



# Laboratory for Atmospheres

## 2009 Technical Highlights



## Cover Photo Captions:

**Top:** SMART-COMMIT mobile laboratories on deployment in Zhangye, China during 2008 Asian Monsoon Year Field Campaign. Also pictured is the “soon to be ACHIEVE'd” radar facility. (<http://smartlabs.gsfc.nasa.gov>)

*The following images are from the JAMEX/TIGERZ/RAJO-MEGHA 2009 campaign in Nepal and India (see section 4.3.1).*

**Background:** Aqua-MODIS RGB image of Indian Sub-Continent from April 25th 2009. The yellow star marks the Langtang site, with other sites nearby.

**Middle Left:** Langtang instrumentation looking over early morning haze layer.

**Bottom Left:** NASA and Duke University scientists showing handheld sun-photometers to Nepalese scientists at Tribuvan University.

**Bottom Center:** NASA and Duke University scientists installing a sun-photometer at Kathmandu University in Nepal

**Bottom Right:** NASA scientist explaining the details of the UV-wavelength lidar system during operations at Kathmandu University in Nepal.



**NASA/TM—2010–215851**



**Laboratory for Atmospheres  
2009 Technical Highlights**

National Aeronautics and  
Space Administration

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

---

**June 2010**

## The NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at <http://www.sti.nasa.gov/STI-homepage.html>
- E-mail your question via the Internet to [help@sti.nasa.gov](mailto:help@sti.nasa.gov)
- Fax your question to the NASA Access Help Desk at (443) 757-5803
- Telephone the NASA Access Help Desk at (443) 757-5802
- Write to:  
NASA Access Help Desk  
NASA Center for AeroSpace Information  
7115 Standard Drive  
Hanover, MD 21076

Available from:

NASA Center for AeroSpace Information  
7115 Standard Drive  
Hanover, MD 21076-1320  
Price Code: A17

National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22161

National Aeronautics and  
Space Administration

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



Dear Reader:

Welcome to the Laboratory for Atmospheres' 2009 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 2009.

The Laboratory's approximately 250 scientists, technologists, and administrative personnel are part of the Earth Sciences Division in the Sciences and Exploration Directorate of the NASA's Goddard Space Flight Center. The Mission of the Laboratory for Atmospheres is to advance knowledge and understanding of the Earth's atmosphere.

Satellite missions, retrieval algorithm development, field campaigns, and related modeling and data analyses, as well as long-term dataset development are important components of the Lab's science activities. These activities are helping us to 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 2009.

Many laboratory scientists participated in the 2009 Joint Aerosol-Monsoon Experiment (JAMEX)/Tigerz/Rajo-Megha Deployment in Nepal and India. Our scientists, working with local scientists, made measurements and collected data on the heavy loadings of dust, smoke, and industrial aerosols observed over the Indo-Gangetic Plain south of the Himalayan mountain range to study the possible influence of aerosol on the Indian Monsoon.

Laboratory scientists also played a critical role in the WAVES 2009 campaign that took place this past winter at the Howard University Research Campus in Beltsville, Maryland. The goals of WAVES were 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).

Scientists also supported the Measurements of Humidity and Validation Experiments (MOHAVE) at the Jet Propulsion Laboratory, Table Mountain Facility (TMF) in Wrightwood, CA. Raman lidars were used successfully to probe upper tropospheric and lower stratospheric water vapor.

Scientists also provided major support to preparations for the 2010 Global Hawk Pacific Experiment (GloPac) mission which will carry 10 science instruments that will sample the chemical composition of air in Earth's stratosphere and troposphere, and observe cloud and particle distributions in the troposphere. The Global Hawk is a unique unmanned aircraft system (UAS) that can fly more than 30 hours, reach altitudes of 65,000 feet, has a range of 11,000 nautical miles (12,659 miles), and can carry payloads greater than 1,500 pounds.

In September, 2009, the TWiLiTE (Tropospheric Wind Lidar Technology Experiment) Doppler lidar completed successful integration and engineering flight testing on the NASA ER-2 high altitude aircraft. These and other campaigns are described in detail in Sections 4 and 5 of this report.

As in previous years, Laboratory scientists garnered many top professional honors. NASA honor awards were received by Anne Douglass, Dave Starr, Jim Irons, Matt McGill, the OMI Instrument Team, Group Achievement Award and the ARCTAS Field Campaign Team Award. GSFC honor awards were received by Richard Stolarski, Jose Rodriguez, and Nickolay Krotkov. Other awards were received by laboratory members from external organizations and societies. Notable among these were: William Lau has been selected Distinguished Alumni of the University of Hong Kong and was appointed a member of the World Climate Research Organization, Global Water and Energy Experiment (GEWEX) Science Steering Group; Robert F. Cahalan was elected a Fellow of the American Meteorological Society; Ralph Kahn was selected by the American Geophysical Union (AGU) to receive the first Yoram J. Kaufman Unselfish Cooperation in Research Awards along with Ross Salawitch (University of Maryland, College Park); Paul Newman received the 2009 Ozone Layer Protection Award from the U.S. Environmental Protection Agency, and Dr. George J. Huffman (SSAI) received the AMS Journal of Hydrometeorology Editor's Award for 2009.

The year 2009 was also a time to bid farewell to retirees Jay Herman and Tom Bell who had 43 and 31 years of service, respectively. Jay has joined the JCET program at UMBC and Tom has joined their Emeritus program. Their research activities will continue even after retirement. Jay will work on PANDORA instruments development and satellite UV and climate data analysis; Tom will carry out research to determine how the climate is changed by aerosols, both natural and man-made.

I am pleased to welcome Gail Jackson, Bob Meneghini, and Luke Oman to our Laboratory's civil servant staff. Gail is the newly appointed Deputy Project Scientist for the GPM mission. Bob Meneghini is a developer of radar algorithms for TRMM and GPM, and Luke is one of our new young scientists who will study the coupling between gas phase chemistry, aerosols, and climate. 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 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: <http://atmospheres.gsfc.nasa.gov>.



Chief, Laboratory for Atmospheres, Code 613

May 2010



## TABLE OF CONTENTS

<b>1. INTRODUCTION</b>	<b>9</b>
<b>2. STAFF, ORGANIZATION, AND FACILITIES</b>	<b>11</b>
2.1 Staff.....	11
2.2 Organization.....	12
2.3 Branch Descriptions.....	12
2.4 Facilities.....	14
<b>3. OUR RESEARCH AND ITS PLACE IN NASA'S MISSION</b>	<b>15</b>
<b>4. MAJOR ACTIVITIES</b>	<b>17</b>
4.1 NASA Missions .....	17
4.2 Measurements.....	28
4.3 Field Campaigns.....	28
4.4 Data Sets .....	32
4.5 Data Analysis .....	39
4.6 Modeling .....	41
4.7 Project Scientists.....	45
4.8 Interactions with Scientific Organizations .....	46
4.9 Commercialization and Technology Transfer .....	49
<b>5. HIGHLIGHTS OF LABORATORY ACTIVITIES</b>	<b>51</b>
5.1 Mesoscale Atmospheric Processes Branch, Code 613.1.....	51
5.2 Climate and Radiation Branch, Code 613.2 .....	54
5.3 Atmospheric Chemistry and Dynamics Branch, Code 613.3. ....	58
5.4 Additional Research Highlights .....	59
5.5 Instrument Development and Testing.....	66
5.6 Awards and Special Recognition.....	67
5.7 External Awards and Recognition.....	68

<b>6. EDUCATION, OUTREACH, AND EXTERNAL COLLABORATION</b>	<b>71</b>
6.1 Introduction.....	71
6.2 Education .....	71
6.3 Summer Programs .....	75
6.4 University Education .....	81
6.5 NASA Postdoctoral Program.....	83
6.6 The Academic Community.....	84
6.7 Open Lecture Series .....	85
6.8 Public Outreach .....	86
<b>ACRONYMS</b>	<b>93</b>
<b>APPENDIX 1: THE LABORATORY IN THE NEWS</b>	<b>103</b>
<b>APPENDIX 2. REFEREED ARTICLES</b>	<b>135</b>
<b>APPENDIX 3. HIGHLIGHTED ARTICLES PUBLISHED IN 2009</b>	<b>147</b>

## PREFACE

The 2009 Report is the 15th issue of the Laboratory Annual Technical Highlights and it continues an ongoing record of scientific accomplishments in Atmospheric Science at Goddard. Due to a pending reorganization this may be the last issue under the Laboratory's current title; it remains to be seen if highlights under another title will be published. Over the years the Laboratory highlights grew from a 5–10 page informal brochure into formal reports with over 100 pages. The issues from 1996 to 2009 are filed on the Laboratory Web site (<http://atmospheres.gsfc.nasa.gov/>) and are the product of the efforts of all the members of the Laboratory throughout the years. 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 which are highlighted in the reports.

This years report was similarly the product of the efforts of all the members of the Laboratory. Production 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. Members of the administrative staff of the Laboratory: Erin Lee, Lynn Shupp, Cathy Newman, Pat Lubert, and Mariellen Pemberton are recognized for helping to gather material for the report and for soliciting the contributions of Lab members. Judith Clark of the Technical Information and Management Services Branch (Code 271), performed the final editing, formatting, and typesetting to turn 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 and the other issues are 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





## 1. INTRODUCTION

The Laboratory for Atmospheres (Code 613) is part of the Earth Sciences Division (Code 610) under the Sciences and Exploration Directorate (Code 600) based at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The Laboratory executes comprehensive research and a 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; 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 sensor calibration and data 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 2009. 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 collocated resource analysts, with a total staff of 250 members. The civil service composition of the laboratory consists of 47 members; 46 scientists and 1 administrative assistant.

An integral part of the Laboratory staff is composed of on-site research associates and contractors. The research associates are primarily members of joint centers involving the Earth Sciences Division and nearby university associations, e.g., the Joint Center for Earth Systems Technology (JCET), the Goddard Earth Sciences and Technology Center (GEST), and the Earth System Science Interdisciplinary Center (ESSIC), or are employed by universities with which the Laboratory has a collaborative relationship, such as George Mason University, University of Arizona, and Georgia Tech. Of the 85 research associates, 92% hold PhDs. The on-site contractors are a very important component of the staffing of the Laboratory. Out of the total of 100 on-site contractors, 25% hold PhDs. In addition to these members, the Laboratory currently hosts 10 Research Fellows and 5 Emeritus Scientists. All hold PhDs. There are also 4 Intern students. The makeup of our Laboratory, therefore, is 19% civil servants, 34% research associates, 40% contractors and 3% Research Fellows, Emeritus Scientists and interns account for 4%.

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 coauthored with outside scientists and

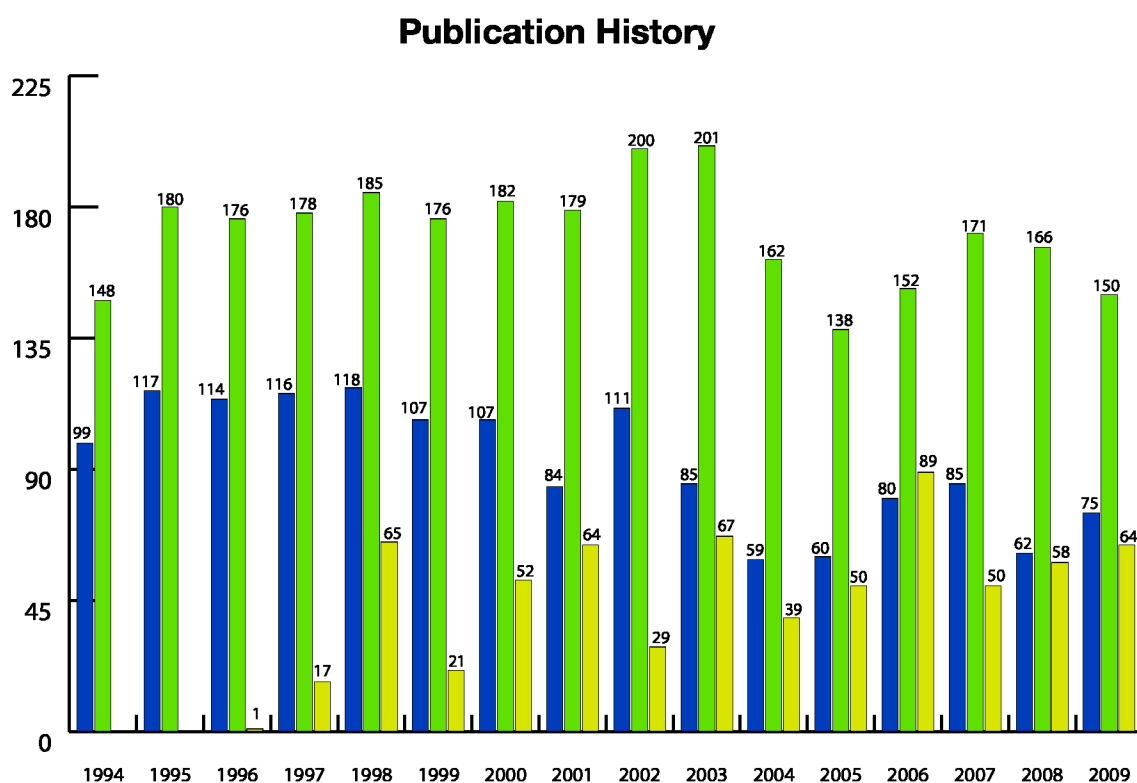


Figure 2.1: Number of proposals and refereed publications by Laboratory for Atmospheres members over the years. The green bar is the total number of publications and the blue bar is the number of publications where a Laboratory member is first author. Proposals submitted are shown in yellow.

## STAFF, ORGANIZATION, AND FACILITIES

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.

### 2.2. Organization

The management and branch structure for the Laboratory for Atmospheres at the end of 2009 is shown in Figure 2.2.

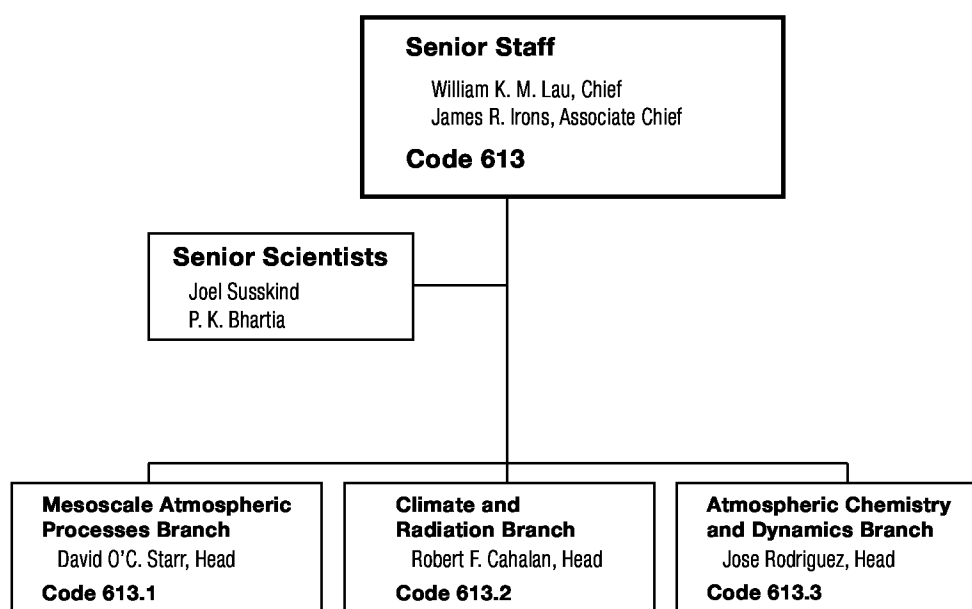


Figure 2.2: Laboratory for Atmospheres management and branch structure.

### 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.

A mission description and Web site address is given below for each of the Laboratory's three Branches. Branch Web sites may also be found by clicking on the Branch icons at the Laboratory's home page <http://atmospheres.gsfc.nasa.gov/>.

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 I through III, respectively.



## Employment Mix

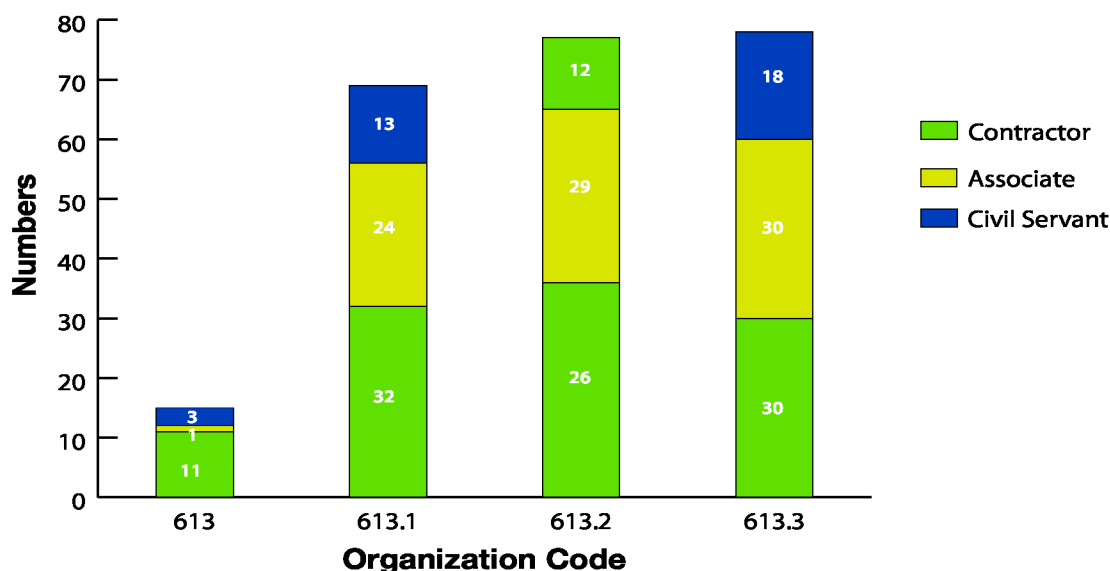


Figure 2.3: Employment composition of the members of the Laboratory for Atmospheres.

### Mesoscale Atmospheric Processes Branch, Code 613.1

The mission of the 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. Further information about Branch activities may be found on the Web at <http://atmospheres.gsfc.nasa.gov/meso/>.

### Climate and Radiation Branch, Code 613.2

The Climate and Radiation Branch has a threefold mission:

- 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;
- To assess the impacts of climate variability and change on society; and
- To consider strategies for adapting to, and mitigating climate variability and change.

Further information about Branch activities may be found at <http://climate.gsfc.nasa.gov/>.

### Atmospheric Chemistry and Dynamics Branch, Code 613.3

The principal mission of the Atmospheric Chemistry and Dynamics Branch is to understand the behavior of stratospheric ozone and trace gases that influence ozone. Ozone and trace gases—such as methane, nitrous oxide, and the chlorofluorocarbons—profoundly influence the habitability of the Earth even though together they comprise less than one percent of the Earth's atmosphere. Ozone itself absorbs nearly all the biologically damaging solar ultraviolet radiation before it reaches the Earth's surface. The Clean Air Act of 1977 assigns the responsibility for studying the ozone layer to NASA. The Atmospheric Chemistry and Dynamics Branch is the center for ozone and related atmospheric research at the Goddard Space Flight Center. Further information on Branch activities may be found on the Web <http://atmospheres.gsfc.nasa.gov/acd/>.

## 2.4. Facilities

---

### Computing Capabilities

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

### Lidar

The Laboratory has well-equipped facilities to develop lidar systems for airborne and ground-based measurements of clouds, aerosols, methane, ozone, water vapor, pressure, temperature, and winds. Lasers capable of generating radiation from 266 nm to beyond 1,000 nm are available, as is a range of sensitive photon detectors for use throughout this wavelength region. Details may be found in the Laboratory for *Atmospheres Instrument Systems Report*, NASA/TP-2005-212783, which is also available on the Laboratory's home page.

### Radiometric Calibration and Development Facility

The Radiometric Calibration and Development Facility (RCDF) supports the calibration and development of instruments for ground- and space-based observations for atmospheric composition including gases and aerosols. As part of the Earth Observatory System (EOS) calibration program, the RCDF provides calibrations for all national and international ultraviolet and visible (UV/VIS) spaceborne solar backscatter instruments. For further information contact Scott Janz, [Scott.J.Janz@nasa.gov](mailto:Scott.J.Janz@nasa.gov).

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

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

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

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. In addition, the Laboratory is also conducting feasibility studies, improving remote sensing measurement design and technology in preparation for the planned decadal mission 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>).

**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 Variability and Prediction
Climate Forecasting	Mesoscale Processes
	Precipitation Systems
	Severe Weather
	Chemistry-Climate Modeling
	Global and Regional Climate Modeling
	Data Assimilation
	Tropospheric Winds
	Solar Variability

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

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 <sup>a</sup> cloud and aerosol	Atmospheric hydrologic cycle	Coupled climate-ocean
Ground	OMI <sup>b</sup> 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	Ozone and trace gases	Radiative transfer
	Column	Radiation	Transport models
	Measurements	UV-B <sup>e</sup> measurements	Weather and climate
	TOVS <sup>c</sup> Pathfinder	Validation studies	
	TRMM <sup>d</sup> global precipitation products		
	TRMM validation products		

<sup>a</sup>Moderate Resolution Imaging Spectroradiometer

<sup>d</sup>Tropical Rainfall Measuring Mission

<sup>b</sup>Ozone Monitoring Instrument

<sup>e</sup>Ultraviolet-B

<sup>c</sup>TIROS Operational Vertical Sounder

The four major classification areas—measurements, data sets, data analysis, and modeling—are somewhat artificial because the activities are strongly interlinked, and cut across science priorities and the organizational structure of the Laboratory. The grouping corresponds to the natural processes of carrying out scientific research: ask the scientific question, identify the variable needed to answer it, conceive the best instrument to measure the variable, generate data sets, analyze the data, model the data, and ask the next question.



## 4. MAJOR ACTIVITIES

### 4.1. NASA Missions

---

#### 4.1.1. Decadal Study Missions

##### 4.1.1.1 ACE

The Aerosols, Clouds, and Ecology (ACE) mission is a mission recommended by the *National Research Council (NRC) Decadal Survey for Earth Sciences*. The plan is to fly one or two satellites in sun-synchronous polar orbit to provide high-resolution global measurements of aerosols, clouds, and ocean ecology (ocean color). In particular, the mission will provide major new measurement capabilities to enable dramatic steps forward in understanding the direct radiative role of aerosols in global climate change; the indirect effects via aerosol interactions with clouds and precipitation, and cloud processes; and to observe key properties of marine ecosystems and ocean carbon pools not presently available from existing sensors. The mission will take strong advantage of the potential synergy between advanced aerosol measurements and next-generation ocean color measurements where atmospheric correction, mostly for aerosol effects, is critically important to the quality of the ecology measurements.

ACE is a Tier-2 mission. The present nominal plan is to launch a platform in 2017 to fly in formation with the European Space Agency (ESA) EarthCare mission (nominal 2015 launch) in sun-synchronous polar orbit at ~400 km altitude, followed by a second platform at ~450 km to be launched in 2019. The ACE-1 platform would have its altitude raised at that time and fly in close formation with ACE-2. In this scenario, ACE-1 will carry the ocean ecology sensor. A international partner, e.g., ESA or CNES, will be sought to provide a polarimeter for aerosols measurements on ACE-1. EarthCare includes a 3-channel, high-spectral-resolution lidar (HSRL) and a w-band radar, both nadir pointing. ACE-2 would carry a 7-channel HSRL and a dual w-band and ka-band radar, also nadir pointing, as well as an advanced polarimeter for aerosol and cloud measurements. Radiometers sensing in the infrared, microwave, and sub-millimeter spectral regions are also included in the optimal mission concept.

Funding has been provided by NASA's Headquarters to Goddard Space Flight Center, Langley Research Center (LaRC), and Jet Propulsion Center (JPL) to develop mission and instrument concepts, the focused scientific questions and measurement requirements for this mission, as well as cost estimates. GSFC Laboratory for Atmospheres' David Starr assumed the role of ACE Science Study Lead toward the end of 2009. Lorraine Remer leads the "Aerosols" Study Group (SG). Ralph Kahn, Peter Colarco, Santiago Gasso/GEST and Robert Levy/SSAI participate in the Aerosol SG. Judd Welton and Matt McGill participate in the "Lidar" SG as well as the Aerosol SG. Vanderlei Martins/JCET contributes in the "Polarimeter" SG as well as the Aerosol SG. Gerry Heymsfield, Lihua Li (555) and Paul Racette (555) are engaged in the "Radar" SG. Steve Platnick, EOS Project Scientist, and David Starr participate in the Cloud SG. Chuck McClain/614 leads the Ocean Ecology SG.

In addition to very active participation and leadership by Goddard and the other NASA centers, there is strong university participation in the various ACE Study Groups. Aerosols and clouds are major factors in modulating global climate change. ACE seeks to provide the necessary measurement capabilities to enable robust investigation of these factors in global change over next decade, especially with regards to

## MAJOR ACTIVITIES

characterizing the processes that are occurring, and will provide the next generation of global data sets on ocean ecosystems. A report on the ACE mission plans will be completed in the coming year. For further information, contact David.Starr@NASA.gov.

### 4.1.1.2 GEO-CAPE

The Geostationary Coastal and Air Pollution Events (GEO-CAPE) is one of the missions recommended by the *NRC Decadal Survey*. This mission will deploy a geostationary satellite over the continental United States, which would carry out measurements of tropospheric pollutants ( $O_3$ ,  $NO_2$ ,  $SO_2$ , aerosols) and ocean color in coastal areas, with high spatial and temporal resolution. Such resolution would allow fine mapping of pollution emission and events, and allow a better understanding of the processes involved in pollution transformation and transport. The mission is a Tier-2 mission, with expected deployment around 2020.

NASA Headquarters has provided funding to different centers in the United States to start exploring the scientific questions and measurement requirements for this mission. Scientists in the Atmospheric Chemistry and Dynamics Branch are playing a leading role in several of the study subgroups. Dr. S. Randall Kawa is one of the two science co-leads for this mission. Drs. Kenneth Pickering and Bryan Duncan participate in the “Atmospheric Variability” Study Group, analyzing global and regional model results to understand the scales of variability for the intended measured species, and thus the required resolution for the measurements. Dr. Joanna Joiner participates in the “Detectability” subteam, which examines the measurements that can be carried out in different wavelength ranges, the expected vertical resolution, and the interference of clouds and aerosols in the retrieval of gas species. Dr. Mian Chin has spearheaded the “Aerosol Science” subgroup, which is defining science questions and measurement requirements for aerosols. Drs. Jose Rodriguez and S. Randall Kawa participate in the Science “Traceability Matrix” subgroup. Dr. Rodriguez also coordinates GEO-CAPE efforts at Goddard.

Details on the GEO-CAPE mission can be found at <http://geo-cape.larc.nasa.gov/> For information on Goddard efforts, contact Jose M. Rodriguez (Jose.M.Rodriguez@nasa.gov).

### 4.1.1.3 ASCENDS

The NASA Active Sensing of  $CO_2$  Emissions over Nights, Days, and Seasons (ASCENDS) mission, recommended for launch in the second phase of missions (2013–2016) by the *2007 NRC Earth Science Decadal Survey*, is considered the technological next step following launch of passive instruments such as the Japanese Greenhouse gases Observing SATellite (GOSAT) in 2009 and the NASA Orbiting Carbon Observatory re-flight (OCO-2) expected in 2013. Using an active laser measurement technique, ASCENDS will extend  $CO_2$  remote sensing capability to include uninterrupted coverage of high-latitude regions and nighttime observations with sensitivity in the lower atmosphere. To enable investigations of the climate-sensitive southern ocean and permafrost regions, provide insight into the diurnal cycle, and plant respiration processes, and provide useful new constraints to global carbon cycle models.

The Laboratory for Atmospheres supports ASCENDS through technology development, instrument definition studies, and carbon cycle modeling and analysis. Bill Heaps (613.3) is Principal Investigator for an Instrument Incubator Program (IIP) project to develop a broadband laser system with Fabry-Perot detection that may be a candidate for the ASCENDS instrument. Lab members also participate on instrument technology projects, led by the Laser Remote Sensing Branch, which target instrument and mission development for ASCENDS. They play a key role in radiative transfer modeling, retrieval algorithm development, test instrument field deployment, and data analysis on Jim Abshire’s IIP project. Based on experience and knowledge of carbon cycle science, they actively help to keep the technology development on track to best achieve the science objectives of ASCENDS. They also support the ASCENDS

flight project directly by performing observing system simulations to help establish science measurement requirements for ASCENDS and to evaluate the impact of various mission technology options. For further information please contact S. Randolph Kawa ([stephan.r.kawa@nasa.gov](mailto:stephan.r.kawa@nasa.gov)), Code 613.3, phone: (301)614-6004, fax: (301)614-5903.

ASCENDS workshop Web site: <http://cce.nasa.gov/ascends/index.htm>.

#### 4.1.1.4 Global 3-D Wind Decadal Survey Mission

The wind field plays an important role in specifying the global initial conditions for numerical weather forecasting. In addition to improving numerical weather prediction, there is also a need to improve accuracy of wind fields to assess long term sensitivity of the general circulation to climate change and to improve horizontal and vertical transport estimates of atmospheric constituents including water vapor, CO<sub>2</sub> and aerosols for climate applications. In spite of its significance, the three-dimensional (3-D) structure of the wind field remains largely unobserved on a global scale. A new satellite mission using Doppler lidar technology to accurately measure the global wind field is needed to fill this important gap in the Global Observing System. The *2007 NRC Decadal Survey for Earth Science* identified the Global Tropospheric 3-D Wind mission as one of the 15 priority missions recommended for NASA's Earth Science program. The *Decadal Survey* panel recommended a two-phase approach to achieving an operational global wind measurement capability. For the first phase, the panel recommends that NASA to develop the technology and fly a pre-operational mission to demonstrate the technology and measurement concept and establish the performance standards for an operational wind mission. The second phase would develop and fly an operational wind system in the 2025 time frame.

In 2009, Laboratory for Atmosphere's scientists made important strides in preparation for the Global 3-D Wind Mission in several areas. In the area of technology readiness, a major milestone was met in February 2009 with the completion of the Tropospheric Wind Lidar Technology Experiment (TWiLiTE) airborne Doppler lidar Instrument Incubator Project (IIP). This was followed in September by engineering flight testing of TWiLiTE on the NASA ER-2 high altitude research aircraft. Also in 2009 significant progress was made in the development of an advanced Observing System Simulation Experiment (OSSE) capability in the GSFC Global Modeling and Assimilation Office. This advanced OSSE capability enables improved understanding of the impact of the Global 3-D Wind Mission observations on future global circulation models and provides insights into Mission requirements and measurement objectives. Finally, new Observing System Experiment (OSE) techniques have been developed to provide simulated wind observation data sets for assimilation in the OSSEs. The new OSE techniques are based on validated lidar instrument models and improved representations of the global distribution of aerosols and clouds as observed by the GLAS and CALIPSO space-based lidar instruments. For additional information contact Bruce Gentry ([Bruce.M.Gentry@nasa.gov](mailto:Bruce.M.Gentry@nasa.gov)).

#### 4.1.1.5 GACM

The Global Atmospheric Composition Mission (GACM) is an Aura follow-on mission recommended by the *NRC Decadal Survey* panel for launch in the 2016–2020 time frame. The objectives of GACM are to improve the understanding of chemical-weather processes on regional and global scales, and to enable better forecasts of air pollution events and surface UV radiation. For this mission NRC had recommended three instruments similar to the ones currently flying on Aura: a limb-viewing microwave sensor to study upper tropospheric and lower stratospheric processes, a nadir-viewing UV/VIS sensor for air pollution studies, and nadir-viewing IR instrument to measure carbon monoxide. Laboratory for Atmospheres scientists are working closely with JPL scientists in designing this mission. We are currently evaluating the best strategy of obtaining enhanced vertical profile information about tropospheric trace gases

## MAJOR ACTIVITIES

and aerosols compared to Aura. The approaches under consideration are multi-angle and stereo-viewing (similar to MISR) and panchromatic (UV-IR) retrieval methods. For more information please contact: P.K. Bhartia (301) 614-5731.

### 4.1.2. NASA Planned Missions

#### 4.1.2.1 GPM Mission

The Global Precipitation Measurement (GPM) Mission is an international space network of satellites designed to provide the next generation precipitation observations around the world every 2 to 4 hours. GPM is a science discovery mission with integrated application goals to advance the understanding of the Earth's water and energy cycle, and to extend current capabilities in a range of precipitation-related applications to directly benefit the society. The GPM concept centers on the deployment of a Core Observatory carrying an advanced radar/radiometer system in a non-Sun-synchronous orbit to serve as a "physics observatory," to gain insights into precipitation systems and provide a calibration reference, and to unify and improve precipitation estimates from a constellation of research and operational satellites. The GPM Mission is currently a partnership between the NASA and the Japan Aerospace and Exploration Agency (JAXA), with additional partnerships with other domestic and international agencies under development. The GPM Core Observatory is scheduled for launch in mid-2013, and the target launch date for a partner-provided GPM Low-Inclination Observatory is late 2014.

Scientists in the Laboratory for Atmospheres play a crucial role in (1) defining the science requirements for advanced instrument capabilities that measure precipitation rates over both ocean and land from the Tropics to high-latitudes, (2) developing algorithms to retrieve precipitation information from active and passive microwave sensors, (3) conducting ground validation field experiments to support pre-launch



*Figure 4:1 The GPM constellation of satellites with the GPM Core Observatory shown at the upper right.*

algorithm development and post-launch product validation, and (4) employing satellite precipitation data in scientific research and practical applications. In 2009 there were over 35 Laboratory scientists involved in GPM science activities.

For more information on GPM, please visit the Precipitation Measurement Missions (PMM) science Web page: <http://pmm.gsfc.nasa.gov/>, or contact the GPM Project Scientist, Dr. Arthur Hou (Arthur.Y.Hou@nasa.gov), or the GPM Deputy Project Scientist, Dr. Gail Skofronick Jackson (Gail.S.Jackson@nasa.gov).

#### 4.1.2.2 NPP

The NPOESS Preparatory Project (NPP) had a good year in 2009. The third and fourth of five instruments were integrated on the NPP spacecraft. The Ozone Mapping and Profiling Suite (OMPS) was integrated early in 2009. OMPS will continue the TOMS/SBUV record of monitoring ozone. The OMPS Limb instrument is a new operational instrument that will continue the SAGE/MLS ozone profile data record. The fourth instrument, the Visible Infrared Imaging Radiometer Suite (VIIRS) was shipped to the NPP spacecraft in December. Engineers completed repairs to the electronics on the fifth instrument, the Cross-track Infrared Sounder (CrIS); it is undergoing final verification testing in the thermal vacuum chamber. The CrIS instrument is scheduled to ship to the NPP spacecraft in June 2010, which results in a NPP launch readiness date of October 2011. Significant progress was made on the algorithm readiness for NPP, and the Integrated Program Office predicts that most of the Environmental Data Records will meet their requirements. The NPP Science Team is finishing its third and final year of funding and will be re-competed in the ROSES 2010 call.

For further information please contact James Gleason ([james.f.gleason@nasa.gov](mailto:james.f.gleason@nasa.gov)) (301) 614-6036.

#### 4.1.2.3 Glory

An accurate description of Earth's energy budget is important for scientists in order to anticipate changes to our climate. Shifts in the global climate and the associated weather patterns impact life by altering landscapes and changing the availability of natural resources. Scientists are working to better understand exactly how and why this energy budget changes. The Glory mission will provide significant contributions toward this critical endeavor.

The science objectives of the Glory mission include: (a) the determination of the global distribution, microphysical properties, and chemical composition of natural and anthropogenic aerosols and clouds with accuracy and coverage sufficient for a reliable quantification of the aerosol direct and indirect effects on climate; and (b) the continued measurement of the total solar irradiance to determine the Sun's direct and indirect effect on the Earth's climate.

These goals are accomplished with two instruments: the Aerosol Polarimetry Sensor (APS) and the Total Irradiance Monitor (TIM). APS is a continuous scanning sensor that has the capability to collect visible, near-infrared, and short-wave infrared data scattered from aerosols and clouds. It is designed to make extremely accurate multi-angle observations of Earth, and atmospheric scene spectral polarization and radiance. APS provides observations of aerosol and cloud optical thickness, aerosol and cloud particle size, aerosol refractive index, aerosol single-scattering albedo, and aerosol particle shape. These observations will contribute new information on aerosol composition and shape that are critical for determining the direct impact of aerosols on the radiation budget of Earth and the effects of aerosols on clouds. TIM is an active cavity radiometer that monitors changes in incident sunlight to Earth's atmosphere with high accuracy and precision. TIM will maintain the continuous record of total irradiance required to determine the Sun's effect on Earth's climate. Eric Wilcox (613.2) was selected as the Deputy Project Scientist.

For more information, contact Eric Wilcox, Code 613.2 ([eric.m.wilcox@nasa.gov](mailto:eric.m.wilcox@nasa.gov)), (301) 614-6409.

#### 4.1.2.4 LDCM

The Landsat Data Continuity Mission (LDCM) is the successor mission to Landsat 7. Landsat satellites have continuously acquired multispectral images of the global land surface since the launch of Landsat 1 in 1972. The Landsat data archive constitutes the longest moderate-resolution record of the global land surface as

## MAJOR ACTIVITIES

viewed from space. The LDCM objective is to extend the ability to detect and quantitatively characterize changes on the global land surface at a scale where natural and man-made causes of change can be detected and differentiated.

The LDCM is the eighth satellite in the Landsat series. The development of LDCM is a partnership between NASA and the U.S. Geological Survey (USGS). The NASA Goddard Space Flight Center (GSFC) is responsible for the development of the overall mission. USGS is responsible for ground system development and will operate LDCM after launch. The LDCM satellite is being developed by General Dynamics Advanced Information Systems and will accommodate two instruments: the Operational Land Imager (OLI) built by Ball Aerospace and Technologies Corporation (BATC), and the Thermal InfraRed Sensor (TIRS) built by NASA GSFC. NASA's Kennedy Space Center is responsible for the Atlas V launch vehicle. The USGS Earth Resources Observation and Science (EROS) Center will receive, archive, and distribute LDCM data.

The Landsat Program has been declared a National Asset by the Office of Science and Technology Policy (OSTP). The Landsat data archive is unmatched in quality, detail, coverage, and value. The data record is essential to studies of land cover and land use change, and vital to understanding the causes and consequences of climate change. Additionally, Landsat data are used operationally for a wide range of agricultural, environmental, economic, water management, and national security applications. The LDCM will expand and improve upon the Landsat data record when launched in December, 2012.

More information can be found on the internet at <http://landsat.gsfc.nasa.gov/> or <http://ldcm.gsfc.nasa.gov/>, or by contacting James R. Irons, LDCM Project Scientist ([james.r.irons@nasa.gov](mailto:james.r.irons@nasa.gov)), (301) 614-6657.

### 4.1.2.5 NPOESS/JPSS

As background, the National Polar Orbiting Environmental Satellite System (NPOESS) is a tri-agency program between NASA and the Department of Commerce (specifically the National Oceanic and Atmospheric Administration, or NOAA), and the Department of Defense (DoD, specifically the Air Force). It is designed to merge the civil and defense weather satellite programs in order to reduce costs, and provide global weather and climate coverage with improved capabilities above the current system. The NPOESS program has experienced several challenges to date, including schedule delays and cost increases. OSTP issued a fact sheet outlining a restructuring of the NPOESS program in FY2011. Following are excerpts from the fact sheet:

The President's FY2011 budget contains a major restructuring of NPOESS in order to put the critical program on a more sustainable pathway toward success. The satellite system is a national priority—essential to meeting both civil and military weather-forecasting, storm-tracking, and climate-monitoring requirements. The major challenge of NPOESS was jointly executing the program between three agencies of different size with divergent objectives and different acquisition procedures. The new system will resolve this challenge by splitting the procurements. NOAA and NASA will take primary responsibility for the afternoon orbit, and DoD will take primary responsibility for the morning orbit. The agencies will continue to partner in those areas that have been successful in the past, such as a shared ground system. NOAA's portion will notionally be named the "Joint Polar Satellite System" (JPSS).

NASA's role in the restructured program will be modeled after the procurement structure of the successful POES and GOES programs, where NASA and NOAA have a long and effective partnership. Work is proceeding rapidly with NOAA to establish a JPSS program at the Goddard Space Flight Center (GSFC). The NASA-developed and operating Earth Observing System (EOS) Aqua satellite and ground system are very similar in scope and magnitude to

the proposed JPSS program. NOAA and NASA will strive to ensure that all current NPOESS requirements are met on the most rapid practicable schedule without reducing system capabilities. NASA program and project management practices have been refined over decades of experience developing and acquiring space systems, and NASA anticipates applying its current practices to JPSS. NASA program and project management processes will include thorough and ongoing review and oversight of project progress. Cost-estimates will be produced at or close to the 80% confidence level.

Laboratory support to the JPSS program will consist of providing laboratory facilities, the Project Scientist and Deputy Project Scientist and recruiting new hires especially instrument scientists.

For further information please contact James Gleason ([james.f.gleason@nasa.gov](mailto:james.f.gleason@nasa.gov)), (301) 614-6036; or Christina Hsu ([christina.hsu@nasa.gov](mailto:christina.hsu@nasa.gov)), (301) 614-5554 .

#### **4.1.2.6 DSCOV**

The instruments on board the Deep Space Climate Observatory (DSCOV) spacecraft are currently undergoing refurbishment at three locations: Lockheed Martin (EPIC), the National Institute of Standards (NISTAR), and GSFC (the magnetometer, Faraday cup, and electron analyzer). The goal of the mission is to supply space weather information for NOAA and the Air Force for protection of satellite assets and for the power grid. In addition to the space weather objective, NASA has been requested to provide a level of earth science support equivalent to the mission's original goals.

These goals are measurements of ozone, aerosols, cloud height, vegetation index, cloud phase (water or ice), and total water content (EPIC), and the earth's radiation balance (NISTAR). The recalibration and refurbishment program, now underway, will correct previously known deficiencies (such as stray light for EPIC) and improve measurements. By replacing the older 393.5 nm and 645 nm channels with two new 680 and 688 nm wavelength channels, scientists will be able to measure cloud height using the oxygen-B band using new algorithms developed at GSFC. After instrument refurbishment, the instruments will be returned to GSFC for integration with the spacecraft. Algorithm development, spacecraft management software, satellite bus refurbishment, ground systems, and data reception and transmission are awaiting future direction from NASA.

For further information please contact Dr. Alexander Marshak ([Alexander.Marshak@nasa.gov](mailto:Alexander.Marshak@nasa.gov)), (301) 614-6122,, or Dr. Jay R. Herman ([Jay.R.Herman@nasa.gov](mailto:Jay.R.Herman@nasa.gov)), (301) 614-6039.

### **4.1.3. NASA Missions of National Interest**

#### **4.1.3.1 CASS**

The Chemical and Aerosol Sounding Satellite (CASS) is a concept being developed by scientists in Code 613.3 (Jose M. Rodriguez, Charles Jackman, Anne Douglass and Luke Oman) to address the future gap in measurements of ozone, aerosol, and trace constituents in the stratosphere and upper troposphere. Measurements of these species are currently being carried out by different instruments, primarily aboard the Aura satellite and the Canadian EnviSat Mission, as well as other European missions. However, these missions are already beyond their 5-year estimated duration, and realistically they are not expected to last beyond 2014. Limb profiles of ozone have not been incorporated in the NPOESS series as of now, and no trace gases measurements are being planned. The next *Decadal Survey* Mission that would carry out these measurements is GACM, a Tier-3 mission that probably would not be launched until late 2020's. This presents a potential gap of more than 10 years in important stratospheric measurements.

## MAJOR ACTIVITIES

CASS would include two instruments: the SAGE-III instrument—already in storage at NASA LaRC—which measures profiles of O<sub>3</sub>, NO<sub>2</sub>, and aerosols by solar and lunar occultation; and a copy of the ACE-FTS instrument which has been very successful in carrying out measurements of a suite of trace gases in the upper troposphere and stratosphere. These instruments would be incorporated in a dedicated satellite at 57° inclination orbit, allowing for monthly from high latitudes to the tropics. An ideal launch date would be 2014–2015, to minimize the data gap. NASA Headquarters funded a preliminary study to assess the status of the SAGE-III instrument at LaRC; this study indicated that the instrument is functioning as expected. However, because CASS is not a mission called by the *Decadal Survey*, NASA Headquarters has not made a final decision regarding this mission. An alternative concept is also being considered that incorporates SAGE-III in the International Space Station. For further information, contact Jose Rodriguez (:Jose.M.Rodriguez@nasa.gov), (301) 614-5736.

### 4.1.4. NASA Active Flight Missions

#### 4.1.4.1 Terra

Launched on 18 December 1999 as NASA's Earth Observing System flagship observatory, Terra carries a suite of five complementary instruments: 1) ASTER, contributed by the Japanese Ministry of Economy, Trade and Industry (with a U.S. Science Team Leader at JPL), provides a unique benefit to Terra's mission as a stereoscopic and high-resolution instrument required to measure and verify processes at fine spatial scales; 2) CERES (LaRC) investigates the critical role clouds, aerosols, water vapor, and surface properties play in modulating the radiative energy flow within the Earth-atmosphere system; 3) MISR (JPL) characterizes physical structure from microscopic scales (aerosol particle sizes and shapes) to the landscape (ice and vegetation roughness, and texture) to the mesoscale (cloud and plume heights and 3-D morphologies); 4) MODIS (GSFC) acquires daily, global, and comprehensive measurements of a broad spectrum of atmospheric, ocean, and land properties, which improves and supplements heritage measurements needed for processes and climate change studies; and, 5) MOPITT, sponsored by the Canadian Space Agency (with an NCAR science team), retrieves carbon monoxide total column amounts as well as mixing ratios for ten pressure levels and its gas correlation approach still produces the best data for studies of horizontal and vertical transport of this important trace gas.

For nearly 10 years, the Terra Mission has been providing the worldwide scientific community with an unprecedented number of high-quality quantitative data sets making a significant contribution to all of NASA's Earth Science Focus Areas. Terra's Basic Mission currently produces 72 core data products, with the primary goals of enabling the science community to address fundamental questions in Earth Science as articulated in NASA's *Science Plan for 2007-2016*, under the overarching question, "How is the Earth changing and what are the consequences for life on Earth?" Terra spacecraft and instruments have performed and continue to perform extremely well and only experienced the expected normal on-orbit degradation of some subsystems or components. Propulsive maneuvers of Terra spacecraft to maintain orbital science requirements are projected to function for approximately eight more years. Scientists in the Laboratory for Atmospheres play important roles in algorithm developments, product generations, and conduct vital research on Earth system sciences. For general information about Terra science team publications, see the following web sites:

ASTER: <http://asterweb.jpl.nasa.gov/bibliography.asp>

CERES: <http://asd-www.larc.nasa.gov/ceres/pubs.html>

MISR: <http://www-misr.jpl.nasa.gov/mission/pub.html>



MODIS: [http://modis.gsfc.nasa.gov/sci\\_team/pubs/](http://modis.gsfc.nasa.gov/sci_team/pubs/)

MOPITT: <http://www.acd.ucar.edu/mopitt/publications.shtml>

For further information contact: Si-Chee Tsay, [Si-Chee.Tsay-1@nasa.gov](mailto:Si-Chee.Tsay-1@nasa.gov).

#### 4.1.4.2 Aqua

The Aqua spacecraft was launched on May 4, 2002, carrying six Earth-observing instruments: AIRS, AMSR-E, AMSU, CERES (two copies), HSB (no longer operating), and MODIS (also flying on Terra). The spacecraft is now beginning its second Extended Mission period after a successful Senior Review process (that begun in Spring 2009) where Aqua data products were recognized as continuing to provide highly valuable Earth science data. In addition to collecting data regarding Earth's water—as highlighted in the name “Aqua”—mission instruments also provide radiative energy fluxes, atmospheric temperature and composition, dust and aerosols, cloud properties, land vegetation, phytoplankton and dissolved organic matter in the oceans, and surface albedo, temperature, and emissivity. These measurements are helping scientists to quantify the state of the Earth system, validate climate models, address key science questions, and serve the applications community.

A number of Laboratory personnel are involved in Aqua science and/or project science efforts. For MODIS, algorithm development is being done by Lorraine Remer (aerosol dark target algorithm), Christina Hsu (aerosol Deep Blue algorithm), and Steve Platnick (cloud optical properties, Atmosphere Team Level-3 gridded products). Steve Platnick became the MODIS Atmosphere Team lead in December 2009. For AIRS, Joel Susskind is responsible for the temperature/moisture profile algorithm. Other Laboratory scientists that continued in 2009 to lead NASA-funded investigations with Aqua satellite data in such diverse areas as clouds, aerosols, biomass burning pollution, Saharan dust, and precipitation include Robert Adler, Robert Cahalan, Mian Chin, Bryan Duncan, Alexander Marshak, Vanderlei Martins, Si-Chee Tsay, Eric Wilcox, and Liguang Wu. Numerous publications authored or coauthored by Laboratory scientists making use of Aqua data can be found in the publications section of this report. Steve Platnick was the Aqua Deputy Project Scientist until his replacement by Lazaros Oreopoulos in February 2010.

Further information on the Aqua mission can be found at <http://aqua.nasa.gov/> or by contacting Lazaros at (301) 614-6128, [Lazaros.Oreopoulos-1@nasa.gov](mailto:Lazaros.Oreopoulos-1@nasa.gov)

#### 4.1.4.3 Aura

The Aura spacecraft was launched July 15, 2004 carrying four instruments to study the composition of the Earth atmosphere. The Ozone Monitoring Instrument (OMI), the Microwave Limb Sounder (MLS), the High Resolution Dynamics Limb Sounder (HIRDLS), and the Tropospheric Emission Spectrometer (TES) make measurements of ozone and constituents related to ozone in the stratosphere and troposphere, aerosols, and clouds. With these measurements the science team addresses questions concerning the stratospheric ozone layer, air quality, and climate.

This year marks the end of Aura's five-year prime mission, and the scientific results and health of the platform and the instruments were evaluated by the Senior Review panel. Aura scientific contributions were recognized as outstanding; and although the panel expressed concerns about the condition of the aging instruments, the Aura platform was heartily endorsed for an extended mission and continued operations.

## MAJOR ACTIVITIES

Additional information about Aura instruments, spacecraft, and science, along with a list of publications are available on the Web site <http://aura.gsfc.nasa.gov/>. For further information contact: Anne Douglass (Anne.R.Douglass@nasa.gov), (310) 614-6028).

### 4.1.4.4 GOES

NOAA's Geostationary Operational Environmental Satellites (GOES) are built, launched, and initialized by GSFC's GOES Project Office under an inter-agency program. The GOES series of satellites carry sensors that continuously monitor the Earth's atmosphere for developing weather events, the magnetosphere for space weather events, and the Sun for energetic outbursts. The Laboratory for Atmospheres provides a project scientist to assure the scientific integrity of the GOES sensors throughout the mission definition, design, development, testing, operations and data analysis phases of each decade-long satellite series. The project scientist operates a GOES ground station that offers real-time, full-resolution, calibrated GOES images to support scientific field experiments and to supply internet users with high-quality data during severe weather events. In 2009, the project scientist supported the launch of GOES-O (renamed GOES-14 in orbit) and helped debug the new image broadcast format adopted by NOAA. Also in 2009, four of the scientific instruments for the next generation of GOES satellites, GOES-R and beyond (2015 launch and beyond), were reviewed at the critical design level, in order to approve them for construction and testing during the next three years. A HDTV quality video was created to illustrate the busy 2008 hurricane season, and the real-time Web site downloaded an average of 100 GB/day of enhanced GOES imagery (<http://goes.gsfc.nasa.gov>). For further information please contact Dennis Chesters, Code 613.1 (GOES Project Scientist, (310) 614-6325).

### 4.1.4.5 SORCE

The Solar Radiation and Climate Experiment (SORCE) is a NASA-sponsored satellite mission that is providing state-of-the-art measurements of incoming x-ray, ultraviolet, visible, near-infrared, and total solar radiation. The measurements provided by SORCE specifically address long-term climate change, natural variability and enhanced climate prediction, and atmospheric ozone and UV-B radiation. These measurements are critical to studies of the Sun, its effect on our Earth system, and its influence on humankind. The SORCE spacecraft was launched on January 25, 2003 on a Pegasus XL launch vehicle to provide NASA's Earth Science Enterprise (ESE) with precise measurements of solar radiation. It launched into a 645 km, 40 degree orbit.

The Earth's radiation budget is in approximate balance between absorbed incoming energy from the Sun and outgoing thermal energy from the Earth. There is a small deficit of the outgoing thermal energy due to the trapping by greenhouse gases and associated with the observed increase of global average temperature, and the ocean heat storage. Solar radiant energy is the primary external driver of the Earth's climate. The input of energy from the Sun is understood increasingly well since we began measuring total solar irradiance (TSI) from space in 1978, and spectral solar irradiance (SSI) since 2003, when the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM)—both onboard the SORCE platform—began measuring TSI and SSI, respectively, with unprecedented precision.

