002], solar radiation reaching the surface [Qian *et al.*, 2007], crop yields [Chameides *et al.*, 1999], and human health [Xu *et al.*, 1998] in the region.

[3] The east Asian aerosols could also impose far-reaching environmental impacts at continental, hemispherical and even global scales, because of long-range transport. East Asia is one of the main warm conveyor belts (WCB) inflow regions, where airstreams rapidly transport the atmospheric boundary layer (ABL) air into the upper troposphere (UT) [Stohl, 2001; Eckhardt *et al.*, 2004]. The ABL pollution can also be lifted to the UT by frontal and postfrontal convection, orographic lifting, and the ABL turbulent mixing. As a result, emissions from Asia can experience rapid vertical transport [Stohl *et al.*, 2002]. Pollutants lifted to the free troposphere travel initially poleward and eastward by midlatitude storm tracks, turn toward the equator thereafter, and then reach mainly the middle and upper troposphere of the northeastern Pacific. Such high-level transpacific transport takes about a week [Holzer *et al.*, 2005]. The polluted Asian air over the northeastern Pacific can then be transported downward to influence the North American ABL through subsidence associated with subtropical Pacific highs

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613.3 Highlighted Articles

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

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[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

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The influence of European pollution on ozone in the Near East and northern Africa

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Abstract. We present a modeling study of the long-range transport of pollution from Europe, showing that European emissions regularly elevate surface ozone by as much as 20 ppbv in summer in northern Africa and the Near East. European emissions cause 50–150 additional violations per year (i.e. above those that would occur without European pollution) of the European health standard for ozone (8-h average $>120 \mu\text{g}/\text{m}^3$ or ~ 60 ppbv) in northern Africa and the Near East. We estimate that European ozone pollution is responsible for 50 000 premature mortalities globally each year, of which the majority occurs outside of Europe itself, including 37% (19 000) in northern Africa and the Near East. Much of the pollution from Europe is exported southward at low altitudes in summer to the Mediterranean Sea, northern Africa and the Near East, regions with favorable photochemical environments for ozone production. Our results suggest that assessments of the human health benefits of reducing ozone precursor emissions in Europe should include effects outside of Europe, and that comprehensive planning to improve air quality in northern Africa and the Near East likely needs to address European emissions.

1 Introduction

Ozone has been associated with increased risk of premature mortality in a large number of epidemiological daily time-series studies (Levy et al., 2001, 2005; Thurston and Ito, 2001; Anderson et al., 2004; Bell et al., 2004, 2005, 2006;

Gryparis et al., 2004; Ito et al., 2005). The adverse health effects of exposure to high ozone have been known for some time (Kleinfield et al., 1957; Challen et al., 1958). The highest ambient concentrations are found in areas near urban/industrial centers and biomass burning activities where short-lived maxima are often observed that can be harmful to human health (e.g. Young et al., 1964; Hallet, 1965; Stockinger, 1965). Consequently, many industrialized nations have adopted ozone control strategies with the intent to keep ambient ozone below levels considered unhealthy to humans. For example, the current European standard is $120 \mu\text{g}/\text{m}^3$ (~ 60 ppbv) taken as an 8-h average.

The long-range transport of ozone and its precursor compounds allows pollution from one region to impact air quality in regions thousands of kilometers downwind. Recent research has focused on the intercontinental transport of ozone and its precursors between the industrialized regions of eastern Asia, North America, and Europe (e.g. Auvray and Bey, 2005; Berntsen et al., 1999; Collins et al., 2000; Fiore et al., 2002a; Jacob et al., 1999; Jaffe et al., 1999; Prather et al., 2003; Stohl et al., 2003; Trickl et al., 2003; Wild et al., 2004). Several modeling studies have shown that pollution from one region can directly elevate the ozone in another, where the contribution of inter-continental transport is generally less than about 10% of the total ozone (e.g. Auvray and Bey, 2005). However, Li et al. (2002) attributed 20% of the violations of the European ozone standard during summer 1997 to North American sources.

European pollution has a much greater direct impact on air quality in downwind populated regions than pollution from either North America or eastern Asia as it is largely exported near the surface over land to the Arctic and Russia in winter and to northern Africa and the Middle East in summer (e.g.



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Short- and medium-term atmospheric constituent effects of very large solar proton events

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Abstract. Solar eruptions sometimes produce protons, which impact the Earth's atmosphere. These solar proton events (SPEs) generally last a few days and produce high energy particles that precipitate into the Earth's atmosphere. The protons cause ionization and dissociation processes that ultimately lead to an enhancement of odd-hydrogen and odd-nitrogen in the polar cap regions ($>60^\circ$ geomagnetic latitude). We have used the Whole Atmosphere Community Climate Model (WACCM3) to study the atmospheric impact of SPEs over the period 1963–2005. The very largest SPEs were found to be the most important and caused atmospheric effects that lasted several months after the events. We present the short- and medium-term (days to a few months) atmospheric influence of the four largest SPEs in the past 45 years (August 1972; October 1989; July 2000; and October–November 2003) as computed by WACCM3 and observed by satellite instruments. Polar mesospheric NO_x ($\text{NO}+\text{NO}_2$) increased by over 50 ppbv and mesospheric ozone decreased by over 30% during these very large SPEs. Changes in HNO_3 , N_2O_5 , ClONO_2 , HOCl , and ClO were indirectly caused by the very large SPEs in October–November 2003, were simulated by WACCM3, and previously measured by Envisat Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). WACCM3 output was also represented by sampling with the MIPAS averaging kernel for a more valid comparison. Although qualitatively similar, there are discrepancies between the model and measurement with WACCM3 predicted HNO_3 and ClONO_2 enhancements being smaller than measured and N_2O_5 enhancements being larger than measured. The HOCl enhancements were fairly

similar in amounts and temporal variation in WACCM3 and MIPAS. WACCM3 simulated ClO decreases below 50 km, whereas MIPAS mainly observed increases, a very perplexing difference. Upper stratospheric and lower mesospheric NO_x increased by over 10 ppbv and was transported during polar night down to the middle stratosphere in several weeks past the SPE. The WACCM3 simulations confirmed the SH HALOE observations of enhanced NO_x in September 2000 as a result of the July 2000 SPE and the NH SAGE II observations of enhanced NO_2 in March 1990 as a result of the October 1989 SPEs.

1 Introduction

The Earth's atmosphere is occasionally bombarded by a large flux of protons during solar proton events (SPEs). Although relatively infrequent, some of the especially large SPEs have been documented to have a substantial influence on chemical constituents in the polar middle atmosphere, especially HO_x , NO_y , and ozone (e.g. Weeks et al., 1972; Heath et al., 1977; Reagan et al., 1981; McPeters et al., 1981; Thomas et al., 1983; McPeters and Jackman, 1985; McPeters, 1986; Jackman and McPeters, 1987; Zadorozhny et al., 1992; Jackman et al., 1995, 2001, 2005a; Randall et al., 2001; Seppala et al., 2004, 2006; López-Puertas et al., 2005a, b; von Clarmann et al., 2005; Orsolini et al., 2005; Degenstein et al., 2005; Rohen et al., 2005; Verronen et al., 2006). The influx of solar protons during large events, which are more frequent near solar maximum, can strongly perturb the chemical composition of the polar middle atmosphere via ionization, dissociation, dissociative ionization, and excitation processes.

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Validation of SO₂ retrievals from the Ozone Monitoring Instrument over NE China

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[1] The Dutch-Finnish Ozone Monitoring Instrument (OMI) launched on the NASA Aura satellite in July 2004 offers unprecedented spatial resolution, coupled with contiguous daily global coverage, for space-based UV measurements of sulfur dioxide (SO₂). We present a first validation of the OMI SO₂ data with in situ aircraft measurements in NE China in April 2005. The study demonstrates that OMI can distinguish between background SO₂ conditions and heavy pollution on a daily basis. The noise (expressed as the standard deviation, σ) is ~ 1.5 DU (Dobson units; $1 \text{ DU} = 2.69 \cdot 10^{16} \text{ molecules/cm}^2$) for instantaneous field of view boundary layer (PBL) SO₂ data. Temporal and spatial averaging can reduce the noise to $\sigma \sim 0.3$ DU over a remote region of the South Pacific; the long-term average over this remote location was within 0.1 DU of zero. Under polluted conditions collection 2 OMI data are higher than aircraft measurements by a factor of two. Improved calibrations of the radiance and irradiance data (collection 3) result in better agreement with aircraft measurements on polluted days. The air mass–corrected collection 3 data still show positive bias and sensitivity to UV absorbing aerosols. The difference between the in situ data and the OMI SO₂ measurements within 30 km of the aircraft profiles was about 1 DU, equivalent to ~ 5 ppb from 0 to 3000 m altitude. Quantifying the SO₂ and aerosol profiles and spectral dependence of aerosol absorption between 310 and 330 nm are critical for an accurate estimate of SO₂ from satellite UV measurements.