During the unusually long solar minimum of cycle 23, TIM has determined a new value for the TSI, given by  $1361 \pm 0.8 \text{ W/m}^2$ . This value is about 3000 ppm (0.3%) lower than previous estimates. There are several reasons for this difference with previous estimates:

- Diffraction corrections were not applied to certain previous instruments.
- Scattered light entered previous instruments due to limiting apertures being internal.

- TIM measures dark (dark space) signal. Others model it.
- TIM is most precisely characterized, with intracone variance less than stated accuracy.

The first end-to-end calibration with a new cryogenic radiometer facility at UCO-LASP, using solar equivalent illumination, has established TIM precision and is now helping resolve discrepancies, as other instruments make use of this facility. NIST has established reproducibility of such cryogenic measurements at the required level of 200 ppm (0.02 %).

Since the location and amount of solar radiation absorbed by Earth's atmosphere-ocean system is strongly wavelength-dependent, it is necessary to monitor not only the TSI, but also the SSI, or Solar Spectral Irradiance. SSI is measured by the SORCE Spectral Irradiance Monitor, or SIM. SIM is the first to provide comprehensive SSI observations, during the decline from the cycle 23 solar maximum, to the current long solar minimum. Already there are several new results:

- Near ultraviolet (NUV) varies in-phase with TSI.
- NUV changes more than TSI, explaining 1.0 K 11-year variations at ~40 km.
- VIS & NIR vary out-of-phase with TSI.
- TSI is comprised of spectral regions that have compensating effects.
- Surface radiative forcing is very small, with 11-year direct surface response <0.1 K.

Impacts of these SSI results are just beginning to be studied in climate models. For an early example, see <http://climate.gsfc.nasa.gov/viewPaperAbstract.php?id=1405>.

The Glory mission will carry a new TIM that uses the same basic design as the SORCE TIM, but with even more precise characterization. Glory will not include the SSI observation, which means that SORCE SIM must continue to provide this required measurement through the launch of the follow-on Total and Spectral Solar Irradiance Sensor (TSIS).

TSIS sensors will continue key climate measurements of total and spectral solar irradiance that contribute to determining the Earth's energy balance and understanding how Earth's climate responds to solar variability. NASA is developing the TSIS Flight Model under a reimbursable agreement with NOAA. TSIS is being prepared to launch in 2014. For further information please contact Robert Cahalan ([robert.f.cahalan@nasa.gov](mailto:robert.f.cahalan@nasa.gov)), (301) 614-5390 .

#### 4.1.4.6 ICESat

The Ice, Cloud and land Elevation Satellite (ICESat) was launched in January of 2003 with the primary objective of mapping the topography of the Earth's ice sheets to a very high precision. Using short pulses of infrared laser light, ICESat can measure the height of the surface to within 10 cm every 175 m along the orbit track. These data are used to measure changes in the height (thickness) of Earth's major ice sheets and glaciers. Several Lab for Atmospheres scientists have been involved in retrieving aerosol and cloud properties (especially for stratospheric clouds common over polar regions) as well as in correcting surface altimetry data for atmospheric contamination.

As it began its 17th science observation period on March 9 2009, ICESat was down to the last of its three lasers. With just 6 mJ of laser energy, ICESat was able to measure the topography of the Earth and the height of ice sheets to within 10 cm. By the end of the observation period, the laser energy had dropped to just 2 mJ. At these energies, altimetry through clear atmosphere is not a problem, but it becomes very difficult to obtain useful data through even relatively thin clouds. This observation period ended on April 11, 2009 with ICESat making a total of 1.9 billion altimetry observations from launch to this time. On September 30, 2009 ICESat was activated for the next observation period which was planned to last

## MAJOR ACTIVITIES

for 33 days, but unfortunately, the last of the three lasers failed on October 11, 2009. Since that time, a number of attempts have been made to restart the lasers but they have not been successful. NASA will continue in this effort for the next few months, but hopes for future observations from ICESat are dim. Find out more about ICESat at the Web site: <http://icesat.gsfc.nasa.gov/>. For further information please contact Stephen Palm (Stephen.P.Palm@nasa.gov), or Alexander Marshak (Alexander.Marshak@nasa.gov).

### Publications:

Yang Y., A. Marshak, J.C. Chiu, W.J. Wiscombe, S.P. Palm, A.B. Davis, D.A. Spangenberg, L. Nguyen, J.D. Spinhirne, and P. Minnis, 2008. Retrievals of cloud optical depth from the Geoscience Laser Altimeter System (GLAS) by calibration of solar background signal. *J. Atmos. Sci.*, 65, 3513-3527  
([http://climate.gsfc.nasa.gov/publications/fulltext/Yang\\_etal\\_JAS\\_2008.pdf](http://climate.gsfc.nasa.gov/publications/fulltext/Yang_etal_JAS_2008.pdf)).

Yang Y., A. Marshak, T. Varnai, W.J. Wiscombe, and P. Yang, 2009. Uncertainties in ice sheet altimetry from a spaceborne 1064-nm single channel lidar due to undetected thin clouds. *IEEE Trans. Geos. Remote Sens.*, 48, 250-259  
([http://climate.gsfc.nasa.gov/publications/fulltext/YY\\_etal\\_IEEETGRS.pdf](http://climate.gsfc.nasa.gov/publications/fulltext/YY_etal_IEEETGRS.pdf)).

## 4.2. Measurements

---

Studies of the atmosphere of Earth require a comprehensive set of observations, relying on instruments borne on spacecraft, aircraft, balloons, or those that are ground-based. Our instrument systems 1) provide information leading to basic understanding of atmospheric processes, and 2) serve as calibration references for satellite instrument validation. Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations. Airborne instruments provide critical in situ and remote measurements of atmospheric trace gases, aerosol, ozone, and cloud properties. Airborne instruments also serve as stepping-stones in the development of spaceborne instruments, and serve an important role in validating spacecraft instruments. Details concerning the laboratory instruments are presented in a separate Laboratory technical publication, the *Instrument Systems Report*, NASA/TP-2009-212783 which is also available on the Laboratory's home page, <http://atmospheres.gsfc.nasa.gov/>.

## 4.3. 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 2009, Laboratory personnel supported activities as scientific investigators, or as mission participants, in the planning and coordination phases.

### 4.3.1. JAMEX/TIGERZ/RAJO-MEGHA 2009 Deployment in Nepal and India

Through interactions with clouds and alteration of radiative energetics, heavy loadings of dust, smoke, and industrial aerosols observed over the Indo-Gangetic Plain to south of the Himalayan mountain range may influence the Indian monsoon [e.g., Menon et al., 2002; Ramanathan et al., 2005; Lau et al., 2006], which is critical for the water supply of this highly populated region. To study the aerosol-cloud-water cycle in this region and to obtain data specifically for testing the proposed Elevated Heat Pump hypothesis [Lau et al., 2006; Lau and Kim, 2006], the JAMEX/TIGERZ/RAJO-MEGHA (cf. Lau et al., 2008)

MODIS/Aqua true color image: 28 April 2009

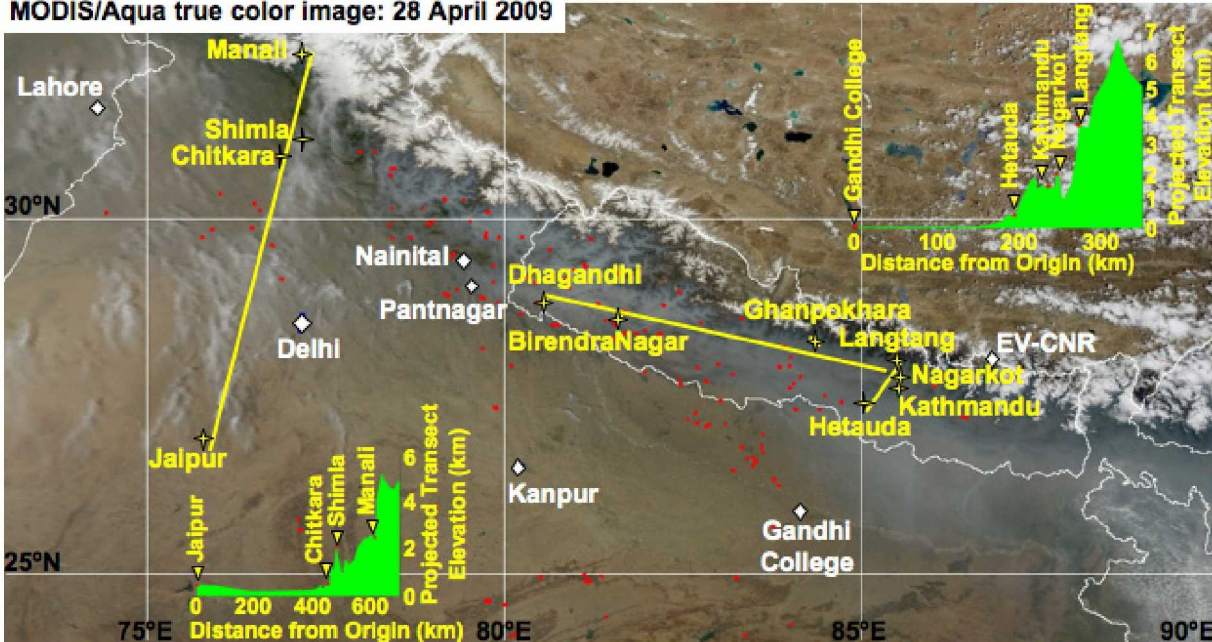


Figure 4.2; JAMEX sites in TIGERZ (white diamonds) and RAJO-MEGHA (yellow stars) deployment, super-imposed on MODIS/Aqua red-green-blue image acquired on 28 April 2009 with numerous fires (red dots) and heavy biomass-burning smoke. The north-south transect in central Nepal, composed of four sites less than 100 km apart but with elevation drastically increasing from 465 m in the south to 3670 m in the north, provides information about the vertical distribution of aerosols piling at south of the Himalayan mountain foothills. Northwestern India represents both the desert dust and forest fire/biomass burning prevalent regions. Thus, a similar setup, from Jaipur near desert regions to Manali in the vicinity of pristine glacier mountains, may indicate pathways of long-range transport of aerosols by westerly-southwesterly winds into free troposphere at elevated locations in the Himalayas.

field experiment was conducted during the pre-monsoon season (April to June) of 2009. In this joint effort between the Kathmandu University, Tribhuvan University, Duke University, Birla Institute of Technology, and NASA's Goddard Space Flight Center, the SMART-COMMIT and Deep Blue teams set up a number of observational sites in northwestern India and Nepal by (<http://climate.gsfc.nasa.gov/>), which encompassed the dust source region as well as the elevated foothill/slopes of the Himalayas (cf. Figure 4.2). These sites at different elevations and locations, together with the TIGERZ deployment of AERONET (<http://aeronet.gsfc.nasa.gov/>), and two lidars set up by the MPLNET team (<http://mplnet.gsfc.nasa.gov/>) helped characterize the distribution and properties of aerosols in the region, particularly along the southern slopes of the Himalayas. Refined aerosol information from this experiment will serve as input for climate models to study the aerosol effects on the monsoon system.

Distinct seasonal transition and synoptic change in aerosol loading and aerosol type were observed during the field experiment. Several long-range transports of dust at higher altitudes were identified, the source regions determined with back trajectory modeling included the deserts in the Arabian Peninsula and the Thar Desert near the India-Pakistan border. A major regional biomass-burning event was witnessed at several sites, between 24 April and the end of the month (Figures 4.2 and 4.3), which included the high-altitude site (Langtang), where the aerosol optical thickness (AOT) exceeded unity (1.0) on 28–29 April. Lidar data suggest that the top of this smoke layer could reach roughly 4.5 km above sea level in the afternoon. Substantial amount of aerosols could have been lofted to high altitudes along the southern



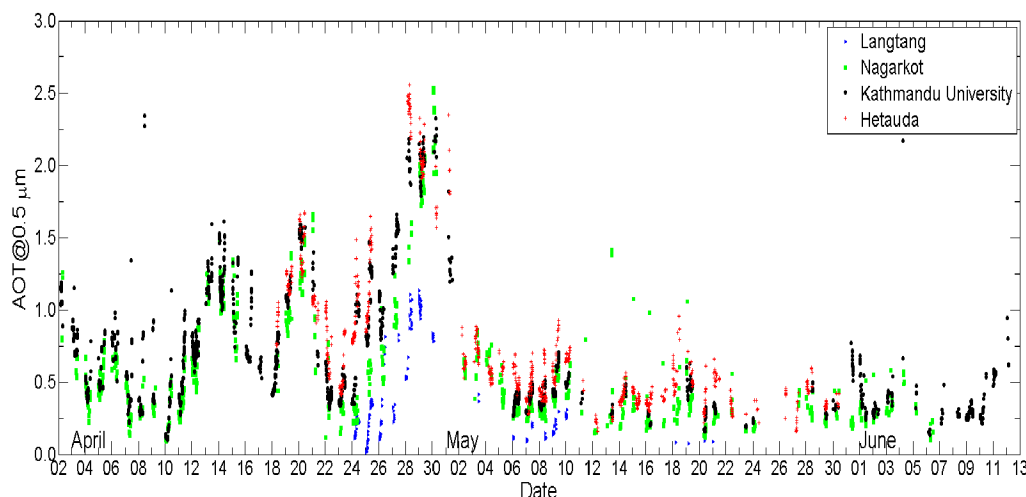


Figure 4.3: AOT observed at four different sites of the central transect in Nepal during the experiment.

slope of the Himalayas and may travel over long distances and impact large areas. Detailed analyses of the properties and radiative effects of aerosols during the field experiment are underway and will help estimate the aerosol effects on radiative energetics and atmospheric heating.

#### 4.3.2. WAVES 2009

The Water Vapor Validation Experiment-Satellite/Sondes 2009 (WAVES 2009) campaign took place this past winter at the Howard University Research Campus in Beltsville, Maryland. The goals were 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 2009 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 (HURL Raman Lidar). The two NASA GSFC lidar assets that participated were the Code 613.3 AT Raman Lidar system and the Code 613.1 ALVICE (Atmospheric Lidar for Validation, Interagency Collaboration and Education). Clear, nighttime conditions were targeted to provide the optimum circumstances for lidar profiling of water vapor extending into the lower stratosphere. Lidar measurements extending to 20 km and revealing lower stratospheric water vapor concentrations of 3–5 ppmv were acquired. For further details, please contact either David Whiteman ([David.N.Whiteman@nasa.gov](mailto:David.N.Whiteman@nasa.gov)) or Tom McGee ([Thomas.J.McGee@nasa.gov](mailto:Thomas.J.McGee@nasa.gov)).

#### 4.3.3. MOHAVE III

The Measurements of Humidity and Validation Experiments (MOHAVE) is underway at the JPL, Table Mountain Facility (TMF) in Wrightwood, CA. The Code 613.1 (David Whiteman, PI) ALVICE and Code 613.3 AT and STROZ (PI, Tom McGee, and Grant Sumnicht) Raman lidar systems are participating. Wildfires, high winds, flocks of moths, and laser power supplies have presented difficulties to the measurement schedule. Nonetheless, Raman lidars are being used successfully to probe upper tropospheric and lower stratospheric water vapor with accuracy consistent with the goals of the Network for the Detection of Atmospheric Composition Change (NDACC). More information regarding the campaign can be found at <http://tmf-lidar.jpl.nasa.gov/index.htm>. Significant events that have occurred during the campaign include

demonstration that optimized Raman water vapor lidars can reliably retrieve water vapor profiles extending into the lower stratosphere quantification of water vapor, and ozone evolution during stratospheric intrusion events. Testing and validation of the latest version of Cryogenic Frostpoint Hygrometer is one of the standards for tropospheric and stratospheric water vapor profiling.

More information regarding the campaign can be found at <http://tmf-lidar.jpl.nasa.gov/index.htm>. For further details please contact David Whiteman (David.N.Whiteman@nasa.gov) or Tom McGee (Thomas.J.McGee@nasa.gov).

#### 4.3.4. GloPac

The Global Hawk Pacific Mission (GloPac) is the first Earth science mission to use the Global Hawk unmanned aircraft system (UAS). The Global Hawk is a unique UAS that can fly more than 30 hours, reach altitudes of 65,000 feet, has a range of 11,000 nautical miles (12,659 miles), and can carry payloads greater than 1,500 pounds. GloPac is scheduled to take place in March and April 2010 from NASA's Dryden Flight Research Center at the Edwards Air Force Base in Southern California. The GloPac mission consists of a series of science flights that will take the Global Hawk over the Pacific Ocean and Arctic regions. The Global Hawk will carry 10 science instruments that will sample the chemical composition of air in Earth's stratosphere and troposphere, and observe cloud and particle distributions in the troposphere. GloPac is being conducted in support of NASA's Aura Validation Experiment (AVE). Aura is one of the flagship missions of NASA's Earth Observing System of satellites and flies in formation with four other Earth observing satellites as part of NASA's "A-Train."

Dr. Paul A. Newman is the co-project scientist of GloPac. GSFC will be flying two instruments on the Global Hawk for GloPac: the Airborne Compact Atmospheric Mapper (ACAM) and the Cloud Physics Lidar (CPL). Dr. Scott Janz is the PI of the ACAM instrument, and Dr. Matt McGill is the PI of the CPL instrument. For more information, contact Paul A. Newman Code 613.3, phone: (301) 614-5985, fax: (301) 614-5903. <http://acdb-ext.gsfc.nasa.gov/People/Newman/>

#### 4.3.5. Application of New Spectrometer Instruments (Pandora and Cleo) for measuring Trace Gas Amounts and Aerosol Properties

Recent development of a new class of low-cost, ground-based spectrometer systems (Pandora and Cleo) allow the measurements of aerosol properties (extinction, optical depth, and absorption) and trace gas amounts ( $\text{NO}_2$ ,  $\text{HCHO}$ ,  $\text{BrO}$ ,  $\text{H}_2\text{O}$ ,  $\text{O}_3$ , and  $\text{SO}_2$ ) both for column content. The Pandora instrument is fully described in a recent paper validating the measured quantities against a reference instrument at two different sites (GSFC and Table Mountain, California) [Herman et al., 2009] along with a comparison to satellite data from OMI. It was found that the OMI  $\text{NO}_2$  column amounts are frequently less than the accurate ground-based, direct-sun measurements in highly polluted areas such as those made at GSFC and Thessaloniki. The instruments were used in a recent inter-comparison campaign in Cabauw, Holland to test the calibration and algorithms used for the Pandora spectrometer system. The result showed excellent agreement between the various groups from the United States and Europe. The Pandora system consists of a 2048 by 16 CCD detector in a miniature, cooled spectrometer connected to a weather-sealed optical head with two filter wheels that is mounted on a miniature sun-tracker. In Cabauw, the suntracker was used to make both direct sun measurements of total column amounts and sky measurements that can be used for profile retrievals. For further information, contact: Jay Herman ([jay.r.herman@nasa.gov](mailto:jay.r.herman@nasa.gov)), (301) 614-6039.

#### **4.4. Data Sets**

---

In the previous discussion, we mentioned the array of instruments and described 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. This section highlights some of the major data sets

##### **4.4.1. Global Precipitation**

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These activities 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. A Global Precipitation Climatology Project (GPCP) was established to develop such global data sets by merging data from both low-Earth orbit satellites and geosynchronous satellites, and ground-based rain gauges to produce research-quality estimates of global precipitation. The GPCP data set provides global, monthly precipitation estimates for the period January 1979 to the present. Updates are being produced on a quarterly basis. For more details, see the TRMM Web site <http://trmm.gsfc.nasa.gov/>, or contact George Huffman, (301) 614-6308, [george.j.huffman@nasa.gov](mailto:george.j.huffman@nasa.gov).

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

A merged satellite total ozone data set exists through August of 2008. Intercalibration includes the NOAA-16 and NOAA-17 SBUV/2 instruments and the OMI instrument on the Aura satellite. It is expected that these data will be useful for trend analyses, for ozone assessments, and for scientific studies in general. For more details, see: [http://code916.gsfc.nasa.gov/Data\\_services/merged](http://code916.gsfc.nasa.gov/Data_services/merged); or contact Richard Stolarski ([Richard.S.Stolarski@nasa.gov](mailto:Richard.S.Stolarski@nasa.gov)) or Stacey Frith ([stacey.m.frith@nasa.gov](mailto:stacey.m.frith@nasa.gov)).

##### **4.4.3. Moderate Resolution Imaging Spectrometer (MODIS)**

Laboratory personnel in Code 613.2 are responsible for the MODIS Level-2 (pixel-level) cloud optical properties and aerosol algorithms, and all Level-3 1° gridded MODIS Atmosphere Team statistical products (daily, eight-day, monthly). Over the past year, an updated processing stream (referred to as “Collection 5.1”) was completed 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. MODIS Terra 5.1 processing is expected to begin soon. The algorithm teams are currently working on refinements and enhancements that will be part of the Collection 6 processing stream, planned to be ready for production in early 2011.

While the MODIS Level-2 and Level -3 algorithm efforts mentioned above are being re-competed through the ROSES 2009 A.41 solicitation, the Terra and Aqua missions were approved in Fall 2009 for extended mission operations via the 2009 Senior Review process. The Senior Review budget provides for MODIS data production and archiving.

All MODIS products are available on-line from the Level-1B and Atmosphere Archive and Distribution System (<http://ladsweb.nascom.nasa.gov>), also located at Goddard (Code 614). Further information, including documentation and browse imagery, is available from the MODIS Atmosphere Team Web site (<http://modis-atmos.gsfc.nasa.gov>), or contact the following people: Steven Platnick (cloud optical proper-



ties, Level-3 products, MODIS Atmosphere Team Lead) (Steven.e.platnick@nasa.gov), (301) 614-6243); Lorraine Remer (aerosol dark target algorithm) (lorraine.a.remer@nasa.gov) (301) 614-6194); and Christina Hsu (deep blue aerosol algorithm) (christina.hsu@nasa.gov) (301) 614-5554).

#### 4.4.4. 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). Most MPLNET sites are collocated 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 obtained online at <http://mplnet.gsfc.nasa.gov>. For questions on the MPLNET project, contact Judd Welton (Judd.Welton@nasa.gov), (301) 614-6279.

#### 4.4.5. TOVS Pathfinder and AIRS Climate Sets

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 TIROS Operational Vertical Sounder TOVS. TOVS is composed of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 until April 2005, when NOAA-14 stopped transmitting data. We used an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The TOVS Pathfinder Path A data set covers the period 1979–2004 and consists of 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 have demonstrated with the 25-year TOVS Pathfinder Path A data set that TOVS data can be used to study interannual variability, trends of surface and atmospheric temperatures, humidity, cloudiness, OLR, and precipitation. The TOVS precipitation data have been incorporated in the monthly and daily GPCP precipitation data sets. We have also developed the methodology used by the AIRS science team to generate products from AIRS for weather and climate studies, and continue to improve the AIRS science team retrieval algorithm. The AIRS Science Team algorithm Version 5.0 is now operational at the Goddard 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 Goddard DISC has generated spot-by-spot AIRS Level-2 soundings, beginning September 2002, using Version 5 of the AIRS science team retrieval algorithm; and it 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–March 2010, can be used to extend the TOVS 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 NCEP and ECMWF. For further information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

### 4.4.6. TOMS and OMI Data Sets

The Atmospheric Chemistry and Dynamics Branch makes periodic ozone assessments. This work has resulted in a number of ozone and related data sets based on the OMI and TOMS instruments. OMI data are given as daily files of total column ozone, reflectivity, aerosol index, and erythral UV flux at the ground. The Nimbus-7, Meteor-3, and Earth Probe TOMS data sets were all processed using the Version 8 algorithm. These data sets are described on the Atmospheric Chemistry and Dynamics Branch Web site, which is available through the Laboratory Web site, <http://atmospheres.gsfc.nasa.gov/>. Select the Code 613.3 Branch site, and then click on “Data Services”. The TOMS spacecraft and data sets are then found by clicking on “TOMS Total Ozone” data. Alternatively, TOMS data can be accessed directly from <http://toms.gsfc.nasa.gov>. For further information please contact Stacey Frith (stacey.m.frith@nasa.gov), (301) 614-5984.

### 4.4.7. Sulfur Dioxide, SO<sub>2</sub>

Sulfur dioxide (SO<sub>2</sub>) is a short-lived atmospheric pollutant that is produced primarily by volcanoes, power plants, refinery emissions and burning of fossil fuels. Where SO<sub>2</sub> remains near the Earth’s surface, it has detrimental health and acidifying effects. Emitted SO<sub>2</sub> is soon converted to sulfate aerosol that reflects solar radiation cooling climate. Since October 2004 Ozone Monitoring Instrument (OMI) on NASA Aura produces global daily column SO<sub>2</sub> data archived Goddard Earth Sciences (GES) Data and Information Services Center (DISC). [http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omso2g\\_v003.shtml](http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omso2g_v003.shtml)

OMI near-real-time SO<sub>2</sub> images, within three hours of the Aura overpass, can be seen at NOAA Web site: <http://satapsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html>. Archived daily OMI SO<sub>2</sub> images are available from UMBC site: <http://so2.umbc.edu/omi/>. For further information please contact Nickolay Krotkov (nickley.a.krotkov@nasa.gov), (301) 614-5553.

Key publications on OMI operational SO<sub>2</sub> data and algorithms:

- Krotkov, N. A., S. A. Carn, A.J. Krueger, P.K. Bhartia, K. Yang, Band residual difference algorithm for retrieval of SO<sub>2</sub> from the AURA Ozone Monitoring Instrument (OMI), *IEEE Transactions on Geoscience and Remote Sensing, AURA special issue*, 44(5), 1259-1266, doi:10.1109/TGRS.2005.861932, 2006
- Yang, K., N.A. Krotkov, A.J. Krueger, S.A. Carn, P.K. Bhartia, P.F. Levelt (2007). Retrieval of large volcanic SO<sub>2</sub> columns from the Aura Ozone Monitoring Instrument (OMI): comparison and limitations. *J. Geophys. Res.*, 112, D24S43, doi:10.1029/2007JD008825.
- Krotkov, N. A., B. McClure, R.R. Dickerson, S.A. Carn, C. Li, P.K. Bhartia, K. Yang, A.J. Krueger, Z. Li, P. Levelt, H. Chen, P. Wang, and D.R. Lu (2008), Validation of SO<sub>2</sub> retrievals from the Ozone Monitoring Instrument over NE China, *J. Geophys. Res.*, 113, D16S40, doi:10.1029/2007JD008818.
- Lee, C., R. V. Martin, A. van Donkelaar, G. O’Byrne, N. Krotkov, A. Richter, L. G. Huey, and J. S. Holloway (2009), Retrieval of vertical columns of sulfur dioxide from SCIAMACHY and OMI: Air mass factor algorithm development, validation, and error analysis, *J. Geophys. Res.*, 114, D22303, doi:10.1029/2009JD012123.

#### 4.4.8. SHADOZ

The Southern Hemisphere Additional OZonesondes (SHADOZ) is a project to augment and archive balloon-borne ozonesonde launches from tropical and subtropical operational sites. The project was initiated in 1998 by NASA's Goddard Space Flight Center and involves United States and international coinvestigator. The collective data set provides the first profile climatology of tropical ozone in the equatorial region, enhances validation studies aimed at improving satellite remote sensing techniques for tropical ozone estimations, and serves as an educational tool for students, especially in the participating countries. As a flexible archive, SHADOZ has grown and evolved as scientific needs and research questioned change.

Data are collected and available publicly at the SHADOZ official Web site: <http://croc.gsfc.nasa.gov/shadoz>. For more information, contact the Principal Investigator: Anne M. Thompson ([anne@met.psu.edu](mailto:anne@met.psu.edu)) or Jacquelyn Witte ([Jacquelyn.C.Witte@nasa.gov](mailto:Jacquelyn.C.Witte@nasa.gov)), (301) 614-5591.

##### Publications:

Thompson, A.M., J.C. Witte, R.D. McPeters, S.J. Oltmans, F.J. Schmidlin, J.A. Logan, M. Fujiwara, V.W.J.H. Kirchhoff, F. Posny, G.J.R. Coetzee, B. Hoegger, S. Kawakami, T. Ogawa, B.J. Johnson, H. Vömel and G. Labow, Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2000 tropical ozone climatology 1. Comparison with Total Ozone Mapping Spectrometer (TOMS) and ground-based measurements, *J. Geophys. Res.*, Vol. 108 No. D2, 8238, doi: 10.1029/2001JD000967, 30 January 2003.

#### 4.4.9. Tropospheric O<sub>3</sub> Data

Measurements from the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) on board 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 Total Ozone Mapping Spectrometer (TOMS) Web page <http://toms.gsfc.nasa.gov>. The Web site also provides long time records of both tropospheric and stratospheric ozone in the tropics for the period January 1979 through December 2005. For more information, please contact Jerry Ziemke ([Jerald.R.Ziemke@nasa.gov](mailto:Jerald.R.Ziemke@nasa.gov)), (301) 614-6034, the Principal Investigator on the American OMI science team for developing tropospheric ozone products.

##### Publications:

Ziemke, J. R., J. Joiner, S. Chandra, P. K. Bhartia, A. Vasilkov, D. P. Haffner, K. Yang, M. R. Schoeberl, L. Froidevaux, and P. F. Levelt, Ozone mixing ratios inside tropical deep convective clouds from OMI satellite measurements, *Atmos. Chem. Phys.*, 9, 573-583, 2009.

#### 4.4.10. Composite Solar Spectral Ultraviolet Irradiance Data Set/SORCE

A composite solar spectral ultraviolet irradiance data set, representing the longest continuous record of solar UV irradiance observations, is now available for general use. This data set is available at the LASP Interactive Solar Irradiance Datacenter (LISIRD) Web site ([http://lasp.colorado.edu/lisird/deland\\_composite.html](http://lasp.colorado.edu/lisird/deland_composite.html)). A complete discussion of the creation process has been recently published:

DeLand and Cebula, *J. Geophys. Res.*, 113, A11103, doi:10.1029/2008JA013401, 2008

For more information, please contact Matt DeLand ([matthew.deland@ssaihq.com](mailto:matthew.deland@ssaihq.com)), (301) 867-2164.

**4.4.11. CRM Merge Product**

The CRM (CPL-Radar-MAS) Merge product was developed at GSFC's Lab of Atmosphere to collocate and fuse ER-2 aircraft data from the Cloud Physics Lidar (CPL), the Cloud Radar System (CRS), and the MODIS Airborne Simulator (MAS). The product has been successfully created for the TC4 field experiment in HDF format. Future plans call for the product to be created for the CLASIC07, CCVEx, and CRYSTAL-FACE field experiments. The nadir pointing lidar profiles complement similar radar reflectivity measurements and together have shown their utility for obtaining accurate vertical cloud and aerosol distribution statistics throughout the troposphere. Cloud radar can easily penetrate dense convective clouds and detect clouds composed of large ice crystals, both of which fully attenuate the lidar signal. On the other hand, backscatter lidars are highly sensitive to optically thin cirrus and aerosol layers that cloud radar cannot detect.

Furthermore, knowledge of the overlap region where lidar and radar signals overlap plus the passive upwelling radiation retrievals from MAS are important for particle size and cloud microphysical properties calculations. Both fundamental and enhanced parameters of the atmospheric column from each instrument make up the product and are calculated each second (~200 m along track) for the nadir view. Parameters included in the combined data file include: reflectance, brightness temperature, cloud fraction, layer and column optical depth, effective radius, cloud top pressure, cloud top temperature, cloud thermodynamic phase, layer top and bottom heights of all layers (aerosol and cloud), layer type and characterization, attenuated backscatter profile, particulate backscatter profile, extinction profile, radar reflectivity profile, and Doppler velocity profile. The data will eventually be archived on the CPL Web site (<http://cpl.gsfc.nasa.gov>), however Dennis Hlavka ([Dennis.L.Hlavka@nasa.gov](mailto:Dennis.L.Hlavka@nasa.gov)), (301) 614-6278, is currently the point of contact for access to the data files.

**4.4.12. EDOP/CRS**

Data is archived from the ER-2 Doppler Radar (EDOP) and the Cloud Radar System (CRS) from various hurricane, convection, and atmospheric radiation field campaigns (<http://har.gsfc.nasa.gov>) ranging back to 1995, with the most recent being TC4 in 2007. The archive contains quick look images from these campaigns, and ASCII data sets containing reflectivity and Doppler velocity measurements. Higher resolution binary data sets of radar reflectivity and Doppler velocity are available on request from G. Heymsfield ([gerald.heymsfield@nasa.gov](mailto:gerald.heymsfield@nasa.gov)), (301) 614-6369.

**4.4.13. Raman Lidar**

Raman lidars have been involved in a large number of field campaigns supporting NASA objectives. For access to data, please contact David Whiteman ([david.n.whiteman@nasa.gov](mailto:david.n.whiteman@nasa.gov)), (301) 614-6703.

**4.4.14. MISR Aerosol Product**

Laboratory personnel in Code 613.2 are partly responsible for the MISR aerosol products, including a leadership role in aerosol product validation, the Research aerosol retrieval algorithm, many applications, and outreach to the wider community. Over the past year, the full 10-year MISR aerosol data product record has been made available with a uniform version of the algorithm (Version 22), and further upgrades are under study, including refined aerosol type retrievals and better optical depth performance at very low and very high aerosol optical depth. Another upgrade under consideration is a regional, higher-resolution aerosol product (the Standard aerosol product is reported at 17.6 km resolution, whereas the radiance

pixel size is between 275 m and 1.1 km). Applications to dust transport, wildfire smoke injection, and air quality are being pursued, taking advantage of MISR's strengths at: (1) aerosol retrievals over bright surfaces, including desert (though not snow and ice); (2) aerosol type (a combination of particle size, shape, and single-scattering albedo constraints); and (3) ability to retrieve aerosol plume height near sources using stereo imaging.

All MISR products, along with documentation, browse imagery, and data analysis tools, are available online from the Atmospheric Science Data Center (ASDC) at NASA Langley (<http://eosweb.larc.nasa.gov>). The GSFC contact for MISR aerosol product science-related questions is Ralph Kahn ([ralph.kahn@nasa.gov](mailto:ralph.kahn@nasa.gov)), (301) 614-6193. Questions about data access and handling should be directed to the Langley ASDC User Services group ([larc@eos.nasa.gov](mailto:larc@eos.nasa.gov)).

#### 4.4.15. TSI

The Total Solar Irradiance (TSI) dataset consists of daily and 6-hourly measurements of top-of-atmosphere TSI based on the Total Irradiance Monitor (TIM) instrument onboard SORCE. These observations indicate a solar constant several W/m<sup>2</sup> smaller than previous measurements. Earlier measurements were less reliable, for reasons discussed in the SORCE summary section. For further information please contact Robert Cahalan ([robert.f.calahan@nasa.gov](mailto:robert.f.calahan@nasa.gov)), (301) 614-5390.

#### 4.4.16. Spectral Solar Irradiance

The SORCE SOLSTICE, SIM, and XPS instruments together provide measurements of the full-disk Solar Spectral Irradiance (SSI) from 0.1 nm to 2400 nm (excluding 34 to 115 nm, which is not covered by the SORCE instruments). The two SOLSTICE instruments measure spectral irradiance from 115 nm to 310 nm with a resolution of 1 nm, the SIM instrument measures spectral irradiance from 310 nm to 2400 nm with a resolution varying from 1 to 34 nm, and the XPS instrument measures six broadband samples from 0.1 to 34 nm and at Lyman-alpha (121.6 nm). Measurements from these instruments are combined into merged daily and 6-hourly\* spectra (\*6-hourly data is currently available for the XPS instrument only and may be available from the other spectral instruments in the future), each containing representative irradiances reported on a uniform wavelength scale, which varies from 1 to 34 nm over the entire spectral interval. Irradiances are reported at a mean solar distance of 1 astronomical unit (AU) with units of W/m<sup>2</sup>/nm.

For further information please contact Robert Cahalan ([robert.f.calahan@nasa.gov](mailto:robert.f.calahan@nasa.gov)), (301) 614-5390..

#### 4.4.17. NO<sub>2</sub>

The Laboratory continued data production for the OMI Nitrogen Dioxide (NO<sub>2</sub>) Data Product and released the Level-3 product to the GSFC DAAC for production and delivery. We are continuing the development of our Version 2 algorithm. The Laboratory will be using the latest GEOS-V based version of the combined stratosphere/troposphere model from the Global Modeling Initiative (GMI)

Western power plants are significant sources of NO<sub>2</sub>. These plants are often in isolated areas far from other sources. The plants also measure the amount of NO<sub>x</sub> emitted from their stacks. The plants can be used as calibration points for checking NO<sub>x</sub> emission methods. Figure 4.4 , below, shows the agreement

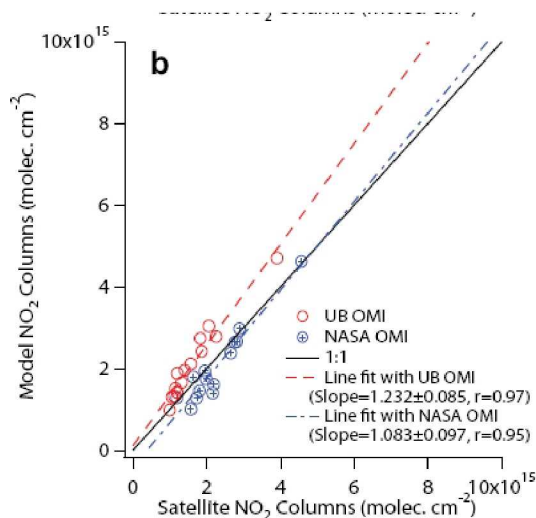


Figure 4.4: OMI measurements

between OMI  $\text{NO}_2$  measurements and a regional chemistry model using the measured stack emissions as input to the model. The agreement indicates some confidence in space based emission inventory techniques.

#### Publications:

$\text{NO}_2$  columns in the western United States observed from space and simulated by a regional chemistry model and their implications for  $\text{NO}_x$  emissions S.-W. Kim, A. Heckel, G. J. Frost, A. Richter, J. Gleason, J. P. Burrows, S. McKeen, E.-Y. Hsie, C. Granier, and M. Trainer, *J. Geophys. Res.*, VOL. 114, D11301, doi:10.1029/2008JD011343, 2009

#### 4.4.18. Earth Surface and Atmospheric Reflectivity ESDR Since 1979 from Multiple Satellites (TOMS, SBUV, SBUV-2, OMI, SeaWiFS, NPP, and NPOESS)

The new climate reflectivity product is based on the production of a continuous ultraviolet reflectivity data record for the surface of the Earth and its atmosphere using multiple satellite data records since 1979. The scene reflectivities of the Earth at blue and ultraviolet (UV) wavelengths (320 nm to 415 nm) are low over most surfaces (except ice and snow), and are almost independent of the seasonal changes in vegetation on land and in the oceans. This makes it ideal for examining changes in radiation reflected back to space from changes in cloud and aerosol amounts, especially as affected by the start of climate change. The ultraviolet reflectivity of the Earth's surface and atmosphere (clouds, aerosols, and Rayleigh scattering) has been accurately measured since the launch of Nimbus-7/TOMS and Nimbus-7/SBUV in October 1978. Gaps in the TOMS data record, most notably the period from 1993 to 1997, and the degrading calibration of Earth-Probe/TOMS (199–2006) after 1999, have made it necessary to join the data record from multiple satellites to produce a continuous climate quality Earth System Data Record (ESDR) quality data set.

The method is based on each satellite viewing the same long-term stable scenes for high reflectivity using Hudson Bay in the winter, and low reflectivity in the central Pacific Ocean and, again, Hudson Bay in the summer. The derived radiance calibration corrections and reprocessing need to be applied to the total existing and future reflectivity data sets to produce a unique long-term ESDR data record. We have combined Nimbus-7/TOMS (1978–1993), Earth-Probe/TOMS (1997–2006), Nimbus-7/SBUV (1978–1985), the NOAA series of SBUV-2 (1988–present), SeaWiFS (1997–present), and OMI

(2004–present), to produce a continuous record of scene reflectivity after removing atmospheric Rayleigh scattering. In addition, we have used OMI (270 to 500 nm in steps of 0.5 nm) to relate reflectivity in the UV wavelengths to reflectivity in the visible wavelengths. This has permitted us to join the higher spatial resolution (4 km) reflectivity data available from SeaWiFS (1997 to present) to obtain a continuous long-term UV reflectivity ESDR. The current reflectivity data record will be extended to include NPP (proposed launch in 2010-2011) followed by NPOESS. The resulting data, documentation, and software are freely available on NASA data servers via FTP bulk download and, for various subsets and images on <ftp://jwocky.gsfc.nasa.gov/pub/tmp/herman/measures>. For further information please contact Jay Herman ([jay.r.herman@nasa.gov](mailto:jay.r.herman@nasa.gov)), (301) 614-6039.

## 4.5. 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.

### 4.5.1. Aerosol and Atmospheric Water Cycle Interaction

Aerosol can influence the regional and global water cycles by changing the surface energy balance (direct effect), suppressing convection (semi-direct effect), and modifying cloud microphysics and rainfall (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 analyses of 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 (AMSR, CloudSat, MODIS, and TRMM) and atmospheric temperatures (MSU and AIRS), in conjunction with analysis of large scale circulation and moisture convergence in different climatic regions of the Earth. This includes the semi-arid regions of the southwestern United States, the Middle East, northern Africa, and central and western Asia. Field campaigns, including ground-based and airborne operations, that measure aerosol properties play an important role in this research.

Observations from satellite and field campaigns are being coordinated with numerical studies using global and regional climate models and cloud-resolving models coupled to land surface, vegetation, and ocean models. A major goal of this research activity is to develop a fully interactive Earth system model, including data assimilation, so that atmospheric water-cycle dynamics can be studied in a unified modeling and observational framework. Currently, the use of Multi-Model Framework (MMF), including the embedding of cloud-resolving models in global general circulation models, is being pursued. This research also calls for the organization and coordination of field campaigns for aerosol and water-cycle measurements in conjunction with the Global Energy and Water Cycle Experiment (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 2008–2012 Asian Monsoon Years (AMY) 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.

## MAJOR ACTIVITIES

Currently, Laboratory scientists are participating the JAMEX/RAJO-MEGHA (Radiation, Aerosol Joint Observations-Monsoon Experiment in the Gangetic-Himalayan Area; 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), Ralph Kahn (Ralph.A.Kahn@nasa.gov) Wei-Kuo Tao (Wei-Kuo.Tao-1@nasa.gov, (301) 614-6269.

### 4.5.2. 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 Scott Braun (scott.a.braun@nasa.gov).

### 4.5.3. 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 Scott Braun (scott.a.braun@nasa.gov).

### 4.5.4. Weekly Cycle

Aerosols (suspended particles in the atmosphere) are known to affect the way the atmosphere is heated and cooled and the way clouds behave as they form, and extensive research is being carried out determining how the climate is changed by aerosols, both natural and man-made. The effect of pollution on rainfall and storm behavior is of particular interest, since their impact on living conditions is so direct. Research by Dr. T. L. Bell and colleagues [Bell et al., 2008] found that average rainfall measured by the TRMM satellite changed with the day of the week in the summertime over the southeastern United States and that the changes were extremely unlikely to have happened by chance. The theory for these changes had already been developed by D. Rosenfeld and others: storms in hot, moist environments climb higher



and grow bigger in the presence of extra aerosol pollution, but the effect varies in strength depending on the atmospheric environment and the types of aerosols. Since these results were published, a number of new research results confirm the weekly changes in atmospheric behavior, including storm heights, wind patterns, cloud cover and cloud heights, and, just recently, lightning activity [Bell et al., 2009].

The figure gives an especially convincing example of how strong the effect is. Data for rainfall from satellite and lightning activity from ground-based equipment were analyzed for each summer, 1998–2009, over the Southeastern United States. The changes in activity with the day of the week were fit to a 7-day sinusoidal curve to estimate the day with maximum activity, and the colored balloons are placed in the sector corresponding to this maximum. (The distance from the origin is an indicator of the strength of the weekly cycle.) The last two digits of each year are given inside each balloon. For 12 summers in a row, maximum activity occurred during the work week, not on the weekends. More information can be found at <http://climate.gsfc.nasa.gov/viewImage.php?id=273>. For more information, contact Tom Bell, [thomas.l.bell@nasa.gov](mailto:thomas.l.bell@nasa.gov).

### Publications:

Bell, T. L., D. Rosenfeld, K.-M. Kim, J.-M. Yoo, M.-I. Lee, and M. Hahnenberger, 2008: Midweek increase in U.S. summer rain and storm heights suggests air pollution invigorates rainstorms. *J. Geophys. Res.*, 113, D02209, doi:10.1029/2007JD008623. (<http://climate.gsfc.nasa.gov/viewPaperAbstract.php?id=1096>)

Bell, T. L., D. Rosenfeld, and K.-M. Kim, 2009: The Weekly Cycle of Lightning: Evidence of Storm Invigoration by Pollution. *Geophys. Res. Lett.*, 36, L23805, doi:10.1029/2009GL040915. (<http://climate.gsfc.nasa.gov/viewPaperAbstract.php?id=1385>)

## 4.6. 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.

### 4.6.1. 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 2009, research topics involved in aerosol modeling include:

- Data analysis for the recent NASA aircraft campaign ARCTAS
- Global view of aerosol vertical distribution from model and CALIPSO data
- Possibilities and challenges in using satellite data for surface PM air quality
- Long-term trends of aerosols and effects on surface radiation
- Biomass burning aerosol emission, plume height, and transport

## MAJOR ACTIVITIES

- Seasonal and interannual variations of dust sources
- Light absorption by pollution, biomass burning, and dust aerosols
- Future satellite mission design (ACE, GEO-CAPE)

For more information, contact Mian Chin (mian.chin@nasa.gov), (301) 614-6007, 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), or Hongbin Yu (hongbin.yu@nasa.gov).

### Publications:

Chin, M., T. Diehl, O. Dubovik, T. F. Eck, B. N. Holben, A. Sinyuk, and D. G. Streets, Light absorption by pollution, dust and biomass burning aerosols: A global model study and evaluation with AERONET data, *Ann. Geophys.*, 27, 3439-3464, 2009.

Bian, H., M. Chin, S. R. Kawa, H. Yu, T. Diehl, Multi-scale carbon monoxide and aerosol correlations from MOPITT and MODIS satellite measurements and GOCART model: implication for their emissions and atmospheric evolutions, *J. Geophys. Res.*, in press, 2010.

Colarco, P. R., A. da Silva, M. Chin, T. Diehl: Online simulations of global aerosol distributions in the NASA GEOS-4 model and comparisons to satellite and ground-based aerosol optical depth, *J. Geophys. Res.*, accepted, 2010.

Yu, H., M. Chin, D. M. Winker, A. H. Omar, Z. Liu, C. Kittaka, and T. Diehl, Global view of aerosol vertical distributions from CALIPSO lidar measurements and GOCART simulations: Regional and seasonal variations, *J. Geophys. Res.*, accepted, 2010.

### 4.6.2. 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 Goddard Earth Observing System (GEOS) general circulation model and will use this to study the past and future coupling of the stratospheric ozone layer to climate. Our emphasis is on the testing of model processes and model simulations using data from satellites and ground-based measurement platforms. We have run simulations of the past starting in 1950 and have extended them into the future to the year 2100. We have recently run the 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 our updated Version 2 of GEOS CCM, coupled into a new version of the general circulation model, GEOS-5. The model ranked as one of the best CCMs in almost every evaluation done during CCMVal. We also now have Version 3, 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 is still being tested and improved. It has been coupled to an aerosol transport code (GOCART) developed by Mian Chin and colleagues at Goddard. This version of the model is now our basic tool for understanding the impact of stratospheric changes on tropospheric chemistry and climate.

The co-PIs are Richard Stolarski (Atmospheric Chemistry and Dynamics Branch) and Steven Pawson (Global Modeling and Assimilation Office). For further information, please contact Richard Stolarski (Richard.S.Stolarski@nasa.gov), (301) 614-5982, Steven Pawson (Steven.Pawson-1@nasa.gov), (301) 614-6159, or Anne Douglass (Anne.R.Douglass@nasa.gov) (301) 614-6028.

#### 4.6.3. 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, including 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 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.

The scientific output from the modeling activities was again exceptional in 2009 with more than 27 new papers published, in press or accepted. Additional details may be found in Chapter 5.4.3. For more information, contact Wei-Kuo Tao (Wei-Kuo.Tao.1@nasa.gov), (301) 614-6269. The web address for the Goddard Mesoscale Dynamic and Modeling group and multi-scale modeling system and its generated cloud library is: <http://portal.nccs.nasa.gov/cloudlibrary/index2.html>.

#### 4.6.4. Global Modeling Initiative (GMI)

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

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

The chemistry, wet and dry deposition, and emission components of GMI have been tested by comparison to ground-based, aircraft, and satellite data. This testing has given confidence to the use of these components in the Chemistry-Climate Model studies being carried out as a collaboration between the Atmospheric Chemistry and Dynamics Branch and the Global Modeling and Analysis Office. This model is being used for multi-year simulations that would examine the impact of climate change on atmospheric composition and vice versa, from the troposphere through the stratosphere. The GMI effort was repropose in ROSES 09, and was funded for four more years. This funding will primarily allow incorporation of new mechanisms in the GMI model for testing and eventual transfer to the Chemistry Climate Model. The GMI model has been used to study the impact of intercontinental transport of pollutants on air quality, and the impact of biomass burning events in Indonesia on ozone concentrations in the Pacific troposphere.

For more information, contact Jose Rodriguez (Jose.M.Rodriguez@nasa.gov), (301) 614-5736.

#### 4.6.5. Cloud Radiation Parameterization in Atmospheric GCM

Cloud and Radiation Parameterization in Global Climate Models (GCM) major impediments in the ability of GCMs to simulate realistic climate change are parameterizations related to cloud, aerosol and radiative processes, especially when all these elements interact. Our emphasis during the 2009 calendar year has been the implementation of cloud microphysical schemes that predict the number and size of (liquid and ice) cloud particles, the parameterizations of aerosol optical properties tailored for specific radiative transfer schemes, the study of the radiation budget effects of cloud heterogeneity, and the introduction of a new thermal infrared radiation scheme in GMAO's GEOS-5 modeling system. As part of the process of evaluating current and candidate GCM radiation schemes, laboratory scientist Lazaros Oreopoulos has deployed the Continual Intercomparison of Radiation Codes (CIRC), endorsed by the GEWEX Radiation Panel and the International Radiation Commission. For more information contact Lazaros Oreopoulos (Lazaros.Oreopoulos@nasa.gov), (301) 614-6128. Web sites: <http://circ.gsfc.nasa.gov> and <http://climate.gsfc.nasa.gov/research/modeling.php>

##### Publications:

- Oreopoulos, L., and E. Mlawer, 2009: The Continual Intercomparison of Radiation Codes (CIRC): Assessing anew the quality of GCM radiation algorithms. *Bull. Am. Met. Soc.* (In press)
- Oreopoulos, L., S. Platnick, G. Hong, P. Yang, and R. F. Cahalan, 2009: The shortwave radiative forcing bias of liquid and ice clouds from MODIS observations. *Atmos. Chem. Phys.* 9, 5865-5875.
- Sud, Y. C., E. M. Wilcox, K.-M. Lau, G. K. Walker, X.-H. Liu, A. Nenes, D. Lee, K.-M. Kim, Y. Zhou, and P. S. Bhattacharjee, 2009: Sensitivity of Boreal-Summer Circulation and Precipitation to Atmospheric Aerosols in Selected Regions, Part I: Africa and India. *Annales Geophysicae*, 27, 3989-4007.

#### 4.6.6. 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. Present effort centers on development and application of the coupled chemistry and climate model (CCM), a general circulation model (GCM) that includes a representation of photochemistry and in which changes in radiatively active gases feedback to the circulation through the radiative code. The CCM has two versions: the first includes a photochemical mechanism that is appropriate for the stratosphere; the second version couples The GCM with the GMI combined stratosphere/troposphere chemical mechanism. This nascent model is being used to investigate linkages among tropospheric composition, air quality and climate.

Simulated constituent fields exhibit many observed features. We have participated in an initiative called CCMVal sponsored by Stratospheric Processes and their Role in Climate (SPARC). CCMVal attempts to decrease uncertainty in prediction by developing tests of model performance based processes that have been identified using observations, and using these tests to evaluate and improve models. More information about the CCM, including a list of publications, can be found at the following Web site: <http://acdbext.gsfc.nasa.gov/Projects/GEOSCCM/index.html>

For more information, contact Anne Douglass. (Anne.R.Douglass@nasa.gov), (301) 614-6028.

#### 4.6.7. Influence of Solar Protons on the Stratosphere and Mesosphere

Certain large solar eruptive events led to significant fluxes of protons at the Earth, mostly connected with solar maximum time periods. The solar protons connected with these events created hydrogen- and nitrogen-containing compounds, which led to the polar ozone destruction. We have used the National Center for Atmospheric Research (NCAR) Whole Atmosphere Community Climate Model (WACCM) to study the short- to long-term (days to a few years) influence of solar protons between 1963 and 2004 on ozone. The four largest events in that time period (August 1972; October 1989; July 2000; and October–November 2003) caused very distinctive polar changes in the stratosphere (12–50 km) and mesosphere (50–90 km). Thus, solar protons need to be considered in understanding polar variations during years of strong solar activity. Our work is summarized in two publications [Jackman et al., 2008, 2009] and includes WACCM simulations and comparison with atmospheric measurements.