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1. Introduction

[2] Sulfur dioxide (SO₂) is a short-lived gas, produced primarily by volcanoes, power plants, refineries, metal smelting and burning of fossil and biofuels. It can be a noxious pollutant or a major player in global climate forcing, depending on altitude. Most fossil fuel burning occurs near the surface where SO₂ is released into the planetary boundary layer (PBL). When SO₂ remains near the Earth's surface, it has detrimental health and acidifying

effects but exerts little impact on global climate or radiative forcing. Emitted SO₂ is soon converted to sulfate aerosol by reaction with OH in air or by reaction with H₂O₂ in aqueous solutions (clouds) [Seinfeld and Pandis, 1998; Chin *et al.*, 2000]. The mean lifetime varies from ~ 1 –2 days or less near the surface to more than a month in the stratosphere [e.g., Krueger *et al.*, 2000; Benkovitz *et al.*, 2004]. The resulting sulfate aerosol, which can be transported distantly in the free troposphere, can have climate effects, including direct radiative forcing and aerosol-induced changes in cloud microphysics. The concentration and lifetime of SO₂, 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 [e.g., Dickerson *et al.*, 2007].

[3] Emission inventories indicate that the largest increases in tropospheric SO₂ emissions have occurred in Asia during the last 20 years [Streets and Waldhoff, 2000; Streets *et al.*, 2003; Larssen *et al.*, 2006; Ohara *et al.*, 2007]. These increased emissions resulted in a positive winter trend (17% per decade) in sulfate aerosol loading over Asia between 1979 and 2000 detected by the NASA Total Ozone Mapping Spectrometer (TOMS) instrument [Massie *et al.*, 2004]. The TOMS aerosol trend is consistent with a pronounced regional increase in aerosol optical

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The governing processes and timescales of stratosphere-to-troposphere transport and its contribution to ozone in the Arctic troposphere

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Abstract. We used the seasonality of a combination of atmospheric trace gases and idealized tracers to examine stratosphere-to-troposphere transport and its influence on tropospheric composition in the Arctic. Maximum stratosphere-to-troposphere transport of CFCs and O₃ occurs in April as driven by the Brewer-Dobson circulation. Stratosphere-troposphere exchange (STE) occurs predominantly between 40° N to 80° N with stratospheric influx in the mid-latitudes (30–70° N) accounting for 67–81% of the air of stratospheric origin in the Northern Hemisphere extratropical troposphere. Transport from the lower stratosphere to the lower troposphere (LT) takes three months on average, one month to cross the tropopause, the second month to travel from the upper troposphere (UT) to the middle troposphere (MT), and the third month to reach the LT. During downward transport, the seasonality of a trace gas can be greatly impacted by wet removal and chemistry. A comparison of idealized tracers with varying lifetimes suggests that when initialized with the same concentrations and seasonal cycles at the tropopause, trace gases that have shorter lifetimes display lower concentrations, smaller amplitudes, and earlier seasonal maxima during transport to the LT. STE contributes to O₃ in the Arctic troposphere directly from the transport of O₃ and indirectly from the transport of NO_y. Direct transport of O₃ from the stratosphere accounts for 78% of O₃ in the Arctic UT with maximum contributions occurring from March to May. The stratospheric contribu-

tion decreases significantly in the MT/LT (20–25% of total O₃) and shows a very weak March–April maximum. Our NO_x budget analysis in the Arctic UT shows that during spring and summer, the stratospheric injection of NO_y-rich air increases NO_x concentrations above the 20 pptv threshold level, thereby shifting the Arctic UT from a regime of net photochemical ozone loss to one of net production with rates as high as +16 ppbv/month.

1 Introduction

Ozone (O₃) plays a vital role in the oxidation capacity of the troposphere and it is an important greenhouse gas, particularly in the upper troposphere (UT). An increase in tropospheric ozone was responsible for one-third (0.4–0.5°C) of the observed warming trend between 1890–1990 in the Arctic during winter and spring (Shindell et al., 2006). The origin, trends, and distribution of ozone in the Arctic have important implications for both air quality and climate change.

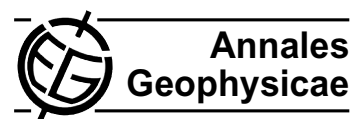
Ozone measurements in the Arctic troposphere show a clear annual cycle with a maximum in spring (Penkett and Brice, 1986; Oltmans and Levy, 1994; Simmonds et al., 1997; Logan et al., 1999). The origin of the spring ozone maximum in the Northern Hemisphere (NH) is still not well-understood (Monks, 2000), despite the extensive observational and modeling efforts in the last few decades to quantify the relative contribution of the stratosphere-to-troposphere transport (STT) of ozone, in situ photochemical production and destruction of tropospheric ozone. This springtime maximum has been attributed to both maximum stratospheric flux



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Stratospheric semi-decadal oscillations in NCEP data

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Abstract. An analysis of the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) data is presented to provide a more complete description of the stratospheric 5-year semi-decadal (SD) oscillation (Mayr et al., 2007). The zonal-mean temperature and zonal wind data from the Atmospheric Research R-1 analysis are employed, covering the years from 1962 to 2002 in the altitude range from 10 to 30 km. For diagnostic purposes, the data are separated into the hemispherically symmetric and anti-symmetric components, and spectral analysis is applied to identify the signatures of the SD oscillations. Through the synthesis or filtering of spectral features, the SD modulations of the annual oscillation (AO) and quasi-biennial oscillation (QBO) are delineated. In agreement with the earlier findings, the magnitude of the SD oscillation is more pronounced when the 30-month QBO dominates during the years from 1975 to 1995. This is consistent with results from a numerical model, which shows that such a QBO generates the SD oscillation through interaction with the 12-month AO. In the zonal winds, the SD oscillation in the NCEP data is confined to equatorial latitudes, where it modulates the symmetric AO and QBO by about 5 m/s below 30 km. In the temperature data, the effect is also seen around the equator, but it is much larger at polar latitudes where the SD oscillation produces variations as large as 2 K. Our data analysis indicates that the SD oscillation is mainly hemispherically symmetric, and it appears to originate at equatorial latitudes where most of the energy resides.

Keywords. Meteorology and atmospheric dynamics (Climatology; Middle atmosphere dynamics; Waves and tides)

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1 Introduction

The equatorial region of the middle atmosphere is controlled to a large extent by wave mean flow interactions that involve the mean zonal circulation. It was demonstrated by Lindzen and Holton (1968), Holton and Lindzen (1972) and others (e.g. Plumb, 1977; Dunkerton, 1985) that the stratospheric quasi-biennial oscillation (QBO), discovered by Reed (1965) and discussed by Pascoe et al. (2005) and Baldwin et al. (2001), can be generated with eastward propagating Kelvin waves and westward propagating Rossby gravity waves. The theory of Lindzen and Holton was applied by Dunkerton (1979) and Hamilton (1986) to simulate also the semi-annual oscillation (SAO) of the zonal circulation, which dominates in the upper stratosphere and lower mesosphere at around 50 km (Hirota, 1980). While it is generally accepted that wave mean flow interactions are required to generate the above equatorial oscillations, more recent modeling studies have shown that small-scale gravity waves (GW) are also likely involved (e.g. Hitchman and Leovy, 1988; Mengel et al., 1995; Takahashi, 1999; Hamilton et al., 2001; Giorgetta et al., 2002). That GWs are of central importance for the dynamics of the upper mesosphere had earlier been recognized by Lindzen (1981) and Dunkerton (1982).

In their seminal theory for the QBO, Lindzen and Holton (1968) emphasized that wave interactions are very effective in generating flow oscillations at equatorial latitudes. Since the Coriolis force vanishes at low latitudes (at the equator exactly), the meridional winds are barely involved in redistributing the flow momentum, and the wave source is balanced mainly by viscous dissipation. Away from the equator, the meridional circulation increasingly comes into play to dissipate and redistribute the zonal flow momentum. As a result, the QBO zonal winds peak at the equator, as observed, even in models that apply a latitude independent wave source (e.g. Mengel et al., 1995); and Haynes (1998) provided a detailed discussion of the process involved.