Solar proton fluxes are accessible at the NOAA Space Weather Prediction Center Web site: <http://www.swpc.noaa.gov/Data/goes.html>. The NCAR Whole Atmosphere Community Climate Model is a community model and is described at the Web site: <http://waccm.acd.ucar.edu/>. For further information please contact Charles Jackman ([charles.h.jackman@nasa.gov](mailto:charles.h.jackman@nasa.gov)), (301) 614-6053.

#### Publications:

Jackman, C. H., D. R. Marsh, F. M. Vitt, R. R. Garcia, E. L. Fleming, G. J. Labow, C. E. Randall, M. Lopez-Puertas, B. Funke, T. von Clarmann, and G. P. Stiller, Short- and medium-term atmospheric constituent effects of very large solar proton events, *Atmos. Chem. Phys.*, 8, 765–785, 2008.

Jackman, C. H., D. R. Marsh, F. M. Vitt, R. R. Garcia, C. E. Randall, E. L. Fleming, and S. M. Frith, Long-term middle atmospheric influences of very large solar proton events, *J. Geophys. Res.*, 114, D11304, doi:10.1029/2008JD011415, 2009.

#### 4.7. Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level manager—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 Scientist**

Project Scientists		Deputy Project Scientists	
Name	Project	Name	Project
Charles Jackman	AIM	Steve Platnick	Aqua
Ann Douglass	Aura	Warren Wiscombe	ARM
Steve Platnick	EOS (Acting)	Bryan Duncan	Aura
Dennis Chesters	GOES	Joanna Joiner	Aura
James Irons	LDCM	Alex Marshak	DSCOVR
James Gleason	NPP	Eric Wilcox	GLORY
Pawan K. Bhartia	OMI	Gail Jackson	GPM
Robert Cahalan	SORCE & TSIS	Christina Hsu	NPP
Scott Braun	TRMM	Si-Chee Tsay	Terra

## MAJOR ACTIVITIES

**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		
			Campaign/Instrument
		Tom McGee	WAVES 2009/AT Raman Lidar
			MOHAVE III
		Jay Herman	Trace Gas Measurements/ PANDORA and Cleo
		David Whiteman	WAVES 2009 MOHAVE III
		Si-Chee Tsay	2009 JAMEX/TIGERZ/ RAJO-MEGHA /SMART/COMMIT
	TRMM	Si-Chee Tsay	Terra
		Paul Newman	The Global Hawk Pacific Mission (GloPac)

### 4.8. Interactions with Scientific Organizations

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

#### 4.8.1. International Commission on Clouds and Precipitation (ICCP)

The International Commission on Clouds and Precipitation (ICCP) is a Commission of the International Association of Meteorology and Atmospheric Sciences (IAMAS). The IAMAS is one of the associations of the International Union of Geodesy and Geophysics (IUGG). The primary purpose of the ICCP is to stimulate scientific research in the area of Clouds and Precipitation through the organization of Germany in July 2012. Symposia are also organized at IAMAS Conferences and for the quadrennial IUGG General Assembly, next in Melbourne, Australia, in 2011. David Starr is currently the Secretary of ICCP. More information on the ICCP can be found at: <http://www.iccp-iamas.org/>. International conferences, workshops and symposia, and thereby encourage the transfer of scientific ideas to scientists throughout the world to facilitate international collaboration. The Commission is formed of elected experts from around the world. The Commission organizes the International Conference on Clouds and Precipitation, which is held every 4 years, last in Cancun, Mexico in July, 2008. The next conference is planned for Leipzig. For further information, contact David Starr (David.Starr@nasa.gov), (301) 614-6191.

#### 4.8.2. International Radiation Commission

In December 2008, IRC officers Robert Cahalan (NASA GSFC), Werner Schmutz (PMOD), and B.J. Sohn (Seoul National University) were elected to serve as President, Vice President, and Secretary, respectively, of the International Radiation Commission (IRC), oldest commission of the International Association of Meteorology and Atmospheric Sciences. They serve the IRC for a 4-year term, from 2008 through 2012. At present the IRC is composed of 42 members from 18 countries, including 21 new

members elected for the new term. These are identified on the new IRC Web site, [www.irc-iamas.org](http://www.irc-iamas.org). This new Web site allows members to login and update their personal and working group information, and to add news items to share with the community.

IRC is soliciting bids for the next radiation symposium, IRS-2012. Proposals for IRS-2012 will be presented to IRC in August 2010, at the next Annual IRC Business Meeting, to be held in conjunction with COSPAR, in Bremen, Germany. The 2011 IRC Business Meeting is planned to be held at IUGG-Melbourne in July, 2011.

At IAMAS MOCA-09 meeting, IRC sponsored sessions on aerosols, solar variability, and 3-dimensional radiative transfer; and is sponsoring similar sessions at IUGG 2011 (Melbourne, Australia). The International Radiation Symposium (IRS-2008) was held in Iguazu, Brazil, during August, 2008 with about 300 participants, including 34 students. The symposium was the first IRS held in the Southern Hemisphere in the long history of IRC (History of IRC 1896-2008 by H. J. Bolle is available for download at: <http://irc-iamas.org/resources/>.) The symposium had excellent presentations and active discussion on optical spectroscopy, scattering phenomena, radiative transfer, remote sensing, energy budget, application to numerical weather prediction and climate modeling, and aerosol-cloud-radiation interactions. The success of IRS-2008 has brought significant interaction between scientists as well as stimulation for students. Dr. Graeme Stephens, Dr. David Tobin, and Dr. Ilan Koren received the Gold Medal and Young Scientists Awards, respectively. Detailed information on the IRC symposia and business meetings are available from the IRC Web site. For further information please contact Robert Cahalan ([robert.f.cahalan@nasa.gov](mailto:robert.f.cahalan@nasa.gov)), (301) 614-5390.

#### 4.8.3. GLOBE

Global Learning and Observations to Benefit the Environment (GLOBE) is a worldwide, hands-on, primary and secondary school-based science and education program, which was announced in 1994 and began operations on Earth Day 1995 (<http://www.globe.gov>). GLOBE's Mission Statement is, *"To promote the teaching and learning of science, enhance environmental literacy and stewardship, and promote scientific discovery"*, and its vision is to create a *"worldwide community of students, teachers, scientists, and citizens working together to better understand, sustain, and improve Earth's environment at local, regional, and global scales."* As of the end of 2009, "the GLOBE network has grown to include representatives from 111 participating countries and 140 U.S. Partners coordinating GLOBE activities that are integrated into their local and regional communities. Due to their efforts, there are more than 50,000 GLOBE-trained teachers representing over 20,000 schools around the world. GLOBE students have contributed more than 20 million measurements to the GLOBE database for use in their "inquiry-based science projects".

Headquartered in Boulder, Colorado, GLOBE has started full scale planning activities for a worldwide Student Climate Research Campaign (SCRC) that will be launched in 2011. This is made possible through the harnessing of support from NASA, the NSF, and GLOBE's own vast network of partners and schools from the United States and around the world. NASA provides the funding support and dedicates the time of a few of its scientists, who actively provide their expertise to assist in the development of the scientific ideas and data to be used in the campaign. Presently, the NASA scientists coordinating this activity are: Charles Ichoku (GSFC/613.2), Robert Cahalan (GSFC/613.2), Charles Gatebe (GEST/UMBC/GSFC/613.2), and Lin Chambers (LaRC/E302). During the last few years, the NSF provided funding to various research groups to develop cutting edge research approaches for GLOBE in four main areas of the earth system sciences. GLOBE is integrating these NASA and NSF resources to develop a robust science

## MAJOR ACTIVITIES

curriculum for the student campaign, which will be implemented from 2011 to 2013 (2 years), with the aim of effectively creating a climate-literate society across the world. For more information, contact Dr. Charles Ichoku ([charles.m.ichoku@nasa.gov](mailto:charles.m.ichoku@nasa.gov)), (301) 614-6212.

### 4.8.4. WMO/UNEP Ozone Assessment

The Montreal Protocol is the international agreement that regulates substances that deplete the ozone layer. As part of that agreement, scientists write a report every four years that documents the science of ozone depletion and submit it to the Parties of the Montreal Protocol. GSFC scientists are now heavily involved with drafting the report, *Scientific Assessment of Ozone Depletion: 2010*. Dr. Paul A. Newman is the cochair the Science Assessment Panel to the Montreal Protocol and is one of the four scientists leading the overall assessment. Dr. Anne R. Douglass is the Coordinating Lead Author of Chapter 2 of the assessment: “Stratospheric Ozone and Surface Ultraviolet Radiation.” There are also a number of GSFC scientists who are authors, contributors, and reviewers of this assessment. For more information, contact Paul A. Newman (<http://acdb-ext.gsfc.nasa.gov/People/Newman/>), (301) 614-5985.

### 4.8.5. The Internal Ozone Commission

The International Ozone Commission (IO<sub>3</sub>C) was established in 1948 as one of the special commissions of the International Union of Geodesy and Geophysics, who represent the entire community of geophysical scientists around the world. The purpose of the IO<sub>3</sub>C is to help organize the study of ozone around the world, including ground-based and satellite measurement programs; and the analyses of the atmospheric chemistry and dynamic processes affecting ozone. The current president of the commission is Professor Christos Zerefos of Greece. The vice-president is Dr. Richard Stolarski of the NASA Goddard Space Flight Center and the current secretary is Dr. Sophie Godin-Beekman of CNRS in Paris, France. Membership in IO<sub>3</sub>C is limited to approximately 30 of the leading scientists in the study of atmospheric processes from around the world. Membership includes Drs. Anne Douglass, Paul Newman, and P.K. Bhartia, all part of the Atmospheric Chemistry and Dynamics Branch at Goddard. More information can be found at <http://ioc.atmos.uiuc.edu/>.

### 4.8.6. ACCRI

The Aviation Climate Change Research Initiative (ACCRI) was established by the FAA three years ago to address outstanding issues in our understanding of the impact of aviation on climate. Dr. Jose Rodriguez, from Code 613.3, has been a member of the Steering Committee since its inception. ACCRI funded a series of white papers to establish priorities for studies that would clarify our understanding of aviation impacts. Based on these white papers, ACCRI had a call for proposals in the Fall 2009. A proposal submitted by Dr. Henry Selkirk and associates in 613.3 was selected for funding; this proposal will use results from the coupled chemistry-climate model and observations to assess our knowledge of water vapor in the upper troposphere, a crucial element in our understanding of the formation of contrails and cirrus clouds due to aviation. Dr. Jose Rodriguez continues to serve in the ACCRI Advisory Committee, representing NASA. Information on ACCRI can be found at: [http://www.faa.gov/about/office\\_org/headquarters\\_offices/aep/aviation\\_climate/](http://www.faa.gov/about/office_org/headquarters_offices/aep/aviation_climate/).

### 4.8.7. U.S. Navy Fleet Numerical Meteorological and Oceanographic Center

The U.S. Navy Fleet Numerical Meteorological and Oceanographic Center announced the operational assimilation of the NASA MODIS aerosol optical thickness products used in Navy’s numerical weather, and aerosol forecasting. The assimilation was done using the Navy Variational Analysis Data Assimilation



System-Aerosol Optical Depth (NAVDAS-AOD) which combines corrected/filtered MODIS over-ocean AOD data with the 6-hour forecast from the Navy Aerosol Analysis and Prediction System (NAAPS). This is an excellent example of NASA earth science satellite products being used by another Federal agency, in a very successful research-to-operation transition. The NASA GSFC MODIS was acknowledged for “their extensive efforts developing the underlying Level-2 products.” The NASA Radiation Science, and the Applied Science Program are cosponsors of this effort.

#### **4.8.8. NOAA Cooperative Institute for Climate and Satellites**

A nationwide consortium led by University of Maryland (UMD) won a competition for a new NOAA supported Cooperative Institute for Climate and Satellites (CICS) that will receive up to \$93 million in funding over the next five years. PIs of the Cooperative Agreement Proposal are Phillip Arkin (UMD/CICS), Antonio Busalacchi (UMD/ESSIC) and Otis Brown (UMD/ESSIC). Bo-Wen Shen (Co-PI, UMD/ESSIC, 613.1), Wei-Kuo Tao (613.1, Collaborator), and Karen Mohr (613.1, Collaborator), who were invited to strengthen the modeling section, which lead the sub-project entitled: “Utilize NOAA Satellite Data to Validate and Advance the Regional and Global Forecast in Short-term (weather) and Seasonal (climate)”.

#### **4.8.9. AMES Airborne Tracking Sunphotometer**

Lorraine Remer (613.2) is collaborated with Phil Russell, Jens Redemann, and the AMES Airborne Tracking Sunphotometer (AATS) group for a period of 6 months (divided into three 2-month periods) to enhance research towards understanding atmospheric composition and the role of changing composition on climate. In particular, the proposed research program will facilitate definition of the *Decadal Survey* ACE mission polarimeter by assisting AMES personnel in defining the PODEX-2010 experiment and helping to bridge the gap between satellite aerosol remote sensing and the suborbital community.

### **4.9. Commercialization and Technology Transfer**

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



## 5. HIGHLIGHTS OF LABORATORY ACTIVITIES

### 5.1. Mesoscale Atmospheric Processes Branch, Code 613.1

The Mesoscale Atmospheric Processes Branch (MAPB) seeks to understand the contributions of meso-scale atmospheric processes to the global climate system. Research is conducted on the physical and dynamical properties, and on the structure and evolution of meteorological phenomena—ranging from synoptic scale down to micro-scales, with a strong focus on the initiation, development, and effects of cloud systems and precipitation. 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 clouds, precipitation, aerosols, water vapor, and winds. There are also world-class research activities in cloud system modeling, and in the analysis, application, and visualization of a variety of data. As of 31 December 2009, the MAPB consisted of 73 on-site personnel. Demographically: 13 civil service scientists (11 with PhDs and one currently enrolled in a PhD program). The Branch maintains Cooperative Agreements with four institutions (UMBC/GEST, UMBC/JCET, GMU, and UMCP/ESSIC), which collectively comprise 24 scientists and programmers (22 PhDs). Since 1990, the Branch has had a contractual relationship with SSAI of Lanham, MD, for scientific, engineering, computer and administrative support. Currently, there are 32 on-site SSAI personnel. The Branch Web site is <http://atmospheres.gsfc.nasa.gov/meso/>, where current information can be found on projects, instruments, field campaigns, publications, and personnel listings.

The TRMM Web site (<http://trmm.gsfc.nasa.gov/>) provides near-real-time precipitation estimations every three 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](http://trmm.gsfc.nasa.gov/publications_dir/multi_resource_tropical.html).

Another important Branch asset is the GOES Project Science Web site (<http://goes.gsfc.nasa.gov/>) that 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 GB/day to 46 thousand 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 Branch activities are described below in the areas of precipitation (and attendant climate-scale research), mission and instrument concept development, instrument systems development, and numerical modeling. Data analysis is a key aspect in each area.

#### 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. Twelve years of high quality TRMM data are now available through the Goddard DAAC. TRMM and other precipitation/latent heating data are used within the Branch for a wide spectrum of studies on precipitating cloud systems, the global water and energy cycles, and precipitation variability. These activities are well represented in our publication record (Appendix 2), also see the 2009 highlight articles by the following lead authors: Grecu, Han, Huffman, Liao, Matsui, and Mohr.

### **5.1.2. Mission and Instrument Concepts Development**

The Branch provides project scientists to assure the scientific integrity of mission definition, design, development, testing, operations, and data analysis phases of each mission. Branch scientists play a crucial role in the Global Precipitation Measurement (GPM) mission that is scheduled to launch in 2013. This involves (1) defining the science requirements for advanced instrument capabilities for measuring precipitation rates over both ocean and land from the Tropics to high-latitudes, (2) developing algorithms to retrieve precipitation information from active and passive microwave sensors, (3) planning and conducting ground validation field experiments to support pre-launch algorithm development and post-launch product validation, and (4) employing satellite precipitation data in scientific research and practical applications. In 2009 there were over 35 Laboratory scientists involved in GPM science activities. Dr. Arthur Hou, GPM Project Scientist, resides in the Branch; and Dr. Gail Jackson is the Deputy GPM Project Scientist.

Dr. Matt McGill recently became Instrument Scientist for the ICESat-2 mission (Tier-1 *Decadal Survey* mission) that is presently in formulation, and Dr. Judd Welton serves as Deputy Project Scientist for Glory that is scheduled to launch late in 2010. David Starr assumed the role of Aerosols, Clouds and Ecology (ACE) Science Study Lead toward the end of 2009. ACE is a Tier-2 *Decadal Survey* flagship-class mission nominally planned for late in the current decade. Branch scientists are involved as leaders or participants in four of the study groups supporting the science and payload requirements for the ACE mission. A report on the ACE mission plans will be completed in the coming year.

In 2009, Laboratory for Atmosphere's scientists made important strides in preparation for the Global 3-D Wind Mission in several areas. In the area of technology readiness, a major milestone was met in February 2009, with the completion of the Tropospheric Wind Lidar Technology Experiment (TWiLiTE) airborne Doppler lidar Instrument Incubator Project. This was followed in September by engineering flight tests of TWiLiTE on the NASA ER-2 high altitude research aircraft. Also in 2009, significant progress was made in the development of an advanced Observing System Simulation Experiment (OSSE) capability in the GSFC Global Modeling and Assimilation Office.

Dr. Scott Braun serves as the TRMM Project Scientist and leads the TRMM Science Team in close coordination with GPM. The TRMM Ground Validation Program continued to provide reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Dr. Dennis Chesters, GOES Project Scientist, supported the launch of GOES-O (renamed GOES-14 on orbit after its launch in 2009) and helped debug the new image broadcast format adopted by NOAA. Also in 2009, four of the scientific instruments for the next generation of GOES satellites, GOES-R and beyond (2015 launch and beyond), were reviewed at the critical design level, in order to approve them for construction and testing during the next three years.

### **5.1.3. Instrument Systems Development**

Development of lidar technology and application of lidar data for atmospheric measurements is a key areas of research in the Branch. 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 CALIPSO simulator (CPL), provides a powerful and unique airborne measurement

synergy within the Branch. CRS is being refurbished and should again be available for deployment in 2011. In addition, three new airborne instruments were essentially completed in 2009: UAV-CPL, HIWRAP, and TWiLiTE.

UAV-CPL was completed and prepared for the first science mission of NASA's Global Hawk scheduled for the Spring of 2010. UAV-CPL will be a critical component of the GloPac campaign in support of Aura validation. The CRM (CPL-Radar-MAS) merged data product was developed this year to collocate and fuse ER-2 aircraft data from the Cloud Physics Lidar (CPL), the Cloud Radar System (CRS), and the MODIS Airborne Simulator (MAS). The product was successfully created for the TC4 field experiment in HDF format. Future plans call for the product to be created for the CLASIC07, CCVEx, and CRYSTAL-FACE field experiments.

The 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. HIWRAP is envisioned as a key element of GPM validation. HIWRAP was completed in 2009, and integrated and test flown on NASA's WB57. It will be integrated on NASA's Global Hawk platform and flown in NASA's Genesis and Rapid Intensification Processes (GRIP) field campaign, which focuses on hurricanes in late summer of 2010.

In September 2009, the TWiLiTE (Tropospheric Wind Lidar Technology Experiment) direct detection Doppler lidar completed successful integration and engineering flight testing on the NASA ER-2 high altitude aircraft. The TWiLiTE Doppler lidar measures vertical profiles of wind by transmitting a short laser pulse into the atmosphere, collecting the laser light scattered back to the lidar by air molecules, and measuring the Doppler shifted frequency of that light. The magnitude of the Doppler shift is proportional to the wind speed of the air in the parcel scattering the laser light.

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 the long time periods required to contribute to climate change studies and provide ground validation for models and satellite sensors in the NASA Earth Observing System (EOS)\*. At present, there are eighteen active sites worldwide, and three more in the planning stage. Numerous temporary sites have been deployed in support of various field campaigns and two more are planned in 2010. Most sites are collocated 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>.

The Measurements of Humidity and Validation Experiments (MOHAVE-II) took place at the JPL's Table Mountain Facility (TMF) in Wrightwood, CA, using the ALVICE instrument to probe upper tropospheric and lower stratospheric water vapor. This activity supports the development of a robust Raman water vapor lidar measurement capability within the NASA-supported Network for the Detection of Atmospheric Composition Change (NDACC). Measurements and fruitful collaboration on measurement of water vapor and aerosols with scientists from Howard University (HU) continued at the HU Beltsville Research (HURB) site in 2009. In the summer of 2009, a wind lidar experiment was also completed at HURB. The goal of the experiment was to compare two of NASA's state-of-the-art wind lidar technology instruments, including GLOW, that are candidates for the NASA *Decadal Survey* 3-D wind experiment (Tier-3).

---

\*see the 2009 article by Campbell et al., highlighted in Appendix III

#### **5.1.4. 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 detailed report on this activity may be found in Section 5.4.3.

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. 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.

#### **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 II 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 and MISR algorithm development and data analysis, SORCE solar irradiance (both total and spectral) data analysis and modeling, and TRMM data analysis. See the section on Climate and Radiation Research Highlights for recent significant findings in these areas.

The Branch continues to serve in key leadership positions on international programs, panels, and committees. Robert Cahalan was elected President of the International Radiation Commission or IRC, for the term 2008 to 2012, succeeding Teriyuki Nakajima of University of Tokyo. Alexander Marshak chairs the IRC's 3-dimensional Radiative Transfer working group, and also leads the International Intercomparison of 3-dimensional Radiation Codes, or I3RC. Lazaros Oraiopoulos chairs the IRC's CIRC working group. Warren Wiscombe, on loan from NASA to DoE to be Chief Scientist of their ARM Program (ended October 2009), participated for most of 2009 in the creation of an expanded direction and a new Science Plan for ARM. ARM merged with DoE's aerosol-climate program to create a new program named ASR, Atmospheric Systems Research. The ASR program took, as its purview, the cycle beginning with aerosol precursors, going to aerosols, to clouds, to precipitation, and back to aerosols again. The big new item was the addition of precipitation. At the same time, ARM received \$60M in stimulus funds for new instruments and is spending roughly half of that on 18 new radars, including several precipitation radars, which promises to make ARM the largest deployer of cloud radars in the world.

Branch personnel continue to serve in key project positions. Robert Cahalan serves as project scientist of Solar Radiation and Climate Experiment (SORCE) launched on 25 January 2003. SORCE is measuring both Total Solar Irradiance (TSI) and Spectral Solar Irradiance (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, Total and Spectral solar Irradiance System (TSIS), due to be launched in 2014. It is 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 now serving as EOS Senior project scientist, following retirement of Michael D. King, who moved to University of Colorado's LASP in 2008.

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, SSAI) 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 GLOBE Student Research Campaign on Climate (SCRC) that 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, as well as Lin Chambers at LARC. (See <http://globe.gov>) NASA Scientists are assisting GLOBE prepare for the SCRC, which will be implemented worldwide between 2011 and 2013. This includes providing expertise on scientific approaches and data, developing the SCRC Planning Document jointly with GLOBE, writing science blogs posted on the GLOBE Web site, producing audio podcasts on scientific approaches for SCRC, responding to science questions from teachers online, outreach activities to encourage participation of schools in non-active regions, as well as participation of scientists.

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.

Characterization of multi-layer cloud scenes is important in characterizing the quality of passive cloud retrievals. The Collection 5 processing algorithm for the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the NASA Earth Observing System EOS Terra and Aqua spacecrafts includes an algorithm for detecting a particular type of multi-layer and/or multiphase cloud scene. Specifically, the algorithm is designed to detect those multi-layer scenes that would present difficulties for retrieving cloud effective radius using single layer plane-parallel cloud models. The algorithm uses the MODIS 0.94  $\mu\text{m}$  water vapor band along with  $\text{CO}_2$  bands to obtain two above-cloud precipitable water retrievals, the difference of which, in conjunction with additional tests, gives a map of multi-layer clouds. If a multi-layer

## HIGHLIGHTS

cloud is present, a large difference in retrievals of above-cloud properties between the CO<sub>2</sub> and the 0.94 μm methods can occur. A theoretical study of the algorithm behavior for simulated multi-layer clouds has been completed and compared to two other comparable passive imager codes (Wind et al., 2010). This theoretical study suggests that the MODIS multi-layer cloud detection algorithm performs well in identifying multi-layer cloud situations of the type mentioned above. A validation study using A-Train active sensors is on-going.

A description of the errors in solar radiation reflected by the planet when cloud variability is neglected in domains of a few thousand square miles is provided in a recent paper<sup>1</sup>. Using MODIS cloud retrievals that provide information on cloud variability within these domains, the differences (biases) between solar reflected flux for (assumed) homogeneous and (actual) heterogeneous clouds were computed. The global average of these biases was found to be at least as big as the additional amount of thermal energy that would be trapped if we were to double carbon dioxide from current concentrations, underscoring the important energetic effects of cloud heterogeneity. The geographical distribution of the biases at the time of satellite overpass was determined for clouds classified to be of liquid and ice phase by the MODIS algorithm. The patterns are distinctly different for the two cloud phases and mirror known patterns of different cloud types.

Cloud reflection enhances the brightness of nearby MODIS observations through a 3-D process. It is important to understand the causes of reflectance enhancements observed near clouds both for ensuring the accuracy of satellite-based aerosol measurements and for improving our knowledge of aerosol-cloud interactions. The enhancement is larger near illuminated than near shadowy cloud sides. The enhancement is stronger near thicker clouds, but only at the shorter wavelengths where 3-D effects can be effective. In addition to aerosol swelling, undetected clouds, and instrument blurring, 3-D radiative processes also play an important role in creating the observed enhancements and should be accounted for in satellite measurements of aerosol properties.<sup>2,3</sup>

Direct aerosol radiative effects (DARE, in units W/m<sup>2</sup>) is defined as the perturbation in radiative fluxes due to the presence of dust aerosols. Quantifying DARE is achieved by integrating the dust optical properties from AERI measurements into a broadband radiative transfer model. Longwave efficiency of DARE ( $F^-$ ) at the surface was studied for several dust cases during NAMMA. A strong linear dependence of DARE with dust aerosol optical thickness (AOT-t) is seen. Longwave DARE is estimated to be ~16 W/m<sup>2</sup> per unit dust AOT, which is about 42% of the diurnally averaged direct shortwave radiative effect (Haywood et al. 2003, Anderson et al. 2007) at the surface. This will partly offset the shortwave losses and is certainly non-negligible in the study of regional climate variation. In short, longwave DARE has important implications on modulating the heat and moisture surface budgets (IPCC, 2007), surface-air exchange processes, and ultimately the general circulation of the atmosphere (Lau et al. 2006).

The Himalayas have a profound effect on the South Asian climate and the regional hydrological cycle; as it forms a barrier for the strong monsoon winds, and serves as an elevated heat source, thus controlling the timing of the onset and distribution of precipitation during the Indian Summer Monsoon. Recent studies have suggested that radiative heating by absorbing aerosols, such as dust and black carbon in northern

---

<sup>1</sup>Oreopoulos, L., S. Platnick, G. Hong, P. Yang, and R. F. Cahalan, 2009: The shortwave radiative forcing bias of liquid and ice clouds from MODIS observations. *Atmos. Chem. Phys.* 9, 5865-5875.

<sup>2</sup>Várnai, T., and A. Marshak, 2009: MODIS observations of enhanced clear sky reflectance near clouds. *Geophys. Res. Lett.*, 36, L06807, doi:10.1029/2008GL037089;

<sup>3</sup>Wen, G., A. Marshak, and R. F. Cahalan, 2008: Importance of molecular Rayleigh scattering in the enhancement of clear sky radiance in the vicinity of boundary layer cumulus clouds. *J. Geophys. Res.*, 113, D24207, doi:10.1029/2008JD010592.)



India, over the Indo-Gangetic Plains and foothills/slopes of the Himalayas, may significantly accelerate the seasonal warming of the Himalayas-Tibetan Plateau, and influence the subsequent evolution of the summer monsoon. Characterization of spatial and vertical distribution of aerosols is critical to the understanding of the associated radiative effects and impacts on monsoon circulation in this region. The enhanced pre-monsoon (April–May) aerosol loading over northern India and the Thar Desert is mapped from the operational MODIS aerosol optical depth products and overlaid on the topography to highlight the aerosol loading along the slopes of the Himalayas. Based on the CALIOP derived depolarization ratio, it is found that the bulk of the regional aerosol loading over northern India is comprised of non-spherical particulates (such as dust and soot). Pre-monsoon aerosol loading extends to elevated altitudes over northern India with peak altitude of ~5.5 km as indicated by CALIOP observations during April–May 2008.

The Multi-angle Imaging SpectroRadiometer (MISR) and MODerate resolution Imaging Spectroradiometer (MODIS) instruments aboard the NASA Earth Observing System's Terra satellite both report aerosol optical depth (AOD), globally. This quantity is a key climate variable, as aerosol direct radiative forcing and indirect impacts on clouds contribute to the global climate-change picture, in addition to the warming effect of increasing atmospheric greenhouse gas concentrations. As such, identifying the strengths and limitations of the MISR and MODIS AOD products, and assessing their overall quality, are essential steps in the climate change application.

Density scatter plots were made to compare coincident MISR and MODIS AOD retrieval results over water and land, respectively, for the entire globe during all of January 2006. The vast majority of points lie along the 1:1 line, and the correlation coefficients are high—0.9 over water, and 0.7 over land. Artifacts and algorithmic differences are also evident, such as quantization noise in the MISR over-water retrievals that appears as horizontal striping in the upper left plot, and negative AOD values allowed by the MODIS algorithm over land in the upper right plot.

Three clusters of outliers are also found in the over-land scatter plot. These are traced geographically to specific, known retrieval issues: (1) mixtures of spherical absorbing smoke particles with non-spherical desert dust in North Africa, (2) strongly absorbing pollution particles in the Indo-Gangetic plain in north India, and (3) unscreened bright surfaces in the MODIS retrievals over Patagonia and north-central Australia. These artifacts represent a tiny fraction of all retrievals; the MISR and MODIS teams are developing algorithm upgrades, based on these assessments and comparisons with coincident field campaign and network ground-truth observations.<sup>4</sup>

Recent observations show a link between geology (volcanic activity) and atmospheric chemistry (tropospheric ozone production) through aerosol effects in clouds. In a region east of the Philippines, Remer and collaborators see an anomalous enhancement in 2005 of aerosol particles, lightning flashes, and tropospheric ozone as observed by the MODIS, TRMM and OMI satellite sensors, respectively. The enhanced particles are due to volcanic activity on Guam. The particles alter convective cloud properties, extending the mixed phase and produce more lightning. Lightning is associated with NO<sub>x</sub> production that can result in enhanced ozone, a greenhouse gas. Thus, we are seeing a source of climate warming in the otherwise pristine ocean, and the key to this feature are the processes between aerosols and clouds (Yuan et al, submitted).

<sup>4</sup>(Kahn, R.A., D.L. Nelson, M. Garay, R.C. Levy, M.A. Bull, D.J. Diner, J.V. Martonchik, S.R. Paradise, E.G. Hansen, and L.A. Remer, 2009. MISR Aerosol product attributes, and statistical comparisons with MODIS. *IEEE Trans. Geosci. Remt. Sens.*, 4095-4114.)

**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 Radiometer (AVHRR) on POES, MODIS on EOS Terra and Aqua, and the Aerosol Polarimetric Sensor (APS) on Glory, as well as from modeling. The branch also is a leader in the integration and execution of the NPP and NPOESS missions.

The data record of the Earth's ozone shield 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 December 2009. The data, and information about how they were constructed, can be found at [http://acdb-ext.gsfc.nasa.gov/Data\\_services/merged/](http://acdb-ext.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).

The Branch has deployed advanced instrument and algorithm capability for ground-based validation of OMI satellite aerosol, NO<sub>2</sub>, SO<sub>2</sub>, and O<sub>3</sub> data. A lot of work this past year has concentrated on sulfur dioxide (SO<sub>2</sub>). Sulfur dioxide is a short-lived atmospheric pollutant that is produced primarily by volcanoes, power plants, refinery emissions and burning of fossil fuels. Where SO<sub>2</sub> remains near the Earth's surface, it has detrimental health and acidifying effects. Emitted SO<sub>2</sub> is soon converted to sulfate aerosol that reflects solar radiation cooling climate. Since October 2004 the Ozone Monitoring Instrument (OMI) on NASA Aura produces global daily column SO<sub>2</sub>. The data is archived at the Goddard Earth Sciences (GES) Data and Information Services Center, (DISC) [http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omso2g\\_v003.shtml](http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omso2g_v003.shtml). OMI Near-real-time SO<sub>2</sub> images within three hours of the Aura overpass can be seen at NOAA Web site: <http://satapsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.htm>. Archived daily OMI SO<sub>2</sub> images are available from UMBC site: <http://so2.umbc.edu/omi/>. The SO<sub>2</sub> data has been extremely useful in monitoring volcanic eruptions, and even individual power plants.

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. The OMI UV cloud algorithm retrieves an optical centroid pressure from the filling in of solar Fraunhofer lines in the ultraviolet due to rotational Raman scattering of air molecules. This pressure is used in some of the OMI trace-gas retrieval algorithms as well as for other applications such as the detection of multi-layer clouds in conjunction with MODIS cloud top pressure. Data and further information can be found in the following Web site: [http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omclrr\\_v003.shtml](http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omclrr_v003.shtml).

The reflectivity data from TOMS, SBUV, SBUV-2, OMI, and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) have been combined and posted to a Web site as a preliminary long-term data set. A number of calibration problems between the various satellites have been detected. The project is now working on correcting the inherent errors in the satellite data sets.

Measurements from the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) on board 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 Total Ozone Mapping Spectrometer (TOMS) Web site: <http://toms.gsfc.nasa.gov>. The Web site also provides long time records of both tropospheric and stratospheric ozone in the tropics for the period January 1979 through December 2005. An example of the application of this data base to develop an Ozone Enso Index is highlighted in page 61. For more information, please contact Jerry Ziemke (Jerald.R.Ziemke@nasa.gov) who is the Principal Investigator on the American OMI science team for developing tropospheric ozone products.

The Global Modeling Initiative was initiated under the auspices of the Atmospheric Effects of Aviation Program in 1995. The chemistry, wet and dry deposition, and emission components of GMI have been tested by comparison to ground-based, aircraft, and satellite data. This testing has given confidence to the use of these components in the Chemistry-Climate Model studies being carried out as a collaboration between the Atmospheric Chemistry and Dynamics Branch and the Global Modeling and Analysis Office (see below). The GMI effort was repropose in ROSES 09, and was funded for four more years. This funding will primarily allow incorporation of new mechanisms in the GMI model for testing and eventual transfer to the Chemistry Climate Model. The GMI model has also been used to study the long-range transport of pollutants, transport processes in the upper troposphere/lower stratosphere, and mechanisms for isoprene emissions.

Present efforts in chemistry/climate coupling center on development and application of the coupled chemistry and climate model (CCM), a general circulation model (GCM) that includes a representation of photochemistry and in which changes in radiatively active gases feedback to the circulation through the radiative code. Simulated constituent fields exhibit many observed features. We have participated in an initiative called CCM Val sponsored by Stratospheric Processes and their Role in Climate (SPARC). CCM Val attempts to decrease uncertainty in prediction by developing tests of model performance based processes that have been identified using observations, and using these tests to evaluate and improve models. The Goddard CCM ranked among one of the best in this comparison. The model also incorporates tropospheric chemistry and aerosols. The use of this model to simulate the stratosphere in the post-CFC era is highlighted in page 60. More information about the CCM, including a list of publications, can be found at the following Web site: <http://acdbext.gsfc.nasa.gov/Projects/GEOSCCM/index.html>. For more information, contact Anne Douglass (Anne.R.Douglass@nasa.gov), Richard Stolarski (Richard.S.Stolarski@nasa.gov, or Steven Pawson (Steven.Pawson-1@nasa.gov).

Finally, branch members are active in the formulation of *Decadal Survey* missions (GEOCAPE, ACE, GACM), and non-*Decadal Survey* missions (CASS). They are also leaders in the integration of the GloPac (Global Hawk Pacific) mission, which will utilize the Global Hawk UAV. The branch also serves in the advisory board and participates in the FAA Aviation Climate Change Research Initiative (ACCRI). Details on the above activities are given on page 53.

## 5.4. Additional Research Highlights

### 5.4.1. Stratospheric Ozone in the post-CFC era.

The expected recovery of ozone during the 21<sup>st</sup> century will be determined not only by the decrease in ozone-depleting substances (primarily CFCs), but also by the impact of climate change on the temperature and circulation of the stratosphere. Current models predict a cooling of the stratosphere, and a strengthening of the stratospheric residual circulation.

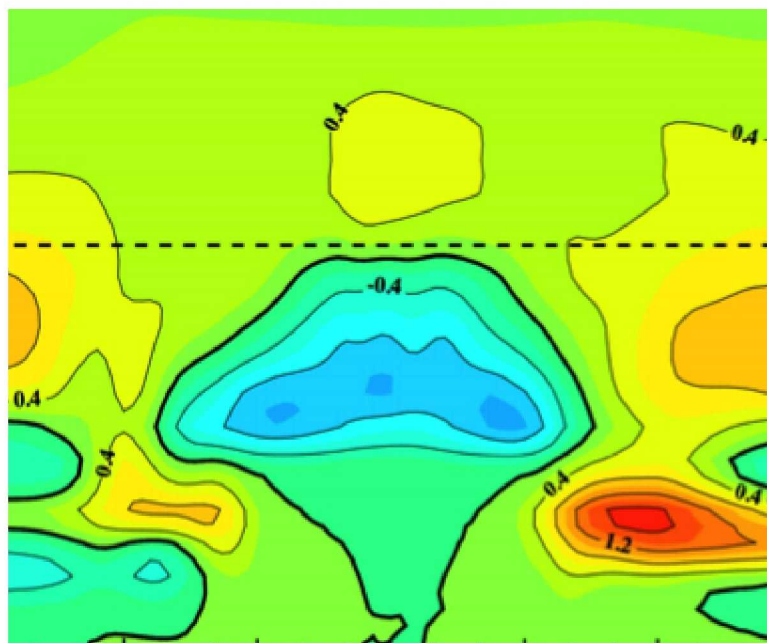


Figure 5.1: Change in ozone as a function of altitude, between 2065 and 1965, as calculated by the Goddard Coupled Chemistry Climate Model (GEOS CCM).

The Goddard Coupled Chemistry-Climate Model (GEOS CCM) has been used to predict the ozone change in the 21<sup>st</sup> century. Figures 5.1 and 5.2 show the change in ozone calculated for the year 2065 (when stratospheric chlorine levels are expected to have recovered to natural levels) and 1965. Both of these years have similar stratospheric chlorine and bromine. However, Figures 5.1 and 5.2 show that the ozone in 2065 is different from 1965.

Figure 5.1 shows the annual average ozone difference between 2065 and 1965, as a function of altitude. The figure shows an increase in ozone relative to 1965 at mid-latitudes. This “super recovery” is primarily a consequence of the cooling of the stratosphere. The ozone-destroying catalytic processes are temperature-dependent, and slower at lower temperatures, thus resulting in higher levels of ozone.

On the other hand, ozone in the tropics decreases relative to 1965. This “sub-recovery” is a consequence of the acceleration of the residual circulation, with stronger upwelling in the tropics, which brings low ozone air into higher levels in the lower stratosphere.

The impact of the super- and sub-recovery of ozone on total column densities of ozone is shown in Figure 5.2. This figure shows an increase in column ozone in the upper stratosphere for all latitudes, and an increase in the lower stratosphere at mid-latitudes. These results in a net increase in column ozone at mid-latitudes. However, the small contribution from the upper stratospheric ozone increase is not enough to counteract the decrease in lower stratospheric ozone shown in Figure 5.2, due to strengthening of the Brewer-Dobson Circulation. Thus, we also see a “sub-recovery” of column ozone in the tropics, and a “super-recovery” at mid-latitudes. This would imply lower UV levels at mid-latitudes, and higher in the tropics.

These results have appeared in: Feng Li, Rich Stolarski, and Paul A. Newman(2009) Stratospheric ozone in the post-CFC era . *Atmos. Chem. Phys.*, 9, 2207–2213, [www.atmos-chem-phys.net/9/2207/2009/](http://www.atmos-chem-phys.net/9/2207/2009/)

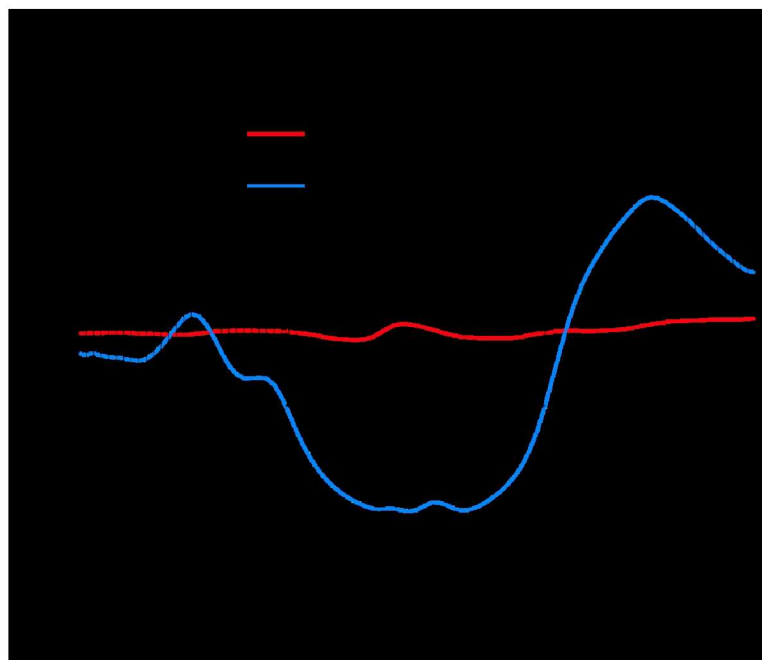


Figure 5.2: Change in total ozone column in the upper stratosphere (red), lower stratosphere (blue), and total ozone column (black) between 2065 and 1965, as calculated by the Goddard Coupled Chemistry Climate Model (GEOS CCM)

#### 5.4.2. A New Ozone ENSO Index (OEI) Derived from Satellite Measurements of Tropospheric Ozone

Total tropospheric ozone column can be deduced from total column measurements of ozone from TOMS and OMI, and stratospheric column ozone deduced from SBUV and MLS (Aura). Analysis of the column ozone in the Western and Eastern Pacific from 1979 and 2009 indicate a “dipole” structure in column ozone, with higher ozone levels in the Western Pacific and lower over the Eastern Pacific during El Niño years. Figure 5.3 shows the high degree of correlation of this dipole with the Enso 3.4 index over the above 30-year period, with positive correlations in the Western Pacific and negative correlations in the Eastern Pacific.

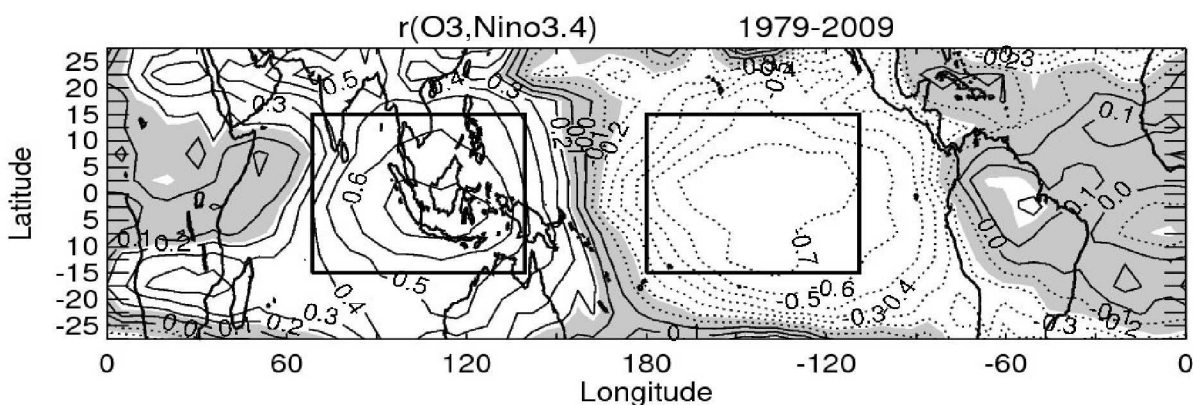


Figure 5.3: Correlation of tropospheric ozone column over the Pacific with the ENSO SST 3.4 index.



Figure 5.4 shows a time series of a new “Ozone Enso Index”, defined as the difference in tropospheric ozone column between the West Pacific and the East Pacific, between 1979 and 2009. This figure also shows the traditional ENSO SST 3.4 index. We can see that both indices track each other very well. Thus, ozone observations can also yield information on El Niño/La Niña conditions.

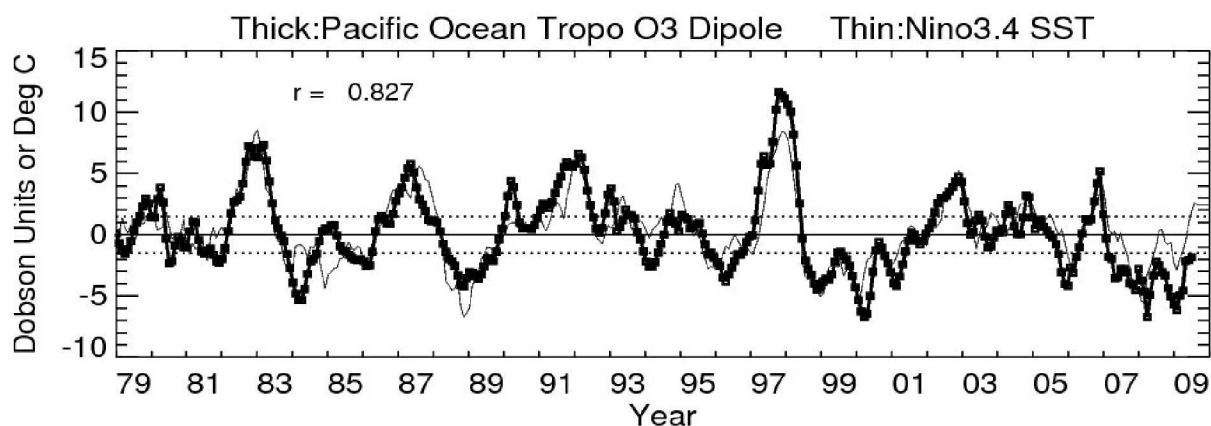


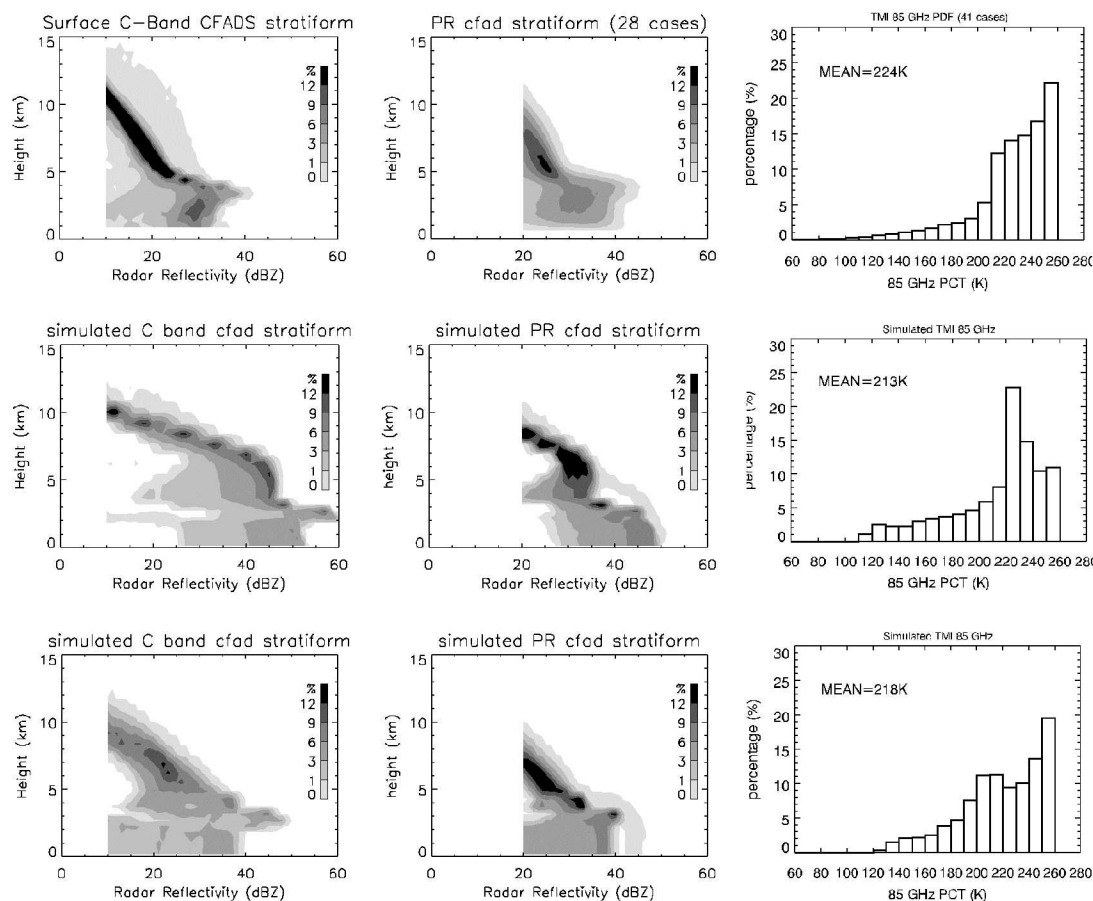
Figure 5.4 Time series of the Ozone Enso Index (in DU) and the ENSO SST 3.4 Index, from 1979 to 2009.

This work has been reported in Chandra, Ziemke, Duncan et al., Effects of the 2006 El Niño on tropospheric ozone and carbon monoxide: implications for dynamics and biomass burning (2009), *Atmos. Chem. Phys.*, 9, 4239-4249.

#### 5.4.3. Cloud and Mesoscale Modeling (Multi-scale Modeling)

Three different coupled modeling systems were again improved over the last year (Tao *et al.* 2009a). 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, including 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 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 or CRM). 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 (Tao *et al.* 2009b). This modeling system has been applied and its performance tested for two different climate scenarios, El Niño (1998) and La Niña (1999), the diurnal variation of precipitation processes, and flood/drought events during three different years (2005-2007). The new, coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, intra-seasonal oscillations, and diurnal variation of precipitation over land, which are very difficult to forecast using even state-of-the-art GCMs. In addition, the fvGCM is being used to conduct very high-resolution simulations (global mesoscale modeling) to simulate the tropical cyclone formation and the Madden-Julian Oscillation (MJO). Results indicate that the high-resolution global model is capable of predicting the genesis of TCs about two to three days in advance and their subsequent movements as well (Shen *et al.* 2009).



**Figure 5.5:** Comparisons between observations (the upper row), original model simulations (the middle row), and the improved microphysics (the lower row). (a) Surface C-band radar CFAD for the stratiform region; (b) TRMM PR CFAD for the stratiform region; (c) TRMM TMI 85 GHz PCT probability density distribution; (d) Original simulated C-band radar CFAD; (e) The same as (d) except for the TRMM; (f) Original simulated TRMM TMI 85 GHz PCT probability density distribution during the mature stage of the system; (g) The same as (d) except for improved microphysics; (h) The same as (e) except for improved microphysics; (i) Same as (f) except for improved microphysics.

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). The CRM-based packages have enabled improved forecasts (or simulations) of various convective systems [e.g., a linear convective system in Oklahoma (International H<sub>2</sub>O project, IHOP-2002), an Atlantic hurricane (Hurricane Katrina, 2005), high latitude snow events (Canadian CloudSat CALIPSO Validation Project, C3VP 2007), and a typhoon (Morakot 2009<sup>5</sup>)]. For example, WRF was run at high-resolution (2 km) with improved Goddard microphysics and radiation to simulate Typhoon Morakot, which impacted Taiwan. The improved Goddard schemes were able to capture key features of the observed rainfall, namely its areal coverage and its maximum intensity. The model also confirmed that the heavy amounts

<sup>5</sup>Typhoon Morakot struck Taiwan on the night of Friday August 7th, 2009, resulting in over 700 fatalities. Local rainfall amounts of as much as 2000 mm (2 m) were reported, which lead to the worst flooding there in 50 years.

of rain over the southern portion of the island of Taiwan were due to persistent southwesterly flow associated with Morakot and its circulation, which was able to draw up copious amounts of moisture from the South China Sea into southern Taiwan where it was able to interact with the steep topography.

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. This new, coupled model system allows us to better understand cloud and precipitation processes in the Tropics as well as snow events and to improve both precipitation retrievals from NASA satellites and the representation of moist processes in global and climate models. The following figure shows an example of using satellite data to improve the microphysical processes used in the GCE model (Li *et al.* 2009).

In addition, simulated physical parameters (i.e., condensates or hydrometeors, temperature, and humidity profiles) from the Multi-Scale Modeling system can be used to simulate top-of-the-atmosphere radiance and backscattering profiles consistent with NASA EOS satellite measurements through the NASA Goddard Earth Satellite Simulator (SDSU, Matsui *et al.* 2009a). The Goddard SDSU is an end-to-end satellite simulator unit, which can compute satellite-consistent measurements (radiance or backscattering signals) from model-simulated or algorithm-assumed atmospheric profiles and aerosol/condensate particles using a passive microwave simulator, a radar simulator, a passive visible-IR simulator, a lidar simulator, and a broadband simulator (Fig. 5.6b). The coupling between the model and SDSU permits (1) better evaluation of the Goddard physical packages by comparing model results with direct EOS satellite measurements (Matsui *et al.* 2009b); and (2) support for current and future NASA's satellite

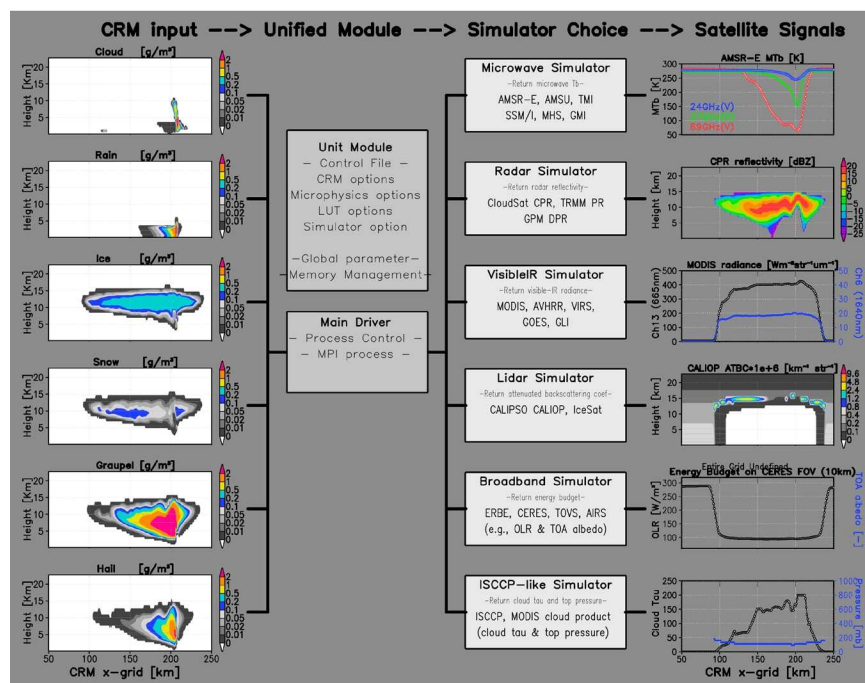


Figure 5.6a: The Goddard SDSU can simulate various satellite signals, which, for example, can be observed from the A-Train constellation of satellites. These transformations from model space to satellite radiance space can be done within a unified physics framework (i.e., simulated condensate amounts and size distributions as well as profiles of temperature and humidity from one model can be used to drive the simulators in same manner as for another model using the same physics package).



missions (i.e., TRMM, CloudSat, Aqua-MODIS, AMSR-E, GPM and ACE) by providing virtual satellite measurements as well as simulated atmospheric environments as an a priori database of physically-based precipitation retrieval algorithms.

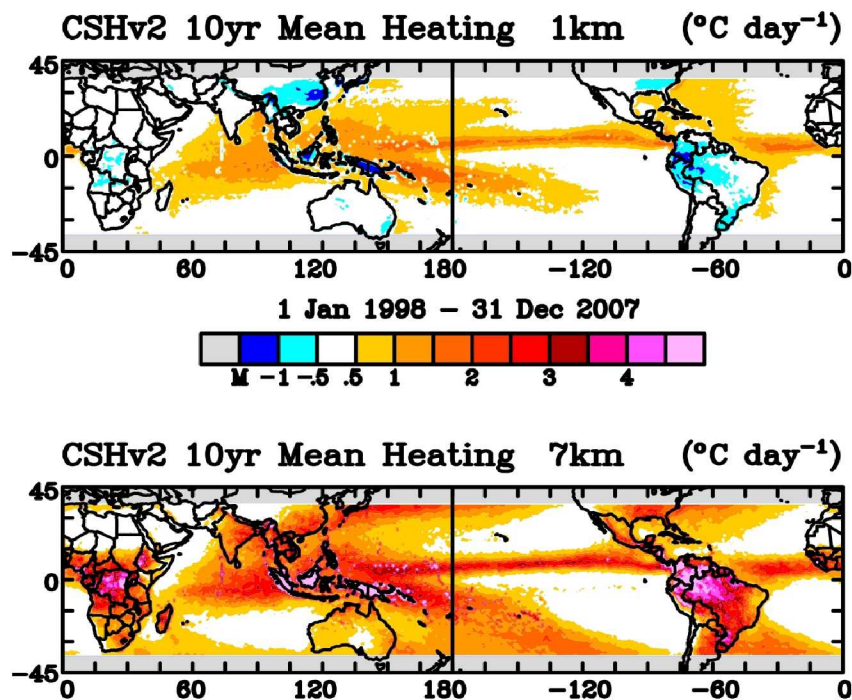
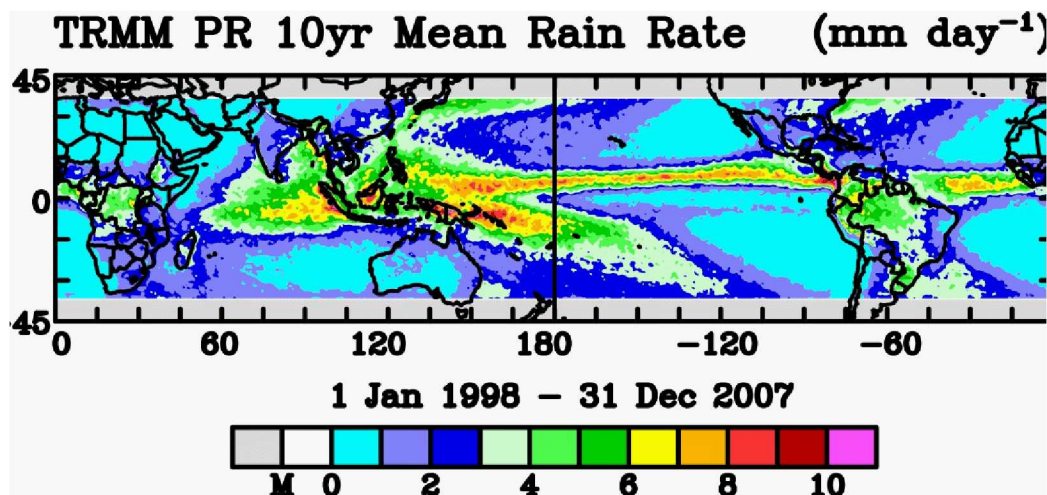


Figure 5.6b: Ten-year (1998-2007) mean cloud heating rates over the global Tropics at 7 and 1 km AGL (upper 2 panels) obtained from the new CSH algorithm using gridded instantaneous TRMM PR rain rates (bottom panel).



The modeling system also allowed us to develop an improved convective-stratiform heating (CSH) algorithm to obtain the 3-D structure of cloud heating over the Tropics based on two sources of information: (1) rainfall information, namely its amount and the fraction due to light rain intensity, observed directly from the Precipitation Radar (PR) on board the TRMM satellite; and (2) synthetic cloud physics

information obtained from cloud-resolving model (CRM) simulations of cloud systems (Fig. 5.6b). The cloud simulations provide details on cloud processes, specifically latent heating, eddy heat flux convergence and radiative heating/cooling that are not directly observable by satellite. Cloud heating data separated into these three components derived from the new CSH algorithm are readily available for a 10-year period at 0.5 x 0.5 degree resolution. The time resolution is approximately daily (Tao et al. 2009c).

The scientific output from the modeling activities was again exceptional in 2009, with more than 27 new papers published, in press, or accepted. For more information, contact Wei-Kuo Tao, Wei-Kuo.Tao.1@nasa.gov. The web address for the Goddard Mesoscale Dynamic and Modeling group and multi-scale modeling system and its generated cloud library is:

<http://portal.nccs.nasa.gov/cloudlibrary/index2.html>.

Li, X., W.-K. Tao, T. Matsui, C. Liu and H. Masunaga, 2009: Improving spectral bin microphysical scheme using TRMM satellite observations. *Quart. J. Roy. Meteor. Soc.* (In press).

Matsui, T., W. Tao, H. Masunaga, C. D. Kummerow, W. S. Olson, N. Teruyuki, M. Sekiguchi, M. Chou, T. Y. Nakajima, X. Li, J. Chern, J. J. Shi, X. Zeng, D. J. Posselt, K. Suzuki, 2009a: Goddard Satellite Data Simulation Unit: Multi-Sensor Satellite Simulators to Support Aerosol-Cloud-Precipitation Satellite Missions, *Eos Trans. AGU*, 90(52), Fall Meet. Suppl., Abstract A21D-0268.

Matsui, T., X. Zeng, W.-K. Tao, H. Masunaga, W. Olson, and S. Lang, 2009b: Evaluation of long-term cloud-resolving model simulations using satellite radiance observations and multifrequency satellite simulators. *Journal of Atmospheric and Oceanic Technology*, 26, 1261-1274.

Shen, B.-W., W.-K. Tao, R. Atlas, Y.-L. Lin, C. D. Peters-Lidard, and K.-S. Kuo, 2009: Forecasts of tropical cyclongenesis with a global mesoscale model: Preliminary results with twin tropical cyclones in May 2002. *J. Geophys. Res.*, (in press).

Tao, W.-K., J. Chern, R. Atlas, D. Randall, X. Lin, M. Khairoutdinov, J.-L. Li, D. E. Waliser, A. Hou, C. Peters-Lidard, W. Lau, and J. Simpson, 2009b: Multi-scale modeling system: Development, applications and critical issues, *Bull. Amer. Meteor. Soc.* 90, 515-534.

Tao, W.-K., D. Anderson, J. Chern, J. Estin, A. Hou, P. Houser, R. Kakar, S. Lang, W. Lau, C. Peters-Lidard, X. Li, T. Matsui, B.-W. Shen, J.-J. Shi, and X. Zeng, 2009a: Goddard Multi-Scale Modeling Systems with Unified Physics, *Annales Geophysics*, 27, 3055-3064.

Tao, W.-K., S. Lang, X. Zeng, S. Shige, Y. Takayabu, 2009c: Relating convective and stratiform rain to latent heating, *J. Climate*, (in press).

## 5.5. Instrument Development and Testing

### 5.5.1. Engineering Flight Testing of the TWiLiTE Doppler lidar

In September, 2009 the TWiLiTE (Tropospheric Wind Lidar Technology Experiment) direct detection Doppler lidar completed successful integration and engineering flight testing on the NASA ER-2 high altitude aircraft. The TWiLiTE Doppler lidar measures vertical profiles of wind by transmitting a short laser pulse into the atmosphere, collecting the laser light scattered back to the lidar by air molecules, and measuring the Doppler shifted frequency of that light. The magnitude of the Doppler shift is proportional to the wind speed of the air in the parcel scattering the laser light.

TwILiTE was developed with funding from the NASA Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP). The primary objectives of the TwILiTE program are twofold: (1) to advance the development of key technologies and subsystems critical for a future space based Global Wind Sounding Mission, as recommended by the National Research Council in the recent *Decadal Survey for Earth Science*; and (2) to develop, for the first time, a fully autonomous airborne Doppler wind lidar instrument to demonstrate tropospheric wind profile measurements from a high altitude downward looking, moving platform to simulate spaceborne measurements.

In February 2009, the team shipped the TwILiTE instrument to Edwards AFB, integrated it into the NASA ER2, and conducted initial engineering test flights that demonstrated autonomous operation and key engineering functions of TwILiTE and generated a wealth of engineering data. Detailed analysis of the data enabled the team to make the modifications necessary to correct any remaining issues. The instrument and team returned to Edwards in September for an extended round of engineering flights to further test the instrument operation. In this deployment, 25 hours of flight data were obtained and a number of challenging problems were identified and addressed culminating in successful operation of the instrument. These flights provided system level validation of the key technologies developed in the TwILiTE program: narrow bandwidth solid-state pulsed lasers; high spectral resolution optical filters and novel holographic optical element telescopes. TwILiTE is the first fully autonomous airborne Doppler wind lidar and represents a critical step on the path to a space based wind lidar system. This important development milestone was explicitly recommended by the *Decadal Survey* panel in their recommendations for the Global 3-D Winds Mission. For additional information contact Bruce Gentry, [Bruce.M.Gentry@nasa.gov](mailto:Bruce.M.Gentry@nasa.gov).

## 5.6. Awards and Special Recognition

---

### 5.6.1. NASA Honors Awards

Anne Douglass, Exceptional Scientific Achievement Medal  
 Dave Starr, Outstanding Leadership Medal  
 Jim Irons, Exceptional Service Medal  
 Matt McGill, Exceptional Service Medal  
 OMI Instrument Team, Group Achievement Award, Accepted by P.K. Bhartia  
 ARCTAS Field Campaign Team, Accepted by Ralph Kahn

### 5.6.2. Goddard Honor Awards

Richard Stolarski, R.H.G. Award of Merit  
 Jose Rodriguez, R.H.G. Leadership Award for Outstanding Leadership.  
 Nickolay Krotkov, GEST/UMBC, R.H.G. Exceptional Achievement Award for Science

**5.7. External Awards and Recognition**

---

Anne Douglass (613.3) was been selected as a member of the AMS council.

Dr. William Lau (613.0) was appointed a member of the World Climate Research Organization, Global Water and Energy Budget (WCRP/GEWEX) Science Steering Group (SSG), which provides science oversight and organization of international programs on a wide range of water and energy cycles studies and applications. The SSG consists of 12 international members. Dr. Lau is one of the three United States representative on the SSG.

Dr. George J. Huffman (SSAI; 613.1) received the AMS Journal of Hydrometeorology Editor's Award for 2009, "for prompt, rigorous, detailed, and constructive reviews, and also adjudication of conflicting reviews."

Mian Chin (GSFC, Code 613.3) was a coordinating lead author for a NASA-led Synthesis and Assessment Product (SAP) titled "Atmospheric Aerosol Properties and Climate Impacts" was issued by the U.S. Climate Change Science Program. Ralph Kahn (GSFC, Code 613.2), Lorraine Remer (GSFC, Code 613.2), Hongbin Yu (GSFC, Code 613.2), and David Rind (GISS) are the lead authors for individual chapters in the report.

The press release can be found at [http://www.nasa.gov/home/hqnews/2009/jan/HQ\\_09-009\\_Aerosols\\_report.html](http://www.nasa.gov/home/hqnews/2009/jan/HQ_09-009_Aerosols_report.html), and the entire report is available at <http://www.climate-science.gov/Library/sap/sap2-3/default.php>

Bo-Wen Shen (613.1/UMCP) was the runner-up in the most readable poster category for "Hurricane Forecasts with a Global Mesoscale Model on the NASA Columbia Supercomputer" at the second Science Exploration Directorate New Year's Poster Party Blowout on January 21, 2009 at the Building 28 Atrium. Coauthors include Wei-Kuo Tao (613.1)

Lazaros Oraiopoulos (613.2) agreed to serve a second term as a member of the American Meteorological Society's Atmospheric Radiation Committee

Paul Newman (613.3) received a 2009 Ozone Layer Protection Award from the U.S. Environmental Protection Agency at a special ceremony on the afternoon of Tuesday, April 21<sup>st</sup> at the Kennedy Center for the Performing Arts in Washington, D.C.

William Lau (613.0) was presented a Certification of Appreciation by the Forensic Science Laboratory, Alcohol, Firearms, Tobacco and Explosive Division, Justice Department for a keynote seminar entitled "What causes the rapid melting of Himalaya glaciers—A forensic science investigation" on Earth Day, April 22, 2009.

Ralph Kahn (613.2) was selected by the American Geophysical Union (AGU) to receive the first Yoram J. Kaufman Unselfish Cooperation in Research Awards along with Ross Salawitch (UMCP). This award is named in honor of Yoram J. Kaufman, an outstanding atmospheric scientist, mentor, and creator of international collaborations who worked on atmospheric aerosols and their influence on the Earth's climate for his entire 30-year career. The citation will read: "The Yoram J. Kaufman Award for broad influence in atmospheric science through exceptional creativity, inspiration of younger scientists, mentoring, international collaborations, and unselfish cooperation in research."

William Lau, Chief, Laboratory for Atmospheres (613.0), has been selected Distinguished Alumni of the University of Hong Kong. He will be honored at the upcoming celebration of the 70<sup>th</sup> Anniversary of the Faculty of Science, University of Hong Kong, Hong Kong in November 2010.

Robert F. Cahalan (613.2), Head of the Climate and Radiation Branch of Goddard's Laboratory for Atmospheres in the Earth Sciences Division, was elected a Fellow of the American Meteorological Society (AMS). He was recognized for his pioneering theoretical and experimental advances in understanding the role of cloud structure in climate; his lead role as Project Scientist of the Solar Radiation and Climate Experiment (SORCE); and his leadership in three-dimensional atmospheric radiative transfer. New Fellows are elected each year by the AMS Executive Council from a slate submitted by the Fellows Committee of not more than one-tenth of 1 percent of all AMS Members. The formal announcement of Dr. Cahalan's election took place at the 90th AMS Annual Meeting in Atlanta, Georgia during January 17-21, 2010.



## 6. EDUCATION, OUTREACH, AND EXTERNAL COLLABORATION

### 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 (ESD, 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, Paul Newman, and Lorraine Remer, are all working 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 on-line 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 pre-college 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

#### 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 Beltsville Center for Climate Change observation (BCCSO) was established as a part of this initiative through a competitive award in 2009 at Howard University (HU), in Washington, D.C. It has also been a goal of the Laboratory and the Earth Sciences Division to partner with BCCSO to establish a self-supporting facility at Howard University 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 MS- and PhD-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 MS and PhD degrees in atmospheric sciences and some of them are employed by NASA.

#### Participation with Howard University on the Beltsville Campus Research Site

For several years, Howard University 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). Bruce Gentry (613.1), Gerry Heymsfield (613.1), Alexander Marshak (612), David Whiteman (613.1), Belay Demoz (613.1, now at Howard University), and others from GSFC are mentoring students and advising on instrument acquisition for the site. One of the main instruments at the site is a world-class Raman lidar built with major involvement from Code 613.1.

#### WAVES

During the summers of 2007, 2008, and 2009, students from HU participated in the WAVES field campaign that has been performed at the Beltsville site and/or participated as BCCSO summer interns at GSFC/Beltsville. WAVES (Water Vapor Validation Experiments Satellite and Sondes) was a satellite validation, sonde, and other instrument inter-comparison field campaign centered on the Howard University Research Campus in Beltsville, Maryland. The main goal of this campaign was to acquire a statistically robust set of measurements of atmospheric water vapor, aerosols, and trace gases useful for Aura/Aqua satellite retrieval studies as well as for performing instrument accuracy assessments, and for case studies of regional water vapor and aerosol variability. WAVES was the first major experiment held at HURB and required coordination within HU and with NASA GSFC, NOAA/Boulder, NWS/Sterling, as well as with many universities, including: University of Maryland, UMCP and UMBC; Penn State; Bowie State; Trinity University in D. C.; University of Virginia, Charlottesville, VA; Smith College, NH; University of Wisconsin; and with universities from Brazil, Italy, and Bolivia.

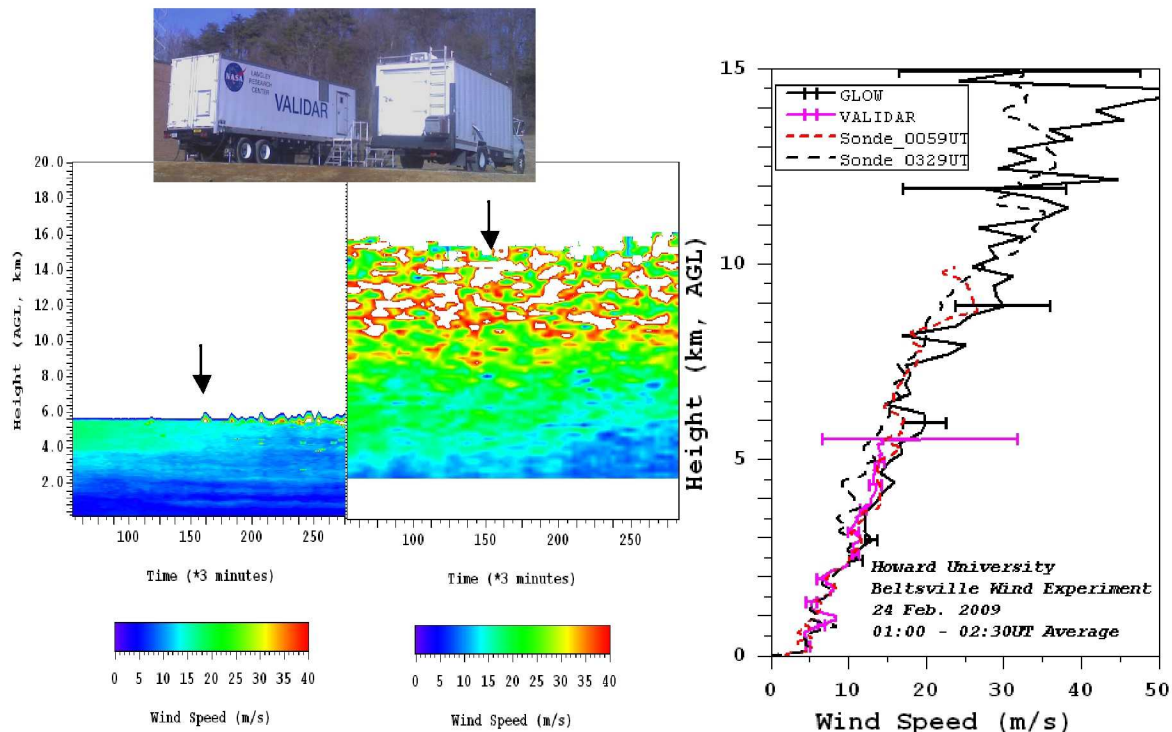


WAVES was funded by NASA/SMD for two years. The core components of the WAVES funding include proposals awarded to HU, UMBC, and GSFC. For further information see the WAVES Web site, <http://tropometrics.com>, or contact David Whiteman (David.N.Whiteman@nasa.gov) or Belay Demoz (bbdemoz@howard.edu).

### Wind Lidar Intercomparison

In the summer of 2009, a wind lidar experiment was also completed at HURB. A field observation phase comparison of wind lidar technology assessment was completed at the Howard University Beltsville Campus. The goal of the experiment was to compare two of NASA's state-of-the-art wind lidar technology instruments and candidates for NASA's *Decadal Survey* 3D wind experiment. The VALIDAR is an aerosol-based lidar system from NASA/LaRC while the GLOW is a molecular-based lidar from GSFC. This is the first experiment where these two systems have been operated side by side. In addition, the commercial wind lidar from Leosphere, France (the WLS70(c)), a 915 MHz profiler, ACARS winds and different types of radiosondes participated.

The Wind Experiment was funded by NASA/SMD for three years under roses 2007. For further information see contact Bruce Gentry (Bruce.Gentry@nasa.gov) or Belay Demoz (bbdemoz@howard.edu).



*Figure 6.1: A summary of wind Coherent and Direct detection wind lidar performance. The profile plot at right was profile of wind speed made by VALIDAR and GLOW (shown at HURB above) and compared to radiosonde data. The plot shows the strength of the merging of these two different techniques leading to profiles that span the ground to 15 km altitude.*

### **DABUL**

In collaboration with UMBC and Judd Welton (613.1), the Depolarization and Backscatter Unattended Lidar (DABUL) is a new MPL-like lidar is being installed at HURB. Timothy Berkoff of UMBC has started the work and is ongoing. The lidar will be operating from HURB and its data will be used for satellite validation as well as air pollution studies. For further information see contact Bruce Gentry (Timothy.Berkoff@nasa.gov) or Belay Demoz (bbdemoz@howard.edu).

### **NDACC Collaboration**

Dr. Demetrius Venable and Ms. Monique Calhoun (Ph.D. student) participated in a two-week lidar measurement campaign at Jet Propulsion Laboratory Table Mountain Facility, Wrightwood CA. The Table Mountain Facility is a part of the Network for Detection of Atmospheric Composition Change (NDACC), which has been making regular measurements of stratospheric ozone and other quantities for more than a decade. The TMF site as upgraded it lidar capabilities to include Raman water vapor lidar measurements. We have been participating in a collaborative effort on “Measurements of Humidity in the Atmosphere: Validation Experiments” (MOHAVE 09). MOHAVE 09 took place in October 2009 and involved several remote sensing and in-situ techniques. Our involvement included providing operations support for the NASA ALVICE lidar system during inter-comparative measurements at the site.

For further information see contact Demetrius Venable (dvenable@howard.edu), David Whiteman (david.n.whiteman@nasa.gov>)

### **University Research Center-BCCSO**

A major collaboration with Howard University was funded in 2009 as part of the NASA University Research Center at HURB. This research which consists of teaching and research has collaborations across the Lab. Extended information on this collaboration is available at <http://bccso.org/>.

### **6.2.3. NASA Earth Science Fellowship**

University of Nebraska-Lincoln geoscience graduate student David Peterson has received a prestigious NASA Earth and Space Science Fellowship, which will fund three years of doctoral research. Peterson, who will finish his master’s degree in meteorology in the fall of 2009, studies the causes of wildfires in the boreal forests of Canada and Alaska. He will continue his research as a doctoral student, using satellite images provided by NASA to study fires caused by dry lightning strikes, in an effort to improve overall forecasting of fire weather. Mr. Peterson was mentored by GEST Visiting Fellow Jun Wang (University of Nebraska-Lincoln), Charles Ichoku (613.2) and Lorraine Remer (613.2) during the 2008 Graduate Student Summer Program at Goddard.

### **6.2.4. UWM Chancellors Award**

Karandana Thishan Dharshana, a graduate student from the University of Wisconsin-Milwaukee (UWM), working with Charles Ichoku (613.2) this summer on “Analysis of Errors Associated with the Estimation of Smoke Emission Rates from Satellite Fire Radiative Power Measurements over North America” has received the UWM Chancellor’s Graduate Student Award for the second consecutive year. The award is intended to attract and retain graduate students with exceptional academic records and high promise of future success.

### 6.3. Summer Programs

#### 6.3.1. The Summer Institute in Earth Sciences (SIES)

The Summer Institute in Atmospheric, Hydrospheric, and Terrestrial Sciences was held from June 1 to August 7, 2009. The program is sponsored by the Earth Sciences Division (Code 610). In 2009, the Institute was coordinated and managed by GEST who also managed the Center Graduate Student Summer Program, GEST-GSSP. The summer institute is designed to introduce undergraduate students majoring in all areas of the physical sciences to research opportunities in these areas. After a one-week series of introductory lectures, the students select from a list of research topics and are mentored by a Goddard scientist for a period of nine weeks. At the conclusion of this period, the students give a presentation of their results. Laboratory for Atmospheres scientists participating in the institute, students, and research topics are shown in Table 6.1. A detailed report prepared by Valeria. Casasanto (GEST) summarizes the 2009 program and is also shown below.

**Table 6.1: 2009 Summer Institute Participants**

Student	School	Mentor	Project Title
Bryon Baumstarck	Rocky Mountain College	P. Colarco	Using Models and Observations to Develop Requirements for New Satellites Observing Earth's Aerosol System
Anuraj Chakraborty	UMBC	B. Meneghini	Analysis of Spaceborne Weather Radar Data
Brandon Cottom	UMBC	E. Wilcox	Tropical Forest Burning and the Hydrological Cycle of the Amazon
Melissa Dawson	University of Oklahoma	A. Molod	The Structure of the Atmospheric Boundary Layer over Land
Ryan Max	UMBC	E. Brown de Colstoun	Assessing the Accuracy of Field-Based Estimates of Tree and Impervious Cover for Earth Satellite Applications
Catherine May	University of Nebraska Lincoln	C. Ichoku	Satellite analysis of fire radiative energy release and smoke aerosol emission rates
Kiran Quaraishi	UMBC	A. Chu	Satellite and model comparisons of AOD/CO ratio in source and downwind regions of boreal biomass burning
Vishana Ramdeen	Rutgers University	D. Mocko	Study of Drought Indices Using Observed Precipitation and Land-Surface Models over North America During the Past 30 Years
Tiffany Townsend	Oregon State University	R. Koster, M. Rodell	Variations of Rainfall in India
Brian Young	IUPUI (Indiana University Purdue University Indianapolis)	P. de Matthaies	Hurricane Intensity and Ocean Vertical Structure



*Figure 6.2: Participants in the 2009 Summer Institute*

### 6.3.2. SIES Program Report

#### Background

SIES is sponsored by NASA Goddard's Earth Sciences Division and managed by the University of Maryland Baltimore County (UMBC) Goddard Earth Sciences Technology Center (GEST). The SIES summer program has been successfully running for the past nine years. In 2009, the complete program management was under the direction of UMBC's GEST Center under the program management of Valerie Casasanto. In addition, Dr. Ali Tokay (Code 613.1), served as selection committee Chair; Dr. Jeffrey Halverson, Associate Director of UMBC's Joint Center for Earth Systems Technology, served as advisor to the summer programs.

#### General information and statistics:

- SIES 2009 took place from June 1 to August 7, 2009;
- Approximately 60 applications were received through GSFC's office of higher education on-line system, of which 10 students were accepted and fully funded;



- All 10 students worked at GSFC in Greenbelt, MD and all matched with a GSFC mentor;
- Non-local GSFC-based students were housed at the University of College Park and were shuttled to GSFC daily.
- In 2009, the program format was changed slightly for the first time. To save valuable time for students to work with mentors, students selected their mentor projects on-line using the Education Office on-line application system. Previously, the first week of the 10-week program was spent listening to mentor presentations. In addition, the program dates were aligned with the other summer programs instead of starting one week later.

### Highlights / Events

- On arrival day, students participated in the joint orientation session conducted by Dr. Jeffrey Halverson, Dr. Ali Tokay, and Ms. Valerie Casasanto. Students were briefed on NASA and the Earth Sciences Division, what it is like working at NASA, how to get the most out of their internship experience, security, busing, IT security, and all other Goddard related issues. Students then met with Ms. Camilla Hyman of UMBC to complete paperwork for payroll. Afterwards, students were treated to a welcome lunch with their mentors and GEST's Program Coordinator, then went with their mentors to begin discussions on their summer research projects.
- The Program Coordinator conducted a tour of NASA Goddard for the students. They enjoyed viewing the various labs, clean rooms, test facilities, centrifuge, and space hardware at GSFC.
- Individual meetings were conducted with each student to monitor progress, mentor relationship, and project comprehension. These meetings were then followed up by visits to each student at their workstations throughout the program.
- Every Friday, students met with the Program Coordinator for an informal lunch outside of the cafeteria, which provided the opportunity to interact with other participants and get updated on the latest news.
- The majority of students had a positive relationship with their mentors.
- The Seminar Series, featured experts in various areas of Earth sciences. These seminars were scattered throughout the program and were approximately 1.5 hours in length. The series culminated in a presentation at the Goddard Visitor's Center utilizing data projected on the *Science on a Sphere*.
- Student final presentation seminars were held in Building 33 on the last day of the program. Each student gave a 15 minute seminar on the work completed this past summer, and time was given for question and answer. Refreshments were provided. Mentors were also present for support.
- A farewell lunch was held at a nearby restaurant in Greenbelt, and certificates and gifts (books) were presented to participants.
- All student papers have been submitted and posted on the GEST Web site:  
[http://gest.umbc.edu/student\\_opp/2009\\_sies\\_reports.html](http://gest.umbc.edu/student_opp/2009_sies_reports.html)

### Notable comments from students

- Overall, students had a very positive experience and excellent camaraderie and felt that this opportunity had provided a unique opportunity and made an impact on their lives and future careers.
- Students enjoyed the "Friday lunches," and looked forward to meeting their peers and Program Coordinator outside in an informal setting.

## EDUCATION AND OUTREACH

- Housing at Leonardtown in College Park was satisfactory.
- Students expressed that they would prefer to have a few rental cars to go back and forth from NASA as well as to use them to purchase groceries.

### Items to consider for 2009 and lessons learned

- Students did not have access to equipment such as a vacuum cleaner to clean their rooms.
- Investigate newer housing.
- Investigate rental of vehicles instead of Shuttle bus.
- The badging/IT process this year at NASA was new. It was very involved and required many steps. Some students did not have IT access until well into the program. The process to obtain computer access was unclear. Badging needs to be started early. The application process must be started earlier. The Program Coordinator needs to work early on with the badging/IT security people to ensure a smooth process.
- More time was available for students to work on their summer projects (since no time was spent listening to mentor presentations of projects during the first week). In addition, since the mentor matching was done ahead of time, there were no problems with computer equipment since the mentor knew he or she would have a student ahead of time.
- Aligning the program dates with all of the other programs proved to be a positive change. Students could take advantage of other program events, and not be left “alone” for the last week of the program.

### 6.3.3. Goddard Earth Sciences and Technology (GEST) Center Graduate Student Summer

#### 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 & 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 2009, Laboratory personnel acted as mentors for four GEST students. Mentors, students, and their research topics are given in Table 6.2. The 2009 program was managed by GEST.

### 6.3.3.1 GSSP Program Report

#### Background

GSSP is sponsored by NASA Goddard's Earth Sciences Division and managed by the University of Maryland Baltimore County (UMBC) Goddard Earth Sciences Technology Center (GEST). The GSSP summer program has been successfully running for the past nine years. Valerie Casasanto of UMBC's GEST Center served as Program Manager. In addition, Dr. Ali Tokay (Code 613.1) served as selection committee Chair and Dr. Jeffrey Halverson, Associate Director of UMBC's Joint Center for Earth Systems Technology, served as advisor to the GSSP summer program.

#### General information and statistics:

- GSSP 2009 took place from June 1 to August 7, 2009;
- Approximately 20 applications were received, of which 8 students were accepted and fully funded;
- Student population included 4 Ph.D. students and 4 Masters students;
- All 8 students worked at GSFC in Greenbelt, MD and all matched with a GSFC mentor;

**Table 6.2: Participants in 2009 GSSP Program**

Student	Citizenship	School	Mentor Name
Karandana Dharshana	Sri Lanka	University of Wisconsin - Milwaukee	Charles Ichoku
Matthew Johnson	US	North Carolina State University	Santiago Gasso
Jahan Kariyeva	Turkmenistan	University of Arizona	Marc Imhoff / Lahouari Bounoua
Wendi Kaufeld	US	University of Illinois at Urbana-Champaign	Christa Peters-Lidard
Prakash Khedun	Mauritius	Texas A&M	John Bolton
Pablo Rivas-Perea	Mexico	University of Texas - El Paso	James Tilton
John Ten Hoeve	US	Stanford University	Lorraine Remer
Aude Valade	France	UC Davis	Joe Santanello

## EDUCATION AND OUTREACH

- Non-local GSFC-based students were housed at the University of College Park and were shuttled to GSFC daily.

### Highlights / Events

- On Arrival day, students participated in the joint orientation session conducted by Dr. Jeffrey Halverson, Dr. Ali Tokay, and Ms. Valerie Casasanto. Students were briefed on NASA and the Earth Sciences division, what it is like working at NASA, how to get the most out of your internship experience, security, busing, IT security, and all other Goddard related issues. Students then met with Ms. Camilla Hyman of UMBC to complete paperwork for payroll. Afterwards, students were treated to a welcome lunch with their mentors and GEST's Program Coordinator, then went with their mentors to begin discussions on their summer research projects.
- A tour of NASA Goddard for students was conducted by the Program Coordinator. Students enjoyed viewing the various labs, clean rooms, test facilities, centrifuge, and space hardware at GSFC.
- Individual meetings were conducted with each student to monitor progress, mentor relationship and project comprehension. These meetings were then followed up by visits to each student at their workstations throughout the program.
- Every Friday, students met with the Program Coordinator for an informal lunch outside of the cafeteria, which provided the opportunity to interact with other participants and get updated on the latest news.
- All students had a positive relationship with their mentors.
- Most students participated in research that will be utilized in their thesis.
- The Seminar Series, featured experts in various areas of Earth sciences. These seminars were scattered throughout the program and were approximately 1.5 hours in length. The series culminated in a presentation at the Goddard Visitor's Center utilizing data projected on the *Science on a Sphere*.
- Student final presentation seminars were held in Building 33 on the last day of the program. Each student gave a 15–20 minute seminar on the work completed this past summer, and time was given for question and answer. Refreshments were provided. Mentors were also present for support.
- A farewell lunch was held at a nearby restaurant in Greenbelt, and certificates and gifts (book) were presented to participants.
- All student papers have been submitted and posted on the GEST Web site:  
([http://gest.umbc.edu/student\\_opp/2009\\_gssp\\_reports.html](http://gest.umbc.edu/student_opp/2009_gssp_reports.html))

### Notable comments from students:

- Overall students had a very positive experience and excellent camaraderie and felt that this opportunity had provided a unique opportunity and made an impact on their lives and future careers.
- Students enjoyed the “Friday lunches,” and looked forward to meeting their peers and Program Coordinator outside in an informal setting.
- Housing at Leonardtown in College Park was satisfactory.
- Students expressed that they would prefer to have a few rental cars to go back and forth from NASA as well as to use them to purchase groceries.



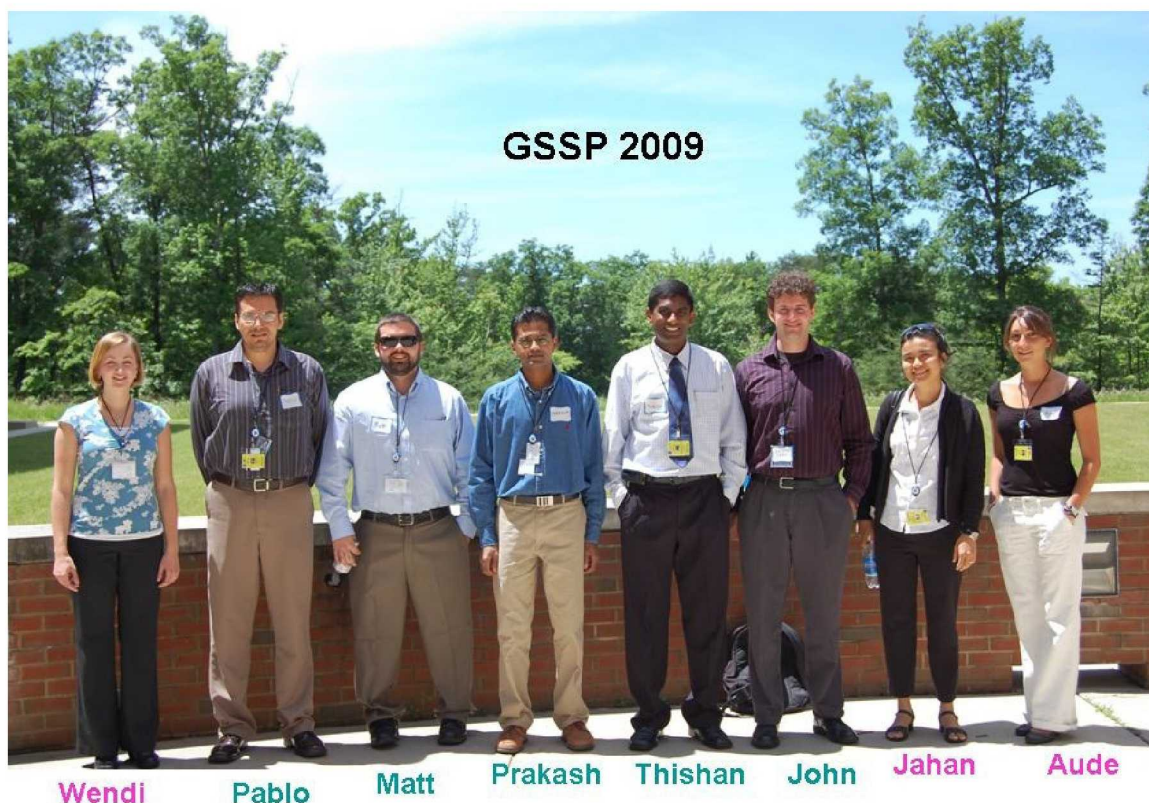


Figure 6.3: Participants in the 2009 GSSP program

#### Items to consider for 2009 and lessons learned:

- Students did not have access to equipment such as a vacuum cleaner to clean their rooms.
- The badging/IT process this year at NASA was new. It was very involved and required many steps. Some students did not have IT access until well into the program. The process to obtain computer access was unclear. Badging needs to be started early. The application process must be started earlier. The Program Coordinator needs to work early on with the badging/IT security people to ensure a smooth process.

#### 6.4. University Education

Laboratory members are active in supporting university education through teaching courses and advising graduate students. Table 6.3 lists instructors and courses taught.

Table 6.3 University Courses Taught

University	Course	Instructor, Code
UMBC	Physics 622, Atmospheric Physics	Tamas Varnai, 613.2/UMBC

On the next page, Table 6.4 lists Laboratory members serving as graduate student advisors and/or sit on student Ph.D. committees.

## EDUCATION AND OUTREACH

**Table 6.4: Graduate Student Advising**

Member, Code	Student	Degree	Institution	Thesis Topic or Area
Gerald Heymsfield, 613.1	Amber Reynolds	PhD	Texas Tech University	Mesoscale Convective Systems
Gerald Heymsfield, 613.1	Steven Guimond	PhD	Florida State University	Hurricane Intensification
Judd Welton, 613.1	Virginia Sawyer	PhD	University of Maryland, College Park	Atmospheric Sciences
David Starr, 613.1	Tamara Singleton	PhD	University of Maryland	Data Assimilation
Karen Mohr, 613.1	Matthew Czikowsky	PhD	University at Albany, SUNY	Hyrometeorology
Karen Mohr, 613.1	Gareth Berry	PhD	University at Albany, SUNY	Tropical Meteorology
Karen Mohr, 613.1	Carl Schreck	PhD	University at Albany, SUNY	Tropical Meteorology
Karen Mohr, 613.1	Stephen Nicholls	PhD	Rutgerd University	Regional Climate Modeling
Scott Braun, 613.1	Matthew Miller	PhD	North Carolina State	Atmospheric Sciences
Scott Braun, 613.1	Sam Trahan	PhD	UMBC	
Ralph Kahn, 613.2	Shirley Mims	.	Caltech	Aerosol Plume Heights
Ralph Kahn, 613.2	Yang Liu	Post-Doc	Emory University	Aerosol contributions to air pollution
Ralph Kahn, 613.2	Maria val Martin	Post-Doc	Harvard	Wildfire smoke injection heights
Ralph Kahn, 613.2	Sero Kassabian		Glendale College Student	Dust storm source regions in North Africa.
Ralph Kahn, 613.2	Jeff Pierce	Post -Doc	Dalhousie	MISR sensitivity to cirrus clouds
Ralph Kahn, 613.2	John Kilby		University of Maryland, UMBC	Saharan dust transport climatology.
Ralph Kahn, 613.2	Allison Hoy		University of Maryland, UMBC	Saharan dust transport climatology.
Charles Gatebe, 613.2	Miguel O. Roman	PhD	Boston University	Satellite estimates of directional reflectance and albedo
Charles Gatebe, 613.2	Jullao J. Cumbane	PhD	University of Johannesburg	Tropospheric Aerosols in southern Africa
Lazaros Oreopoulos, 613.2	Hye Lim Yoo	PhD	University of Maryland	Atmospheric and Ocean Sciences
Petet Colarco, 613.3	Ed Nowotnick	PhD	ESSIC, University of Maryland	Aerosols/Dust
Ken Pickering, 613.3	James Cipriani	MS	University of Maryland, College Park	Analysis and Modeling of Convection
Ken Pickering, 613.3	Theodore Lyons	MS	University of Maryland, College Park	Analysis of GMI model output in relation to the NASA TC4 experiment
Ken Pickering, 613.3	Kristin Cummings	MS	University of Maryland, College Park	Analysis and Modeling of Deep Convection

## 6.5. NASA Postdoctoral Program

The Laboratory for Atmospheres actively participates in the NPP, a postdoctoral fellowship program administrated by the Oak Ridge Associated University (URAU). NPP is aimed at early career scientists, who are interested to come to work at NASA with a sponsor (usually a civil servant scientist), on space and earth science research. The Lab sponsors NPP research in a wide range areas including aerosol, clouds, precipitation, radiation, mesoscale processes, climate dynamics, stratospheric and tropospheric chemistry, and their roles and interactions with climate change, with emphases on the use of NASA satellite data, modeling tools, and development of mission related technology. The NPP provides a key pipeline for future generation of NASA civil servant scientists, as well as candidates for faculty positions at universities. In 2009, the list of NPP candidates included:

### Ended in 2009

**Alexandre (Alex) Correia**

Sponsor: Lorraine Remer

Research: Remote sensing of Aerosol-Cloud Interactions.

**Jeffery Pierce**

Sponsor: Lorraine Remer

Research: Evaluation of aerosol indirect effects using MODIA, CALISPO, and Cloudsat data in combination with global 3-D model simulation.

**Cynthia Randles**

Sponsor: Peter Collierco

Research: Improved estimation of the aerosol direct effect on climate through inclusion of on-line aerosols with dynamical feedbacks and aerosol microphysics in a GCM.

**Qing Liang**

Sponsor: Richard Stolarski

Research: Convective scheme for the Goddard chemistry Climate Model

### 2009 Participants

**Jason Sipple (2nd year)**

Sponsor: Scott Braun,

Research: Investigated the role of the Saharan air layer in the evolution of Tropical Storm Debby using a 30-member high-resolution numerical model ensemble. Data from the 30 simulations is used to relate different aspects of the storm's environment to its intensification. Jason is also developing data assimilation techniques for the assimilation of airborne radar and lidar wind data.

**Segalye Thompson (2nd year)**

Sponsor: W.K.Tao

Research: Dr. Segalye Thompson used the new version of the Weather Research and Forecasting (WRF) model on the NASA system to conduct more detailed studies of the impact of lidar assimilation on precipitation forecasting over the Washington, DC area. Worked with GPM in rainfall data assimilation. Also worked with Goddard Mesoscale Modeling and Dynamics group in improving microphysics schemes for NASA Goddard Cumulus Ensemble (GCE) model and NASA unified WRF.

**Aaron Pratt (2nd year)**

Sponsor: Jerry Heymsfield

Research: Investigated the effects of Saharan dust on intensification of convection in tropical systems using a modeling and observational approach.

**Kerry Meyer (3rd year)**

Sponsor: Steve Platnick

Research: Kerry: Quantifying the information content in the 1.38  $\mu\text{m}$  MODIS band for use in thin cirrus detection and retrievals which represents an important component to a major NASA satellite data set.

**Maragret Hurwitz (2nd year)**

Sponsor: Paul Newman

Research: Worked on improving the understanding of Stratospheric Polar Vortex dynamics and is investigating the impact of tropical sea surface temperatures on the Antarctic ozone hole.

**Afusat Dirisu (2nd year)**

Sponsor: Dave Whiteman,

Research: Dr. Dirisu's work is in the development of advanced calibration techniques for the Raman water vapor lidar. This work includes fundamental measurements Raman scattering cross section needed in an absolute calibration effort. These efforts directly relate to the need to quantify atmospheric water vapor with sufficient accuracy to detect trends due to climate change.

### 6.6. 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. 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 preestablished areas. Visiting Fellows are appointed for up to one year and are free to carry out research projects of their own design.

## 6.7. Open Lecture Series

---

### Distinguished Lecture 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 2009:

#### January – December 2009

January 29, 2009

**Bill Skamarock**

NCAR/MMM

*Atmospheric Solvers for Future Climate and Weather Models*

February 19, 2009

**William Cotton**

Colorado State University

*Weather and Climate Engineering*

March 19, 2009

**Doug Davis**

Georgia Tech

*The Antarctic Plateau Revisited: A Decade of Atmospheric Studies has Revealed the Need for a New Chemical Paradigm*

April 16, 2009

**V. Ramaswamy**

NOAA/GFDL

*What have the Aerosols done to Climate?*

May 21, 2009

**Rong Fu**

University of Texas at Austin

*Detecting, understanding and projecting climate change over tropical land*

June 11, 2009

**Chidong Zhang**

University of Miami

*Effect of Aerosol on Tropical Large-Scale Precipitation*

August 20, 2009

**Natalie Mahowald**

Cornell University

*Mineral Aerosol Interactions With Climate And Biogeochemistry*

September 14, 2009

**Mr. William J. Kramber** (Idaho Department of Water Resources);

**Mr. Anthony E. Morse III** (Geospatial Technology at Idaho Department of Water Resources);

**Dr. Richard G. Allen** (University of Idaho) Joint Laboratory for Atmospheres, Hydrospheric and Biospheric Sciences Laboratory,

LDCM Project Office Seminar

*Landsat Thermal Data: Mapping Evapotranspiration over Large Areas with High Fidelity and its Use in Taming Water Resources Lions*

October 22, 2009

**Steven Pawson**

NASA GSFC GMAO

*Understanding the roles of ozone and other trace gases in climate*

November 19, 2009

**Syed Iqbal Hasnain**

The Energy and Resources Institute

*Disappearing Himalayan Ice: Impact of Long-Lived and Short-Lived Climate Forcing Agents*

January 14, 2010

**Peter Pilewskie**

University of Colorado at Boulder

*The Sun, Climate, and the Total and Spectral Solar Irradiance Sensor*

February 18, 2010

**Bill Randel**

NCAR

*The Asian monsoon anticyclone, pollution near the tropopause and transport to the stratosphere*

### 6.8. Public Outreach

---

#### January

**William Lau** (613.0), **Si-Chee Tsay** (613.2), and **Judd Welton** (613.1) attended the 2nd International Workshops on TIGERZ and 7 South East Asian Studies (7-SEAS) at the Indian Meteorological Department in New Delhi, India. These studies are a part of the Asian Monsoon Years Aerosol-Cloud Observations. They participated in site visits and technical training for aerosol-cloud interactions and aerosol long-range transport observations.

On January 11, GMAO (610.1) hosted a short course on its MERRA (Modern Era Retrospective-analysis for Research and Applications) at the AMS meeting in Phoenix, AZ. There were 15 attendees from a variety of backgrounds, research and applications, universities, and government. The objective was to

provide the basic understanding of the system, information on system validation, on how to use the data in research and how to access the data with traditional methods, and newer online software access. The short course was led by M. Bosilovich and A. da Silva (610.1) and included presentations and hands-on exercises by them and by S. Berrick and D. Ostrenga (both 610.2).

**Jim Irons** (613.0), LDCM Project Scientist, gave a talk on “Extending the Landsat Legacy, Progress Towards the Launch of the Landsat Data Continuity Mission” to the Washington/Northern Virginia Chapter of the IEEE Geoscience and Remote Sensing Society at the Goddard Visitors’ Center on January 21.

Eight scientists from Code 613.1 gave presentations at the 89th American Meteorological Society’s Annual Meeting.

**Charles Ichoku** attended a GLOBE Climate Change Research & Education Meeting in Geneva, Switzerland, January 25–28, 2009, where he presented a paper entitled “Atmospheric Aerosols and Climate;” and participated in deliberations on planning the Global Student Research Campaign on Climate Change, being organized by GLOBE, and scheduled to take place from 2011 to 2013.

**C. Jackman** (Code 613.3) and **M. DeLand** (SSAI/613.3) attended the Ground Level Enhancement (GLE) Coordinated Data Analysis Workshop (CDAW), held at the Lockheed Martin facility in Palo Alto, CA, from Jan. 6–9, 2009. GLEs are measurements of significant increases in the count rates of ground-level neutron monitors due to extremely high energy solar particles, which occur as a result of very large solar explosions. **N. Gopalswamy**, Code 695, was one of the two primary organizers of the workshop, which was attended by about 25 scientists.

On January 29, 2009, 613.2 branch members **Shaun Bell** and **Clare Salustro** as well as other SSAI employees volunteered at the Gaywood Elementary School Science Fair. As judges of the students’ projects, they helped to further students’ interest and involvement in scientific endeavors through direct discussion with individual students.

Graduate student **Susanna Ebmeier** of the Department of Earth Sciences from the University of Oxford will be visiting **Dr. Santiago Gassó** (GEST/UMBC) February 9–13. She and her advisor, **Dr. Tamsin Mather**, are interested in the interactions that occur between the Earth’s interior and its atmosphere, in particular at active volcanoes.. For additional information, view January 20, 2008 Image of the Week: <http://climate.gsfc.nasa.gov/viewImage.php?id=226>.

## February

**Alexander Marshak** (613.2) gave a colloquium at Michigan Tech entitled, “How simple radiative transfer helps to interpret satellite measurements; examples from active and passive remote sensing” on February 2, 2009.

**Ralph Kahn** (613.2) was asked to give a Practical Uses of Math and Science (PUMAS) workshop to 65 teachers in Chester County, Pennsylvania on February 3, 2009. <http://pumas.gsfc.nasa.gov>

**David Whiteman** (613.1) gave a presentation to a group of Delaware elementary, middle and high school teachers on atmospheric profiling and satellite validation using laser remote sensing. The teachers were sponsored by the Delaware Aerospace Education Foundation in conjunction with the Delaware Teachers Center and were visiting GSFC hosted by the Aerospace Education program on February 11.

**David Whiteman** (613.1) attended the first Implementation Meeting for the GCOS Reference Upper Air Network (GRUAN) held in Norman, OK March 2–4. Dr. Whiteman attended as the NASA contact for the upper air activities at the Howard University Beltsville Campus which is one of the initially invited

GRUAN sites. Among the goals of the meeting was to establish a uniform radiosonde launch protocol so that the upper air soundings from GRUAN can begin to form a high quality dataset for climate monitoring purposes.