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HIRDLS observations and simulation of a lower stratospheric intrusion of tropical air to high latitudes

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[1] On 26 January 2006, the High Resolution Dynamic Limb Sounder (HIRDLS) observed low mixing ratios of ozone and nitric acid in a ~ 2 km layer near 100 hPa extending from the subtropics to 55°N over North America. The subsequent evolution of the layer is simulated with the Global Modeling Initiative model and substantiated with HIRDLS observations. Air with low mixing ratios of ozone is transported poleward to 80°N. Although there is evidence of mixing with extratropical air, much of the tropical intrusion returns to the subtropics. This study demonstrates that HIRDLS and the GMI model resolve thin intrusion events. The observations combined with simulation are a first step towards development of a quantitative understanding of the lower stratospheric ozone budget. **Citation:** Olsen, M. A., A. R. Douglass, P. A. Newman, J. C. Gille, B. Nardi, V. A. Yudin, D. E. Kinnison, and R. Khosravi (2008), HIRDLS observations and simulation of a lower stratospheric intrusion of tropical air to high latitudes, *Geophys. Res. Lett.*, 35, L21813, doi:10.1029/2008GL035514.

1. Introduction

[2] Rapid isentropic poleward transport of air with young stratospheric “age” and tropical composition has been inferred from time- and spatially-averaged satellite observations of the lower stratosphere. *Trepte et al.* [1993] demonstrated quasi-isentropic, poleward mixing of air just above the tropical tropopause with observations of aerosols from the eruption of Pinatubo. Easterly winds are a barrier to wave-driven transport and thus the Northern Hemisphere meridional transport in the first months following the eruption was confined to altitudes just above the tropical tropopause. *Randel et al.* [2001] used Halogen Occultation Experiment (HALOE) water vapor data to show fast transport between the tropics and midlatitudes in the lower stratosphere between ~ 380 – 420 K isentropic surfaces. Evidence of similar transport is also found in observations of radioactive isotopes [e.g., *Feely and Spar*, 1960] and CO₂ [e.g., *Boering et al.*, 1995]. Theoretical studies have shown wave driven isentropic mixing between the tropics and extratropical lower stratosphere [e.g., *Waugh*, 1996]. These mixing events occur frequently in thin layers. *Newman and*

Schoeberl [1995] examined aircraft data from the Stratosphere Troposphere Exchange Project (STEP) and showed that differential advection by Rossby waves can generate vertically thin ozone laminae in the lower stratosphere.

[3] Previous satellite observations have lacked the sensitivity, vertical resolution, and/or horizontal coverage to sufficiently resolve lower stratospheric laminar events. An observational synoptic view throughout the lifetime of an intrusion event has not been possible. Accordingly, synoptic scale validations of intrusion event simulations have been inadequate. The combination of high vertical resolution (~ 1 km), lower stratospheric sensitivity, and horizontal coverage of the High Resolution Dynamic Limb Sounder (HIRDLS) on NASA's Aura satellite provides the opportunity for unprecedented observations following these isentropic, quasi-horizontal transport events. Here we examine a January 2006 Northern Hemisphere poleward intrusion of low ozone air in a layer between 400 K and 420 K potential temperature simulated by the Global Modeling Initiative (GMI) chemistry and transport model (CTM) driven by meteorological analyses. HIRDLS made observations of the event for more than eleven days and we show that the event is represented well by the simulation. The evolution of the event is examined using both the simulation and HIRDLS data. This combined analysis of observations and simulation demonstrates the potential to quantify the relative contributions by processes that determine the lower stratospheric ozone budget.

2. Data and Model Description

2.1. HIRDLS

[4] HIRDLS is one of the instruments on NASA's Aura, which was launched 15 July 2004 [*Gille et al.*, 2008]. HIRDLS makes limb measurements of temperature, aerosols and constituents including ozone from the UTLS to the mesosphere with improved vertical resolution compared to prior space-based observations. We use the latest v004 Level-2 HIRDLS observations of ozone and nitric acid. The vertical resolution is ~ 1 km and profiles are spaced ~ 65 km along the track of about fifteen polar, sun-synchronous orbits per day.

[5] HIRDLS measurements of temperature, ozone, and nitric acid have been validated with sondes, lidar, satellite observations, and assimilated data [*Gille et al.*, 2008; *Nardi et al.*, 2008; *Kinnison et al.*, 2008]. HIRDLS ozone is biased high at lower altitudes compared with correlative observations, particularly below 50 hPa (100 hPa) at low (mid to high) latitudes. HIRDLS temperatures are ~ 1 K warm compared to ECMWF analyses from 10–100 hPa. Reduction of these biases is expected in future versions of the

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Goddard Earth Observing System chemistry-climate model simulations of stratospheric ozone-temperature coupling between 1950 and 2005

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[1] Links between the stratospheric thermal structure and the ozone distribution are explored in the Goddard Earth Observing System chemistry-climate model (CCM). Ozone and temperature fields are validated using estimates based on observations. An experimental strategy is used to explore sensitivities of temperature and ozone using the CCM alongside the underlying general circulation model (GCM) with ozone specified from either observations or from a chemistry-transport model (CTM), which uses the same chemical modules as the CCM. In the CTM, upper stratospheric ozone is biased low compared to observations; GCM experiments reveal that using CTM ozone reduces a warm temperature bias near the stratopause in the GCM, and this improvement is also seen in the CCM. Near 5 hPa, the global-mean ozone profile is biased low in the CTM but is close to observations in the CCM, which suggests that the temperature feedbacks are important in simulating the ozone distribution in the middle stratosphere. In the low stratosphere there is a high bias in simulated ozone, which forces a warm bias in the CCM. The high ozone also leads to an overestimate in total column ozone of several tens of Dobson units in the polar regions. In the late part of the twentieth century the seasonal activation of chlorine, especially over Antarctica, destroys ozone as expected, so that chlorine-induced ozone decreases are overestimated in the CCM compared to the real atmosphere. Ozone-change experiments reveal that the thermal structures of the GCM and CCM respond in a similar manner to ozone differences between 1980 and 2000, with a peak ozone-induced temperature change of about 1.5 K (over 20 years) near the stratopause, which is at the low end of the range computed by other models. Greenhouse-gas-induced cooling increases with altitude and, near the stratopause, contributes an additional 1.3 K to the cooling near 1 hPa between 1980 and 2000. In the Antarctic, the ozone hole is simulated with some success by the CCM. As with many other models, the polar vortex is too persistent in late winter, but counteracting this, the CCM undergoes too much midwinter variability, meaning the ozone hole is more variable than it is in the real atmosphere. Temperature decreases associated with the ozone hole in the CCM are similar to those computed with other models.

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1. Introduction

[2] Interactions among different physical and chemical processes in the stratosphere motivate development of coupled models of ozone chemistry and circulation (chemistry-climate models, CCMs) and their application to numerous questions of relevance to the environment. This study presents Version 1 of the Goddard Earth Observing System (GEOS) CCM and demonstrates some of its strengths and weaknesses as a tool for studies of stratospheric ozone and climate, whose interactions are important but complex.

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A new technique for retrieval of tropospheric and stratospheric ozone profiles using sky radiance measurements at multiple view angles: Application to a Brewer spectrometer

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[1] This paper describes and applies a new technique for retrieving diurnal variability in tropospheric ozone vertical distribution using ground-based measurements of ultraviolet sky radiances. The measured radiances are obtained by a polarization-insensitive modified Brewer double spectrometer located at Goddard Space Flight Center, in Greenbelt, Maryland, USA. Results demonstrate that the Brewer angular (0–72° viewing zenith angle) and spectral (303–320 nm) measurements of sky radiance in the solar principal plane provide sufficient information to derive tropospheric ozone diurnal variability. In addition, the Brewer measurements provide stratospheric ozone vertical distributions at least twice per day near sunrise and sunset. Frequent measurements of total column ozone amounts from direct-sun observations are used as constraints in the retrieval. The vertical ozone profile resolution is shown in terms of averaging kernels to yield at least four points in the troposphere–low stratosphere, including good information in Umkehr layer 0 (0–5 km). The focus of this paper is on the derivation of stratospheric and tropospheric ozone profiles using both simulated and measured radiances. We briefly discuss the necessary modifications of the Brewer spectrometer that were used to eliminate instrumental polarization sensitivity so that accurate sky radiances can be obtained in the presence of strong Rayleigh scattering and aerosols. The results demonstrate that including a site-specific and time-dependent aerosol correction, based on Brewer direct-sun observations of aerosol optical thickness, is critical to minimize the sky radiance residuals as a function of observing angle in the optimal estimation inversion algorithm and improve the accuracy of the retrieved ozone profile.