**Scott Braun** (613.1) gave an invited seminar at Penn State University entitled “Improving our understanding of Atlantic hurricanes through knowledge of the Saharan Air Layer: Hope or hype?”

### March

**Paul Newman** (613.3) gave a talk on the “World Avoid: What would have happened to ozone and UV if CFCs had not been regulated?” at the Environmental Protection Agency on March 11. The meeting was for the stakeholders in the “Don’t Fry-Day” public outreach effort that will occur on May 22, 2009. This public outreach program is intended to promote the avoidance of excessive sun exposure at the beginning of summer. The stakeholders included participants from various Federal agencies, public health organizations, and associations of skin cancer experts.

**Mr. Ricardo Forno** completed a 6-week stay at GSFC as a visiting researcher from the Laboratory for Atmospheric Physics at the Universidad Mayor de San Andres in La Paz, Bolivia. During his time at GSFC, he worked with **David Whiteman** (613.1) in cryogenic frostpoint measurements of atmospheric water vapor in support of the Network for the Detection of Atmospheric Composition Change (NDACC).

A delegation of about 30 graduate and undergraduate students—who hail from various universities across the country, and who participate in the MS PHD’S (Minorities Striving and Pursuing Higher Degrees of Success in Earth System Science) program (<http://www.msphds.org/>)—visited GSFC on March 17, 2009.

**Charles Ichoku** (613.2) and **Molly Brown** (614.4) gave talks to the student delegation on “Aerosols, radiation, and climate”, and “Food security, agriculture and satellite remote sensing”, respectively.

### April

**Alexander Marshak** (613.2) and **Tamas Varnai** (613.2/UMBC) were interviewed for the article entitled “Light Reflected by Clouds can Brighten Air Kilometers Away” featured in *NatureNews*. <http://www.nature.com/news/2009/090403/full/news.2009.215.html>

A NASA Headquarter news release entitled “NASA Experiments Stir up Hope for Forecasting Deadliest Cyclones” was announced in April, highlighting the recently published paper in *Geophys. Res. Lett.* by **Dr. Oreste Reale** (Code 613.0 / UMBC) and his associates, which demonstrated significant improvements in forecasting tropical storm Nargis, using assimilating AIRS cloudy-sky retrievals in the GEOS-5 forecasts. The paper represents the first successful attempt to “hindcast” tropical cyclone Nargis using a global, high-resolution forecast model.

**William Lau** (Code 613.0) attended the Aerosol-Cloud-Precipitation-Climate (ACPC) Science Steering Committee meeting in BERN, Switzerland, to complete the writing of an ACPC Science Implementation Plan. The ACPC is a cross-cut initiative between the World Climate Research Program (WCRP) and the International Geosphere-Biosphere Program (IGBP) involving the integrated use of satellite, aircraft remote sensing, in situ observations and modeling to study interaction of aerosol and climate.

On April 15, **Dr. Matthew McGill** (613.1) hosted a tour of the Cloud Physics Lidar lab for Center management and visiting House Science and Technology Committee staffers. Their interest was in seeing the new lidar instrument for the Global Hawk unmanned aircraft, as well as to discuss new science applications that will be possible using the Global Hawk.



**B.T. Johnson, G. Skofronick-Jackson**, 2009: The influence of non-spherical particles and land surface emissivity on combined radar / radiometer precipitation retrievals, European Geosciences Union General Assembly, Vienna Austria, Friday, April 24, 2009. This oral presentation described recent advances of falling snow retrieval over land surfaces, using combined radar and radiometer observations. The simulations/retrievals are based on Global Precipitation Measurement Mission (GPM) instruments and observations, and are part of the path toward developing the official GPM combined radar/radiometer retrieval algorithm.

## May

**William Lau** (613.0) was presented with a Certification of Appreciation by the Forensic Science Laboratory, Alcohol, Firearms, Tobacco and Explosive Division, Justice Department for a keynote seminar entitled, “What causes the rapid melting of Himalaya glaciers—A forensic science investigation” on Earth Day, April 22. During the seminar, he presented evidences gathered from the “crime scene”, and an increasing body of “circumstantial” evidences, from NASA satellites, field observations, and modeling results—all pointing towards dust and black carbon aerosols as the most probable suspect. The seminar was very well received and generated much discussion among the audience of forensic scientists.

On April 16, 2009, **Raymond Hoff**, **Charles Ichoku** (613.2), Juying Warner, and **Ralph Kahn** (613.2) participated in the **Chieko Kittaka** Celebration of Life Memorial at Hampton College, Virginia which was sponsored by her colleagues at NASA/Langley. **Ralph Kahn**, on behalf of GSFC and the AeroCenter community, read the following statement:

“I wanted to speak briefly for myself, and I think for many of Chieko’s scientific colleagues at NASA Goddard and elsewhere. Although we come from an enormous diversity of backgrounds, we share a common thread of extraordinary commitment and dedication to our science. Studying the climate of Earth, with its implied impact on Civilization, is a calling of immense significance that binds us into a fairly close-knit community. I think Chieko would have been surprised at how many fellow scientists she touched, just as many of us, some of whom knew her primarily through our joint research projects, have kept recalling during the past few weeks the positive energy and enthusiasm she brought to her work on air quality modeling and observation, and CALIPSO aerosol remote sensing. We will keep recalling her energy and her contributions, and through our ongoing efforts to better understand our planet, will continue honoring Chieko Kittaka, and ourselves.”

April 29, 2009 marks the 10th anniversary of the launch of NASA’s Earth Observatory Web site. Over the past 10 years, the Earth Observatory has worked with scientists and education and outreach partners from across the Agency to publish thousands of images and hundreds of articles about NASA’s Earth science and climate change research. Images from the Earth Observatory regularly appear in the mass media, popular science magazines, textbooks, and blogs. URL: <http://earthobservatory.nasa.gov/Features/10thAnniversary/>

**Richard Kleidman** (613.2/SSAI) and **Jun Wang** (613.2) taught a Remote Sensing and Air Quality Applications workshop in Singapore May 11–15, 2009. Participants from Singapore, Thailand, Taiwan, The Philippines and India attended the workshop

**David Whiteman** (613.1) gave a talk at Trinity Washington University on April 21 as part of their Mathematics Awareness Week activities. His talk focused on the role of water vapor in the climate system and the use of mathematical models to optimize systems to measure atmospheric water vapor.

## EDUCATION AND OUTREACH

**David Whiteman** (613.1) participated in the Greenbelt Middle School career day on May 12 presenting to 4 classes at the school about typical work activities of an atmospheric scientist working at NASA.

### July

The Landsat 7 and LDCM Project Scientists, **Darrel Williams** (614.0) and **Jim Irons** (613.0), respectively, presented their views on past, present, and future Landsat interagency partnership at the invitation of a National Academy of Science (NAS) committee convened to examine Impediments to Interagency Cooperation on Space and Earth Science Missions. The presentation was made during committee meetings on July 31 at the NAS building in Washington, DC. The committee was cochaired by James Baker, former NOAA administrator, and included **A. Thomas Young**, former GSFC Director, and **Mark Schoeberl** (610), currently the Chief Scientist of the GSFC Earth Science Division, Code 610.

**Scott Braun** (613.1) presented a seminar entitled “A Climatological Perspective of the Role of the Saharan Air Layer on Tropical Cyclogenesis and Evolution” at the Naval Post-Graduate School in Monterey, CA, on July 31, 2009.

### August

**Ralph Kahn** (613.2) presented the keynote speech; and **N. Christina Hsu** (613.2) presented an invited talk at the 439<sup>th</sup> WE-Heraeus Seminar in Bad Honnef, Germany, August 17–19, 2009.

### September

**Bo-Wen Shen** (UMCP/ESSIC, 613.1) published two news articles to discuss the challenges of intensity and rainfall predictions for landfalling Typhoons in Taiwan, including deadly Typhoon Morakot, and the recent advance in high-resolution global models and supercomputer technology at NASA that show a potential for improving intensity predictions. Morakot (2009) devastated Taiwan and Eastern China, and caused tremendous damage by dumping a total of about 2.5 meters (100 inches) of rain in Taiwan in early August, 2009. These two articles in Chinese were published by Want daily forum and China times, which are available at:

<http://news.chinatimes.com/2007Cti/2007Cti-News/2007Cti-News-Content/0%2C4521%2C11051404%2B112009090800385%2C00.htm>

<http://tech.chinatimes.com/2007Cti/2007Cti-News/Inc/2007cti-news-Tech-inc/Tech-Content/0%2C4703%2C171703%2B112009081400797%2C00.html>

**Bo-Wen Shen** (UMCP/ESSIC, 613.1) was interviewed by *EARTH Magazine* (<http://www.earthmagazine.org/>), published by American Geological Institute, to give comments on the recent article entitled “Maximum hurricane intensity preceded by increase in lightning frequency” by Price et al. (2009), which was published in *Nature Geoscience*. The article with Shen’s comments was published in the July issue of *EARTH*.

### October

**Bo-Wen Shen** (UMCP/ESSIC, 613.1) was invited by the Editor of *Want Daily* to provide comments on the diverse forecasts of the recent typhoon Parma in early October 2009 from different operational weather centers in the world. He suggested that further improvement of track forecasts for this case

would rely on the accurate representation of the steering flows in the saddle region between Taiwan and Philippines, and therefore on the deployment of high-resolution observation system (e.g., NASA Satellites) and data assimilation system. This article in Chinese was published by *Want Daily* in:

<http://news.chinatimes.com/2007Cti/2007Cti-News/2007Cti-News-Content/0%2C4521%2C11051404%2B112009100700490%2C00.htm>

**Anne Douglass** (Code 613.3) chaired and **Mark Olsen** Code (613.3) sat on a panel discussion “Parenthood: The Elephant in the Laboratory” at the Women in Astronomy and Space Science 2009 meeting on October 22 in College Park, MD. The discussion was based on the book *Motherhood: The Elephant in the Laboratory* and focused on the many ways in which women and men can successfully combine parenthood and a career in the sciences.

A news article featuring recent research on the day-of-the-week dependence of lightning statistics by **Dr. Thomas Bell** (613.2/Emeritus) in the Climate and Radiation Branch appeared October 15 in the environmental news Web site published by the Brazilian organization O Eco Association. The Web site is <http://www.oeco.com.br/reportagens/37-reportagens/22665-eletricidade-intensificada>. O Eco Association is a non-profit organization that has been running an environmental news Web site since 2004. Its focus is on nature conservancy.

## November

**Charles Gatebe** (UMBC-GEST/613.2) was featured on *The GLOBE Program Online News*, November 2009: <http://www.globe.gov/content/newsbriefs/November2009>

On November 17, AeroCenter went “live” with a WebEx broadcast of the seminar. This is the second week in which aerosol scientists from outside of Goddard could link in to view, hear, and participate in the science presentation and discussion. Twenty-three outside participants were noted and included people from NASA Langley, NASA GISS, NASA Ames, and several NOAA facilities. AeroCenter, a cross disciplinary community of NASA Goddard scientists, has long been a global leader in aerosol research. With the WebEx broadcasts the community has been significantly expanded, placing Goddard squarely at the center of global aerosol research.

**Gail Skofronick Jackson** co-hosted “Career Day for Girls, Inc” (a national program to encourage middle school girls to be interested in STEM careers) at the Goddard Visitor Center on Saturday November 14, 2009. The event was scheduled 12:00–3:30 p.m. with about 50 girls bused up from Washington DC. The girls toured the visitor center, met with approximately 20 women in STEM Careers (10 minute rotations with 2-3 girls per woman), and watched a *Science on a Sphere* movie.

## December

**Richard Kleidman** (SSAI/613.2) will be presented a one-day training on the use of NASA remote sensing products to the user communities of the greater San Francisco Bay Area, on Tuesday, December 8, 2009. The training is sponsored by UCSC and will be held at the UCSC facility adjacent to NASA Ames. Participants include students, researchers and applied scientists from UCSC, NASA Ames, Stanford University and local air pollution control managers.



## 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.

AATS	Ames Airborne Tracking Sunphotometer
ACAM	Airborne Compact Atmospheric Mapper
ACARS	Aircraft Communications Addressing and Reporting System
ACCRI	Aviation Climate CHange Research Initiative
ACDB	Atmospheric Chemistry and Dynamics Branch
ACE	Aerosol–Clouds and Ecology
ACPC	Aerosol-Cloud-Precipitation-Climate
AERI	Atmospheric Emitted Radiance Interferometer
AERONET	Aerosol Robotic Network
AFB	Air Force Base
AGL	Above ground level
AGU	American Geophysical Union
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
AOT	Aerosol Optical Thickness
APS	Aerosol Polarimetric Sensor
ARC	Ames Research Center
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
ARM	Atmospheric Radiation Measurement (Program)
ASCENDS	Active Sensing of CO <sub>2</sub> Emissions over Night, Days, and Seasons

## ACRONYMS

ASCII	American Standard Code for Information Interchange
ASDC	Atmospheric Science Data Center
APS	Aerosol Polarimetric Sensor
ASR	Atmospheric Systems Research
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer)
AT	AT-Lidar (Aerosol and Temperature Lidar)
ATL	Aerosol and Temperature Lidar
ATMS	Advanced Technology Microwave Sounder
AU	Astronomical Unit
AVE	Aura Validation Experiment
AVHRR	Advanced Very High Resolution Radiometer
BATC	Ball Aerospace and Technologies Corporation
BCCSO	The Beltsville Center for Climate Change Observation
BUV	Backscatter Ultraviolet
C3VP	Canadian CloudSat/CALIPSO Validation Program
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CASS	Chemical and Aerosol Sounding Satellite
CCD	Charge-Coupled Device
CCM	Chemistry Climate Model
CCMVal	Chemistry–Climate Model Validation exercise
CDAW	Coordinated Data Analysis Workshop
CERES	Clouds and the Earth’s Radiant Energy System
CFCs	Chlorofluorocarbons
CIMSS	Cooperative Institute of Meteorological Satellite Studies
CIRC	Continuous Intercomparison of Radiation Codes
CLASIC	Cloud and Land Surface Interaction Campaign
CVPP	Climate Variability and Predictability Programme
CMOS	Complementary metal–oxide–semiconductor
CNRS	Centre National de la Recherche Scientifique (France)
COMBO	Combined Stratospheric-Tropospheric Model
COMMIT	Chemical, Optical, and Microphysical Measurements of <i>In situ</i> Troposphere
COSPAR	Committee on Space Research

CPL	Cloud Physics Lidar
CR-AVE	Costa Rica-Aura Validation Experiment
CRM	CPL-Radar-MAS
CRS	Cloud Radar System
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment
CTM	Chemical Transport Model
DAAC	Distributed Active Archive Center
DABUL	Depolarization and Backscatter Unattended Lidar
DARE	Direct aerosol radiative effects
DFRC	Dryden Flight Research Center
DISC	Data and Information Services Center
DoD	Department of Defense
DoE	Department of Energy
DSCOVER	Deep Space Climate Observatory (formerly Triana)
DU	Dobson Unit
ECC	Electrochemical Concentration Cell
ECMWF	European Centre for Medium-Range Weather Forecasts
EDOP	ER-2 Doppler Radar
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)
EROS	Earth Resources Observation and Science
ESA	European Space Agency
ESD	Earth Sciences Division
ESDR	Earth System Data Record
ESE	Earth Science Enterprise
ESSIC	Earth System Science Interdisciplinary Center
ESTO	Earth Science Technology Office
EU	European Union

## ACRONYMS

FAA	Federal Aviation Administration
FOV	Field of View
FTP	File Transfer Protocol
fvGCM	Finite volume General Circulation Model
GACM	Global Atmospheric Composition Mission
GCE	Goddard Cumulus Ensemble model
GCM	General Circulation Model
GCOS	Global Climate Observing System
GEO-CAPE	Geostationary Coastal and Air Pollution Events
GEOS	Goddard Earth Observing System
GES DISC	Goddard Earth Sciences Data and Information Services Center
GEST	Goddard Earth Sciences and Technology Center
GEST-GSSP	Goddard Earth Sciences and Technology (GEST) Center Graduate Student Summer Program
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecasting System
GISS	Goddard Institute for Space Studies
GLAS	Geoscience Laser Altimeter System
GLE	Ground Level Enhancement
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
GOSAT	Greenhouse gas Observing Satellite
GOES	Geostationary Operational Environmental Satellite
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GPS	Global Positioning System



GRIP	Genesis and Rapid Intensification Processes
GRUAN	GCOS Reference Upper Air Network
GSFC	Goddard Space Flight Center
GSSP	Graduate Student Summer Program
GSWP	Global Soil Wetness Project
GV	Ground Validation
GVP	Ground Validation Program
HBCUs	Historically Black Colleges and Universities
HDF	Hierarchical Data Format
HDTV	High-definition television
HIRDLS	High Resolution Dynamics Limb Sounder
HIRS	High Resolution Infrared Sounder
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
HSB	Humidity Sounder Brazil
HSRL	High-Spectral-Resolution Lidar
HU	Howard University
HUPAS	Howard University Program in Atmospheric Sciences
HURB	Howard University Research site at Beltsville
HURL	Howard University Raman Lidar
I3RC	International Intercomparison of 3-Dimensional Radiation Codes
IAMAS	International Association of Meteorology and Atmospheric Sciences
IAMAS -MOCA	IAMAS Montreal, Canada
ICCP	International Commission on Clouds and Precipitation
ICESat	Ice, Cloud, and Land Elevation Satellite
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IHOP	International H <sub>2</sub> O Project
IIP	Instrument Incubator Program
IO <sub>3</sub> C	International Ozone Commission
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IRC	International Radiation Committee
IRC IRS–2012	IRC International Radiation Symposium 2012
IT	Information Technology

## ACRONYMS

IUGG	International Union of Geodesy and Geophysics
JAXA	Japan Aerospace Exploration Agency
JAMEX	Joint Aerosol Monsoon Experiment
JCET	Joint Center for Earth Systems Technology
JCOSS	Joint Center for Observation System Science
JGR	Journal of Geophysical Research
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
LaRC	Langley Research Center
LASP	Laboratory for Atmospheric and Space Physics
LDCM	Landsat Data Continuity Mission
LIDAR	Light Detection and Ranging
LISIRD	LASP Interactive Solar Irradiance Datacenter
MAP	Modeling and Analysis Program
MAPB	Mesoscale Atmospheric Processes Branch
MAS	MODIS Airborne Simulator
MERRA	Modern Era Retrospective-analysis for Research and Applications
MILAGRO	Megacity Initiative: Local And Global Research Observations
MISR	Multi-Angle Imaging Spectroradiometer
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
MSU	Microwave Sounding Unit
NAS	National Academy of Sciences

NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCAS	NOAA (Howard University) Center for Atmospheric Science
NCEP	National Center for Environmental Prediction
NDACC	NASA-supported Network for the Detection of Atmospheric Composition Change
NEO	NASA Earth Observations
NGST	Northrop Grumman Space Technology
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NISTAR	National Institute of Standards and Technology Advanced Radiometer
NOAA	National Oceanic and Atmospheric Administration
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
NUV	Near Ultraviolet
NWS	National Weather Service
OEI	Ozone ENSO Index
OGO	Orbiting Geophysical Observatory
OLI	Operational Land Imager
OLR	Outgoing Longwave Radiation
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
OOAT	Ozone Operational Algorithm Team
OSSE	Observing System Simulation Experiment
OSTP	Office of Science and Technology Policy
PDF	Portable Document Format
PDR	Preliminary Design Review
PI	Principal Investigator
PM	Particulate Matter

## ACRONYMS

PMM	Precipitation Measurement Missions
PMOD	Physikalisch-Meteorologisches Observatorium Davos (Switzerland)
POES	Polar Orbiting Environmental Satellite
PODEX	Polarimeter Definition Experiment
PR	Precipitation Radar
PUMAS	Practical Uses of Math and Science
RAJO-MEGHA	Radiation, Aerosol Joint Observations-Monsoon Experiment in the Gangetic-Himalayan Area
RASL	Raman Airborne Spectroscopic Lidar
RCDF	Radiometric Calibration and Development Facility
RFP	Request for Proposal
ROSES	Research Opportunities in Space and Earth Sciences
RRS	Radiosonde Replacement System
SAGE	Stratospheric Aerosol and Gas Experiment
SAP	Synthesis and Assessment Product
SAP	Scientific Assessment Panel
SBIR	Small Business Innovative Research
SBUV	Solar Backscatter Ultraviolet
SBUV/2	Solar Backscatter Ultraviolet/version 2
SCIAMACHY	Scanning Imaging Absorption SpectroMeter for Atmospheric CHartography
SCRC	Student Climate Research Campaign
SDSU	Satellite Data Simulation Unit
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SESI	Scientific and Engineering Student Internship program
SG	Study Group
SHADOZ	Southern Hemisphere ADditional OZonesondes
SIM	Spectral Irradiance Monitor
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMD	Science Mission Directorate
SOLSTICE	Solar-Stellar Irradiance Comparison Experiment
SOP	Special Observing Period
SORCE	Solar Radiation and Climate Experiment
SIES	Summer Institute in Earth Sciences
SPARC	Stratospheric Processes and their Role in Climate

SSAI	Science Systems and Applications, Inc.
SSG	Science Steering Group
SST	Sea-Surface Temperature
SSU	Spectral Sensor Unit
STEM	Science, Technology, Engineering, and Mathematics
STROZ	Stratospheric Ozone
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
SUNY	State University of New York
TC4	Tropical Composition, Cloud, and Climate Coupling
TES	Tropospheric Emission Spectrometer
TIM	Total Irradiance Monitor
TIROS	Television Infrared Observation Satellite
TIRS	Thermal InfraRed Sensor
TMF	Table Mountain Facility
TMI	TRMM Microwave Imager
TMPA	TRMM Multi-satellite Precipitation Analysis
TOA	Top of Atmosphere
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
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UAV-CPL	Unmanned Aerial Vehicle-Cloud Physics Lilar
UMBC	University of Maryland, Baltimore County
UMD	University of Maryland
UMCP	University of Maryland, College Park
UNEP	United Nations Environment Programme
URAD	UAV Radar
USDA	United States Department of Agriculture

## ACRONYMS

USGS	U.S. Geological Survey
UV	Ultraviolet
UV-A	Ultraviolet-A radiation
UV-B	Ultraviolet radiation
UV-IR	Ultraviolet-Infrared
UV/VIS	Ultraviolet/ Visible
UWM	University of Wisconsin-Milwaukee
VALIDAR	Validation Lidar
VIIRS	Visible/Infrared Imager/Radiometer Suite
VIS	Visible
WACCM	Whole Atmosphere Community Climate Model
WAVES	Water Vapor Validation Experiment – Satellite and Sondes
WCRP	World Climate Research Program
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WRF-Chem	Weather Research and Forecasting—Chemistry
XPS	X-ray Photoelectron Spectroscopy

## APPENDIX 1: THE LABORATORY IN THE NEWS

[e! Science News](#)

## Report calls aerosol research key to improving climate predictions

Published: Saturday, January 17, 2009 - 02:10

Scientists need a more detailed understanding of how human-produced atmospheric particles, called aerosols, affect climate in order to produce better predictions of Earth's future climate, according to a NASA-led report issued by the U.S. Climate Change Science Program on Friday. "Atmospheric Aerosol Properties and Climate Impacts," is the latest in a series of Climate Change Science Program reports that addresses various aspects of the country's highest priority climate research, observation and decision-support needs. The study's authors include scientists from NASA, the National Oceanic and Atmospheric Administration and the Department of Energy.

"The influence of aerosols on climate is not yet adequately taken into account in our computer predictions of climate," said Mian Chin, report coordinating lead author from NASA's Goddard Space Flight Center in Greenbelt, Md. "An improved representation of aerosols in climate models is essential to more accurately predict the climate changes."

Aerosols are suspended solid or liquid particles in the air that often are visible as dust, smoke and haze. Aerosols come from a variety of natural and human processes. On a global basis, the bulk of aerosols originate from natural sources, mainly sea salt, dust and wildfires. Human-produced aerosols arise primarily from a variety of combustion sources. They can be the dominant form of aerosol in and downwind of highly populated and industrialized regions, and in areas of intense agricultural burning.

Although Earth's atmosphere consists primarily of gases, aerosols and clouds play significant roles in shaping conditions at the surface and in the lower atmosphere. Aerosols typically range in diameter from a few nanometers to a few tens of micrometers. They exhibit a wide range of compositions and shapes, but aerosols between 0.05 and 10 micrometers in diameter dominate aerosols' direct interaction with sunlight. Aerosols also can produce changes in cloud properties and precipitation, which, in turn, affect climate.

Current predictions of how much Earth's average surface temperature will increase in the future fall in a wide range. If the amount of carbon dioxide and other greenhouse gases double from the levels in the atmosphere in 1990, the increase in temperature is expected to be from 2.2 to 7.9 degrees Fahrenheit, according to the U.N. Intergovernmental Panel on Climate Change. The role of greenhouse gases in global warming is fairly well established, but the degree to which the cooling effect of human-produced aerosols offsets the warming is still inadequately understood. The report states that scientists should strive to improve their understanding of aerosols' climate influences with the goal of cutting that range of uncertainty by nearly two-thirds.

The report states that to achieve the goal of reducing uncertainties in aerosol impacts on climate, an advanced, multi-disciplinary approach that integrates surface, aircraft, and space-based measurements with models will have to be developed. Scientists have made gains in modeling aerosol effects, but this capability has not yet been fully incorporated into climate simulations, according to the report.

The report advocates the development of new space-based, field, and laboratory instruments and the incorporation of more realistic simulations of aerosol, cloud, and atmospheric processes into climate models. The United States faces the challenge of maintaining and enhancing its existing aerosol monitoring capability from space. Satellites have been providing global aerosol observations since the late 1970s, with major improvements in accuracy since the late 1990s. But some of these missions, such as NASA's suite of Earth Observing System satellites, are reaching or exceeding their design lives, the report notes.

**Source:** [NASA/Goddard Space Flight Center](#)

[e! Science News](#)

## **NASA global precipitation measurement mission passes major review**

Published: Tuesday, December 8, 2009 - 15:41

NASA's effort to deploy the first satellite mission to advance global precipitation observations from space moved closer to this goal when agency officials approved critical elements for the Global Precipitation Measurement (GPM) mission on Dec. 2. NASA gave GPM the green light to proceed to the mission implementation phase in a review meeting chaired by NASA's Associate Administrator Christopher Scolese.

Building on the success of the Tropical Rainfall Measuring Mission (TRMM), a joint project between NASA and the Japan Aerospace Exploration Agency (JAXA), GPM will usher in a new generation of space-based observations of global precipitation, a key element of the Earth's climate and also the primary source of freshwater. GPM is an international collaboration that currently includes NASA and JAXA, with anticipated contributions from additional international partners.

"This joint NASA/JAXA mission is scientifically important and stands as a prime example of the power of international cooperation in Earth observations," said NASA's Earth Science Division director Michael Freilich. "GPM's global precipitation measurements will advance our abilities to monitor and accurately predict precipitation on a global basis. GPM builds on the strong scientific and technical collaborations developed between NASA and JAXA. GPM instruments will also provide key calibration references to allow measurements from a wide variety of other satellite missions, including those from other U.S. and international organizations, to be combined to provide accurate predictions and global data sets."

The heart of the GPM mission is a spaceborne Core Observatory that serves as a reference standard to unify and advance measurements from a constellation of multinational research and operational satellites carrying microwave sensors. GPM will provide uniformly calibrated precipitation measurements globally every 2-4 hours for scientific research and societal applications. The GPM Core Observatory sensor measurements will for the first time make quantitative observations of precipitation particle size distribution, which is key to improving the accuracy of precipitation estimates by microwave radiometers and radars.

The GPM Core Observatory will carry a Dual-frequency Precipitation Radar (DPR) and a multi-channel GPM Microwave Imager (GMI). DPR will have greater measurement sensitivity to light rain and snowfall compared to the TRMM radar. GMI uses a set of frequencies to retrieve heavy, moderate, and light precipitation from emission and scattering signals of water droplets and ice particles.

GPM is the cornerstone of the multinational Committee on Earth Observation Satellites Precipitation Constellation that addresses one of the key observations of the Global Earth Observation System of Systems.

NASA is responsible for the GPM Core Observatory spacecraft bus, the GMI carried on it, the Core Observatory integration, launch site processing, mission operation and science data processing and distribution. NASA is also responsible for the development of a second GMI to be flown on a partner-provided Low-Inclination Observatory (LIO) and the Instrument Operational Center for the LIO. The GPM Core Observatory is scheduled for launch in July 2013 from JAXA's Tanegashima launch site on an H-IIA rocket.

NASA's Goddard Space Flight Center in Greenbelt, Md., manages the GPM mission on behalf of the Earth Science Division of the Science Mission Directorate at NASA Headquarters. Goddard oversees the in-house Core Observatory development and the GMI acquisition from Ball Aerospace & Technologies Corporation of Boulder, Colo. The GPM project life cycle cost is \$978 million.

**Source:** [NASA/Goddard Space Flight Center](#)




[Print](#)
[Close](#)

## Feature

### UV Exposure Has Increased Over the Last 30 Years, but Stabilized Since the Mid-1990s

03.16.10

NASA scientists analyzing 30 years of satellite data have found that the amount of ultraviolet (UV) radiation reaching Earth's surface has increased markedly over the last three decades. Most of the increase has occurred in the mid-and-high latitudes, and there's been little or no increase in tropical regions.

The new analysis shows, for example, that at one line of latitude — 32.5 degrees — a line that runs through central Texas in the northern hemisphere and the country of Uruguay in the southern hemisphere, 305 nanometer UV levels have gone up by some 6 percent on average since 1979.

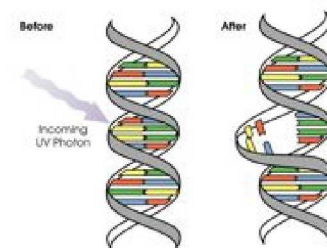
The primary culprit: decreasing levels of stratospheric ozone, a colorless gas that acts as Earth's natural sunscreen by shielding the surface from damaging UV radiation.

The finding reinforces previous observations that show UV levels are stabilizing after countries began signing an international treaty that limited the emissions of ozone-depleting gases in 1987. The study also shows that increased cloudiness in the southern hemisphere over the 30-year period has impacted UV.

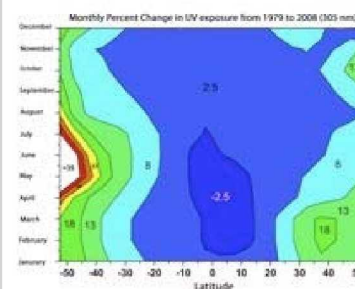
Jay Herman, a scientist at NASA's Goddard Space Flight Center in Greenbelt, Md., stitched together data from several earth observing satellites — including NASA's Aura satellite, NOAA weather satellites, and commercial satellites — to draw his conclusions. The results were published in the *Journal of Geophysical Research* in February.

"Overall, we're still not where we'd like to be with ozone, but we're on the right track," said Jay Herman. "We do still see an increase in UV on a 30-year timescale, but it's moderate, it could have been worse, and it appears to have leveled off."

In the tropics, the increase has been minimal, but in the mid-latitudes it has been more obvious. During the summer, for example, UV has increased by more than 20 percent in Patagonia and the southern portions of South America. It has risen by nearly 10 percent in Buenos Aires, a city that's about the same distance from the equator as Little Rock, Ark. At Washington, D.C.'s latitude — about 35 degrees north — UV has increased by about 9 percent since 1979.


[Larger image](#)

Ultraviolet radiation can damage DNA by distorting its structure. **Credit:** NASA's Earth Observatory/David Herring


[Larger image](#)

The largest increases in UV (shown in white, red, orange, and yellow) have occurred in the southern hemisphere during April, May and June. In the tropics, increases in UV have been minimal (shown in blue). Though the size of UV wavelengths ranges from 290 to 400 nanometers, 305 nanometer UV is one of the most damaging types for humans. **Credit:** NASA's Goddard Space Flight Center/Jay Herman

## APPENDIX 1: THE LABORATORY IN THE NEWS

The southern hemisphere tends to have more UV exposure because of the ozone hole, a seasonal depletion of the ozone layer centered on the South Pole. There are also fewer particles of air pollution — which help block UV — due to the comparatively small numbers of people who live in the southern hemisphere.

Despite the overall increases, there are clear signs that ultraviolet radiation levels are on the verge of falling. Herman's analysis, which is in agreement with a World Meteorological Report published in recent years, shows that decreases in ozone and corresponding increases in UV irradiance leveled off in the mid-nineties.

### The Many Sides of Radiation

Shorter ultraviolet wavelengths of light contain more energy than the infrared or visible portions of sunlight that reach Earth's surface. Because of this, UV photons can break atmospheric chemical bonds and cause complex health effects.

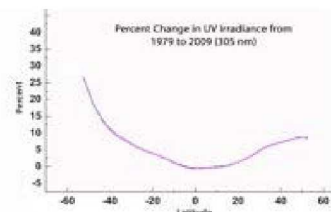
Longer wavelengths (from 320 to 400 nanometers) — called UV-A — cause sunburn and cataracts. Yet, UV-A can also improve health by spurring the production of Vitamin D, a substance that's critical for calcium absorption in bones and that helps stave off a variety of chronic diseases.

UV-B, which has slightly shorter wavelengths (from 320 to 290 nanometers), damages DNA by tangling and distorting its ladder-like structure, causing a range of health problems such as skin cancer and diseases affecting the immune system.

As part of his study, Herman developed a mathematical technique to quantify the biological impacts of UV exposure. He examined and calculated how changing levels of ozone and ultraviolet irradiance affect life. For Greenbelt, Md., for example, he calculated that a 7 percent increase in UV yielded a 4.4 percent increase in the damage to skin, a 4.8 percent increase in damage to DNA, a 5 percent increase in Vitamin D production, and less than a percent of increase in plant growth.

"If you go to the beach these days, you're at slightly higher risk of getting skin cancer (without protection)," Herman said, though he noted the risk would have been even greater in the absence of regulations on ozone-depleting substances.

Last year, one of Herman's Goddard colleagues, Paul Newman, published a study showing that the ozone hole likely would have become a year-round fixture and UV radiation would increase 650 percent by 2065 in mid-latitude cities if not for the Montreal Protocol, an international treaty signed in 1987 that limited the amount of ozone-depleting gases countries could emit.



#### > Larger image

The high latitudes of the southern hemisphere have seen ultraviolet exposure increase by as much as a quarter. The low latitudes have seen little increase, and the mid-and-high latitudes of the northern hemisphere have seen about a five percent increase. Though the size of UV wavelengths ranges from 290 to 400 nanometers, 305 nanometer UV is one of the most damaging wavelengths for humans. **Credit:** NASA's Goddard Space Flight Center/Jay Herman

#### > Exploring Ozone Video

This short video, produced in 2008, describes the status of the stratospheric ozone hole. **Credit:** NASA/Goddard Space Flight Center



#### > Larger image

Electromagnetic radiation exists in a range of wavelengths, which are delineated into major divisions for our convenience. Ultraviolet-B, from 290 to 320, poses the greatest threat to living organisms, though it represents just a small portion of the spectrum. **Credit:** NASA's Earth Observatory/Robert Simmon

### Clouds and Hemispheric Dimming

In addition to analyzing ozone and ultraviolet trends, Herman also used satellite data to study whether changes in cloudiness have affected UV trends. To his surprise, he found that increased cloudiness in the southern hemisphere produced a dimming effect that increased the shielding from UV compared to previous years.

In the higher latitudes especially, he detected a slight reduction — typically of 2 to 4 percent -- in the amount of UV passing through the atmosphere and reaching the surface due to clouds. "It's not a large amount, but it's intriguing," Herman said. "We aren't sure what's behind it yet."

Vitali Fioletov, a Canadian scientist and member of the World Meteorological Organization's advisory group on ultraviolet radiation, agreed that Herman's findings about cloudiness warrant additional investigation. "I found the cloud effects on the global scale to be the most interesting aspect of the study," he said. "This isn't something you could see without satellites."

Herman synthesized measurements from the Total Ozone Mapping Spectrometer (TOMS) aboard Nimbus 7 and Earth Probe, the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite, NASA's Sea-Viewing Wide Field-of-view sensor (SeaWiFS) on the commercial SeaStar satellite, and the Solar Backscatter Ultraviolet Instrument (SBUV) on several polar orbiting NOAA weather satellites.

#### Find this article at:

<http://www.nasa.gov/topics/solarsystem/features/uv-exposure.html>

## APPENDIX 1: THE LABORATORY IN THE NEWS

A NASA Hq news release entitled “ NASA Experiments Stir up Hope for Forecasting Deadliest Cyclones” highlights the recently published paper in *Geophys. Res. Lett.* by Dr. Oreste Reale (Code 613.0 / UMBC) and his collaborators which was the first successful attempt to “hindcast” tropical storm Nargis, using assimilating AIRS cloudy-sky retrievals in the GEOS-5 forecasts, a global, high-resolution forecast model.

[Print](#)[Close](#)

### Feature

#### NASA Experiment Stir Up Hope for Forecasting Deadliest Cyclones

04.13.09

NASA satellite data and a new modeling approach could improve weather forecasting and save more lives when future cyclones develop.

About 15 percent of the world's tropical cyclones occur in the northern Indian Ocean, but because of high population densities along low-lying coastlines, the storms have caused nearly 80 percent of cyclone-related deaths around the world. Incomplete atmospheric data for the Bay of Bengal and Arabian Sea make it difficult for regional forecasters to provide enough warning for mass evacuations.

In the wake of last year's Cyclone Nargis -- one of the most catastrophic cyclones on record -- a team of NASA researchers re-examined the storm as a test case for a new data integration and mathematical modeling approach. They compiled satellite data from the days leading up to the May 2 landfall of the storm and successfully "hindcasted" Nargis' path and landfall in Burma.

"Hindcasting" means that the modelers plotted the precise course of the storm. In addition, the retrospective results showed how forecasters might now be able to produce multi-day advance warnings in the Indian Ocean and improve advance forecasts in other parts of the world. Results from their study were published March 26 in *Geophysical Research Letters*.

"There is no event in nature that causes a greater loss of life than Northern Indian Ocean cyclones, so we have a strong motivation to improve advance warnings," said the study's lead author, Oreste Reale, an atmospheric scientist with the Goddard Earth Sciences and Technology Center, a partnership between NASA and the University of Maryland-Baltimore County.

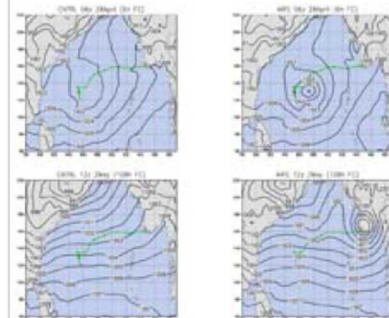
In late April 2008, weather forecasters tracking cyclone Nargis initially predicted the storm would make landfall in Bangladesh. But the storm veered unexpectedly to the east and intensified from a category 1 storm to a category 4 in just 24 hours. When it made landfall in Burma (Myanmar) on May 2, the storm and its surge killed more than 135,000 people, displaced tens of thousands, and destroyed about \$12 billion in property.

In the months that followed, Reale and his U.S.-based team tested the NASA-created Data Assimilation and Forecasting System known as GEOS-5 and its NASA/NOAA-created analysis technique using data from the days leading up to Nargis because the storm was particularly fatal and highly characteristic of cyclones in the northern Indian Ocean.



The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured this image of Cyclone Nargis as it churned over the Bay of Bengal between India and Burma (Myanmar) at 10:40 a.m. local time on May 2, 2008. **Credit: NASA**

[> Larger image](#)



[> View larger images](#)

**Top images:** The actual forecast (left) and Reale's team's hindcast (right) of the location of a growing Cyclone Nargis on April 28, 2008 show differing results. When compared to the storm's starting point (the start of the green control line), the bulls-eye in the middle of the enclosing circular shape on the right, aided by AIRS partially-cloudy data, indicates an effective hindcast.



Cyclones in the Bay of Bengal – stretching from the southern tip of India to Thailand – are particularly difficult to analyze because of "blind spots" in available atmospheric data for individual storms, as well as the small dimensions of the Bay, which ensure that storms do not have much time to develop or circulate. In most instances, regionally strong wind shear suppresses cyclone development.

But when tropical cyclones do form, flooding waves and storm surges can quickly reach the narrow basin's shores. And that unusual wind shear, which is fueled by large temperature contrasts between sea and land, can also lead to erratic storm tracks. Forecasting is also made particularly difficult by the "blind spots," Reale noted. Land-based weather stations monitor the edges of the bay, but they cannot see much when a storm is brewing several hundred miles from the coastline.

Forecasters from the India Meteorological Department and the U.S. Navy's Joint Typhoon Warning Center lack access to the fleet of "hurricane hunting" airplanes that fly through Atlantic storms. They have to rely on remote satellite measurements that can only assess atmospheric and ocean temperatures under "clear-sky," or cloudless, conditions -- not exactly common in the midst of a cyclone.

In their modeling experiment, Reale's team detected and tracked Nargis' path by employing novel 3-dimensional satellite imagery and atmospheric profiles from the Atmospheric Infrared Sounder (AIRS) instrument aboard NASA's Aqua satellite to see into the heart of the storm.

AIRS has become increasingly important to weather forecasting because of its ability to show changes in atmospheric temperature and moisture at varying altitudes. Until recently, many weather modelers were only using AIRS data from cloud-free skies.

In 2007, atmospheric scientist Joel Susskind of NASA Goddard Space Flight Center, Greenbelt, Md., successfully demonstrated through a technique developed by NASA research scientist Moustafa Chahine that accurate atmospheric temperatures could be obtained using real (versus hypothetical data in a 2003 Susskind study) AIRS partly-cloudy data. Reale's team used the temperature data products from Susskind's work to run the NASA model with the added information from partially-cloudy areas of sky that traditionally got left out.

AIRS cloudy-sky data can now be integrated into what are called shared data assimilation systems, which combine millions of data points from Earth-observing satellites, instrumented ocean buoys, ground-based sensors, aircraft-based instruments, and man-on-the-scene observations. Data assimilation transforms the data into digital local maps that models can "read" to produce either hindcasts or advance projections of future weather conditions.

Lau, chief of Goddard's Laboratory for Atmospheres, believes that regional forecasting agencies monitoring the region can readily access AIRS' data daily and optimize forecasts for cyclones in the Indian Ocean. According to Lau, the same technique can be useful to forecasts of hurricanes in the Atlantic and typhoons in the western Pacific, particularly when the storm is formed over open oceans out of flight range of hurricane-hunting airplanes.

"With this approach, we can now better define cyclones at the early stages and track them in the models to know what populations may be most at risk," explained Reale. "And every 12 hours we gain in these forecasts means a gain in our chances to reduce loss of life."

Find this article at: [http://www.nasa.gov/topics/earth/features/deadly\\_cyclone.html](http://www.nasa.gov/topics/earth/features/deadly_cyclone.html)

Alternatively, the lack of a bulls-eye point on the left image belies the existence of a storm at all.

**Bottom images:** AIRS partially-cloudy data was responsible for enabling researchers to hindcast (right image) where Nargis made landfall on May 2, 2008 (the end of the green control line). The left forecast image, meanwhile, does not render a bulls-eye storm destination at all.

**Credit:** NASA



[Print](#)

[Close](#)

### NASA People

#### NASA Weather Pioneer Joanne Simpson Passes

03.05.10

Dr. Joanne Simpson, one of NASA's leading weather scientists of the past 30 years, and a world-renowned atmospheric scientist, died on Thursday, March 4, 2010 at George Washington University Hospital, in Washington.

Until her recent retirement, Simpson was Chief Scientist Emeritus for Meteorology, Earth Sun Exploration Division, at NASA's Goddard Space Flight Center in Greenbelt, Md. She worked with a science group on Cloud and Mesoscale modeling and studied hurricanes. She has authored or co-authored over 190 scientific articles.

Dorothy Zukor, Deputy Director of Earth Sciences at Goddard, said "Joanne was a joy to work with. In addition to being excited and enthusiastic about her own research, she was always helping students to become scientists. Many are practicing in the field today because of her guidance and encouragement. She has left a true legacy, not only from her own work but for the future of the field."

Joanne was born in 1923, and was a pioneer by the time she was in her twenties. As a student pilot during World War II, she studied meteorology. Joanne then spent the rest of the war teaching meteorology to Aviation Cadets. She earned a B.S. in Meteorology from the University of Chicago under Carl-Gustaf Rossby. Rossby was a Swedish-U.S. meteorologist who first explained the large-scale motions of the atmosphere in terms of fluid mechanics. In 1949, Simpson became the first woman to earn a Ph.D. in meteorology, focused her research on clouds, and went on to serve on the faculty of the University of Chicago.

Simpson really made her mark in meteorology in the late 1950s, when she and her former professor, Herbert Riehl came up with an explanation of how the atmosphere moved heat and moisture away from the tropics to higher latitudes. That explanation included the "hot tower" hypothesis that later shed light on hurricane behavior.

A "hot tower" is a tropical cumulonimbus cloud that penetrates the tropopause. Basically, the cloud top breaches the top of the troposphere, the lowest layer of the atmosphere and reaches into the stratosphere. These clouds are called "hot" because they rise high due to the large amount of latent heat released as water vapor condenses into liquid.

Simpson developed the first mathematical cloud model using a slide rule to do the calculations because computers weren't available. Her work sparked a brand new field of study in meteorology. In the early 1960s, she developed the first computer cloud model.

Joanne came to NASA Goddard in 1979 as the Chief of the Severe Storms Branch of NASA's Laboratory for Atmosphere. Her arrival at NASA followed an academic career that included the University of Chicago, Woods Hole Oceanographic Institution in Woods Hole, Mass., and the National Oceanic and Atmospheric Administration (NOAA), where she was the head of NOAA's Experimental Meteorology Laboratory in Miami, Fla., for a long period. She also taught as a professor at the University of California at Los Angeles and the University of Virginia, Charlottesville, Va., before



[View slightly larger image](#)

Dr. Joanne Simpson, Credit: NASA



[View slightly larger image](#)

The Navy provided a PBY flying boat to the Woods Hole Oceanographic Institute so Joanne Simpson could study tropical clouds. In this photograph she stands with her crew in front of the aircraft. Credit: Joanne Simpson and the Schlesinger Library

coming to NASA.

During her career at NASA, Joanne's research focused on convective cloud systems and tropical cyclones using numerical cloud models and observations. She made integral contributions to several historic NASA field missions, including the Convection And Moisture EXperiment (CAMEX) missions, the Tropical Ocean Global Atmospheres/Coupled Ocean Atmosphere Response Experiment (TOGA COARE), the GARP Atlantic Tropical Experiment (GATE), and the Winter Monsoon Experiment (Winter MONEX).

In 1986, NASA asked Joanne to lead the science study for the proposed Tropical Rainfall Measuring Mission (TRMM), a satellite to carry both active and passive microwave instruments to accurately measure rainfall across the tropics and subtropics. TRMM is a joint mission between NASA and JAXA, Japan's Aerospace Exploration Agency.

Between 1986 and the launch in November 1997, Joanne served first as Study Scientist and then Project Scientist for TRMM, bringing it from concept to reality. TRMM continues to fly today and provide unique surface rainfall and hydrometeor profile data for climate and atmospheric process studies and for real-time operational applications related to convective systems and hurricanes. Joanne often stated that TRMM was the most important accomplishment of her career.

Joanne recently inquired about TRMM and was very enthusiastic about TRMM's potential overlap with Goddard's Global Precipitation Measurement (GPM) mission, to be launched in 2013. Dr. Robert Adler, now a Senior Research Scientist at the University of Maryland, College Park, was formerly Joanne's Deputy on TRMM and also TRMM Project Scientist later in the mission, says "Joanne was the heart and soul of TRMM during the pre-launch phase, sharpening the scientific focus of the mission, resolving critical choices related to instruments, orbit, etc. and fighting (and winning) the budget and political battles to get us to launch and beyond. TRMM would not exist if it hadn't been for Joanne."

Joanne had a career filled with awards and recognition of her research. She was elected to the National Academy of Engineering, awarded the Carl-Gustaf Rossby Award (the highest honor bestowed by the American Meteorological Society), presented with a Guggenheim Fellowship, served as President of the American Meteorological Society and received numerous NASA and Goddard awards. In 2002, she was awarded the prestigious International Meteorological Organization Prize. She was the first woman to receive the award.

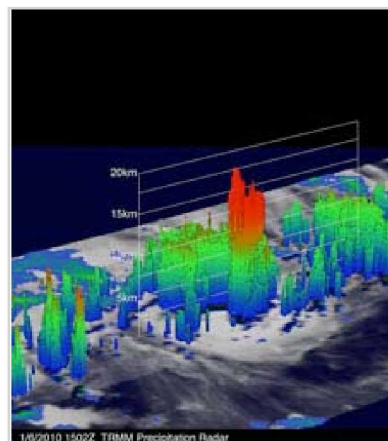
Joanne's contributions will forever live on in NASA hurricane research and are a tremendous part of meteorological history.

#### Related Link:

[> In-depth article about Dr. Simpson's career](#)

#### Find this article at:

<http://www.nasa.gov/topics/people/features/joanne-simpson.html>



[> View larger image](#)

TRMM data provided a 3-D look at the cloud heights; temperature and rainfall in Tropical Storm Edzani, revealing a "Hot Tower" or towering cloud near 17 km (10.6 miles) high indicating a strong storm.

Credit: NASA/SSAI, Hal Pierce





Print

Close

### Image Feature

#### A Unique Geography -- and Soot and Dust -- Conspire Against Himalayan Glaciers

12.14.09

"So many disparate elements, both natural and man-made, converge in the Himalayas," said William Lau, a climatologist from NASA's Goddard Space Flight Center in Greenbelt, Md. "There's no other place in the world that could produce such a powerful atmospheric heat pump," referring to a [new hypothesis](#) he's put forward to explain the rapid retreat of Himalayan glaciers in recent decades.

The Himalayas, home to the tallest mountains on Earth, include more than 110 peaks and stretch 2,500 kilometers (1,550 miles). Bounded to the north by the Tibetan Plateau, to the west by deserts, and to the south by a bowl-like basin teeming with people, the mountains hold 10,000 glaciers.

These massive rivers of ice spill off mountain sides and grind down through creviced valleys. In the spring, when the monsoon carries moist air from the Indian Ocean, the glaciers begin to thaw, replenishing lakes, streams, and some of Asia's mightiest rivers, on which more than a billion people depend.

South of the Himalayas -- which forms the east-west edge of the table-like Tibetan Plateau -- the mountains give way to the Indo-Gangetic plain, one of the most fertile and densely populated areas on Earth. The plain has become a megalopolis of cities including Delhi, Dhaka, Kanpur, and Karachi, as well as a hotspot for air pollution, with a steady supply of industrial soot mixing with ash and other particles in the air.

To the west, in the northwestern part of the Indian subcontinent, the Thar Desert stretches across 200,000 square kilometers (77,000 square miles) of arid, dusty land. During the spring, westerly winds pluck dust and sand from the Thar and blow it toward the Indo-Gangetic plain.

The dust joins a mash of industrial pollutants to create a massive brown cloud visible from space. Underneath the brown cloud, some solar radiation is blocked from reaching the surface, causing the under-lying land surface to cool.

"Surprisingly, these brown aerosol clouds seem to have potent climate consequences that affect the entire region," Lau said.

The thick soot and dust layer absorbs solar radiation, and heats up the air around the Himalayan foothills. The warm, rising air enhances the seasonal northward flow of humid monsoon winds, forcing moisture and hot air up the slopes of the Himalayas.



[View larger image](#)

A blanket of haze is common in the Indo-Gangetic Plain. The haze piles up along the Himalaya Mountains, forming a strip of white-gray that obscures the ground. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this true-color image on December 2, 2009. Credit: Earth Observatory, NASA



[View larger image](#)

Massive rivers of ice spill off the sides of mountains and grind through creviced valleys in the Himalayas. In the spring, when the monsoon carries moist air from the Indian Ocean, the glaciers begin to thaw, replenishing lakes, streams, and



As the aerosol particles rise on the warm, convecting air, they produce more rain over northern India and the Himalayan foothill, which further warms the atmosphere and fuels a "heat pump" that draws yet more warm air to the region.

"The phenomenon changes the timing and intensity of the monsoon, effectively transferring heat from the low-lying lands over the subcontinent to the atmosphere over the Tibetan Plateau, which in turn warms the high-altitude land surface and hastens glacial retreat," Lau said. His modeling shows that aerosols -- particularly black carbon and dust -- likely cause as much of the glacial retreat in the region as greenhouse gases via this "heat pump" effect.

many replenishing lakes, streams, and some of Asia's mightiest rivers, on which more than a billion people depend. This view of glaciers in Bhutan was created by draping an ASTER simulated natural color image over digital topography from the ASTER Global Digital Elevation Model (GDEM) data set. Credit: NASA

**Find this article at:**

<http://www.nasa.gov/topics/earth/features/terrain-heat-pump.html>

### [e! Science News](#)

## New study turns up the heat on soot's role in Himalayan warming

Published: Monday, December 14, 2009 - 17:29

### Related images



NASA

Soot from fire in an unventilated fireplace wafts into a home and settles on the surfaces of floors and furniture. But with a quick fix to the chimney flue and some dusting, it bears no impact on a home's long-term environment. A new modeling study from NASA confirms that when tiny air pollution particles we commonly call soot – also known as black carbon – travel along wind currents from densely populated south Asian cities and accumulate over a climate hotspot called the Tibetan Plateau, the result may be anything but inconsequential.