Citation: Tzortziou, M., N. A. Krotkov, A. Cede, J. R. Herman, and A. Vasilkov (2008), A new technique for retrieval of tropospheric and stratospheric ozone profiles using sky radiance measurements at multiple view angles: Application to a Brewer spectrometer, *J. Geophys. Res.*, 113, D06304, doi:10.1029/2007JD009093.

1. Introduction

[2] Ozone (O₃) is a critical atmospheric constituent that is involved in the photochemistry of both the troposphere and stratosphere and in shielding the Earth's surface from Ultraviolet-B (UV-B) radiation (280–320 nm). In addition to regulating the oxidation capacity of the lower atmosphere and influencing background levels of trace chemicals, O₃ is an important greenhouse gas, affecting radiative balance and global climate. Ozone absorption in the UV-B region of

the solar spectrum affects many photochemical and biological processes. Variations in O₃ concentration affect the amount and spectral properties of surface UV radiation with far-reaching consequences for both terrestrial and aquatic ecosystems [e.g., *Diffey*, 1991; *Tevini*, 1993]. Increased ground-level O₃ concentrations are toxic upon inhalation or contact, posing serious threats to agricultural productivity and human health. The vertical distribution of O₃ in the troposphere typically shows strong seasonal and diurnal variability, especially in polluted urban areas where there is often more tropospheric O₃ in the afternoon as photochemical smog builds up [*Taubman et al.*, 2006]. Thus, frequent (e.g., hourly) measurements of tropospheric O₃ concentrations and vertical distribution are essential for determining short timescale changes in O₃ amounts close to the ground, and quantifying the role of tropospheric O₃ on local and regional environmental degradation, tropospheric chemistry, surface UV-B levels, human health and radiative forcing.

[3] Two main techniques have been available for measuring tropospheric O₃ at high vertical resolution: (1) in situ sensing from balloon sondes and aircraft [e.g., *Thompson et*

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Evaluation of the OMI cloud pressures derived from rotational Raman scattering by comparisons with other satellite data and radiative transfer simulations

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[1] In this paper we examine differences between cloud pressures retrieved from the Ozone Monitoring Instrument (OMI) using the ultraviolet rotational Raman scattering (RRS) algorithm and those from the thermal infrared (IR) Aqua/MODIS. Several cloud data sets are currently being used in OMI trace gas retrieval algorithms including climatologies based on IR measurements and simultaneous cloud parameters derived from OMI. From a validation perspective, it is important to understand the OMI retrieved cloud parameters and how they differ with those derived from the IR. To this end, we perform radiative transfer calculations to simulate the effects of different geophysical conditions on the OMI RRS cloud pressure retrievals. We also quantify errors related to the use of the Mixed Lambert-Equivalent Reflectivity (MLER) concept as currently implemented of the OMI algorithms. Using properties from the Cloudsat radar and MODIS, we show that radiative transfer calculations support the following: (1) The MLER model is adequate for single-layer optically thick, geometrically thin clouds, but can produce significant errors in estimated cloud pressure for optically thin clouds. (2) In a two-layer cloud, the RRS algorithm may retrieve a cloud pressure that is either between the two cloud decks or even beneath the top of the lower cloud deck because of scattering between the cloud layers; the retrieved pressure depends upon the viewing geometry and the optical depth of the upper cloud deck. (3) Absorbing aerosol in and above a cloud can produce significant errors in the retrieved cloud pressure. (4) The retrieved RRS effective pressure for a deep convective cloud will be significantly higher than the physical cloud top pressure derived with thermal IR.