In fact, the new research, by NASA's William Lau and collaborators, reinforces with detailed numerical analysis what earlier studies suggest: that soot and dust contribute as much (or more) to atmospheric warming in the Himalayas as greenhouse gases. This warming fuels the melting of glaciers and could threaten fresh water resources in a region that is home to more than a billion people.

Lau explored the causes of rapid melting, which occurs primarily in the western Tibetan Plateau, beginning each year in April and extending through early fall. The brisk melting coincides with the time when concentrations of aerosols like soot and dust transported from places like India and Nepal are most dense in the atmosphere.

"Over areas of the Himalayas, the rate of warming is more than five times faster than warming globally," said William Lau, head of atmospheric sciences at NASA's Goddard Space Flight Center in Greenbelt, Md. "Based on the differences it's not difficult to conclude that greenhouse gases are not the sole agents of change in this region. There's a localized phenomenon at play."

Nicknamed the "Third Pole", the region in fact holds the third largest amount of stored water on the planet beyond the North and South Poles. But since the early 1960s, the acreage covered by Himalayan glaciers has declined by over 20 percent. Some Himalayan glaciers are melting so rapidly, some scientists postulate, that they may vanish by mid-century if trends persist. Climatologists have generally blamed the build-up of greenhouse gases for the retreat, but Lau's work suggests that may not be the complete story.

He has produced new evidence suggesting that an "elevated heat pump" process is fueling the loss of ice, driven by

airborne dust and soot particles absorbing the sun's heat and warming the local atmosphere and land surface. A related modeling study by Lau and colleagues has been submitted to Environmental Research Letters for publication.

A unique landscape plays supporting actor in the melting drama. The Himalayas, which dominate the plateau region, are the source of meltwater for many of Asia's most important rivers—the Ganges and Indus in India, the Brahmaputra in Bangladesh, the Salween through China, Thailand and Burma, the Mekong across Laos, Cambodia and Vietnam, and the Yellow and Yangtze rivers in China. When fossil fuels are burned without enough oxygen to complete combustion, one of the byproducts is black carbon, an aerosol that absorbs solar radiation (Most classes of aerosols typically reflect incoming sunlight, causing a cooling effect). Rising populations in Asia, industrial and agricultural burning, and vehicle exhaust have thickened concentrations of black carbon in the air.

Sooty black carbon travels east along wind currents latched to dust – its agent of transport – and become trapped in the air against Himalayan foothills. The particles' dark color absorbs solar radiation, creating a layer of warm air from the surface that rises to higher altitudes above the mountain ranges to become a major catalyst of glacier and snow melt.

Building on work by Veerabhardran Ramanathan of the Scripps Institution of Oceanography, San Diego, Calif., Lau and colleagues conducted modeling experiments that simulated the movement of air masses in the region from 2000 to 2007. They also made detailed numerical analyses of how soot particles and other aerosols absorb heat from the sun.

"Field campaigns with ground observations are already underway with more planned to test Lau's modeling results," said Hal Maring who manages the Radiation Sciences program at NASA Headquarters in Washington. "But even at this stage we should be compelled to take notice."

"Airborne particles have a much shorter atmospheric lifespan than greenhouse gases," continued Maring. "So reducing particle emissions can have much more rapid impact on warming."

"The science suggests that we've got to better monitor the flue on our 'rooftop to the world,'" said Lau. "We need to add another topic to the climate dialogue."

**Source:** [NASA/Goddard Space Flight Center](#)

[Print](#)[Close](#)

### Feature

#### The Dark Side of Carbon: Will Black Carbon Siphon Asia's Drinking Water Away?

12.14.09

##### *Briefing Materials*

*A media briefing about black carbon's impact on Himalayan glaciers*

WASHINGTON -- Soot from fire in an unventilated fireplace wafts into a home and settles on the surfaces of floors and furniture. But with a quick fix to the chimney flue and some dusting, it bears no impact on a home's long-term environment.

A new modeling study from NASA confirms that when tiny air pollution particles we commonly call soot – also known as black carbon – travel along wind currents from densely populated south Asian cities and accumulate over a climate hotspot called the Tibetan Plateau, the result may be anything but inconsequential.

In fact, the new research, by NASA's William Lau and collaborators, reinforces with detailed numerical analysis what earlier studies suggest: that soot and dust contribute as much (or more) to atmospheric warming in the Himalayas as greenhouse gases. This warming fuels the melting of glaciers and could threaten fresh water resources in a region that is home to more than a billion people.

For the complete story, [click here](#).

---

### Background Information on Teleconference Speakers

- › William Lau, chief, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Md.
- › Susan Kaspari, assistant professor, Central Washington University, Ellensburg, Wa.
- › Jeffrey Kargel, senior associate research scientist, Dept. of Hydrology and Water Resources, University of Arizona, Tucson
- › Brent Holben, principal investigator, AERONET, NASA Goddard Space Flight Center, Greenbelt, Md.

---

### Images and Multimedia in Support of the News Conference

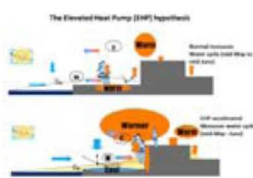
**Presenter:** William Lau, NASA Goddard Space Flight Center

› [Download presentation slides \(PDF\)](#)

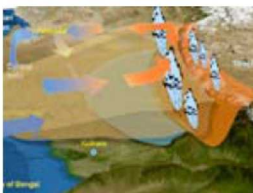


**Video:** Tiny air pollution particles commonly called soot, but also known as black carbon, are in the air and on the move throughout our planet. The Indo-Gangetic plain, one of the most fertile and densely populated areas on Earth, has become a hotspot for emissions of black carbon (shown in purple and white). Winds push thick clouds of black carbon and dust, which absorb heat from sunlight, toward the base of the Himalayas where they accumulate, rise, and drive a "heat pump" that affects the region's climate. **Credit:** NASA's Scientific Visualization Studio

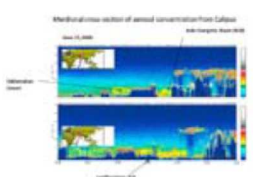
› [Watch movie](#)



**Figure 2:** Black carbon may drive an atmospheric feedback loop in the Himalayan region called the "elevated heat pump". The hypothesis suggests that black carbon causes the following: A) Warming and moistening of the upper troposphere over the Tibetan Plateau. B) An advance of the rainy season in northern India/Nepal region in May and June. C) Increased convection that spreads from the foothills of the Himalayas to central India that results in an intensification of the Indian monsoon in June and July. D) Subsequent reduction of monsoon rain in central India in July and August. E) Enhanced snowmelt and rapid retreat of glaciers in the region. **Credit:** William Lau, NASA  
[Larger image](#)



**Figure 3:** Tiny, dark-colored aerosols — specifically black carbon — travel along wind currents from Asian cities and accumulate over the Tibetan Plateau and Himalayan foothills. Seen here as a light brown mass, these brown clouds of soot absorb sunlight, creating a layer of warm air (seen in orange) that rises to higher altitudes, amplifying the melting of glaciers and snow. **Credit:** NASA/Sally Bensusen  
[Watch animation](#)



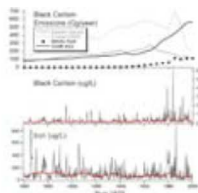
**Figure 4:** Data collected by a lidar instrument on NASA's Calipso satellite shows high levels of aerosols accumulating over northern India and the Himalayas foothills against the steep slopes of the Tibetan Plateau during June 21 (upper panel) and June 22 (lower panel). The green, yellow and red color shows low, medium and high aerosol concentrations of aerosols respectively. In the lower panel, some aerosols can be seen over the top of the Himalayas. **Credit:** William Lau, NASA  
[Larger image](#)

**Presenter:** Susan Kaspari, Central Washington University

[Download presentation slides \(PDF\)](#)



**Figure 1:** Clouds containing a mixture of soot and other aerosol particles are clearly visible looking South from a point near the crest of the Himalayas in Nepal. In contrast, the view to the North is relatively clear. **Credit:** Susan Kaspari, Central Washington University  
[Larger image \(North\)](#)  
[Larger image \(South\)](#)



**Figure 2:** As shown in the top figure, estimated black carbon emissions in Asia have increased significantly since the 1950s. The lower two figures show that black carbon concentrations collected from an ice core at Mount Everest, which spans from 1860 to 2000, have increased threefold from 1970 to present relative to pre-1970 levels. In the same core, there has been no notable increase in iron, which is used as a proxy for dust. **Credit:** Susan Kaspari, University of Washington / Tami Bond, University of Illinois  
[Larger image](#)



**Figure 3:** Large impurity layers, which are deposits of black carbon and dust, are clearly visible on the surface and in crevasse profiles on Mera glacier in Nepal. Black carbon is shown with a black line. Iron (Fe), a proxy for dust, is shown in red. Such impurities reduce the reflectivity of glaciers and likely cause glacier melt. **Data Credit:** Susan Kaspari, Central Washington University / **Photo Credit:** Jesse Cunningham, Jesse Cunningham Photography  
[Larger image](#)



**Presenter:** Jeffrey Kargel, University of Arizona

› [Download presentation slides \(PDF\)](#)



**Figure 1:** A satellite image shows debris-covered glacial tongues melting in North Bhutan as blue glacial lakes form in valleys at the base of the tongues. Such melting has been common, especially in the Eastern Himalaya, since the 1950s and 1960s. **Credit:** ASTER Science Team, NASA

› [Larger image](#)



**Figure 2:** Some glaciers in the Mount Everest area are stable, but others are known to be thinning and slowly losing mass along their long debris-covered tongues. Khumbu, the biggest glacier in the upper left quadrant of the image, flows from the Southern slope of Mount Everest and is stable. Imja Glacier, in contrast, is retreating rapidly. **Credit:** ASTER Science Team, NASA

› [Larger image \(labeled\)](#)

› [Larger image \(unlabeled\)](#)

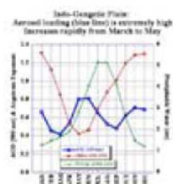
**Presenter:** Brent Holben, NASA

› [Download presentation slides \(PDF\)](#)



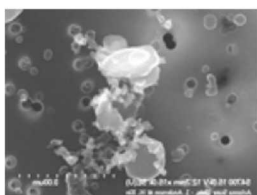
**Figure 1:** Lamp-sized instruments called sun-photometers can be used to detect black carbon and dust, though the rugged topography of the Himalayas makes collecting the data challenging. The instruments measure the intensity of light filtering through a given column of atmosphere making it possible to deduce the size, shape, and chemical composition of black carbon and other airborne particles. This instrument, located in central Tibet at Langtang National Park, is part of a network of sun photometers called AERONET. **Credit:** NASA

› [Larger image](#)



**Figure 2:** Aerosol loading (blue line) is extremely high and increases rapidly from March to May in the Indo-Gangetic Plain. The aerosol type (red line) shows a marked shift between March to May to larger particles, which are indicative of dust, while the black carbon concentration remains largely the same. The available water vapor (green line) increases rapidly until precipitation begins in July with the arrival of the monsoon. **Credit:** Brent Holben, NASA

› [Larger image](#)



**Figure 3:** Black carbon associates easily with some other types of aerosols particles. In this image, small black soot particles have attached to larger white dust minerals. Above the Indo-Gangetic Plain, dust from the Thar desert often transports black carbon toward the Himalayan foothills. **Credit:** James Anderson, Arizona State University

› [Larger image](#)

Find this article at: <http://www.nasa.gov/topics/earth/features/carbon-pole-briefing.htm>

## SCIENCE: Soot, dust, melting Himalayan glaciers

By BRADLEY J. FIKES - [bfikes@nctimes.com](mailto:bfikes@nctimes.com) | Posted: Friday, December 18, 2009 6:35 pm

Dust and soot contribute as much or more than greenhouse gases to the melting of glaciers and snow in the Himalayas and the Tibetan plateau, according to a new study from NASA.

Continued melting in that region would put the drinking water relied on by a billion people into jeopardy, according to those who say global warming is a serious threat.

The NASA study provides evidence that reducing the level of carbon dioxide in the air, the primary goal of the Copenhagen climate summit, is not necessarily the most effective way to quickly stop warming.

Rapid glacial and snow melting in the Himalayas and Tibet takes place from April to early fall. This correlates with when soot, dust and other dark "aerosols" are densest in the atmosphere, said study leader William Lau, head of atmospheric sciences at NASA's Goddard Space Flight Center in Greenbelt, Md.

The aerosols create brown clouds that absorb sunlight, warming the air. The warmed air then rises and helps melt the snow and ice.

"Over areas of the Himalayas, the rate of warming is more than five times faster than warming globally," Lau said in a NASA news release. "Based on the differences, it's not difficult to conclude that greenhouse gases are not the sole agents of change in this region. There's a localized phenomenon at play."

These aerosols leave the atmosphere much more quickly than do greenhouse gases, so cutting down on these emissions will have a much more rapid effect on warming, according to Hal Maring, manager of Radiation Sciences program at NASA Headquarters in Washington.

The study provides more evidence for recent research about non-carbon dioxide causes of warming by Veerabhardran Ramanathan and Mario Molina of UC San Diego's Scripps Institution of Oceanography.

Reducing the levels of black carbon soot, ozone and hydrofluorocarbons, and increased trapping of carbon in vegetation, provide the "fastest climate response" to counteract global warming, according to the Scripps paper, published in October in the Proceedings of the National Academy of Sciences.

In the Himalayan region, the soot and dust primarily drift north and east from factories, farms and other sources in the Indian subcontinent, a rapidly developing region.

Almost all climate researchers say that Earth's climate is warming at least in part due to human activity, a theory called anthropogenic global warming. However, there is some disagreement about the potential mechanisms by which humans influence climate, and also on how much weight each potential mechanism should be given.

Moreover, research indicates that variations in solar activity and ocean currents significantly contribute to climate change.

For example, a study published in the scientific journal *Nature* in 2008 suggested that ocean current changes would cause North America and Europe to slightly cool over the next decade, while tropic Pacific Ocean temperatures remain nearly unchanged.

Also, a study published this year in the journal *Geophysical Research Letters* provides evidence that decreases in cosmic rays correlate with increased warmth.

Increased solar activity caused an extraordinary rate of melting in European Alpine glaciers in the 1940s, higher than that in recent years, according to another study published earlier this month in *Geophysical Research Letters*.

Climate scientist Roger Pielke Sr., of the University of Colorado at Boulder, cited the paper on his blog as more evidence that climate models that only focus on surface air temperatures provide an "oversimplified" view of the climate system.

Call staff writer Bradley J. Fikes at 760-739-6641. Read his blogs at [bizblogs.nctimes.com](http://bizblogs.nctimes.com).

### [e! Science News](#)

# Climate change and atmospheric circulation will make for uneven ozone recovery

Published: Friday, April 10, 2009 - 13:28

Earth's ozone layer should eventually recover from the unintended destruction brought on by the use of chlorofluorocarbons (CFCs) and similar ozone-depleting chemicals in the 20th century. But new research by NASA scientists suggests the ozone layer of the future is unlikely to look much like the past because greenhouse gases are changing the dynamics of the atmosphere. Previous studies have shown that while the buildup of greenhouse gases makes it warmer in troposphere – the level of atmosphere from Earth's surface up to 10 kilometers (6 miles) altitude – it actually cools the upper stratosphere – between 30 to 50 kilometers high (18 to 31 miles). This cooling slows the chemical reactions that deplete ozone in the upper stratosphere and allows natural ozone production in that region to outpace destruction by CFCs.

But the accumulation of greenhouse gases also changes the circulation of stratospheric air masses from the tropics to the poles, NASA scientists note. In Earth's middle latitudes, that means ozone is likely to "over-recover," growing to concentrations higher than they were before the mass production of CFCs. In the tropics, stratospheric circulation changes could prevent the ozone layer from fully recovering.

"Most studies of ozone and global change have focused on cooling in the upper stratosphere," said Feng Li, an atmospheric scientist at the Goddard Earth Sciences and Technology Center at the University of Maryland Baltimore County, Baltimore, Md. and lead author of the study. "But we find circulation is just as important. It's not one process or the other, but both."

The findings are based on a detailed computer model that includes atmospheric chemical effects, wind changes, and solar radiation changes. Li's experiment is part of an ongoing international effort organized by the United Nations Environment Programme's Scientific Assessment Panel to assess the state of the ozone layer. Li and colleagues published their analysis in March in the journal *Atmospheric Chemistry and Physics*.

Working with Richard Stolarski and Paul Newman of NASA's Goddard Space Flight Center, Greenbelt, Md., Li adapted the Goddard Earth Observing System Chemistry-Climate Model (GEOS-CCM) to examine how climate change will affect ozone recovery. The team inserted past measurements and future projections of ozone-depleting substances and greenhouse gases into the model. Then the model projected how ozone, the overall chemistry, and the dynamics of the stratosphere would change through the year 2100.

"In the real world, we have observed statistically significant turnaround in ozone depletion, which can be attributed to the banning of ozone-depleting substances," said Richard Stolarski, an atmospheric chemist at Goddard and a co-author of the study. "But making that connection is complicated by the response of ozone to greenhouse gases."

The researchers found that greenhouse gases alter a natural circulation pattern that influences ozone distribution. Brewer-Dobson circulation is like a pump to the stratosphere, moving ozone from the lower parts of the atmosphere, into the upper stratosphere over the tropics. Air masses then flow north or south through the stratosphere, away from the tropics toward the poles.

In Li's experiment, this circulation pump accelerated to a rate where the ozone flowing upward and outward from the



tropics created a surplus at middle latitudes. Though the concentration of chlorine and other ozone-depleting substances in the stratosphere will not return to pre-1980 levels until 2060, the ozone layer over middle latitudes recovered to pre-1980 levels by 2025.

The Arctic – which is better connected to mid-latitude air masses than the Antarctic -- benefitted from the surplus in the northern hemisphere and from the overall decline of ozone-depleting substances to recover by 2025. Globally averaged ozone and Antarctic concentrations catch up by 2040, as natural atmospheric production of ozone resumes.

This recovery in the middle and polar latitudes has mixed consequences, Li noted. It might have some benefits, such as lower levels of ultraviolet radiation reaching the Earth's surface and correspondingly lower rates of skin cancer. On the other hand, it could have unintended effects, such as increasing ozone levels in the troposphere, the layer of atmosphere at Earth's surface. The model also shows a continuing ozone deficit in the stratosphere over the tropics. In fact, when the model run ended at year 2100, the ozone layer over the tropics still showed no signs of recovery.

In February, researchers from Johns Hopkins University, Baltimore, teamed with Stolarski and other NASA scientists on a similar paper suggesting that increasing greenhouse gases would delay or even postpone the recovery of ozone levels in the lower stratosphere over some parts of the globe. Using the same model as Li, Stolarski, and Newman, the researchers found that the lower stratosphere over tropical and mid-southern latitudes might not return to pre-1980s levels of ozone for more than a century, if ever.

**Source:** [NASA/Goddard Space Flight Center](#)

[Latest Science News Articles](#)

[e! Science News](#)

## **NASA researchers explore lightning's 'NOx-ious' impact on pollution, climate**

Published: Friday, October 30, 2009 - 09:49

Every year, scientists learn something new about the inner workings of lightning. With satellites, they have discovered that more than 1.2 billion lightning flashes occur around the world every year. (Rwanda has the most flashes per square kilometer, while flashes are rare in polar regions.) Laboratory and field experiments have revealed that the core of some lightning bolts reaches 30,000 Kelvin (53,540 °F), a temperature hot enough to instantly melt sand and break oxygen and nitrogen molecules into individual atoms.

And then there is this: each of those billion lightning flashes produces a puff of nitrogen oxide gas (NO<sub>x</sub>) that reacts with sunlight and other gases in the atmosphere to produce ozone. Near Earth's surface, ozone can harm human and plant health; higher in the atmosphere, it is a potent greenhouse gas; and in the stratosphere, it blocks cancer-causing ultraviolet radiation.

In 1827, the German chemist Justin von Liebig first observed that lightning produced NO<sub>x</sub>—scientific shorthand for a gaseous mixture of nitrogen and oxygen that includes nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>). Nearly two centuries later, the topic continues to attract the attention of scientists.

Fossil fuel combustion, microbes in the soil, lightning, and forest fires all produce NO<sub>x</sub>. Scientists think lightning's contribution to Earth's NO<sub>x</sub> budget—probably about 10 percent—is relatively small compared to fossil fuel emissions. Yet they haven't been sure whether global estimates of NO<sub>x</sub> produced by lightning are accurate.

"There's still a lot of uncertainty about how much NO<sub>x</sub> lightning produces," said Kenneth Pickering, an atmospheric scientist who studies lightning at NASA's Goddard Space Flight Center in Greenbelt, Md. "Indeed, even recent published estimates of lightning's global NO<sub>x</sub> production still vary by as much as a factor of four. We're trying to narrow that uncertainty in order to improve the accuracy of both global climate models and regional air quality models."

Using data gleaned from aircraft observations and satellites, Pickering and Goddard colleague Lesley Ott recently took steps toward a better global estimate of lightning-produced NO<sub>x</sub> and found that lightning may have a considerably stronger impact on the climate in the mid-latitudes and subtropics—and less on surface air quality—than previously thought.

According to a new paper by Ott and Pickering in the *Journal of Geophysical Research*, each flash of lightning on average in the several mid-latitude and subtropical thunderstorms studied turned 7 kilograms (15.4 pounds) of nitrogen into chemically reactive NO<sub>x</sub>. "In other words, you could drive a new car across the United States more than 50 times and still produce less than half as much NO<sub>x</sub> as an average lightning flash," Ott estimated. The results were published July.

When the researchers multiplied the number of lightning strokes worldwide by 7 kilograms, they found that the total amount of NO<sub>x</sub> produced by lightning per year is 8.6 terragrams, or 8.6 million metric tons. "That's somewhat high compared to previous estimates," said Pickering.

More remarkable than the number, however, is where the NO<sub>x</sub> is produced. A decade ago, many researchers believed

cloud-to-ground lightning produced far more NO<sub>x</sub> per flash than intracloud lightning, which occurs within a cloud and far higher in the atmosphere.

The new evidence suggests that the two types of lightning produce approximately the same amount of NO<sub>x</sub> per flash on average. But since most lightning is intracloud, this suggests a great deal more NO<sub>x</sub> is produced and remains higher in the atmosphere. Compounding this effect, the research also shows that strong updrafts within thunderstorms help transfer lower level NO<sub>x</sub> to higher altitudes in the atmosphere.

"We've really started to question some of our old assumptions as we've gotten better at measuring lightning in the field," said Ott.

The observations spring out of field projects conducted in Germany, Colorado, Florida, Kansas, and Oklahoma between 1985 and 2002. For example, in a NASA field campaign called the Cirrus Regional Study of Tropical Anvils and Cirrus Layers Florida – Florida Area Cirrus Experiment (CRYSTAL-FACE) aircraft flew headlong through anvil-shaped thunderheads to measure the anatomy of the thunderstorms. Sensors sampled the pressure, humidity, temperature, wind, and the amount of trace gases such as NO<sub>x</sub> and ozone.

Later, Ott input this data, as well as additional data from the U.S. National Lightning Detection Network and NASA's Total Ozone Mapping Spectrometer (TOMS), into a complex computer model that simulated the six storms and calculated the amount of NO<sub>x</sub> that the average flash of lightning produced. With that number, she could then estimate the amount of NO<sub>x</sub> that lightning produces globally each year.

"One of the things we're trying to understand is how much ozone changes caused by lightning affect radiative forcing, and how that might translate into climate impacts," said Pickering.

There's a possibility that lightning could produce a feedback cycle that accelerates global warming. "If a warming globe creates more thunderstorms," Pickering noted, "that could lead to more NO<sub>x</sub> production, which leads to more ozone, more radiative forcing, and more warming," Pickering emphasizes that this is a theory, and while some global modeling studies suggest this is indeed the case, it has not yet been borne out by field observations.

The new findings also have implications for regional air quality models. Scientists from the U.S. Environmental Protection Agency (EPA), for example, are already plugging the new numbers into a widely-used air quality model called the Community Multi-scale Air Quality Model. "Lightning is one of the smaller factors for surface ozone levels, but in some cases a surge of ozone formed from lightning NO<sub>x</sub> could be enough to put a community out of compliance with EPA air quality standards during certain times of the year," said Pickering.

Pickering offered one important caveat to the findings: The value of 7 kilograms per flash was derived without consideration of lightning from storms in the tropics, where most of the Earth's lightning occurs. Only very recently have data become available for tropical regions, he noted.

**Source:** [NASA/Goddard Space Flight Center](#)

[e! Science News](#)

## **New simulation shows consequences of a world without Earth's natural sunscreen**

Published: Thursday, March 19, 2009 - 09:48

The year is 2065. Nearly two-thirds of Earth's ozone is gone -- not just over the poles, but everywhere. The infamous ozone hole over Antarctica, first discovered in the 1980s, is a year-round fixture, with a twin over the North Pole. The ultraviolet (UV) radiation falling on mid-latitude cities like Washington, D.C., is strong enough to cause sunburn in just five minutes. DNA-mutating UV radiation is up 650 percent, with likely harmful effects on plants, animals and human skin cancer rates. Such is the world we would have inherited if 193 nations had not agreed to ban ozone-depleting substances, according to atmospheric chemists at NASA's Goddard Space Flight Center, Greenbelt, Md., Johns Hopkins University, Baltimore, and the Netherlands Environmental Assessment Agency, Bilthoven.

Led by Goddard scientist Paul Newman, the team simulated "what might have been" if chlorofluorocarbons (CFCs) and similar chemicals were not banned through the treaty known as the Montreal Protocol. The simulation used a comprehensive model that included atmospheric chemical effects, wind changes, and radiation changes. The analysis has been published online in the journal *Atmospheric Chemistry and Physics*.

"Ozone science and monitoring has improved over the past two decades, and we have moved to a phase where we need to be accountable," said Newman, who is co-chair of the United Nations Environment Programme's Scientific Assessment Panel to review the state of the ozone layer and the environmental impact of ozone regulation. "We are at the point where we have to ask: Were we right about ozone? Did the Montreal Protocol work? What kind of world was avoided by phasing out ozone-depleting substances?"

Ozone is Earth's natural sunscreen, absorbing and blocking most of the incoming UV radiation from the sun and protecting life from DNA-damaging radiation. The gas is naturally created and replenished by a photochemical reaction in the upper atmosphere where UV rays break oxygen molecules ( $O_2$ ) into individual atoms that then recombine into three-part molecules ( $O_3$ ). As it is moved around the globe by upper level winds, ozone is slowly depleted by naturally occurring atmospheric gases. It is a system in natural balance.

But chlorofluorocarbons -- invented in 1928 as refrigerants and as inert carriers for chemical sprays -- upset that balance. Researchers discovered in the 1970s and 1980s that while CFCs are inert at Earth's surface, they are quite reactive in the stratosphere (10 to 50 kilometers altitude, or 6 to 31 miles), where roughly 90 percent of the planet's ozone accumulates. UV radiation causes CFCs and similar bromine compounds in the stratosphere to break up into elemental chlorine and bromine that readily destroy ozone molecules. Worst of all, such ozone depleting substances can reside for several decades in the stratosphere before breaking down.

In the 1980s, ozone-depleting substances opened a wintertime "hole" over Antarctica and opened the eyes of the world to the effects of human activity on the atmosphere. By 1987, the World Meteorological Organization and United Nations Environment Program had brought together scientists, diplomats, environmental advocates, governments, industry representatives, and non-governmental organizations to forge an agreement to phase out the chemicals. In January 1989, the Montreal Protocol went into force, the first-ever international agreement on regulation of chemical pollutants.

"The regulation of ozone depleting substances was based upon the evidence gathered by the science community and

the consent of industry and government leaders," Newman noted. "The regulation pre-supposed that a lack of action would lead to severe ozone depletion, with consequent severe increases of solar UV radiation levels at the Earth's surface."

In the new analysis, Newman and colleagues "set out to predict ozone losses as if nothing had been done to stop them." Their "world avoided" simulation took months of computer time to process.

The team started with the Goddard Earth Observing System Chemistry-Climate Model (GEOS-CCM), an earth system model of atmospheric circulation that accounts for variations in solar energy, atmospheric chemical reactions, temperature variations and winds, and other elements of global climate change. For instance, the new model accounts for how changes in the stratosphere influence changes in the troposphere (the air masses near Earth's surface). Ozone losses change the temperature in different parts of the atmosphere, and those changes promote or suppress chemical reactions.

The researchers then increased the emission of CFCs and similar compounds by 3 percent per year, a rate about half the growth rate for the early 1970s. Then they let the simulated world evolve from 1975 to 2065.

By the simulated year 2020, 17 percent of all ozone is depleted globally, as assessed by a drop in Dobson Units (DU), the unit of measurement used to quantify a given concentration of ozone. An ozone hole starts to form each year over the Arctic, which was once a place of prodigious ozone levels.

By 2040, global ozone concentrations fall below 220 DU, the same levels that currently comprise the "hole" over Antarctica. (In 1974, globally averaged ozone was 315 DU.) The UV index in mid-latitude cities reaches 15 around noon on a clear summer day (a UV index of 10 is considered extreme today.), giving a perceptible sunburn in about 10 minutes. Over Antarctica, the ozone hole becomes a year-round fixture.

In the 2050s, something strange happens in the modeled world: Ozone levels in the stratosphere over the tropics collapse to near zero in a process similar to the one that creates the Antarctic ozone hole.

By the end of the model run in 2065, global ozone drops to 110 DU, a 67 percent drop from the 1970s. Year-round polar values hover between 50 and 100 DU (down from 300-500 in 1960). The intensity of UV radiation at Earth's surface doubles; at certain shorter wavelengths, intensity rises by as much as 10,000 times. Skin cancer-causing radiation soars.

"Our world avoided calculation goes a little beyond what I thought would happen," said Goddard scientist and study co-author Richard Stolarski, who was among the pioneers of atmospheric ozone chemistry in the 1970s. "The quantities may not be absolutely correct, but the basic results clearly indicate what could have happened to the atmosphere. And models sometimes show you something you weren't expecting, like the precipitous drop in the tropics."

"We simulated a world avoided," said Newman, "and it's a world we should be glad we avoided."

The real world of CFC regulation has been somewhat kinder. Production of ozone-depleting substances was mostly halted about 15 years ago, though their abundance is only beginning to decline because the chemicals can reside in the atmosphere for 50 to 100 years. The peak abundance of CFCs in the atmosphere occurred around 2000, and has decreased by roughly 4 percent to date.

Stratospheric ozone has been depleted by 5 to 6 percent at middle latitudes, but has somewhat rebounded in recent years. The largest recorded Antarctic ozone hole was recorded in 2006.

"I didn't think that the Montreal Protocol would work as well as it has, but I was pretty naïve about the politics," Stolarski added. "The Montreal Protocol is a remarkable international agreement that should be studied by those involved with global warming and the attempts to reach international agreement on that topic."

December 15, 2009 | [48 comments](#)

## Subcontinental Smut: Is Soot the Culprit Behind Melting Himalayan Glaciers?

Greenhouse gases alone cannot explain the warming climate in the Himalayas. New studies are pointing to soot

By [Davide Castelvecchi](#)



**BLACKENED GLACIERS:** Soot might be to blame for some of the warming climate in the Himalaya Mountain region. ISTOCKPHOTO

### More to Explore

#### Video

[The Indo-Gangetic plain, one of the most fertile and densely populated areas on Earth, has become a hotspot for emissions of black carbon \(shown in purple and white\)](#)

SAN FRANCISCO—The Himalaya Mountain region is warming up three to five times faster than the global trends—or about half a degree Celsius per decade—and many of its glaciers are rapidly losing mass. Greenhouse gases alone cannot explain this warming, however, and several new studies are pointing to an old form of pollution: soot.

A thick cloud of soot covers most of India, produced in part by millions of small cooking stoves, which typically burn wood. Soot, also known as black carbon, is made of particles less than a micron wide resulting from incomplete, inefficient combustion. (A micron is one millionth of a meter.) Globally, soot from sources such as forest fires and power stations is considered a major contributor to climate. The particles linger in the air, where they absorb sunlight and contribute to warming the atmosphere; they may also affect cloud formation and precipitation. But soot also eventually falls to the ground. When it lands on snow it can significantly darken it, so that glaciers absorb more sunlight and are warmed.

Using data from an [international atmospheric observatory in Nepal](#), Teepi Yasunari of the NASA Goddard Space Flight Center in Greenbelt, Md., and his colleagues estimated the amount of soot that falls on a typical Himalayan glacier. The team's

computer simulations suggested that the soot can cause a decrease of between 1.6 and 4.1 percent in the glacier's albedo—a measure of its sunlight-reflecting "whiteness"—and that the resulting heating can cause up to a 24 percent increase in the annual snowmelt, Yasunari reported here Monday at a meeting of the American Geophysical Union (AGU). The team made conservative assumptions when estimating the albedo reduction, Yasunari said, neglecting other potentially important factors. "Dust deposition, snow algae, wind and turbulence could bring further reductions," he said.

Also at the AGU meeting, Yasunari's co-author and Goddard colleague William Lau presented the results of a separate study today suggesting that soot heating the atmosphere over India could accelerate the glacier-melting effects of the warm currents that rise up to the Himalayan chain, in a "heat pump" effect.

Soot has already been implicated in [the melting of the polar ice caps](#), and heating of the atmosphere over India was [directly measured](#) in 2007 by Veerabhadran Ramanathan of the Scripps Institution of [Oceanography](#) at the University of California, San Diego, and his colleagues. In that study the researchers also used a climate simulation to show that the soot could help melt the mountain range's glaciers. Ramanathan, who also spoke at the meeting Monday, says that the study by Yasunari and colleagues included a more detailed, local model of an actual glacier. "It's all looking at different pieces of the puzzle," he said.

Whereas the greenhouse gases already in the atmosphere will contribute to warming the planet for many decades to come, Ramanathan says, the good news about warming agents such as black carbon is that they don't linger in the atmosphere for more than a few weeks. Mitigation efforts could show quick results. In fact, Ramanathan is leading a [pilot project to introduce low-cost, low-pollution cooking stoves](#) to rural Indian villages. The project is testing three approaches: wood-burning stoves that are more efficient and thus leave less black-carbon residue; stoves that burn natural gas produced from waste; and solar cookers. In addition to mitigating climate change, the new stoves could also make homes safer: In his talk, Ramanathan said that indoor cooking causes two million deaths per year in India alone.

Jeffrey Kargel of the University of Arizona, Tucson, said in a press conference Monday that the role of soot "adds a new wrinkle" to the story of glacier melting, but that in the big picture of climate change the main villains are still gases such as CO<sub>2</sub>. "I do want to make sure we keep our eyes on the 800-pound gorilla in the room, and that's greenhouse gases," he said.

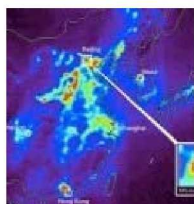


[e! Science News](#)

## New satellite data reveal impact of Olympic pollution controls

Published: Tuesday, December 16, 2008 - 12:54

### Related images



#### NASA

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 (NO<sub>2</sub>)—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 (SO<sub>2</sub>), which has a longer lifetime in the atmosphere. Although satellites detected reductions in levels of SO<sub>2</sub>—a major byproduct of coal-fired power plants and a key ingredient of acid rain—the decline

## APPENDIX 1: THE LABORATORY IN THE NEWS

was more widespread due to a larger effort to reduce SO<sub>2</sub> emissions across China, explained Kenneth Pickering, another Goddard scientist involved in the research .

Witte and colleagues presume that winds carried SO<sub>2</sub> 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 SO<sub>2</sub> 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.

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.

**Source:** [NASA/Goddard Space Flight Center](#)

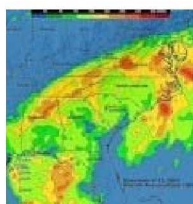


[e! Science News](#)

## NASA's TRMM satellite mapped 'Ida the Low's' rainfall from space

Published: Monday, November 16, 2009 - 15:32

### Related images



NASA/SSAI, Hal Pierce

The Tropical Rainfall Measuring Mission satellite known as "TRMM" has the ability to measure rainfall from space, and assessed the heavy rainfall from last week's coastal low pressure area, formerly known as "Ida" that drenched the U.S. east coast. Tropical storm Ida came ashore early on November 10, 2009, quickly weakened to a tropical depression and then became extratropical. A strong pressure gradient then developed between the remnants of Ida (a "coastal low pressure area") and an area of high pressure that had moved over New England. This resulted in strong winds blowing toward east coast shorelines that resulted in coastal flooding. Flooding tides in Virginia were near the values set by hurricane Isabel in 2003. The remnants of Ida also dropped heavy rainfall from the Gulf Coast to New Jersey resulting in flash floods.

Hal Pierce, a meteorologist who works on the TRMM science team at NASA's Goddard Space Flight Center in Greenbelt, Md. created a rainfall analysis that merged rainfall Data (3B42) from TRMM, other NASA satellites, U.S. Department of Defense satellites, National Oceanic and Atmospheric Administration polar-orbit satellites, and geostationary satellites. The analysis shows Ida's remnants resulted in large areas of very heavy rainfall with maximums in Alabama, North Carolina and Virginia. The analysis shows a maximum value over land of over 240 mm (~9.4 inches).

Heavy rain amounts (from satellites) and flood potential calculations (from a hydrological model) are updated every three hours globally with the results shown on the "Global Flood and Landslide Monitoring" TRMM web site pages.

**Source:** [NASA/Goddard Space Flight Center](#)

### [e! Science News](#)

## TRMM sees 05B winding down off the Sri Lanka coast

Published: Monday, December 14, 2009 - 21:23

### Related images



NASA/SSAI, Hal Pierce

Tropical Depression 05B is dissipating on the east coast of Sri Lanka today and over the next couple of days, but not before bringing some moderate and heavy rain over the next couple of days to some areas in Sri Lanka and the southeast coast of India, from Chennai, southward. The Joint Typhoon Warning Center issued its final advisory on Tropical Depression 05B, also known as Tropical Storm Ward, on Sunday, December 13 at 2100 UTC (4 p.m. ET). At that time, 05B's maximum sustained winds were near 34 mph. At that time, its center of circulation was located about 140 miles northeast of Colombo, Sri Lanka near 8.8 North latitude and 81.3 North longitude. It was crawling to the west-southwest near 4 mph.

The Tropical Rainfall Measuring Mission (TRMM) satellite is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall, and it captured 05B's rainfall on December 11.

The TRMM satellite monitors the global tropics as it circles the earth every 92.5 minutes at a height of 403 km (~250.4 miles). The TRMM satellite passed over 05B when it was newly formed in the Bay of Bengal on December 11, 2009 at 1610 UTC. TRMM's Microwave Imager (TMI) and Precipitation Radar (PR) instruments were used in the rainfall analysis. That data is used to create visual images at NASA's Goddard Space Flight Center, located in Greenbelt, Md. The TRMM data showed a large area of rainfall near the center of the storm with some areas of intense rainfall greater than 50 mm/hr (~2 inches). The analysis was overlaid on an infrared image from TRMM's Visible and Infrared Scanner (VIRS). Tropical cyclone 05B was above tropical storm strength with winds over 35 knots (~40.3 mph) at that time.

The Precipitation Radar (PR) instrument has the unique capability of seeing through clouds to show tropical cyclones such as 05B in 3-D. An intense thunderstorm near the center of 05B was found by TRMM's PR to extend to heights above 13 km (~8 miles). Since that time, 05B has weakened into a tropical depression and its cloud heights have dropped.

Tropical cyclone 05B (Ward) that had been predicted to impact the southeastern coast of India, weakened to a tropical depression while moving over northeastern Sri Lanka. 05B was producing heavy rainfall over areas of the southwestern Bay Of Bengal and eastern Sri Lanka when the TRMM satellite passed over on December 14, 2009 at 0509 UTC. The

rainfall analysis was derived from TRMM's Microwave Imager (TMI) and Precipitation Radar (PR) instruments and was overlaid on a combination infrared and visible image from TRMM's Visible and Infrared Scanner (VIRS).

Chennai and southeastern India will see scattered thunderstorms over the next several days as the system winds down. The areas in the southeast will experience scattered thunderstorms with light winds. Some downpours could be heavy at times. The current forecast calls for thunderstorms to diminish over southeastern India by Thursday, December 17.

In Sri Lanka, the Meteorology Department issued a cyclone warning on Sunday, December 13, and noted that the effects from the storm would peak by mid-day on Monday, December 14. Fishermen were cautioned against going out to sea because of rough seas and gusty winds. Scattered showers are expected today in the Northern, Eastern, Uva and North-Central Provinces of the country.

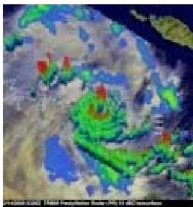
**Source:** [NASA/Goddard Space Flight Center](#)

[e! Science News](#)

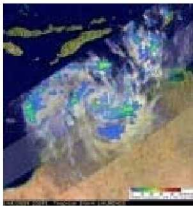
## **Tropical Cyclone Laurence menaces Northern Australia**

Published: Wednesday, December 16, 2009 - 16:41

### **Related images**



NASA/SSAI, Hal Pierce



NASA/SSAI, Hal Pierce

Laurence is still a tropical cyclone even though the storm has made landfall in northern West Australia and is moving over land. The Tropical Rainfall Measuring Mission (TRMM) satellite noticed some powerful and high thunderstorms in Laurence before he made landfall, and the storm is still maintaining intensity for now, but that will wane as the storm continues to interact with the friction caused by traveling over land. The TRMM satellite is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. When the TRMM satellite passed overhead on 14 December 2009 at 2329 UTC getting rainfall data Tropical Cyclone Laurence was close to hurricane strength. The rotating rain bands around Laurence's center of circulation off the coast of northern Australia were clearly revealed by TRMM's Precipitation Radar (PR) instrument as it peered through obscuring thunderstorm clouds.

Data from TRMM's Precipitation Radar (PR) instrument were used to create a dramatic 3-D view of the storm that showed towering thunderstorms up to 9 miles high around Laurence's developing eye wall.

At 0600 UTC, or 1 a.m. ET today, December 16, Cyclone Laurence was still a powerful cyclone with maximum sustained winds near 103 mph (90 knots) making it a Landfalling Category 2 hurricane on the Saffir-Simpson Scale.

Laurence's center was near 16.3 South latitude and 124.2 East longitude about 440 nautical miles from Port Hedland, Australia. Closer to the Laurence's center, and feeling his full hurricane-force wrath today are Koolan Island, Cockatoo Island, Molema Island, Kingfisher Island and the towns of Kimbolton, Derby, Meda on the mainland.

By 1:46 p.m. ET, The Australian Government Bureau of Meteorology reported that Laurence's winds had already started waning and were near 75 knots (86 mph). That means that in 12 hours, Laurence weakened from a Category 2 hurricane to a Category 1 hurricane.

The bulletin on the Australian Bureau of Meteorology website said "Severe Tropical Cyclone Laurence has crossed the Kimberley coast north northeast of Derby as a small but intense system." Laurence had a minimum central pressure of 1003 millibars and was near 16.6 South and 124.1 East, northeast of Kimbolton, and moving slowly southward at 4 mph. For updates on the Australian Government Web Site visit: <http://www.bom.gov.au/weather/cyclone/>.

Laurence is also proceeding into the mainland on a track southward. Its moving south near 10 mph. It is then expected to shift and move southwestward.

**Source:** [NASA/Goddard Space Flight Center](#)



## APPENDIX 2. REFEREED ARTICLES

Asterisks indicate articles highlighted in Appendix 3.

Laboratory members' names are in boldface.

## Code 613 2009 Publications

Krishnamurti, T. N., A. Chakraborty, A. Martin, **W. K. Lau**, **K. Kim**, Y. Sud, and G. Walker (2009), Impact of Arabian Sea pollution on the Bay of Bengal winter monsoon rains, *J. Geophys. Res.*, 114, D06213, doi:10.1029/2008JD010679.

**Lau, K. M.**, and H. T. Wu, 2009: Characteristics of rainfall, clouds and latent heating associated with the Madden and Julian Oscillation. *J. Climate*, 23, 504-518, DOI: 10.1175/2009JCLI2920.1

Lau, K. M., K. M. Kim, C. Hsu and B. Holben, 2009: Possible influences of air pollution, dust and sandstorms on the Indian monsoon. *WMO Bulletin*, 58 (1), 22-30

**Lau, K. M.**, Kim, K. M., Sud, Y. C., and Walker, G. K., 2009: A GCM study of the response of the atmospheric water cycle of West Africa and the Atlantic to Saharan dust radiative forcing, *Ann. Geophys.*, 27, 4023-4037, www.ann-geophys.net/27/4023/2009/

Pielke, R., K. Beven, G. Brasseur, J. Calvert, M. Chahine, R. Dickerson, D. Entekhabi, E. Foufoula-Georgiou, H. Gupta, V. Gupta, W. Krajewski, E. Philip Krider, **W. K. M. Lau**, J. McDonnell, W. Rossow, J. Schaake, J. Smith, S. Sorooshian, E. Wood, 2009: Climate Change: The need to consider human forcings besides greenhouse gases. *EOS Newsletter*, 90, 10 November issue.

**Reale, O.**, **K-M Lau**, K-M Kim, and E. Brin, 2009: Atlantic tropical cyclogenetic processes during SOP-3 NAMMA in the GEOS-5 global data assimilation and forecast system. *J. Atmos. Sci.*, 66, 3563-3578.

**Reale, O.**, **K. M. Lau**, J. Susskind, and E. Brin, L. P. Riishojgaard, M. Fuentes, and R. Rosenberg, 2009: AIRS impact on the analysis and forecast track of tropical cyclone Nargis in a global data assimilation and forecasting system. *Geophys. Res. Lett.*, 36, L06812, doi:10.1029/2008GL037122, 2009.

Sun, D., **K. M. Lau**, M. Kafatos, Z. Boybei, G. Leptoukh, and C. Yang, 2009: A numerical simulation of the impacts of African dust aerosols and associated Saharan air layer on Atlantic tropical cyclone development. *J. Climate*, 22, 6230-6250, doi:10.1175/2009JCLI2738.1.

**J. Susskind**, **J. Blaisdell**, **L. Iredell**, and **F. Keita**, IEEE Transactions on Geoscience and Remote Sensing, 2010: Improved Temperature Sounding and Quality Controlled Methodology Using AIRS/AMSU Data: The AIRS Science Team Version 5 Retrieval Algorithm," in press.

Wu, M.-L., **O. Reale**, S. Schubert, M. J. Suarez, R. Koster, P. Pegion, 2009: African Easterly Jet: Structure and Maintenance. *Journal of Climate*, 22, 4459-4480.

## Code 613.1 2009 Publications

Behrangi, A., B. Imam, K. Hsu, S. Sorooshian, **G.J. Huffman**, and R.J. Kuligowski (2009). PERSIAN-MSA: A precipitation estimation method from satellite-based multi-spectral analysis *J. Hydrometeor.*, 10(6), 1414-1429 DOI: 10.1175/2009JHM1139.1

**Bolvin, D.**, **R. Adler**, **G.J. Huffman**, **E. Nelkin**, and J.P. Poutiainen (2009). Comparison of GPCP monthly and daily precipitation estimates with high-latitude gauge observations *Appl. Meteor. Climat.*, 48(9), 1843-1857 DOI: 10.1175/2009JAMC2147.1

## APPENDIX 2: REFERREED ARTICLES

- Campbell R, J., [E.J. Welton](#), and J.D. Spinhirne (2009). Continuous Lidar Monitoring of Polar Stratospheric Clouds at the South Pole *Bull.Amer.Meteor.Soc.*, 22(9), 5232–5250  
DOI: 10.1175/2009JCLI2949.1
- Chiu, L., R. Chokngamwong, C.-L. Shie, and Y. Xing (2009). Variations in global oceanic evaporation datasets *Acta Ocea. Sinica*, 27(3), 124-135
- Crow, W.T., **G.J. Huffman**, R. Bindlish, and **T. Jackson** (2009). Improving Satellite-Based Rainfall Accumulation Estimates Using Spaceborne Surface Soil Moisture Retrievals *J. Hydrometeor.*, 10(1), 199-212  
DOI: 10.1175/2008JHM986.1
- Grecu, M., W.S. Olson, C. Shie, T.S. LeCuyer, and W. Tao** (2009). Combining satellite microwave radiometer and radar observations to estimate atmospheric latent heating profiles *J. Clim.*, 22(23), 6356–6376  
DOI: 10.1175/2009JCLI3020.1
- Han, M., S. Braun, P.O. G. Persson, and J.-W. Bao** (2009). Along-front variability of precipitation associated with a midlatitude frontal zone: TRMM observation and MM5 simulation *Mon. Wea. Rev.*, 137(3), 1008-1028  
DOI: 10.1175/2008MWR2465.1
- Heymsfield, A.J., A. Bansemer, **G.M. Heymsfield**, and A.O. Fierro (2009). Microphysics of maritime tropical convective updrafts at temperatures from -20 to -60C *J. Atmos. Sci.*, 66(12), 3530-3562  
DOI: 10.1175/2009JAS3107.1
- Hong, Y., **R. Adler**, and **G.J. Huffman** (2009). Applications of TRMM-based multi-satellite precipitation estimation for global runoff simulation: Prototyping a global flood monitoring system., 245-265  
ISBN: 978-90-481-2914-0
- Huffman, G.J., R. Adler, D. Bolvin, and G. Gu** (2009). Improving the Global Precipitation Record: GPCP Version 2.1 *J. Geophys. Res. Lett.*, 36(L17808) DOI:10.1029/2009GL040000
- Huffman, G.J., R. Adler, D. Bolvin, and E. Nelkin** (2009). Chapter 1 in :The TRMM multi-satellite precipitation analysis (TMPA), 3-22 ISBN: 978-90-481-2914-0
- Jensen, E. J. , P. Lawson, B. Baker, B. Pilon, Q. Mo, A. J. Heymsfield, A. Bansemer, T. P. Bui, **M. McGill**, D. Hlavka, G. Heymsfield, S. Platnick, G. T. Arnold, and S. Tanelli, 2009: On the importance of small ice crystals in tropical anvil cirrus, *Atmos. Chem. Phys.*, 9, 5519-5537.
- Kirschbaum, D.B., **R. Adler**, Y. Hong, and A. Lerner-Lam (2009). Evaluation of a preliminary satellite-based landslide hazard algorithm using global landslide inventories *Nat. Haz. Earth Sys.Sci.*, 9(3), 673-686  
<http://www.nat-hazards-earth-syst-sci.net/9/673/20>
- Li, X., W.-K. Tao, A. Khain, J. Simpson, and D. Johnson** (2009). Sensitivity of (bulk vs explicit-bin) microphysics in cloud-resolving model simulated mid-latitude squall line: Part I: Model validation *J. Atmos. Sci.*, 66(1), 3-21 DOI: 10.1175/2008JAS2646.1
- Li, X., D. Johnson, J. Simpson, A. Khain, and W.-K. Tao** (2009). Sensitivity of a cloud-resolving model to bulk and explicit-bin microphysics schemes:: Part II: Cloud microphysics and storm dynamics interactions *J. Atmos. Sci.*, 66(1), 22-40 DOI: 10.1175/2008JAS2647.1
- Liao, L., R. Menenghini, L. Tian, and G.M. Heymsfield** (2009). Simulations of radar bright band for X and W-band radars *J. Appl. Meteor.*, 48(11), 2215–2226 DOI: 10.1175/2009JAMC2033.1
- Marks, D., D.B. Wolff, D. Silberstein, A. Tokay, J. Pippitt, and J. Wang** (2009). Availability for high quality TRMM ground validation data from Kwajalein, RMI: A practical application of the Relative Calibration Adjustment Technique *J. Atmos. Ocea. Tech.*, 26(3), 413-429 DOI: 10.1175/2008JTECHA1174.1



- Matsui, T., X. Zeng, W.-K. Tao, H. Masunaga, W.S. Olson, and S. Lang** (2009). Evaluation of long-term cloud-resolving model simulations using satellite radiance observations and multi-frequency satellite simulators *J. Atmos. Ocean. Tech.*, 27(7), 1261–1274 DOI: 10.1175/2008JTECHA1168.1
- Medaglia, C.M., S. Pinori, C. Adamo, S. Dietrich, F. Fierli, A. Mugnai, E. Smith, and G.J. Tripoli** (2009). Model and satellite analysis of the November 9–10, 2001 Algeria flood *Measuring Precipitation from Space: EURAINSAT and the Future*, 28(7), 521–534 DOI: 10.1007/978-1-4020-5835-6
- Miloshevich, L., H. Voemel, D. Whiteman, and T. Leblanc** (2009). Accuracy assessment and correction of Vaisala RS92 radiosonde water vapor measurements *J. Geophysical Res.*, 114(011305) DOI: 10.1029/2008JD011565
- Mohr, K.I., J. molinari, and C. Thorncroft** (2009). The interannual stability of cumulative frequency distributions for convective system size and intensity *J. Clim.*, 22(19), 5218–5231 DOI: 10.1175/2009JCLI2940.1
- Noel, V., M. Winker, M. Haeffelin, and M. McGill** (2009). Comparison of depolarization ratio observed in convective ice clouds during CRYSTAL-FACE with a midlatitude synoptic cirrus clouds climatology from the SIRTa observatory *J. Geophys. Res.*, 109(D24) DOI:10.1029/2004JD004883.
- Norris, P.M., X. Zeng, W.-K. Tao, A. Hou, and L. Oreopoulos** (2009). Clouds and copulas: Part I: Theory for water clouds *Q. J. Roy. Meteor. Soc.*, 134(636), 1843–1864 DOI: 10.1002/qj.321
- Shie, C.-L., L.S. Chiu, R. Adler, P. Xie, I.-I. Lin, F.-C. Wang, E. Nelkin, R. Chokngamwong, and W.S. Olson** (2009). Reviving the production of Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) dataset *J. of Ocea. Univ. China*, 26(6), 1071–1080 DOI: 10.1007/s00376-009-8138-z
- Tao, W.-K., D. Anderson, J. Chern, J. Entin, A. Hou, P. Houser, R. Kakar, S. Lang, K.M. Lau, C. Peters-Lidard, X. Li, T. Matsui, M. Rienecker, M. R. Schoeberl, B.-W. Shen, J. J. Shi, and X. Zeng**, 2009: The Goddard multi-scale modeling system with unified physics *Ann. Geophys.*, 27, 3055–3064.
- Tao, W.-K., J. Chern, R. Atlas, D. Randall, X. Lin, M. Khairoutdinov, J. Li, D. Waliser, A. Hou, C. Peters-Lidard, W. Lau, and J. Simpson** (2009). A Multi-scale modeling system: Development, applications and critical issues *Bull. Amer. Meteor. Soc.*, 90(4), 515–534 DOI: 10.1175/2008BAMS2542.1
- Tao, W.-K., and M. Moncrieff** (2009). Cloud-System Resolving Models: Status and Prospects *Reviews of Geophysics*, 47(RG4002) DOI: 10.1029/2008RG000276
- Tokay, A., P. Hartman, A. Battaglia, K. Gage, W. Clark, and C. Williams** (2009). A Field Study of Reflectivity and Z-R Relations using Vertically Pointing Radars and Disdrometers *J. Atmos. Ocean. Tech.*, 26(6), 1120–1134 DOI: 10.1175/2008JTECHA1163.1
- Van Zadelhoff, G., A. Heymsfield, D. Donovan, and M. McGill** (2009). Validating lidar-radar microphysics retrieval using in-situ measurements *J. Geophys. Res.*, 112(D9) DOI: 10.1029/2006JD007202.
- Veselovskiy, I., D. Whiteman, A. Kolgotin, E. Andrews, and M. Korenski** (2009). Demonstration of aerosol property profiling by multi-wavelength lidar under varying relative humidity conditions *J. Atmos. Ocean. Tech.*, 26(8), 1543–1557 DOI: 10.1175/2009JTECHA1254.1
- Wang, J., and D.B. Wolff** (2009). Comparisons of reflectivities from the TRMM Precipitation Radar and Ground-Based Radars *J. Atmos. Ocean. Tech.*, 26(5), 857–875 DOI: 10.1175/2008JTECHA1175.1
- Wang, J., and D.B. Wolff** (2009). Evaluation of TRMM Ground-Validation Radar-Rain Errors Using Rain Gauge Measurements *J. Applied Meteor. Climatol.* DOI: 10.1175/2009JAMC2264.1

## APPENDIX 2: REFERREED ARTICLES

- Whiteman, D.**, L. Miloshevich, H. Voemel, and T. Leblanc (2009). Accuracy assessment and correction of Vaisala RS92 radiosonde water vapor measurements *J. Geophys. Res.*, **114**(D11)  
DOI: 10.1029/2008JD011565
- Wolff, D.B.**, and **B.L. Fisher** (2009). Assessing the Relative Performance of Microwave-Based Satellite Rain Retrievals Using TRMM Ground Validation Data *J. Appl. Meteor. Clim.*, **48**(6), 1069–1099  
DOI: 10.1175/2008JAMC2127.1
- Yorks, J.**, **M. McGill**, S. Rodier, M. Vaughan, Y. Hu, and **D. Hlavka** (2009). Radiative effects of African dust and smoke observed from CERES and CALIOP data *J. Geophys. Res.*, **114**(D00H04)  
DOI: 10.1029/2009JD012000
- Zeng, X.**, W.-K. Tao, and **J. Simpson** (2009). Microphysical Timescales in Clouds and their Application in Cloud-Resolving Modeling *J. Meteor. Soc. of Japan*, **86**(0026-1165), 839-856 DOI: 10.2151/JMSJ.86.839
- Zeng, X.**, **J. Simpson**, **X. Li**, D.O. Starr, **X. Li**, **S. Lang**, **S. Xie**, **A. Hou**, **M. Zhang**, and **W. Tao** (2009). The indirect effect of ice nuclei on atmospheric radiation *J. Atmos. Sci.*, **66**(1), 41-61 DOI: 10.1175/2008JAS2778.1
- Zeng, Xiping.**, **W. Tao**, **M. Zhang**, **Y. Arthur Hou**, **S. Xie**, **S. Lang**, **X. Li**, **David OC Starr**, and **X. Li** (2009). A Contribution by Ice Nuclei to Global Warming *Q. J. Roy. Meteor. Soc.*, **135**(638) DOI: 10.1002/qj.576

### Code 613.2 2009 Publications

---

- Bell, T. L.**, D. Rosenfeld, and **K.-M. Kim**, 2009: The Weekly Cycle of Lightning: Evidence of Storm Invigoration by Pollution. *Geophys. Res. Lett.* **36**, L23805, DOI:10.1029/2009GL040915.
- Bell, T. L.**, J. -M. Yoo, and M. -I. Lee, 2009: Note on the weekly cycle of storm heights over the southeast United States. *J. Geophys. Res.*, **114**, D15201, DOI:10.1029/2009JD012041.
- Bi, L.**, P. Yang, G.W. Kattawar, and **R. Kahn**, 2009. Modeling optical properties of mineral aerosol particles by using non-symmetric hexahedra, *Appl. Opt.* **49**, 334-342.
- Bosilovich, M. G.**, **D. M. Mocko**, J. O. Roads, and A. Ruane, 2009: A Multi-model Analysis for the Coordinated Enhanced Observing Period (CEOP). *J. Hydrometeorol.*, **10**(4), 912–934, DOI: 10.1175/2009JHM1090.1, 2009.
- Chen, Y.**, Q. Li, **R. Kahn**, J. T. Randerson, and D. J. Diner, 2009: Quantifying aerosol direct radiative effect with MISR observations: 1. TOA albedo change by aerosols based on land surface types. *J. Geophys. Res.*, **114**, D02109, DOI:10.1029/2008JD010754.
- Chen, Y.**, Q. Li, J. T. Randerson, E. A. Lyons, **R. A. Kahn**, D. L. Nelson, and D. J. Diner, 2009: The sensitivity of CO and aerosol transport to the temporal and vertical distribution of North American boreal fire emissions. *Atmos. Chem. Phys.*, **9**, pp 6559-6580.
- Chiu, J. C.**, **A. Marshak**, Y. Knyazikhin, P. Pilewskie, and **W. Wiscombe**, 2009: Physical interpretation of the spectral radiative signatures in the transition zone between cloud-free and cloudy regions. *Atmos. Chem. Phys.*, **9**, 1419-1430.
- Davis, A. B.**, I. N. Polonski, and **A. Marshak**, 2009: Space-Time Green Functions for Diffusive Radiation Transport, in Application to Active and Passive Cloud Probing. *In Light Scattering Reviews*, **4**. Single Light Scattering and Radiative Transfer, A.A. Kokhanovsky [Ed.], Springer, 169-292.
- Davis A.B.** and **A. Marshak**, 2009. Solar radiation transport in the cloudy atmosphere: A 3D perspective on observations and climate impacts. *Reports on Progress in Phys.*, **73**, 026801 (70pp).

- El-Askary H., R. Farouk, **C. Ichoku**, and M. Kafatos, 2009: Transport of dust and anthropogenic aerosols across Alexandria, Egypt, *Ann. Geophys.*, **27**, 2869–2879.
- Fischer, E. V., **N. C. Hsu**, D. A. Jaffe, **M.-J. Jeong**, and S. L. Gong, 2009: A decade of dust: Asian dust and springtime aerosol load in the U.S. Pacific Northwest. *Geophys. Res. Lett.*, **36**, L03821, DOI:10.1029/2008GL036467.
- Gatebe, C. K.**, O. Dubovik, M. D. King, and A. Sinyuk, 2009: Simultaneous retrieval of aerosol and surface optical properties from combined airborne- and ground-based direct and diffuse radiometric measurements. *Atmos. Chem. Phys. Discuss.*, **9**, 26491–26538.
- Gautam, R.**, **N. C. Hsu**, **K. M. Lau**, **S. C. Tsay**, and M. Kafatos, 2009: Enhanced Pre-Monsoon Warming over the Himalayan-Gangetic Region from 1979 to 2007. *Geophys. Res. Lett.*, **36**, L07704, DOI:10.1029/2009GL037641.
- Gautam, R.**, **N. C. Hsu**, **K.-M. Lau**, and M. Kafatos, 2009: Aerosol and Rainfall Variability over the Indian Monsoon Region: Distributions, Trends and Coupling. *Annales Geophysicae*, Special Issue: From Deserts to Monsoons, **27**, 3691–3703.
- Gautam, R.**, Z. Liu, R. P. Singh, and **N. C. Hsu**, 2009: Two Contrasting Dust-dominant periods over India observed from MODIS and CALIPSO data. *Geophys. Res. Lett.*, **36**, L06813, DOI:10.1029/2008GL036967.
- Georgiev, G. T., **C. K. Gatebe**, J. J. Butler, and M. D. King, 2009: BRDF analysis of savanna vegetation and salt-pan samples. *IEEE Trans. Geosci. Remote Sens.*, **47**, 2546–2556.
- Gultepe, I., G. Pearson, J. A. Milbrandt, B. Hansen, **S. Platnick**, P. Taylor, M. Gordon, J. P. Oakley, and S. G. Cober, 2009: The Fog Remote Sensing and Modeling (FRAM) Field Project, *Bull. Amer. Meteor. Soc.*, **90**, 341–359.
- Hu, J.C., W.J. Chen, **J.C. Chiu**, J.L. Wang and G.R. Liu, 2009: Quantitative precipitation estimation over ocean using Bayesian approach from microwave observations during the typhoon season. *Terr. Atmos. Oceanic. Sci.*, **20**, 817–832.
- Johnson, B. T., S. Christopher, J. M. Haywood, S. R. Osborne, S. McFarlane, **N. C. Hsu**, **C. Salustro**, and **R. Kahn**, 2009: Measurements of aerosol properties from aircraft, satellite and ground-based remote sensing: A case study from the Dust and Biomass burning Experiment (DABEX). *Q.J. Roy. Meteor. Soc.*, **135**, 922–934.
- Kahn, R. A.**, D. L. Nelson, M. Garay, **R. C. Levy**, M. A. Bull, J. V. Martonchik, D. J. Diner, S. R. Paradise, D. L. Wu, E. G. Hansen, and **L. A. Remer**, 2009: MISR Aerosol product attributes, and statistical comparisons with MODIS. *IEEE Trans. Geosci. Rem. Sens.*, **47**, No. 12, 4095–4114.
- Kahn, R. A.**, **H. Yu**, S. E. Schwartz, M. Chin, G. Feingold, **L. A. Remer**, D. Rind, **R. Halthore**, and P. DeCola, 2009: Introduction, Atmospheric Aerosol Properties and Climate Impacts. *A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.), National Aeronautics and Space Administration, Washington, D.C., USA.
- Kato, S. and **A. Marshak**, 2009. Solar zenith and viewing geometry-dependent errors in satellite retrieved cloud optical thickness: Marine stratocumulus case. *J. Geophys. Res.*, **114**, D01202, DOI:10.1029/2008JD010579.
- Koren, I.**, **L. A. Remer**, K. Longo, F. Brown, and R. Lindsey, 2009: Reply to comment by W. Schroeder et al. on Reversal of trend of biomass burning in the Amazon. *Geophys. Res. Lett.*, **36**, L03807.
- Lee, J. P. Yang, A. Dessler, B.-C. Gao, and **S. Platnick**, 2009: Distribution and radiative forcing of tropical thin cirrus clouds, *J. Atmos. Sci.*, **10.1175/2009JAS3183.1**, 3721–3731.

## APPENDIX 2: REFERREED ARTICLES

- Levy, R., G. Leptoukh, R. Kahn, V. Zubko, A. Gopalan, and L. Remer, 2009: A critical look at deriving monthly aerosol optical depth from satellite data. *IEEE Trans. Geosci. Remote Sens.*, **47**, No. 9, 2942-2956.
- Liang, L., L. Di Girolamo, and S. Platnick, 2009: View-angle consistency in reflectance, optical depth, and spherical albedo of marine water clouds off the coast of California through MISR-MODIS fusion, *Geophys. Res. Lett.*, **36**, L09811, DOI:10.1029/2008GL037124.
- Liu, H., J. H. Crawford, D. B. Considine, S. Platnick, P. M. Norris, B. N. Duncan, R. B. Pierce, G. Chen, and R. M. Yantosca, 2009: Sensitivity of photolysis frequencies and key tropospheric oxidants in a global model to cloud vertical distributions and optical properties, *J. Geophys. Res.*, **114**, D10305, DOI:10.1029/2008JD011503.
- Lyapustin, A., C. K. Gatebe, R. Kahn, R. Brandt, J. Redemann, P. Russell, M. D. King, C. A. Pedersen, S. Gerland, R. Poudyal, A. Marshak, Y. Wang, C. Schaaf, D. Hall, and A. Kokhanovsky, 2009: Analysis of snow BRF from ARCTAS Spring-2008 campaign. *Atmos. Chem. Phys. Disc.*, **9**, 21993-22040.
- Marshak, A., Y. Knyazikhin, J. C. Chiu, and W. J. Wiscombe, 2009: Spectral invariant behavior of zenith radiance around cloud edges observed by ARM SWS. *Geophys. Res. Lett.*, **36**, L16802, DOI:10.1029/2009GL039366.
- Martins, J. V., P. Artaxo, Y. J. Kaufman, A. D. Castanho, and L. A. Remer, 2009: Spectral absorption properties of aerosol particles from 350-2500nm. *Geophys. Res. Lett.*, **36**, DOI: 10.1029/2009GL037435, L13810.
- Martonchik, J.V., R.A. Kahn, and D.J. Diner, 2009. Retrieval of Aerosol Properties over Land Using MISR Observations. In: Kokhanovsky, A.A. and G. de Leeuw, ed., *Satellite Aerosol Remote Sensing Over Land*. Springer, Berlin.
- McComiskey, A., G. Feingold, A. S. Frisch, D. Turner, M. Miller, J. C. Chiu, Q. Min, and J. Ogren, 2009: An assessment of aerosol-cloud interactions in marine stratus clouds based on surface remote sensing. *J. Geophys. Res.*, **114**, D09203, DOI:10.1029/2008JD011006.
- Meskhidze, N., L. A. Remer, S. Platnick, R. N. Juarez, A. M. Lichtenberger, A. Aiyyer, 2009: Exploring the differences in cloud properties observed by the Terra and Aqua MODIS sensor, *Atmos. Chem. Phys.*, **9**, 3461-3475.
- Mims, S.R., R.A. Kahn, C.M. Moroney, B.J. Gaitley, D.L. Nelson, and M.J. Garay, 2009. MISR Stereo-heights of grassland fire smoke plumes in Australia. *IEEE Trans. Geosci. Rem. Sens.* **48**, 25-35.
- Oreopoulos, L., and E. Mlawer, 2009: CIRC to Provide Key Intercomparisons of GCM Radiative Transfer Codes Prior to Next IPCC Assessment. GEWEX Feb 09 Newsletter, 8.
- Oreopoulos, L., E. Mlawer, J. Delamere, and T. Shippert, 2009: The Continual Intercomparison of Radiation Codes (CIRC): A New Standard for Evaluating GCM Radiation Codes. *Current Problems in Atmospheric Radiation (IRS 2008 Proceedings)*, 73-76.
- Oreopoulos, L., S. E. Platnick, G. Hong, P. Yang, and R. F. Cahalan, 2009: The Shortwave Radiative Forcing Bias of Homogeneous Liquid and Ice Clouds Observed by MODIS. *Current Problems in Atmospheric Radiation (IRS 2008 Proceedings)*, **9**, 5865-5875.
- Oreopoulos, L., S. Platnick, G. Hong, P. Yang, and R. F. Cahalan, 2009: The shortwave radiative forcing bias of liquid and ice clouds from MODIS observations. *Atmos. Chem. Phys.* **9**, 5865-5875.
- Prigarin, S., and A. Marshak, 2009: A simple stochastic model for generating broken cloud optical depth and cloud-top height fields. *J. Atmos. Sci.*, **66**, 92-104.

- Remer, L. A., M. Chin, P. DeCola, G. Feingold, R. Halthore, R. A. Kahn, P. K. Quinn, D. Rind, S. E. Schwartz, D. Streets, and H. Yu**, 2009: Executive Summary, Atmospheric Aerosol Properties and Climate Impacts. *A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.), National Aeronautics and Space Administration, Washington, D.C., USA.
- Rind, D., **R. A. Kahn**, M. Chin, S. E. Schwartz, **L. A. Remer**, G. Feingold, **H. Yu**, P. K. Quinn, and **R. Halthore**, 2009: The Way Forward: Atmospheric Aerosol Properties and Climate Impacts. *A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.), National Aeronautics and Space Administration, Washington, D.C., USA.
- Sud, Y. C., E. M. Wilcox, K.-M. Lau, G. K. Walker, X.-H. Liu, A. Nenes, D. Lee, K.-M. Kim, Y. Zhou, and P. S. Bhattacharjee**, 2009: Sensitivity of Boreal-Summer Circulation and Precipitation to Atmospheric Aerosols in Selected Regions, Part I: Africa and India. *Annales Geophysicae*, **27**, 3989-4007.
- Tsay, S.-C., G.-R. Liu, N. C. Hsu, W.-Y. Sun, and et. al.**, 2009: Outbreaks of Asian dust storms: An overview from satellite and surface perspectives. *Recent Progress in Atmospheric Sciences: Applications to the Asia Pacific Region*, World Scientific, 373-401.
- Varnai, T., and A. Marshak**, 2009: MODIS observations of enhanced clear sky reflectance near clouds. *Geophys. Res. Lett.*, **36**, L06807, DOI:10.1029/2008GL037089.
- Wilcox, E. M., Harshvardhan, and S. Platnick**, 2009: Estimate of the impact of absorbing aerosol over cloud on the MODIS retrievals of cloud optical thickness and effective radius using two independent retrievals of liquid water path. *J. Geophys. Res.*, **114**, D05210, DOI:10.1029/2008JD010589.
- Wilcox, E. M., Y. C. Sud, and G. K. Walker**, 2009: Sensitivity of Boreal-Summer Circulation and Precipitation to Atmospheric Aerosols in Selected Regions, Part II: The Americas. *Annales Geophysicae*, **27**, 4009-4021.
- Yang, Y., A. Marshak, T. Varnai, W. J. Wiscombe, and P. Yang**, 2009: Uncertainties in ice sheet altimetry from a space-borne 1064 nm single channel lidar due to undetected thin clouds. *IEEE Trans. Geos. Remote Sens.*, **48**, 250-259.
- Yu, H., M. Chin, L. A. Remer, R. G. Kleidman, N. Bellouin, H. Bian, and T. Diehl**, 2009: Variability of marine aerosol fine-mode fraction and estimates of anthropogenic aerosol component over cloud-free oceans from the Moderate resolution Imaging Spectroradiometer (MODIS). *J. Geophys. Res.*, **114**, D10206, DOI:10.1029/2008JD010648.
- Yu, H., P. K. Quinn, G. Feingold, L. A. Remer, R. A. Kahn, M. Chin, and S. E. Schwartz**, 2009: Remote Sensing and In Situ Measurements of Aerosol Properties, Burdens, and Radiative Forcing, in *Atmospheric Aerosol Properties and Climate Impacts. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.), National Aeronautics and Space Administration, Washington, D.C., USA.
- Zerefos, C. S., K. Eleftheratos, C. Meleti, S. Kazadzis, A. Romanou, **C. Ichoku**, G. Tselioudis, and A. Bais, 2009: Solar dimming and brightening over Thessaloniki, Greece, and Beijing, China, *Tellus*, DOI: 10.1111/j.1600-0889.2009.00425.x.
- Zhang, Y., R. Fu, **H. Yu**, Y. Qian, R. E. Dickinson, M. A. F. Silva Dias, P. L. da Silva Dias, and K. Fernandes, 2009: Impact of biomass burning aerosol on the monsoon circulation transition over Amazonia. *Geophys. Res. Lett.*, **36**, L10814, DOI:10.1029/2009GL037180.

## APPENDIX 2: REFERREED ARTICLES

Zipser, E.J., C.H. Twohy, **S-C. Tsay**, K.L. Thornhill, S. Tanelli, R. Ross, T.N. Krishnamurti, Q. Ji, G. Jenkins, S. Ismail, N.C. Hsu, R. Hood, G.M. Heymsfield, **A. Heymsfield**, J. Halverson, M.W. Goodman, R. Ferrare, J.P. Dunion, M. Douglas, R. Cifelli, G. Chen, E.V. Browell, B. Anderson, and (2009). The Saharan air layer and the fate of the African easterly waves – NASA’s AMMA 2006 field program to study tropical cyclogenesis: NAMMA *Bull. Amer. Meteor. Soc.*, 90(8), 1137–1156 DOI: 10.1175/2009BAMS2728.1

### Code 613.3 2009 Publications

---

Anton, M., J. M. Vilaplana, M. Kroon, **R. McPeters**, M. Banon, and A. Serrano, 2009: Validation of OMI-TOMS and OMI-DOAS total column ozone using five Brewer spectroradiometers at the Iberian peninsula, *J. Geophys. Res.*, 114 (10.1029/2009JD012003).

Benze, S., C. E. Randall, **M. T. DeLand**, G. E. Thomas, D. W. Rusch, S. M. Bailey, J. M. Russell III, W. McClintock, A. W. Merkel, and C. Jeppesen, 2009: Comparison of polar mesospheric cloud measurements from the Cloud Imaging and Particle Size experiment and the Solar Backscatter Ultraviolet instrument, *J. Atmos. Solar-Terr. Phys.*, 71, 365-372.

**Bian, H., M. Chin, J. Rodriguez**, H. Yu, J. E. Penner, and **S. E. Strahan**, 2009: Sensitivity of aerosol optical thickness and aerosol direct radiative effect to relative humidity, *Atmos. Chem. Phys.*, 9, 2375-2386.

Cagnazzo, C., E. Manzini, N. Calvo, **A. Douglass**, H. Akiyoshi, S. Bekki, M. Chipperfield, M. Dameris, M. Deushi, A. M. Fischer, H. Garny, A. Gettelman, M. A. Giorgetta, D. Plummer, E. Rozanov, T. G. Shepherd, K. Shibata, A. Stenke, H. Struthers, and W. Tian, 2009: Northern winter stratospheric temperature and ozone responses to ENSO inferred from an ensemble of Chemistry Climate Models, *Atmos. Chem. Phys.*, 9, 8935-8948.

**Chandra S., J. R. Ziemke, B. N. Duncan, T. L. Diehl**, N. J. Livesey, and L. Froidevaux, 2009: Effects of the 2006 El Nino on tropospheric ozone and carbon monoxide: Implications for dynamics and biomass burning, *J. Atmos. Chem & Phys.*, 9, 4239-4249.

**Chin, M., T. Diehl**, O. Dubovik, T. F. Eck, B. N. Holben, A. Sinyuk, and D. G. Streets, 2009: Light absorption by pollution, dust and biomass burning aerosols: A global model study and evaluation with AERONET data, *Ann. Geophys.*, 27, 3439-3464.

Collins, R. L., M. J. Taylor, K. Nielsen, K. Mizutani, Y. Murayama, K. Sakanoi, and **M. T. DeLand**, 2009: Noctilucent cloud in the Western Arctic in 2005: Simultaneous lidar and camera observations and analysis, *J. Atmos.-Solar-Terr. Phys.*, 71, 446-452.

Corr, C., **N. A. Krotkov**, S. Madronich, J. R. Slusser, B. Holben, W. Gao, J. Flynn, B. Leter, and S. M. Kreidenweis, 2009: Retrieval of aerosol single scattering albedo at ultraviolet wavelengths at the T1 site during MILAGRO (2009), *Atmos. Chem Phys. Discuss.*, 9, 4971-5008.

**Duncan, B., Y. Yoshida**, M. Damon, **A. Douglass**, and **J. Witte**, 2009: Temperature dependence of factors controlling isoprene emissions, *Geophys. Res. Lett.*, 36 (L05813, DOI:10.1029/2008GL037090).

Fiore, A., et al, 2009: Multi-model estimates of intercontinental source-receptor relationships for ozone pollution, *J. Geophys. Res.*, 114 (D04301, DOI:10.1029/2008JD010816).

Flynn, L. E., D. McNamara, C. T. Beck, I. Petrapavlovskikh, E. Beach, Y. Pachepsky, Y. P. Li, **M. DeLand**, **L. K. Huang**, C. S. Long, **C. S. Seftor**, **R. Tiruchirapalli**, and **S. Taylor**, 2009: Measurements and products from the Solar Backscatter Ultraviolet (SBUV/2) and the Ozone Mapping and Profiler Suite (OMPS) instruments, *J. Rem. Sens.*, 30, 4259-4272.

- Fogt, R. L., J. Perlwitz, S. Pawson, and **M. A. Olsen**, 2009: Intra-annual relationships between polar ozone and the SAM, *Geophys. Res. Lett.*, 36 (L04707, DOI:10.10.
- Herman, J. R., G. Labow**, N. C. Hsu, and **D. Larko**, 2009: Change in cloud and aerosol cover (1980-2006) from reflectivity time series using SeaWiFS, N7-TOMS, EP-TOMS, SBUV-2, and OMI radiance data, *J. Geophys. Res.*, 114 (D01201, DOI:10.1029/2007JD009508).
- Herman, J. R., A. Cede**, E. Spinei, G. Mount, **M. Tzortziou**, and **N. Abuhassan**, 2009: NO<sub>2</sub> column amounts from ground-based Pandora and MFDOAS spectrometers using the Direct-Sun DOAS technique, *J. Geophys. Res.*, 114 ( DOI:10.1029/2009JD011848).
- Jackman, C. H.**, D. R. Marsh, F. M. Vitt, R. R. Garcia, C. E. Randall, **E. L. Fleming**, and **S. M. Frith**, 2009: Long-term middle atmospheric influences of very large solar proton events, *J. Geophys. Res.*, 114 (D11304, doi:10.1029/2008JD011415).
- Jiang, J. H., H. Su, S. Massie, **P. Colarco**, M. Schoeberl, and S. Platnick, 2009: Aerosol-CO relationship and aerosol effect on ice cloud particle size: Analyses from Aura MLS and Aqua MODIS observations, *J. Geophys. Res. - Atmos.*, 114 (D20207, DOI:10.1029/2009JD04242).
- Joiner, J.**, M. R. Schoeberl, **A. P. Vasilkov**, L. Oreopoulos, P. Levelt, N. Livesey, and S. Platnick, 2009: Accurate satellite-derived estimates of tropospheric ozone radiative forcing, *Atmos. Chem. Phys.*, 9, 4447-4465.
- Kawa, S. R., R. S. Stolarski, P. A. Newman, A. R. Douglass**, M. Rex, D. J. Hofmann, M. L. Santee, and K. Frieler, 2009: Sensitivity of Polar Stratospheric Ozone Loss to Uncertainties in Chemical Reaction Kinetics, *Atmos. Chem. Phys.*, 9, 8651-8660.
- Koch, D., M. Schulz, S. Kinne, G. Schuster, T. C. Bond, A. Clarke, D. W. Fahey, S. Freitag, C. McNaughton, J. R. Spackman, Y. Kondo, N. Moteki, L. Sahu, H. Sakamoto, N. Takegawa, Y. Zhao, Y. Balkanski, Susanne Bauer, T. Bernsten, T. Berglen, O. Boucher, **M. Chin**, F. Dentener, **T. Diehl**, R. Easter, H. Feichter, D. Fillmore, S. Ghan, P. Ginoux, S. Gong, A. Grini, L. Horowitz, T. Iversen, A. Kirkevåg, M. Krol, **X. Liu**, R. Miller, V. Montanaro, G. Myhre, J. Penner, J. Perlwitz, G. Pitari, S. Reddy, Ø. Seland, P. Stier, T. Takemura, C. Textor, Z. Klimont, and J. A. van Aardenne, 2009: Evaluation of Black Carbon Estimations in Global Aerosol Models,, *Atmos. Chem. Phys.*, 9, 9001-9026.
- Lee, C., R. V. Martin, A. van Donkelaar, G. O'Byrne, **N. Krotkov**, A. Richter, L. G. Huey, and J. S. Holloway, 2009: Retrieval of vertical columns of sulfur dioxide from SCIAMACHY and OMI: Air mass factor algorithm development, validation, and error analysis, *J. Geophys. Res.*, 114 (D22303, DOI:10.1029/2009JD012123).
- Li, F., R. S. Stolarski**, and **P. A. Newman**, 2009: Stratospheric ozone in the post-CFC era,, *Atmos. Chem. and Phys.*, 9, 2207-2213.
- Liang, Q., A. R. Douglass, B. N. Duncan, R. S. Stolarski**, and **J. C. Witte**, 2009: The governing processes and timescales of stratosphere-to-troposphere transport and its contribution to ozone in the Arctic troposphere, *Atmos. Chem. Phys.*, 9, 3011-3025.
- Liu, H., J. H. Crawford, D. B. Considine, S. Platnick, P. M. Norris, **B. N. Duncan**, R. B. Pierce, G. Chen, and R. M. Yantosca, 2009: Sensitivity of photolysis frequencies and key tropospheric oxidants in a global model to cloud vertical distributions and optical properties, *J. Geophys. Res.*, 114 (D10305, DOI:10.1029/2008JD011503).
- Mayr, H. G., J. G. Mengel**, F. T. Huang, and **E. R. Nash**, 2009: Solar cycle signatures in the NCEP equatorial annual oscillation, *Ann. Geophys.*, 27, 3225 - 3235.



## APPENDIX 2: REFERREED ARTICLES

- Mayr, H. G., J. G. Mengel,** and F. T. Huang, 2009: Modeling the temperature of the polar mesopause region: Part 1 - Inter-annual and long-term variations generated by the stratospheric QBO, *J. Atmos. and Sol. Terr. Phys.*, 71, 497-507.
- Mayr, H. G., J. G. Mengel,** F. T. Huang, and S. M. Bailey, 2009: Modeling the temperature of the polar mesopause region: Part II - Intra-seasonal monthly oscillations, *J. Atmos. and Sol. Terr. Phys.*, 71, 508-517.
- Mayr, H. G., J. G. Mengel,** F. T. Huang, and **E. R. Nash**, 2009: Intra-seasonal monthly oscillations in stratospheric NCEP data and model results, *J. Atmos. and Sol. Terr. Phys.*, 71, 1299-1308.
- Newman, P. A., L. D. Oman, A. R. Douglass, E. L. Fleming, S. M. Frith, M. M. Hurwitz, S. R. Kawa, C. H. Jackman, N. A. Krotkov, E. R. Nash,** J. E. Nielsen, S. Pawson, **R. S. Stolarski,** and G. J. M. Velders, 2009: What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated?, *Atmos. Chem. Phys.*, 9, 2113-2128.
- Oman, L.,** D. W. Waugh, S. Pawson, **R. S. Stolarski,** and **P. A. Newman**, 2009: On the influence of anthropogenic forcings on changes in the stratospheric mean age, *J. Geophys. Res.*, 114 (D03105, DOI:10.1029/2008JD010378).
- Ott, L. E.,** J. Bacmeister, S. Pawson, **K. Pickering,** M. Suarez, H. Huntrieser, M. Loewenstein, J. Lopez, I. Xueref-Remy, and G. Stenchikov, 2009: Analysis of convective transport and parameter sensitivity in a single column version of the Goddard Earth Observation System, Version 5, General Circulation Model, *J. Atmos. Sci.*, 66, 627-645.
- Pickering, K.,** H. Huntrieser, and U. Schumann, 2009: Lightning and NO<sub>x</sub> production in global models, Springer, *Chapter in Lightning: Principles, Instruments and Applications*, H. Benz, U. Schumann, P Laroche, Eds., 551-571.
- Rind, D., M. Chin,** G. Feingold, D. Streets, R. A. Kahn, S. E. Schwartz, and H. Yu, 2009: Modeling the Effects of Aerosols on Climate: Atmospheric Aerosol Properties and Climate Impacts. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.), National Aeronautics and Space Administration, Washington, D.C., USA.
- Schutz, M., M. Chin,** and S. Kinne, 2009: Aerosol model comparison project, AeroCom, Phase II: Clearing up diversity, *IGAC Newsletter*, 41 (May 2009).
- Shettle, E. P., M. T. DeLand,** G. E. Thomas, and J. J. Olivero, 2009: Long term variations in the frequency of polar mesospheric clouds in the northern hemisphere from SBUV, *Geophys. Res. Lett.*, 36 (L02803, DOI:10.1029/2008GL036048).
- Steinbrecht, W.,** H. Claude, F. Schönenborn, I.S. McDermid, T. Leblanc, S. Godin-Beekmann, P. Keckhut, A. Hauchecorne, J.A.E. Van Gijssel, D.P.J. Swart, G.E. Bodeker, A. Parrish, I.S. Boyd, N. Kämpfer, K. Hocke, **R.S. Stolarski, S.M. Frith,** L.W. Thomason, E.E. Remsberg, C. von Savigny, and A. Rozanov J.P. Burrows, 2009: Ozone and temperature trends in the upper stratosphere at five stations of the Network for the Detection of Atmospheric Composition Change, *J. Remote Sensing*, 30, 3875-3886.
- Strahan, S. E., M. R. Schoeberl,** and **S. D. Steenrod**, 2009: The impact of tropical recirculation on polar composition, *Atmos. Chem. Phys. Disc.*, 9, 2471-2480.
- Streets, D. G.,** F. Yan, **M. Chin, T. Diehl,** N. Mahowald, M. Schultz, M. Wild, Y. Wu, and C. Yu, 2009: Anthropogenic and natural contributions to regional trends in aerosol optical depth, 1980-2006, *J. Geophys. Res.*, 114 (D00D18, DOI:10.1029/2008JD011624).

- Vassilkov, A. P., J. Joiner, L. Oreopoulos, J. F. Gleason, P. Veefkind, E. Bucsela, E. A. Celarier, R. J. D. Spurr, and S. Platnick, 2009:** Impact of tropospheric nitrogen dioxide on the regional radiation budget, *Atmos. Chem. Phys.*, 9, 6389-6400.
- Vermote, E., E. Ellicott, O. Dubovik, T. Lapyonok, M. Chin, L. Giglio, and G. J. Roberts, 2009:** An approach to estimate global biomass burning emissions of organic and black carbon from MODIS fire radiative power, *J. Geophys. Res.*, 114 (D18205, DOI:10.1029/2008JD011188).
- Waugh, D. W., L. Oman, P. A. Newman, R. S. Stolarski, S. Pawson, J. E. Nielsen, and J. Perlwitz, 2009:** Effect of zonal asymmetries in stratospheric ozone on simulated southern hemisphere climate trends, *Geophys. Res. Lett.*, 36 (L18701, DOI:10.1029/2009GL040419).
- Waugh, D. W., L. Oman, S. R. Kawa, R. S. Stolarski, S. Pawson, A. R. Douglass, P. A. Newman, and J. E. Nielsen, 2009:** Impacts of climate change on stratospheric ozone recovery, *Geophys. Res. Lett.*, 36 (L03805, DOI:10.1029/2008GL036223).
- Witte, J. C., M. R. Schoeberl, A. R. Douglass, J. F. Gleason, N. A. Krotkov, J. C. Gille, K. E. Pickering, and N. Livesey, 2009:** Satellite observations of changes in air quality during the 2008 Beijing Olympics and Paralympics, *Geophys. Res. Lett.*, 36 (L17803).
- Wu, S., B. Duncan, D. Jacob, A. Fiore, and O. Wild, 2009:** Chemical nonlinearities in relating intercontinental ozone pollution to anthropogenic emissions, *Geophys. Res. Lett.*, 36 (L05806, DOI:10.1029/2008GL036607).
- Yang, K., N. A. Krotkov, A. J. Krueger, S. A. Carn, P. K. Bhartia, and P. F. Levelt, 2009:** Improving retrieval of volcanic sulfur dioxide from backscattered UV satellite observations, *Geophys. Res. Lett.*, 36 (L03102, DOI:10.1029/2008GL036036).
- Yang, K., N. A. Krotkov, A. J. Krueger, and S. A. Carn, 2009:** Estimating the altitude of volcanic sulfur dioxide plumes from space borne hyper-spectral UV measurements, *Geophys. Res. Lett.*, 36 (L10803, DOI:10.1029/2009GL038025).
- Yu, H., M. Chin, L.A. Remer, R.G. Kleidman, N. Bellouin, H. Bian, T. Diehl, and , 2009:** Variability of maritime aerosol fine-mode fraction and estimates of anthropogenic aerosol component over cloud-free oceans from the Moderate Resolution Imaging Spectroradiometer (MODIS), *J. Geophys. Res.*, 114 (D10206, DOI:10.1029/2008JD010648).
- Ziemke, J. R., S. Chandra, B. N. Duncan, M. R. Schoeberl, M. R. Damon, O. Torres, and P. K. Bhartia, 2009:** Recent biomass burning events in the tropics and elevated concentrations of tropospheric ozone, *Geophys. Res. Lett.*, 36 (L15819, DOI:10.1029/2009GL039303).
- Ziemke, J. R., J. Joiner, S. Chandra, P. K. Bhartia, A. Vasilkov, D. P. Haffner, K. Yang, M. R. Schoeberl, L. Froidevaux, and P. F. Levelt, 2009:** Ozone mixing ratios inside tropical deep convective clouds from OMI satellite measurements", *Atmos. Chem. Phys.*, 9, 573-583.



## APPENDIX 3. HIGHLIGHTED ARTICLES PUBLISHED IN 2009

## Code 613.1 Highlighted Articles


**IN BOX**  
 INSIGHTS and INNOVATIONS

## Continuous Lidar Monitoring of Polar Stratospheric Clouds at the South Pole

BY JAMES R. CAMPBELL, ELLSWORTH J. WELTON, AND JAMES D. SPINHIRNE

**P**olar stratospheric clouds (PSC) play a primary role in the formation of annual “ozone holes” over Antarctica during the austral sunrise. Meridional temperature gradients in the lower stratosphere and upper troposphere, caused by strong radiative cooling, induce a broad dynamic vortex centered near the South Pole that decouples and insulates the winter polar airmass. PSC nucleate and grow as vortex temperatures gradually fall below equilibrium saturation and frost points for ambient sulfate, nitrate, and water vapor concentrations (generally below 197 K). Cloud surfaces promote heterogeneous reactions that convert stable chlorine and bromine-based molecules into photochemically active ones. As spring nears, and the sun reappears and rises, photolysis decomposes these partitioned compounds into individual halogen atoms that react with and catalytically destroy thousands of ozone molecules before they are stochastically neutralized.

Nitrates are most efficient at inhibiting catalytic ozone-destroying cycles. However, their vapor uptake during PSC growth and subsequent particle sedimentation, arising from accompanying increases in fall velocity, cause molecular redistribution to lower levels (i.e., denitrification of the lower stratosphere). Satellite limb-sounder measurements indicate that nitric acid (HNO<sub>3</sub>), for example, may be completely removed near

18.0 km above mean sea level (MSL) in air surrounding the South Pole by mid-June each season. In the absence of nitrates, it is only with the overturning of the polar vortex in spring that catalytic processes cease and ozone concentrations are replenished through airmass exchange with the lower latitudes.

Despite a generic understanding of the “ozone hole” paradigm, many key components of the system, such as cloud occurrence, phase, and composition; particle growth mechanisms; and denitrification of the lower stratosphere have yet to be fully resolved. Satellite-based observations have dramatically improved the ability to detect PSC and quantify seasonal polar chemical partitioning. However, coverage directly over the Antarctic plateau is limited by polar-orbiting tracks that rarely exceed 80°S.

Ground-based measurements of PSC can supplement gaps in satellite coverage. Such data are fundamental given that lower-stratospheric temperatures are climatologically coldest there relative to surrounding regions. PSC properties at the South Pole represent those at one end of a longitudinal cross-section of the polar vortex where cloud microphysical and denitrification processes likely vary as a function of thermal and dynamic structure. Furthermore, the meridional mixing of air across the polar vortex boundary from baroclinic disturbances and planetary-scale wave breaking—which incrementally replenishes necessary cloud components during winter diminished by particle growth and fallout (i.e., nitric acid and water vapor)—is negligible nearest the pole. Unfortunately, the deployment of suitable instrumentation atop the Antarctic plateau is limited by accessible infrastructure.

**CONTINUOUS PSC MONITORING AT THE SOUTH POLE.** A NASA Micropulse Lidar Network<sup>1</sup> instrument (NASA MPLNET; 0.527  $\mu\text{m}$  in current instruments) was first deployed in December

**AFFILIATIONS:** CAMPBELL—University Corporation for Atmospheric Research, Visiting Scientist Programs, Naval Research Laboratory, Monterey, California; WELTON—NASA Goddard Space Flight Center, Greenbelt, Maryland; SPINHIRNE—Department of Electrical and Computer Engineering, University of Arizona, Tucson, Arizona

**CORRESPONDING AUTHOR:** James R. Campbell, c/o Naval Research Laboratory, 7 Grace Hopper Ave., Stop 2, Monterey, CA 93943

E-mail: jamesc@ucar.edu

DOI:10.1175/2008BAMS2754.1

©2009 American Meteorological Society

<sup>1</sup> <http://mplnet.gsfc.nasa.gov>



## Combining Satellite Microwave Radiometer and Radar Observations to Estimate Atmospheric Heating Profiles

MIRCEA GRECU

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

WILLIAM S. OLSON

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

CHUNG-LIN SHIE

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

TRISTAN S. L'ECUYER

*Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado*

WEI-KUO TAO

*Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland*

(Manuscript received 7 January 2009, in final form 1 July 2009)

### ABSTRACT

In this study, satellite passive microwave sensor observations from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) are utilized to make estimates of latent + eddy sensible heating rates ( $Q_1 - Q_R$ ) where  $Q_1$  is the apparent heat source and  $Q_R$  is the radiative heating rate in regions of precipitation. The TMI heating algorithm (herein called TRAIN) is calibrated or "trained" using relatively accurate estimates of heating based on spaceborne Precipitation Radar (PR) observations collocated with the TMI observations over a one-month period. The heating estimation technique is based on a previously described Bayesian methodology, but with improvements in supporting cloud-resolving model simulations, an adjustment of precipitation echo tops to compensate for model biases, and a separate scaling of convective and stratiform heating components that leads to an approximate balance between estimated vertically integrated condensation and surface precipitation.

Estimates of  $Q_1 - Q_R$  from TMI compare favorably with the PR training estimates and show only modest sensitivity to the cloud-resolving model simulations of heating used to construct the training data. Moreover, the net condensation in the corresponding annual mean satellite latent heating profile is within a few percent of the annual mean surface precipitation rate over the tropical and subtropical oceans where the algorithm is applied. Comparisons of  $Q_1$  produced by combining TMI  $Q_1 - Q_R$  with independently derived estimates of  $Q_R$  show reasonable agreement with rawinsonde-based analyses of  $Q_1$  from two field campaigns, although the satellite estimates exhibit heating profile structures with sharper and more intense heating peaks than the rawinsonde estimates.

### 1. Introduction

The latent heat released or consumed during phase changes of water substance is a major component of the

atmospheric energy budget, and one that dominates other diabatic processes in the deep tropics (see Newell et al. 1969; Schaack et al. 1990). Latent heating is also responsible for the creation of available potential energy, one mechanism by which convective clouds can interact with the larger-scale atmospheric circulations of their environment (Nitta 1970, 1972; Yanai et al. 2000), and the atmospheric response to heating is sensitive to

*Corresponding author address:* Dr. Mircea Grecu, NASA Goddard Space Flight Center, Code 613.1, Greenbelt, MD 20771.  
E-mail: mircea.grecu-1@nasa.gov

DOI: 10.1175/2009JCLI3020.1

© 2009 American Meteorological Society

## Alongfront Variability of Precipitation Associated with a Midlatitude Frontal Zone: TRMM Observations and MM5 Simulation

MEI HAN

*Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, and Mesoscale Atmospheric Process Branch, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland*

SCOTT A. BRAUN

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

P. OLA G. PERSSON

*Cooperative Institute for Research in Environmental Sciences, University of Colorado, and NOAA/Environmental Technology Laboratory, Boulder, Colorado*

JIAN-WEN BAO

*NOAA/Environmental Technology Laboratory, Boulder, Colorado*

(Manuscript received 20 November 2007, in final form 17 April 2008)

### ABSTRACT

On 19 February 2001, the Tropical Rainfall Measuring Mission (TRMM) satellite observed complex alongfront variability in the precipitation structure of an intense cold-frontal rainband. The TRMM Microwave Imager brightness temperatures suggested that, compared to the northern and southern ends of the rainband, a greater amount of precipitation ice was concentrated in the middle portion of the rainband where the front bowed out. A model simulation conducted using the fifth-generation Pennsylvania State University–National Center for Atmospheric Research (PSU–NCAR) Mesoscale Model (MM5) is examined to explain the distribution of precipitation associated with the cold-frontal rainband. The simulation reveals that the enhanced precipitation ice production and the implied mean ascent along the central part of the front were associated with a synergistic interaction between a low-level front and an upper-level front associated with an intrusion of high-PV stratospheric air. The low-level front contributed to an intense bow-shaped narrow cold-frontal rainband (NCFR). The upper-level front was dynamically active only along the central to northern portion of the NCFR, where the upper-level PV advection and  $\mathbf{Q}$ -vector convergence were most prominent. The enhanced mean ascent associated with the upper-level front contributed to a wide cold-frontal rainband (WCFR) that trailed or overlapped with the NCFR along its central to northern segments. Because of the combination of the forcing from both lower- and upper-level fronts, the ascent was deepest and most intense along the central portion of the front. Thus, a large concentration of precipitation ice, attributed to both the NCFR and WCFR, was produced.

### 1. Introduction

The National Aeronautics and Space Administration's (NASA's) Tropical Rainfall Measuring Mission (TRMM) was designed to measure and monitor pre-

cipitation throughout the tropics using a combination of a Precipitation Radar (PR) and a TRMM Microwave Imager (TMI; Kummerow et al. 1998). Extensive research has been carried out on understanding the distribution and variability of tropical precipitation from climate scales to storm scales based on TRMM observations (e.g., Adler et al. 2000; Cecil et al. 2005). Although the TRMM satellite samples precipitation systems at lower midlatitudes (the TMI coverage extends from  $\sim 38^{\circ}\text{S}$  to  $\sim 38^{\circ}\text{N}$ ), it is primarily an observing

---

*Corresponding author address:* Mei Han, Mesoscale Atmospheric Process Branch, Laboratory for Atmospheres, NASA GSFC, Code 613.1, Greenbelt, MD 20771.  
E-mail: mei.han-1@nasa.gov

## Sensitivity of a Cloud-Resolving Model to Bulk and Explicit Bin Microphysical Schemes. Part II: Cloud Microphysics and Storm Dynamics Interactions

XIAOWEN LI

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

WEI-KUO TAO

*Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland*

ALEXANDER P. KHAIN

*The Hebrew University of Jerusalem, Jerusalem, Israel*

JOANNE SIMPSON

*Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland*

DANIEL E. JOHNSON

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

(Manuscript received 12 October 2007, in final form 17 April 2008)

### ABSTRACT

Part I of this paper compares two simulations, one using a bulk and the other a detailed bin microphysical scheme, of a long-lasting, continental mesoscale convective system with leading convection and trailing stratiform region. Diagnostic studies and sensitivity tests are carried out in Part II to explain the simulated contrasts in the spatial and temporal variations by the two microphysical schemes and to understand the interactions between cloud microphysics and storm dynamics. It is found that the fixed raindrop size distribution in the bulk scheme artificially enhances rain evaporation rate and produces a stronger near-surface cool pool compared with the bin simulation. In the bulk simulation, cool pool circulation dominates the near-surface environmental wind shear in contrast to the near-balance between cool pool and wind shear in the bin simulation. This is the main reason for the contrasting quasi-steady states simulated in Part I. Sensitivity tests also show that large amounts of fast-falling hail produced in the original bulk scheme not only result in a narrow trailing stratiform region but also act to further exacerbate the strong cool pool simulated in the bulk parameterization.

An empirical formula for a correction factor,  $r(q_r) = 0.11q_r^{-1.27} + 0.98$ , is developed to correct the overestimation of rain evaporation in the bulk model, where  $r$  is the ratio of the rain evaporation rate between the bulk and bin simulations and  $q_r(\text{g kg}^{-1})$  is the rain mixing ratio. This formula offers a practical fix for the simple bulk scheme in rain evaporation parameterization.

### 1. Introduction

Mesoscale convective systems (MCSs) are well-organized, long-lived precipitation systems that contribute 30%–70% of the total rainfall over the United

States during the warm season (Fritsch et al. 1986). Research into the organization and structure of continental MCSs is important for local precipitation forecasts as well as for understanding the atmospheric energy and water budget (e.g., Houze 2004). In Part I of this paper (Li et al. 2009, hereafter Part I) a summertime MCS over Kansas and Oklahoma [Preliminary Regional Experiment for Storm-Scale Operational and Research Meteorology (PRE-STORM), 10–11 June

*Corresponding author address:* Xiaowen Li, Code 613.1, NASA GSFC, Greenbelt, MD 20770.  
E-mail: xiaowen.li-1@nasa.gov

DOI: 10.1175/2008JAS2647.1

© 2009 American Meteorological Society

## Measurements and Simulations of Nadir-Viewing Radar Returns from the Melting Layer at X and W Bands

LIANG LIAO

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

ROBERT MENEGHINI

*NASA Goddard Space Flight Center, Greenbelt, Maryland*

LIN TIAN

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

GERALD M. HEYMSFIELD

*NASA Goddard Space Flight Center, Greenbelt, Maryland*

(Manuscript received 6 May 2008, in final form 31 March 2009)

### ABSTRACT

Simulated radar signatures within the melting layer in stratiform rain—namely, the radar bright band—are checked by means of comparisons with simultaneous measurements of the bright band made by the ER-2 Doppler radar (EDOP; X band) and Cloud Radar System (CRS; W band) airborne Doppler radars during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers–Florida–Area Cirrus Experiment (CRYSTAL-FACE) campaign in 2002. A stratified-sphere model, allowing the fractional water content to vary along the radius of the particle, is used to compute the scattering properties of individual melting snowflakes. Using the effective dielectric constants computed by the conjugate gradient–fast Fourier transform numerical method for X and W bands and expressing the fractional water content of a melting particle as an exponential function in particle radius, it is found that at X band the simulated radar brightband profiles are in an excellent agreement with the measured profiles. It is also found that the simulated W-band profiles usually resemble the shapes of the measured brightband profiles even though persistent offsets between them are present. These offsets, however, can be explained by the attenuation caused by cloud water and water vapor at W band. This is confirmed by comparisons of the radar profiles made in the rain regions where the unattenuated W-band reflectivity profiles can be estimated through the X- and W-band Doppler velocity measurements. The brightband model described in this paper has the potential to be used effectively for both radar and radiometer algorithms relevant to the satellite-based Tropical Rainfall Measuring Mission and Global Precipitation Measuring Mission.

### 1. Introduction

The bright band, a layer of enhanced radar echo associated with melting hydrometeors, is often observed in stratiform rain. Understanding the microphysical properties of melting hydrometeors and their scattering and propagation effects is of great importance in accurately

estimating parameters of precipitation from spaceborne radar and radiometers (Bringi et al. 1986; Fabry and Szymer 1999; Olson et al. 2001a,b; Meneghini and Liao 2000; Liao and Meneghini 2005; Sassen et al. 2005, 2007). These instruments include the precipitation radar and Tropical Rainfall Measuring Mission (TRMM) Microwave Imager on TRMM and the dual-wavelength precipitation radar and Global Precipitation Measuring Mission (GPM) Microwave Imager on the proposed GPM. However, one of the most difficult problems in the study of the radar signature of the melting layer is the determination of the effective dielectric constants of

---

*Corresponding author address:* Dr. Liang Liao, Goddard Earth Sciences and Technology Center/UMBC, Code 613.1, NASA/GSFC, Greenbelt, MD 20771.  
E-mail: liang.liao-1@nasa.gov



## Evaluation of Long-Term Cloud-Resolving Model Simulations Using Satellite Radiance Observations and Multifrequency Satellite Simulators

TOSHIHISA MATSUI AND XIPING ZENG

*Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, and Goddard Earth Science and Technology Center, University of Maryland, Baltimore County, Baltimore, Maryland*

WEI-KUO TAO

*Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland*

HIROHIKO MASUNAGA

*Hydrospheric Atmospheric Research Center, Nagoya University, Nagoya, Japan*

WILLIAM S. OLSON

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

STEPHEN LANG

*Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, and Science Systems and Applications, Inc., Lanham, Maryland*

(Manuscript received 7 May 2008, in final form 24 November 2008)

### ABSTRACT

This paper proposes a methodology known as the Tropical Rainfall Measuring Mission (TRMM) Triple-Sensor Three-Step Evaluation Framework (T3EF) for the systematic evaluation of precipitating cloud types and microphysics in a cloud-resolving model (CRM). T3EF utilizes multisensor satellite simulators and novel statistics of multisensor radiance and backscattering signals observed from the TRMM satellite. Specifically, T3EF compares CRM and satellite observations in the form of combined probability distributions of precipitation radar (PR) reflectivity, polarization-corrected microwave brightness temperature ( $T_b$ ), and infrared  $T_b$  to evaluate the candidate CRM.