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1. Introduction

[2] The Aura Ozone Monitoring Instrument (OMI), alone and in combination with other Aura instruments, has been used to retrieve tropospheric amounts of the U.S. Environmental Protection Agency (EPA) criteria pollutants ozone (O₃) (and ozone precursor formaldehyde, HCHO), NO₂, SO₂, and aerosol at higher spatial resolution than any previous instrument. The full-width half-maximum (FWHM) pixel edges are 14 and 24 km in the along- and across-track directions, respectively, at nadir and 30 by 160 km at the

swath edge. More details on the OMI instrument are given by Levelt *et al.* [2006].

[3] Clouds affect every algorithm used to derive information about trace gases and aerosol from OMI. Clouds may be considered a nuisance for some remote sensing applications. However, in the visible (VIS) and ultraviolet (UV), their effects can be accounted for to first order with relatively simple models. Therefore, information about trace gases can be accurately retrieved in their presence.

[4] Cloud pressures are retrieved from the Ozone Monitoring Instrument (OMI) using either atmospheric rotational Raman scattering (RRS) in the UV [Joiner *et al.*, 2004] or oxygen dimer (O₂-O₂) absorption near 477 nm in the VIS channel [Acarreta *et al.*, 2004]. The RRS algorithm uses a fitting window of 346–354 nm in the UV-2 channel that has an average spectral sampling distance of 0.15 nm and a FWHM slit width of 0.45 nm. Both OMI cloud algorithms are based on the fact that clouds screen the atmosphere below from satellite observations [e.g., Joiner and Bhartia, 1995]. Therefore, clouds in general reduce the amount of RRS and absorption seen by satellite-borne instruments.

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The Quasi-biennial Oscillation and annual variations in tropical ozone from SHADOZ and HALOE

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Abstract. We examine the tropical ozone mixing ratio perturbation fields generated from a monthly ozone climatology using 1998 to 2006 ozonesonde data from the Southern Hemisphere Additional Ozonesondes (SHADOZ) network and the 13-year satellite record from 1993 to 2005 obtained from the Halogen Occultation Experiment (HALOE). The long time series and high vertical resolution of the ozone and temperature profiles from the SHADOZ sondes coupled with good tropical coverage north and south of the equator gives a detailed picture of the ozone structure in the lowermost stratosphere down through the tropopause where the picture obtained from HALOE measurements is blurred by coarse vertical resolution. Ozone perturbations respond to annual variations in the Brewer-Dobson Circulation (BDC) in the region just above the cold-point tropopause to around 20 km. Annual cycles in ozone and temperature are well correlated. Above 20 km, ozone and temperature perturbations are dominated by the Quasi-biennial Oscillation (QBO). Both satellite and sonde records show good agreement between positive and negative ozone mixing ratio anomalies and alternating QBO westerly and easterly wind shears from the Singapore rawinsondes with a mean periodicity of 26 months for SHADOZ and 25 months for HALOE. There is a temporal offset of one to three months with the QBO wind shear ahead of the ozone anomaly field. The meridional length scales for the annual cycle and the QBO, obtained using the temperature anomalies and wind shears in the thermal wind equation, compare well with theoretical calculations.

1 Introduction

One of the principal sources of interannual variability of the ozone distribution in the tropical mid-stratosphere is the quasi-biennial oscillation of the zonal wind (QBO). The QBO is characterized by downward propagation of alternating westerly and easterly wind regimes with a period varying from 20 months to 30 months (Reed et al., 1961). The QBO arises from the interaction of vertically propagating equatorial waves acting on the zonal mean flow (e.g., Baldwin et al., 2001 and references therein). The effect of the QBO can be seen on trace gases and temperature, both of which vary with the phase of the wind shear.

The Brewer-Dobson Circulation (BDC) also influences the tropical stratospheric circulation. The BDC is characterized by rising motion in the tropics from the troposphere into the stratosphere with poleward transport and descending motion in the stratosphere at middle and polar latitudes (Brewer, 1949; Dobson, 1956). Significant topographic differences between the northern and southern hemisphere change the wave activity and hence the strength of the BDC. These differences are apparent in the distribution of trace gases such as ozone (Fusco and Salby, 1999). The BDC varies annually and is stronger during northern hemisphere winter due to higher stratospheric wave activity.

We use the SHADOZ temperature profiles to develop a high vertical resolution tropical temperature perturbation time series. Using the temperature perturbations we can use the tropical thermal wind equation to compute the meridional length scales of the QBO and BDC, following the theoretical model of Plumb and Eluszkiewicz (1999).



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