T3EF is used to evaluate the Goddard Cumulus Ensemble (GCE) model for cases involving the South China Sea Monsoon Experiment (SCSMEX) and the Kwajalein Experiment (KWAJEX). This evaluation reveals that the GCE properly captures the satellite-measured frequencies of different precipitating cloud types in the SCSMEX case but overestimates the frequencies of cumulus congestus in the KWAJEX case. Moreover, the GCE tends to simulate excessively large and abundant frozen condensates in deep precipitating clouds as inferred from the overestimated GCE-simulated radar reflectivities and microwave  $T_b$  depressions. Unveiling the detailed errors in the GCE's performance provides the better direction for model improvements.

### 1. Introduction

Cloud-resolving models (CRMs) explicitly resolve convective clouds and cloud systems on fine spatial and

temporal scales. CRMs with a one-moment bulk microphysics scheme explicitly predict the evolution of cloud dynamics associated with liquid and ice condensate masses and their associated latent heating and evaporative cooling in contrast to the implicit prediction in single-column schemes (SCMs); therefore, CRM simulations agree well with the observation in comparison with SCM simulations (Xu et al. 2002; Tao et al. 2003).

---

*Corresponding author address:* Toshihisa Matsui, Code 613.1, NASA Goddard Space Flight Center, Greenbelt, MD 20771.  
E-mail: toshihisa\_matsui-1@nasa.gov

DOI: 10.1175/2008JTECHA1168.1

© 2009 American Meteorological Society

## The Interannual Stability of Cumulative Frequency Distributions for Convective System Size and Intensity

KAREN I. MOHR,\* JOHN MOLINARI, AND CHRIS D. THORNCROFT

*Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York*

(Manuscript received 19 November 2008, in final form 22 April 2009)

### ABSTRACT

The characteristics of convective system populations in West Africa and the western Pacific tropical cyclone basin were analyzed to investigate whether interannual variability in convective activity in tropical continental and oceanic environments is driven by variations in the number of events during the wet season or by favoring large and/or intense convective systems. Convective systems were defined from Tropical Rainfall Measuring Mission (TRMM) data as a cluster of pixels with an 85-GHz polarization-corrected brightness temperature below 255 K and with an area of at least 64 km<sup>2</sup>. The study database consisted of convective systems in West Africa from May to September 1998–2007, and in the western Pacific from May to November 1998–2007. Annual cumulative frequency distributions for system minimum brightness temperature and system area were constructed for both regions. For both regions, there were no statistically significant differences between the annual curves for system minimum brightness temperature. There were two groups of system area curves, split by the TRMM altitude boost in 2001. Within each set, there was no statistically significant interannual variability. Subsetting the database revealed some sensitivity in distribution shape to the size of the sampling area, the length of the sample period, and the climate zone. From a regional perspective, the stability of the cumulative frequency distributions implied that the probability that a convective system would attain a particular size or intensity does not change interannually. Variability in the number of convective events appeared to be more important in determining whether a year is either wetter or drier than normal.

### 1. Introduction

In tropical continental regions with wet and dry seasons, an important scientific and economic objective is a better understanding of the mechanisms responsible for above-normal and below-normal wet seasons. The review paper on Sahelian climate by Nicholson (2000) identified one of the outstanding questions in this area of research: are above-normal years characterized by more precipitation events or by a tendency of precipitation events to be larger and/or more intense? Conflicting observations from recent papers on this topic add urgency to investigating this open question.

\* Current affiliation: Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland.

*Corresponding author address:* Karen I. Mohr, Code 613.1, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, MD 20771.  
E-mail: karen.mohr-1@nasa.gov

DOI: 10.1175/2009JCLI2940.1

© 2009 American Meteorological Society

In this paper, we show results from the very different environments of West Africa (Fig. 1) and the western Pacific Ocean (Fig. 2) to test the hypothesis that interannual variability in convective system activity in tropical continental and oceanic environments is driven by variations in the number of events during the wet season and not by favoring large and/or intense events. Because this study considers two very large regions, we use 85-GHz orbital resolution data from the Tropical Rainfall Measuring Mission (TRMM) satellite to analyze the convective system number, size, and intensity. Although studies based on microwave remote sensing are not directly measuring precipitation on the ground, the use of the 85-GHz brightness temperature is a well-established proxy for discerning the intensity of convective updrafts and thus the potential for precipitation on the ground (e.g., Mohr and Zipser 1996; Nesbitt et al. 2000; Toracinta et al. 2002; Cecil et al. 2005).

Nicholson (2000) summarizes papers on the daily precipitation climatology (1950–90) of a study site in Niger by Le Barbé and Lebel (1997) and precipitation

# A MULTISCALE MODELING SYSTEM

## Developments, Applications, and Critical Issues

BY WEI-KUO TAO, JUIN-DAR CHERN, ROBERT ATLAS, DAVID RANDALL, MARAT KHAIROUTDINOV,  
JUI-LIN LI, DUANE E. WALISER, ARTHUR HOU, XIN LIN, CHRISTA PETERS-LIDARD,  
WILLIAM LAU, JONATHAN JIANG, AND JOANNE SIMPSON

NASA's new modeling framework for integrating cloud processes explicitly within each grid column of a general circulation model can improve realism over the conventional model that parameterizes clouds, but it also introduces new biases.

**T**he foremost challenge in parameterizing convective clouds and cloud systems in large-scale models are the many coupled dynamical and physical processes that interact over a wide range of scales, from microphysical scales to the synoptic and planetary scales. This makes the comprehension and representation of convective clouds and cloud systems one of the most complex scientific problems in Earth science. During the past decade, the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS) has pioneered the use of single-column models (SCMs) and cloud-resolving models (CRMs) for the evaluation of the cloud and radiation param-

eterizations in general circulation models (GCMs; e.g., GEWEX Cloud System Science Team 1993). These activities have uncovered many systematic biases in the radiation, cloud and convection parameterizations of GCMs and have led to the development of new schemes (e.g., Zhang 2002; Pincus et al. 2003; Zhang and Wu 2003; Wu et al. 2003; Liang and Wu 2005; Wu and Liang 2005, and others). Comparisons between SCMs and CRMs using the same large-scale forcing derived from field campaigns have demonstrated that CRMs are superior to SCMs in the prediction of temperature and moisture tendencies (e.g., Das et al. 1999; Randall et al. 2003b; Xie et al. 2005). This

**AFFILIATIONS:** TAO, LAU, AND SIMPSON—Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland; CHERN—Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, and Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, Maryland; ATLAS—NOAA/Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida; KHAIROUTDINOV—Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado; LI, WALISER, AND JIANG—Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California; HOU—Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland; LIN—Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, and Global Modeling

and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland; PETERS-LIDARD—Hydrological Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland

**CORRESPONDING AUTHOR:** Dr. Wei-Kuo Tao, Code 613.1, NASA Goddard Space Flight Center, Greenbelt, MD 20771  
E-mail: Wei-Kuo.Tao-1@nasa.gov

*The abstract for this article can be found in this issue, following the table of contents.*

DOI: 10.1175/2008BAMS2542.1

In final form 3 July 2008  
©2009 American Meteorological Society

## Demonstration of Aerosol Property Profiling by Multiwavelength Lidar under Varying Relative Humidity Conditions

I. VESELOVSKII

*Physics Instrumentation Center, Troitsk, Moscow Region, Russia*

D. N. WHITEMAN

*NASA Goddard Space Flight Center, Greenbelt, Maryland*

A. KOLGOTIN

*Physics Instrumentation Center, Troitsk, Moscow Region, Russia*

E. ANDREWS

*CIRES, University of Colorado, Boulder, Colorado*

M. KORENSKII

*Physics Instrumentation Center, Troitsk, Moscow Region, Russia*

(Manuscript received 13 November 2008, in final form 21 February 2009)

### ABSTRACT

The feasibility of using a multiwavelength Mie–Raman lidar based on a tripled Nd:YAG laser for profiling aerosol physical parameters in the planetary boundary layer (PBL) under varying conditions of relative humidity (RH) is studied. The lidar quantifies three aerosol backscattering and two extinction coefficients and from these optical data the particle parameters such as concentration, size, and complex refractive index are retrieved through inversion with regularization. The column-integrated, lidar-derived parameters are compared with results from the AERONET sun photometer. The lidar and sun photometer agree well in the characterization of the fine-mode parameters, however the lidar shows less sensitivity to coarse mode. The lidar results reveal a strong dependence of particle properties on RH. The height regions with enhanced RH are characterized by an increase of backscattering and extinction coefficient and a decrease in the Ångström exponent coinciding with an increase in the particle size. The hygroscopic growth factor calculated for a select case is consistent with previous literature results despite the lack of collocated radiosonde data. These results demonstrate the potential of the multiwavelength Raman lidar technique for the study of aerosol humidification process.

### 1. Introduction

The radiation balance of the earth is strongly influenced by atmospheric aerosols of natural and anthropogenic origin (D’Almeida et al. 1991; Pilinis et al. 1995). For accurate modeling of corresponding radiative forcing, knowledge of the vertical distribution of particle macro- and microphysical parameters is needed. During

recent years ground-based and airborne lidars have become important tools for profiling tropospheric aerosols using either single or multiple wavelengths (Kovalev and Eichinger 2004). For quantitative studies of the optical properties of tropospheric aerosol, Raman lidars have proven to be most useful (Ansmann et al. 1992; Ferrare et al. 1998a,b; Ansmann et al. 2000; Turner et al. 2002). This lidar type measures elastically backscattered light simultaneously with Raman backscatter from molecules (nitrogen or oxygen), thus allowing independent calculation of particle backscattering and extinction coefficients without the need for

---

*Corresponding author address:* I. A. Veselovskii, Physics Instrumentation Center, Troitsk, Moscow Region 142190, Russia.  
E-mail: igorv@pic.troitsk.ru

## Code 613.1 Highlighted Articles

GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L23805, doi:10.1029/2009GL040915, 2009



## Weekly cycle of lightning: Evidence of storm invigoration by pollution

Thomas L. Bell,<sup>1</sup> Daniel Rosenfeld,<sup>2</sup> and Kyu-Myong Kim<sup>1,3</sup>

Received 23 September 2009; revised 28 October 2009; accepted 3 November 2009; published 9 December 2009.

[1] We have examined summertime 1998–2009 U.S. lightning data from the National Lightning Detection Network (NLDN) to look for weekly cycles in lightning activity. As was found by Bell et al. (2008) for rain over the southeast U.S., there is a significant weekly cycle in afternoon lightning activity that peaks in the middle of the week there. The weekly cycle appears to be reduced over population centers. Lightning activity peaks on weekends over waters near the SE U.S. The statistical significance of weekly cycles over the western half of the country is generally small. We found no evidence of a weekly cycle of synoptic-scale forcing that might explain these patterns. The lightning behavior is entirely consistent with the explanation suggested by Bell et al. (2008) for the cycles in rainfall and other atmospheric data from the SE U.S., that aerosols can cause storms to intensify in humid, convectively unstable environments. **Citation:** Bell, T. L., D. Rosenfeld, and K.-M. Kim (2009), Weekly cycle of lightning: Evidence of storm invigoration by pollution, *Geophys. Res. Lett.*, **36**, L23805, doi:10.1029/2009GL040915.

### 1. Introduction

[2] Bell et al. [2008, hereafter B08] recently reported strong evidence that average rainfall is highest during the middle of the week (Tue–Thu) over the non-coastal southeast U.S. during the summer months of 1998–2005. The midweek increase was due in part to increases of the area with rain and in part to increases in the intensity of rain where it was raining. A theory was proposed to explain the changes in rain statistics with the day of the week, attributing it to the effects of weekly variations in pollution (U.S. pollution tends to be highest in the middle of the work week). This theory suggests that increased pollution in the moist, convectively unstable environment over the summertime SE U.S. leads to more intense storms through increased vertical transport of water in the form of smaller droplets to altitudes where additional latent heat is released by freezing of the water [Rosenfeld et al., 2008]. The theory suggested that the effect should be particularly pronounced in the afternoon hours, when convective potential is at its highest, and that midweek storms should tend to climb to higher altitudes, both of which were seen by B08 in Tropical Rainfall Measuring Mission (TRMM) satellite data. The midweek increase in storm heights was recently confirmed

by Bell et al. [2009]. A slightly weaker weekly cycle was seen in rain-gauge data from the area. A weekly cycle in large-scale low-level convergence and upper-level divergence of the winds over the SE U.S. was seen in reanalysis data.

[3] The theory presented by B08 suggests that mixed-phase processes should be increased during the middle of the week when pollution is at a maximum. The cloud electrification that leads to lightning is believed to be generated by ice processes in storms, particularly by the charging of riming graupel by ice particle collisions [e.g., Saunders 1994], often associated with vigorously growing clouds that carry water above the zero-isotherm level. Lightning therefore serves as an indicator of the presence of such storms. Petersen and Rutledge [1998, 2001], for instance, provide examples of this well known connection. We therefore examined the dependence on the day of the week of lightning statistics in the vicinity of the U.S. using National Lightning Detection Network (NLDN) data. Information about the collection of the data and their accuracy are given by Cummins et al. [1998] and Idone et al. [1998].

[4] An earlier search for weekly cycles in lightning activity by Mullayarov et al. [2005] found evidence in data for 1979–1994 of a midweek peak in activity for areas in the neighborhood of East Siberia and Africa. Numerous other studies of possible weekly variation in atmospheric behavior have appeared in the literature, but the quality of their statistical analyses varies widely and there is insufficient space to review them here.

### 2. Weekly Cycle in Lightning Over the SE U.S.

[5] The lightning data were provided by the NASA Lightning Imaging Sensor (LIS) instrument team and the LIS data center via the Global Hydrology Resource Center (GHRC). They are in gridded form everywhere within detection range of U.S. antenna stations, with grid box sizes of about 8 km × 8 km, at 15-minute intervals. Data for summers (June–August) 1998–2009 were analyzed, overlapping the time period examined by B08. The data were current as of 14 Sept 2009. Results reported here, except for Figure 2, are all based on 1998–2006. Some results in the auxiliary material are based on slightly different periods, as discussed there.<sup>4</sup>

[6] We note that it would be possible to carry out the studies described here using data from the LIS on the TRMM satellite, but sample sizes would be considerably smaller than the NLDN data provides.

[7] The strength of a weekly cycle is determined by fitting time-dependent data  $r(t)$  to a 7-day sinusoid

$$r(t) = r_0 + r_7 \cos[\omega_7(t - \phi_7)], \quad (1)$$

<sup>1</sup>Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

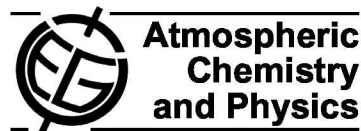
<sup>2</sup>Institute of Earth Sciences, Hebrew University of Jerusalem, Jerusalem, Israel.

<sup>3</sup>Goddard Earth Sciences and Technology Center, University of Maryland Baltimore County, Baltimore, Maryland, USA.

Copyright 2009 by the American Geophysical Union.  
0094-8276/09/2009GL040915\$05.00

<sup>4</sup>Auxiliary materials are available in the HTML. doi:10.1029/2009GL040915.

Atmos. Chem. Phys., 9, 1419–1430, 2009  
 www.atmos-chem-phys.net/9/1419/2009/  
 © Author(s) 2009. This work is distributed under  
 the Creative Commons Attribution 3.0 License.



## Physical interpretation of the spectral radiative signature in the transition zone between cloud-free and cloudy regions

J. C. Chiu<sup>1</sup>, A. Marshak<sup>2</sup>, Y. Knyazikhin<sup>3</sup>, P. Pilewski<sup>4</sup>, and W. J. Wiscombe<sup>2,5</sup>

<sup>1</sup>University of Maryland Baltimore County, Baltimore, MD, USA

<sup>2</sup>NASA/Goddard Space Flight Center, Greenbelt, MD, USA

<sup>3</sup>Boston University, Boston, MA, USA

<sup>4</sup>University of Colorado at Boulder, Boulder, CO, USA

<sup>5</sup>Brookhaven National Laboratory, New York, NY, USA

Received: 29 July 2008 – Published in Atmos. Chem. Phys. Discuss.: 26 September 2008

Revised: 26 January 2009 – Accepted: 26 January 2009 – Published: 23 February 2009

**Abstract.** One-second-resolution zenith radiance measurements from the Atmospheric Radiation Measurement program's new shortwave spectrometer (SWS) provide a unique opportunity to analyze the transition zone between cloudy and cloud-free air, which has considerable bearing on the aerosol indirect effect. In the transition zone, we find a remarkable linear relationship between the sum and difference of radiances at 870 and 1640 nm wavelengths. The intercept of the relationship is determined primarily by aerosol properties, and the slope by cloud properties. We then show that this linearity can be predicted from simple theoretical considerations and furthermore that it supports the hypothesis of inhomogeneous mixing, whereby optical depth increases as a cloud is approached but the effective drop size remains unchanged.

### 1 Introduction

The aerosol indirect effect is the largest source of uncertainty in the radiative forcing of climate (The Intergovernmental Panel on Climate Change, IPCC, Fourth Assessment Report, 2007). Using 11 GCM models, Stephens (2002) also showed the importance of cloud feedbacks in modeling responses of climate to a doubling of carbon dioxide. We cannot evaluate performance of climate models without accurate knowledge of aerosol forcing and cloud feedbacks (Diner et al., 2004).

Studies on aerosol direct and indirect effects demand a precise separation of cloud-free and cloudy areas (Charlson et al., 2007; Koren et al., 2007). However, separation between cloud-free and cloudy areas from remotely sensed

measurements is ambiguous. From the ground, separations have been made using broadband pyranometer, microwave radiometer, total sky imager, radar, lidar, and ceilometer data (Long and Ackerman, 2000; Berendes et al., 2004; Long et al., 2006a, b; Taylor et al., 2008). Each instrument has a different field of view, sensitivity, and sampling resolution; in addition, each method uses different thresholds for the separation. From satellites, the separation depends on spatial resolution, illumination and observation geometry, surface types, and screening algorithms (Ackerman et al., 1998; Martins et al., 2002; Brennan et al., 2005; Gomez-Chova et al., 2007). While a separation is not free of ambiguity at any scale (Koren et al., 2008), it is important to understand the transition zone between cloud-free and cloudy areas.

Many investigators have studied the transition zone, each with their own definition and each finding a different range for its horizontal extent. From extensive analyses of aircraft in situ data and model simulations, Perry and Hobbs (1996) and Lu et al. (2003) found haloes of enhanced humidity around cloud boundaries. The humidity halo typically extended from 150 m to 3 km from the cloud boundary. Platt and Gambling (1971) reported enhancements of lidar backscatter and downward infrared flux in the zones between clouds and “visually clear” areas, and suggested that the enhancements were caused by increased humidity and aerosol swelling near cloud boundaries. Their transition zone could extend up to 1–4 km away from the cloud boundary, consistent with what Su et al. (2008) found from airborne High Spectral Resolution Lidar data. Koren et al. (2007) found a transition zone that extended tens of kilometers, due mainly to undetected clouds and humidified aerosols.



Correspondence to: J. C. Chiu  
 (christine.chiu@nasa.gov)

Published by Copernicus Publications on behalf of the European Geosciences Union.

# MISR Aerosol Product Attributes and Statistical Comparisons With MODIS

Ralph A. Kahn, David L. Nelson, Michael J. Garay, Robert C. Levy, Michael A. Bull, David J. Diner, John V. Martonchik, Susan R. Paradise, Earl G. Hansen, and Lorraine A. Remer

**Abstract**—In this paper, Multi-angle Imaging SpectroRadiometer (MISR) aerosol product attributes are described, including geometry and algorithm performance flags. Actual retrieval coverage is mapped and explained in detail using representative global monthly data. Statistical comparisons are made with coincident aerosol optical depth (AOD) and Angstrom exponent (ANG) retrieval results from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. The relationship between these results and the ones previously obtained for MISR and MODIS individually, based on comparisons with coincident ground-truth observations, is established. For the data examined, MISR and MODIS each obtain successful aerosol retrievals about 15% of the time, and coincident MISR-MODIS aerosol retrievals are obtained for about 6%–7% of the total overlap region. Cloud avoidance, glint and oblique-Sun exclusions, and other algorithm physical limitations account for these results. For both MISR and MODIS, successful retrievals are obtained for over 75% of locations where attempts are made. Where coincident AOD retrievals are obtained over ocean, the MISR-MODIS correlation coefficient is about 0.9; over land, the correlation coefficient is about 0.7. Differences are traced to specific known algorithm issues or conditions. Over-ocean ANG comparisons yield a correlation of 0.67, showing consistency in distinguishing aerosol air masses dominated by coarse-mode versus fine-mode particles. Sampling considerations imply that care must be taken when assessing monthly global aerosol direct radiative forcing and AOD trends with these products, but they can be used directly for many other applications, such as regional AOD gradient and aerosol air mass type mapping and aerosol transport model validation. Users are urged to take seriously the published product data-quality statements.

**Index Terms**—Aerosols, Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging SpectroRadiometer (MISR), remote sensing.

Manuscript received February 12, 2009; revised April 1, 2009. First published September 15, 2009; current version published November 25, 2009. This work was supported by the National Aeronautics and Space Administration (NASA) Climate and Radiation Research and Analysis Program under the Atmospheric Composition Program and the Earth Observing System—Multi-angle Imaging SpectroRadiometer (EOS-MISR) Project. The work of R. A. Kahn was supported in part by the NASA Climate and Radiation Research and Analysis Program under H. Maring and NASA Atmospheric Composition Program under P. DeCola and EOS-MISR project.

R. A. Kahn and L. A. Remer are with the Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA (e-mail: Ralph.Kahn@nasa.gov).

D. L. Nelson and M. J. Garay are with Raytheon Intelligence and Information Systems, Pasadena, CA 91101 USA.

R. C. Levy is with Science Systems and Applications, Inc., Lanham, MD 20706 USA, and also with the NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA.

M. A. Bull, D. J. Diner, J. V. Martonchik, S. R. Paradise, and E. G. Hansen are with the NASA Jet Propulsion Laboratory, Pasadena, CA 91109 USA.

Color versions of one or more of the figures in this paper are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/TGRS.2009.2023115

## I. INTRODUCTION

SPACEBORNE Earth-orbiting instruments make it possible to monitor conditions over the entire planet, a capability of increasing importance as questions about climate change gain urgency. Since the advent of the global Earth observation era, vast amounts of data have been collected and processed into records related to geophysical quantities.

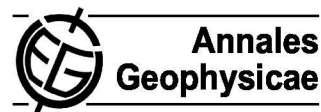
Satellite-derived geophysical quantities are typically aggregated into statistical summaries aimed at characterizing current environmental conditions and revealing trends, whereas subsets of these data are studied for the information they yield about specific natural and anthropogenic events. In many cases, a detailed understanding of the strengths and limitations of the derived quantities is central to the application. However, the retrieval algorithms for many of these newly derived quantities are quite complex, and at present, the algorithms continue to be refined, based partly on the results obtained during field campaigns and other validation exercises. In addition, techniques for assessing and for reporting the meaning, quality, and uncertainty of the results are still developing.

The Multi-angle Imaging SpectroRadiometer (MISR) aerosol product [1] falls into this category. The product has been used with considerable success to retrieve aerosol optical depth (AOD) over land and water [2]–[13], aerosol type [14]–[17], aerosol radiative forcing [18]–[21], and aerosol plume height [16], [22]. However, some of the retrieval products are still being refined, and some aspects of the products have not yet been fully described in the literature.

This paper fills several key gaps in the published work describing MISR aerosol product attributes and performance, and provides links between MISR and MODIS aerosol products. It begins with descriptions of MISR product-sampling characteristics, retrieval-algorithm approach, and retrieval quality information reported in the Level-2 Standard aerosol product (MIL2ASAE). Comparisons are then made with the Standard aerosol product from MODIS, which flies aboard the Terra satellite with MISR. MODIS is a single-view multispectral imager, having a wide swath that encompasses the MISR field of view (FOV). The MODIS aerosol product [23], [24] is increasingly being used in conjunction with MISR, as the greater MODIS coverage and shorter revisit time complement the particle microphysical property information, and retrievals over bright desert and over ocean regions excluded by glint in the near-nadir view, provided by MISR [25]. This paper concludes with a summary of product performance, implications for using MISR aerosol products in scientific applications, and reflections on some other published assessments of these products.



Ann. Geophys., 27, 4023–4037, 2009  
 www.ann-geophys.net/27/4023/2009/  
 © Author(s) 2009. This work is distributed under  
 the Creative Commons Attribution 3.0 License.



## A GCM study of the response of the atmospheric water cycle of West Africa and the Atlantic to Saharan dust radiative forcing

K. M. Lau<sup>1</sup>, K. M. Kim<sup>2</sup>, Y. C. Sud<sup>1</sup>, and G. K. Walker<sup>3</sup>

<sup>1</sup>Laboratory for Atmospheres, NASA/GSFC, Greenbelt, MD, USA

<sup>2</sup>Goddard Earth Science Technology Center, UMBC, Baltimore, MD, USA

<sup>3</sup>SAIC/General Sciences Operation, Beltsville, MD, USA

Received: 27 February 2009 – Revised: 25 September 2009 – Accepted: 10 October 2009 – Published: 23 October 2009

**Abstract.** The responses of the atmospheric water cycle and climate of West Africa and the Atlantic to radiative forcing of Saharan dust are studied using the NASA finite volume general circulation model (fvGCM), coupled to a mixed layer ocean. We find evidence of an “elevated heat pump” (EHP) mechanism that underlines the responses of the atmospheric water cycle to dust forcing as follow. During the boreal summer, as a result of large-scale atmospheric feedback triggered by absorbing dust aerosols, rainfall and cloudiness are enhanced over the West Africa/Eastern Atlantic ITCZ, and suppressed over the West Atlantic and Caribbean region. Short-wave radiation absorption by dust warms the atmosphere and cools the surface, while longwave has the opposite response. The elevated dust layer warms the air over West Africa and the eastern Atlantic. As the warm air rises, it spawns a large-scale onshore flow carrying the moist air from the eastern Atlantic and the Gulf of Guinea. The onshore flow in turn enhances the deep convection over West Africa land, and the eastern Atlantic. The condensation heating associated with the ensuing deep convection drives and maintains an anomalous large-scale east-west overturning circulation with rising motion over West Africa/eastern Atlantic, and sinking motion over the Caribbean region. The response also includes a strengthening of the West African monsoon, manifested in a northward shift of the West Africa precipitation over land, increased low-level westerly flow over West Africa at the southern edge of the dust layer, and a near surface westerly jet underneath the dust layer over the Sahara. The dust radiative forcing also leads to significant changes in surface energy fluxes, resulting in cooling of the West African land and the eastern Atlantic, and warming in the West Atlantic and Caribbean. The EHP effect is most effective for mod-

erate to highly absorbing dusts, and becomes minimized for reflecting dust with single scattering albedo at 0.95 or higher.

**Keywords.** Atmospheric composition and structure (Aerosols and particles) – Meteorology and atmospheric dynamics (Precipitation; Radiative processes)

### 1 Introduction

The Saharan region is a major source of atmospheric dust. It has been estimated that over 50% of the total annual dust loading in the atmosphere, estimated at 2–4 billion tons globally, comes from the Saharan desert (Goudie and Middleton, 2001; Ginoux et al., 2001). Unlike aerosols from industrial pollution, which are mostly trapped within the stable, low-level atmospheric boundary layer, Saharan dusts are found in a much deeper boundary layer over the hot desert, and often are swept up by strong winds and lofted into the middle and upper troposphere. The elevated dust particles are transported thousands of kilometer from the source region across the entire Atlantic to the Caribbean, the southeastern US and elsewhere (Chin et al., 2007). Saharan dust might impact the climate and the water cycle of the entire West Africa, tropical Atlantic and the Caribbean (WAAC) region (Prospero and Lamb, 2003). The transport of Saharan dust and its impacts could extend far beyond the WAAC region, spreading to the Mediterranean, Eurasia and the North Pacific (Moulin et al., 1997; Kim et al., 2006).

Several general circulation model (GCM) studies have provided a reasonable understanding of the fundamental processes associated with direct radiative effects of dust on the earth's climate and water cycle. Miller and Tegen (1998) found that dust radiative effect may increase or decrease precipitation in different regions depending on whether deep



Correspondence to: K. M. Lau  
 (william.k.lau@nasa.gov)



# A Critical Look at Deriving Monthly Aerosol Optical Depth From Satellite Data

Robert C. Levy, Gregory G. Leptoukh, Ralph Kahn, Victor Zubko, Arun Gopalan, and Lorraine A. Remer

**Abstract**—Satellite-derived aerosol data sets, such as those provided by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instruments, are greatly improving our understanding of global aerosol optical depth (AOD). Yet, there are sampling issues. MODIS' specific orbital geometry, convolved with the need to avoid bright surfaces (glint, desert, clouds, etc.), means that AOD can be under- or over-sampled in places. When deriving downstream products, such as daily or monthly gridded AOD, one must consider the spatial and temporal density of the measurements relative to the gradients of the true AOD. Additionally, retrieval confidence criteria should be considered. Averaged products are highly dependent on choices made for data aggregation and weighting, and sampling errors can be further propagated when deriving regional or global "mean" AOD. Different choices for aggregation and weighting result in estimates of regional and global means varying by 30% or more. The impacts of a particular averaging algorithm vary by region and surface type and can be shown to represent different tolerance for clouds and retrieval confidence.

**Index Terms**—Aerosol optical depth (AOD), averaging, global, Moderate Resolution Imaging Spectroradiometer (MODIS), monthly, sampling.

## I. INTRODUCTION

AEROSOLS affect the climate system, but unlike greenhouse gases, their distribution, microphysical properties, and, thus, impact vary widely across multiple spatial and temporal scales. Depending on atmospheric conditions, aerosols can be transported over long distances from their sources as discrete plumes, can dissipate by mixing processes within the atmosphere, or may be quickly redeposited on the surface as a result of gravitational settling, cloud processing, or dry deposition. Because aerosol properties exhibit such large gradients on so many scales, no set of measurements can satisfy all scales necessary for understanding the true aerosol effect on climate. Some climate problems, however, can be studied using monthly statistics of aerosol properties [1].

Aerosol optical depth (AOD) is a first-order quantity in the Earth's radiative budget and is determined by certain properties

(loading, size distribution, and refractive index) of the columnar aerosol. Aerosol direct radiative effect (DRE) is generally linearly correlated with AOD; thus, characterizing global AOD is a useful first step [2]. In cloud-free daylight conditions, AOD can be retrieved from passive satellite observations of solar reflectance. Given the low expected uncertainty of modern satellite retrievals [3], [4], it is tempting to use these products for addressing questions of aerosol trends, radiative forcing, and aerosol/cloud interactions. In fact, multiyear satellite data are being compared with each other and to models [5] to assess AOD trends [6] and to calculate climate effects [7].

Nominal satellite AOD products characterize the state of the atmosphere in the satellite's field of view (FOV) at overpass, so that a month's data essentially represent a composite of many overpasses. In hopes of making the data processing and interpretation less cumbersome for end users, satellite data teams may provide monthly statistics [8] of their own product. In addition, new Web-based analysis tools, such as Giovanni (<http://giovanni.gsfc.nasa.gov/>) [9], enable a user to easily visualize and analyze monthly AOD products. Although such tools and products enable a wide range of users to analyze satellite data, they should be used with caution.

Quantitative analyses of monthly satellite data products require a good understanding of the uncertainties of the FOV aerosol retrieval algorithm, as well as the temporal and spatial sampling of the products. The uncertainty in the retrieval algorithm is often assessed by comparing nominal satellite products to ground-truth observations, such as those from sun photometers [3]. For the purpose of this study, we will assume that, as a result of such "validation" exercises, satellite FOV data are unbiased during the overpass of the ground sites. The ground sites, however, have their own uncertainties and are unevenly distributed globally and temporally. This means that the ground-truth sun photometer data cannot provide an independent measure of the satellite sampling, in the way that radar measurements might provide for satellite estimates of rainfall [10].

Thus, present monthly aerosol statistics are created on incomplete sampling of a spatially and temporally inhomogeneous field. Since AOD values are derived only within the clear-sky satellite FOV, they will not represent AOD over nonobserved locations (e.g., overcast) and times of day (e.g., nighttime). In addition, since many of the sensors are in polar orbit, their sampling patterns exacerbate the problem. Each day, there are coverage gaps in the tropics, as well as multiple views of the summertime poles. Therefore, the orbital geometry, combined with avoidance of clouds and nighttime, leads to non-uniform and incomplete aerosol sampling. Furthermore, as each

Manuscript received August 22, 2008; revised December 29, 2008. This work was supported in part by the U.S. Department of Commerce under Grant BS123456.

R. C. Levy and A. Gopalan are with Science Systems and Applications, Inc. (SSAI), Lanham, MD 20706 USA, and also with the NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA (e-mail: robert.c.levy@nasa.gov).

G. G. Leptoukh, R. Kahn, and L. A. Remer are with the NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA.

V. Zubko is with ADNET, Rockville, MD 20850 USA, and also with the NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA.

Color versions of one or more of the figures in this paper are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/TGRS.2009.2013842

0196-2892/\$25.00 © 2009 IEEE



## Spectral invariant behavior of zenith radiance around cloud edges observed by ARM SWS

A. Marshak,<sup>1</sup> Y. Knyazikhin,<sup>2</sup> J. C. Chiu,<sup>3</sup> and W. J. Wiscombe<sup>1</sup>

Received 29 May 2009; revised 13 July 2009; accepted 17 July 2009; published 19 August 2009.

[1] The ARM Shortwave Spectrometer (SWS) measures zenith radiance at 418 wavelengths between 350 and 2170 nm. Because of its 1-sec sampling resolution, the SWS provides a unique capability to study the transition zone between cloudy and clear sky areas. A spectral invariant behavior is found between ratios of zenith radiance spectra during the transition from cloudy to cloud-free. This behavior suggests that the spectral signature of the transition zone is a linear mixture between the two extremes (definitely cloudy and definitely clear). The weighting function of the linear mixture is a wavelength-independent characteristic of the transition zone. It is shown that the transition zone spectrum is fully determined by this function and zenith radiance spectra of clear and cloudy regions. An important result of these discoveries is that high temporal resolution radiance measurements in the clear-to-cloud transition zone can be well approximated by lower temporal resolution measurements plus linear interpolation. **Citation:** Marshak, A., Y. Knyazikhin, J. C. Chiu, and W. J. Wiscombe (2009), Spectral invariant behavior of zenith radiance around cloud edges observed by ARM SWS, *Geophys. Res. Lett.*, **36**, L16802, doi:10.1029/2009GL039366.

### 1. Introduction

[2] Though clouds seem to have a distinct boundary, remote sensing measurements find it difficult to distinguish between cloudy and cloud free air [Charlson *et al.*, 2007]. This transition zone is neither precisely clear nor precisely cloudy [Koren *et al.*, 2008, 2009]. This problem has major climatic consequences, in particular on aerosol direct and indirect effect studies, which demand a precise separation of clear and cloudy zones.

[3] *From satellites*, many studies found that the brightness of cloud-free areas systematically increases near clouds [Ignatov *et al.*, 2005; Loeb and Manalo-Smith, 2005; Matheson *et al.*, 2005; Zhang *et al.*, 2005; Koren *et al.*, 2007; Loeb and Schuster, 2008]. The enhanced brightness can result from several factors [Twohy *et al.*, 2009; Varnai and Marshak, 2009], including: small-cloud contamination [e.g., Zhang *et al.*, 2005]; cloud-aerosol microphysics like swelling and increase of number concentration of aerosols in the humid environment near clouds [e.g., Su *et al.*, 2008]; and three-dimensional (3D) radiative interactions between

clouds and surrounding clear areas [e.g., Wen *et al.*, 2007; Marshak *et al.*, 2008]. Due to enhanced molecular scattering [Wen *et al.*, 2008], the latter leads to a change in spectral color of the scattered light that Marshak *et al.* [2008] called the “apparent bluing” of the aerosols.

[4] *From aircraft*, Redemann *et al.* [2009] used sunphotometer measurements to retrieve aerosol optical depth (AOD). They reported a spectrally neutral increase in AOD in the vicinity of clouds. Su *et al.* [2008] used High Spectral Resolution Lidar data to infer aerosol properties as a function of the distance from the nearest cloud. In agreement with Redemann *et al.* [2009], they found an increase in AOD of 10–20% near clouds compared to far away. Their observed backscatter Angstrom exponents did not show any clear trends near clouds. Recently, Twohy *et al.* [2009] studied relative humidity as a function of the distance to the boundaries of small cumulus clouds. Areas of enhanced humidity near cloud boundaries are sometimes called “cloud halos” [Perry and Hobbs, 1996; Lu *et al.*, 2003]. Twohy *et al.* found that the increase in relative humidity close to clouds leads to an increase in scattering cross sections that in turn produces a 35–65% enhancement in the aerosol direct radiative effect compared to cloud-free areas far away from clouds.

[5] *From the ground*, Koren *et al.* [2007] showed that AOD retrieved from AERONET sunphotometers [Holben *et al.*, 1998] decreases with time after the passage of clouds, while Angstrom exponent increases. Chiu *et al.* [2009] used the Atmospheric Radiation Measurement (ARM) Shortwave Spectrometer (SWS) measurements to study the transition zone between cloud-free and cloudy areas. The SWS is a ground instrument based upon the design of the airborne Solar Spectral Flux Radiometer [Pilewskie *et al.*, 2003]; it measures zenith radiance (field of view 1.4°) at 418 wavelengths between 350 and 2170 nm with 1-s temporal resolution. In the clear-cloud transition zone, Chiu *et al.* found a remarkable linear relationship between the sum and difference of radiances at 870 and 1640 nm wavelengths. The intercept of the relationship is determined primarily by aerosol properties, the slope by cloud properties. They also showed that this linearity could be well predicted from simple radiative transfer considerations.

[6] Here we extend the Chiu *et al.* [2009] analysis using all SWS measurements rather than just two wavelengths. The important questions we address are: what are the full-spectral radiative characteristics of the clear-cloud transition zone; and what is the spectral signature of a weak evaporating cloud? We will also show that SWS observations of the transition zone have wavelength-independent characteristics that were earlier observed in reflectance spectra of vegetated surfaces [Knyazikhin *et al.*, 1998;

<sup>1</sup>NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

<sup>2</sup>Department of Geography and Environment, Boston University, Boston, Massachusetts, USA.

<sup>3</sup>Joint Center for Earth Systems Technology, UMBC, Baltimore, Maryland, USA.



## Spectral absorption properties of aerosol particles from 350–2500nm

J. Vanderlei Martins,<sup>1</sup> Paulo Artaxo,<sup>2</sup> Yoram J. Kaufman,<sup>3</sup> Andrea D. Castanho,<sup>2,4</sup> and Lorraine A. Remer<sup>3</sup>

Received 30 January 2009; revised 22 April 2009; accepted 5 May 2009; published 14 July 2009.

[1] The aerosol spectral absorption efficiency ( $\alpha_a$  in  $\text{m}^2/\text{g}$ ) is measured over an extended wavelength range (350–2500 nm) using an improved calibrated and validated reflectance technique and applied to urban aerosol samples from Sao Paulo, Brazil and from a site in Virginia, Eastern US, that experiences transported urban/industrial aerosol. The average  $\alpha_a$  values ( $\sim 3 \text{ m}^2/\text{g}$  at 550 nm) for Sao Paulo samples are 10 times larger than  $\alpha_a$  values obtained for aerosols in Virginia. Sao Paulo aerosols also show evidence of enhanced UV absorption in selected samples, probably associated with organic aerosol components. This extra UV absorption can double the absorption efficiency observed from black carbon alone, therefore reducing by up to 50% the surface UV fluxes, with important implications for climate, UV photolysis rates, and remote sensing from space. **Citation:** Martins, J. V., P. Artaxo, Y. J. Kaufman, A. D. Castanho, and L. A. Remer (2009), Spectral absorption properties of aerosol particles from 350–2500nm, *Geophys. Res. Lett.*, 36, L13810, doi:10.1029/2009GL037435.

### 1. Introduction

[2] In recent years aerosol absorption, mainly by black carbon (BC), has been highlighted in climate change studies for its strong effects. BC absorbs solar energy over most of the solar spectrum, therefore, contrary to other aerosols (e.g., sulfates from urban pollution or even desert dust), BC acts like a greenhouse gas, and contributes to global warming. Hansen and Sato [2001] estimate a global average total forcing of non-absorbing aerosols of about  $-1.3 \text{ W/m}^2$  and the forcing due to black carbon of  $+0.8 \text{ W/m}^2$ . The absorption properties of aerosol particles are still one of the largest uncertainties in estimating aerosol forcing of the climate. Global measurements of BC are not available and are badly needed. In situ aerosol absorption measurements are often inaccurate, and usually cover a narrow spectral range missing significant absorption features. This work presents spectral measurements of aerosol absorption efficiency in a broad spectral range (350–2500 nm) highlighting some characteristics of BC and other aerosol absorbers. We also discuss implications of these results to atmospheric studies. BC is the main absorbing material present in atmospheric aerosols, but it is not the only one. Soil dust absorbs light in the UV and visible, some organic materials absorb in the UV,

and there is recent evidence that some organic materials also absorb light across the solar spectrum [Kirchstetter *et al.*, 2004].

### 2. Aerosol and BC Mass Absorption Efficiencies

[3] The interaction between aerosols and solar radiation in the Earth's atmosphere is well represented by three main parameters: the aerosol optical thickness ( $\tau$ ), the phase function, and the single scattering albedo ( $\omega_0$  = ratio between scattering and extinction properties). Other representations of the particle properties can be more appropriate for specific applications. For instance, the mass scattering or absorption efficiencies ( $\text{m}^2/\text{g}$ ) are the most appropriate parameters relating the aerosol mass (or particle mass emissions) with the particle optical properties. This is an essential connection between optics and aerosol transport and chemical models. Although optical measurements do not measure mass directly, the relationship between aerosol absorption and the mass of the absorber (BC for instance) is represented by the mass absorption efficiency. The aerosol absorption optical thickness ( $\tau_{\text{abs}}$ ) itself can be decomposed into aerosol absorption efficiency ( $\alpha_a$  in  $\text{m}^2/\text{g}$ ) multiplied by the aerosol total mass column per unit area ( $\sigma$  in  $\text{g/m}^2$ ):

$$\tau_{\text{abs}} = \sigma \cdot \alpha_a \quad (1)$$

[4] As shown in equation (2), the aerosol mass absorption efficiency can be defined as the ratio between the aerosol absorption coefficient ( $\beta_a$  [ $\text{m}^{-1}$ ]) and the aerosol mass concentration ( $M$  [ $\text{g/m}^3$ ]). A similar definition can be applied to the BC mass absorption efficiency ( $\alpha_{\text{aBC}}$ ) by taking the ratio between  $\beta_a$  and the BC mass concentration ( $M_{\text{BC}}$  [ $\text{g/m}^3$ ]). Also,  $\alpha_a$  and  $\alpha_{\text{aBC}}$  are related to each other by the fraction of BC mass to the total aerosol mass concentrations ( $r_{\text{BC}}$ ).

$$\alpha_a = \frac{\beta_a}{M}, \quad (2)$$

and

$$\alpha_{\text{aBC}} = \frac{\beta_a}{M_{\text{BC}}} = \frac{\alpha_a}{r_{\text{BC}}} \quad (3)$$

Martins *et al.* [1998] show large variability for both  $\alpha_{\text{aBC}}$  and  $r_{\text{BC}}$  for the Amazonian biomass burning aerosols ( $3\text{--}20 \text{ m}^2/\text{g}$  and  $2\text{--}15\%$  respectively). Since the mass of black carbon cannot be measured directly,  $\alpha_a$  is a more straightforward parameter to be measured and can be obtained by collecting aerosol particles on filters and measuring the collected aerosol mass and the light absorption on the filter. This work reports  $\alpha_a$  results for aerosols from two areas

<sup>1</sup>Physics Department and Joint Center for Earth Systems Technology, University of Maryland Baltimore County, Baltimore, Maryland, USA.

<sup>2</sup>Institute of Physics, University of Sao Paulo, Sao Paulo, Brazil.

<sup>3</sup>NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

<sup>4</sup>Now at Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.



## MODIS observations of enhanced clear sky reflectance near clouds

Tamás Várnai<sup>1</sup> and Alexander Marshak<sup>2</sup>

Received 19 December 2008; revised 17 February 2009; accepted 24 February 2009; published 26 March 2009.

[1] Several recent studies have found that the brightness of clear sky systematically increases near clouds. Understanding this increase is important both for a correct interpretation of observations and for improving our knowledge of aerosol-cloud interactions. However, while the studies suggested several processes to explain the increase, the significance of each process is yet to be determined. This study examines one of the suggested processes—three-dimensional (3-D) radiative interactions between clouds and their surroundings—by analyzing a large dataset of MODIS (Moderate Resolution Imaging Spectroradiometer) observations over the Northeast Atlantic Ocean. The results indicate that 3-D effects are responsible for a large portion of the observed increase, which extends to about 15 km away from clouds and is stronger (i) at shorter wavelengths (ii) near optically thicker clouds and (iii) near illuminated cloud sides. This implies that it is important to account for 3-D radiative effects in the interpretation of solar reflectance measurements over clear regions in the vicinity of clouds. **Citation:** Várnai, T., and A. Marshak (2009), MODIS observations of enhanced clear sky reflectance near clouds, *Geophys. Res. Lett.*, 36, L06807, doi:10.1029/2008GL037089.

### 1. Introduction

[2] Aerosol effects on clouds constitute one of the most important yet least known aspects of anthropogenic climate change. Satellite observations revealed complex relationships between nearby cloud and aerosol properties, and provided many important insights into aerosol-cloud interactions [Ignatov *et al.*, 2005; Kaufman *et al.*, 2005; Loeb and Manalo-Smith, 2005; Matheson *et al.*, 2005; Loeb and Schuster, 2008]. An important recent finding was the presence of a transitional zone around clouds [Koren *et al.*, 2007]. Observing this transitional zone from the ground [Chiu *et al.*, 2009] or from satellites [Koren *et al.*, 2007], researchers found that the brightness of cloud-free areas systematically increases near clouds.

[3] Several factors were proposed to explain the enhanced brightness values, including (i) Swelling of aerosol particles in the humid environment near clouds; (ii) Increased number of aerosol particles due to aerosol-generating processes associated with clouds; (iii) Undetected cloud particles, due to detrainment or thin subpixel-size clouds; (iv) Instrument limitations such as a slight blurring of satellite images;

(v) Three-dimensional (3-D) radiative interactions between clouds and surrounding clear areas. As discussed in earlier studies [e.g., Marshak *et al.*, 2008; Wen *et al.*, 2008], 3-D effects enhance clear sky reflectances when light reflected from clouds moves to nearby clear areas where it gets scattered toward the satellite, mostly by air molecules. (The dominance of molecular scattering is true at shorter wavelengths for cases of low-level clouds over dark surfaces, with aerosol below cloud top.) While all the factors mentioned above are likely to contribute to the enhanced brightness, their relative importance has not yet been established.

[4] Our main concern here is whether 3-D effects contribute significantly to the observed increases: Current aerosol retrieval algorithms rely on 1-D theory, and could misinterpret 3-D-related brightness enhancements as a sign of increased aerosol concentration. Moreover, 3-D related overestimations of aerosol content would be stronger near thicker clouds because they reflect more sunlight toward nearby clear areas, and this could create a spurious correlation between retrieved values of aerosol and cloud optical thickness. However, while theoretical simulations suggested strong 3-D effects [Cahalan *et al.*, 2001; Wen *et al.*, 2006, 2007], observations could not yet confirm this unequivocally: Some remote sensing studies found a stronger reflectance enhancement at shorter wavelengths [Loeb and Schuster, 2008] in a way consistent with 3-D effects called “apparent aerosol bluing” by Marshak *et al.* [2008], but other observations did not support such “bluing” and instead found some of the other proposed factors significant [Kaufman and Koren, 2006; Koren *et al.*, 2008; Redemann *et al.*, 2009]. Recently, Su *et al.* [2008] found only a relatively small increase (10–15%) in aerosol optical thickness near clouds using airborne lidar measurements not affected by 3-D radiative processes.

[5] This paper examines the importance of 3-D radiative effects through a statistical analysis of a large dataset of MODIS (Moderate Resolution Imaging Spectroradiometer) observations. Specifically, it examines whether reflectance increases near clouds display statistical behaviors that can undoubtedly be attributed to 3-D radiative effects.

### 2. Data and Methodology

[6] In this study we analyze 1 km resolution MODIS reflectances at several visible and near infrared wavelengths, as well as brightness temperatures at 11  $\mu\text{m}$ . We also consider the 1 km and 250 m resolution MODIS cloud masks, the 1 km resolution cloud optical thickness product, and the 5 km resolution cloud top pressure product.

[7] The study area lies Southwest of the United Kingdom in the North Atlantic Ocean, between 45°–50°North and 5°–25°West. In the analysis we combine all daytime MODIS Terra observations for this area for the two week long period of September 14–29 in eight consecutive years,

<sup>1</sup>Joint Center for Earth System Technology, NASA Goddard Space Flight Center, University of Maryland Baltimore County, Greenbelt, Maryland, USA.

<sup>2</sup>Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.



## Estimate of the impact of absorbing aerosol over cloud on the MODIS retrievals of cloud optical thickness and effective radius using two independent retrievals of liquid water path

Eric M. Wilcox,<sup>1</sup> Harshvardhan,<sup>2</sup> and Steven Platnick<sup>1</sup>

Received 11 June 2008; revised 29 October 2008; accepted 7 January 2009; published 14 March 2009.

[1] Two independent satellite retrievals of cloud liquid water path (*LWP*) from the NASA Aqua satellite are used to diagnose the impact of absorbing biomass burning aerosol overlaying boundary-layer marine water clouds on the Moderate Resolution Imaging Spectrometer (MODIS) retrievals of cloud optical thickness ( $\tau$ ) and cloud droplet effective radius ( $r_e$ ). In the MODIS retrieval over oceans, cloud reflectance in the 0.86- $\mu\text{m}$  and 2.13- $\mu\text{m}$  bands is used to simultaneously retrieve  $\tau$  and  $r_e$ . A low bias in the MODIS  $\tau$  retrieval may result from reductions in the 0.86- $\mu\text{m}$  reflectance, which is only very weakly absorbed by clouds, owing to absorption by aerosols in cases where biomass burning aerosols occur above water clouds. MODIS *LWP*, derived from the product of the retrieved  $\tau$  and  $r_e$ , is compared with *LWP* ocean retrievals from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E), determined from cloud microwave emission that is transparent to aerosols. For the coastal Atlantic southern African region investigated in this study, a systematic difference between AMSR-E and MODIS *LWP* retrievals is found for stratocumulus clouds over three biomass burning months in 2005 and 2006 that is consistent with above-cloud absorbing aerosols. Biomass burning aerosol is detected using the ultraviolet aerosol index from the Ozone Monitoring Instrument (OMI) on the Aura satellite. The *LWP* difference (AMSR-E minus MODIS) increases both with increasing  $\tau$  and increasing OMI aerosol index. During the biomass burning season the mean *LWP* difference is  $14 \text{ g m}^{-2}$ , which is within the 15–20  $\text{g m}^{-2}$  range of estimated uncertainties in instantaneous *LWP* retrievals. For samples with only low amounts of overlaying smoke (OMI *AI*  $\leq 1$ ) the difference is 9.4, suggesting that the impact of smoke aerosols on the mean MODIS *LWP* is  $5.6 \text{ g m}^{-2}$ . Only for scenes with OMI aerosol index greater than 2 does the average *LWP* difference and the estimated bias in MODIS cloud optical thickness attributable to the impact of overlaying biomass burning aerosol exceed the instantaneous uncertainty in the retrievals.

**Citation:** Wilcox, E. M., Harshvardhan, and S. Platnick (2009), Estimate of the impact of absorbing aerosol over cloud on the MODIS retrievals of cloud optical thickness and effective radius using two independent retrievals of liquid water path, *J. Geophys. Res.*, 114, D05210, doi:10.1029/2008JD010589.

### 1. Introduction

[2] Satellite measurements of visible and near-infrared reflectance are now used routinely to simultaneously retrieve cloud optical thickness ( $\tau$ ) and cloud drop effective radius ( $r_e$ ). These data are used in climate studies, among other applications, to evaluate the radiative impact of clouds on the climate system [e.g., Han *et al.*, 1994; Quaas *et al.*, 2006]. These retrievals, however, may be biased in cases where a layer of absorbing aerosol resides above the cloud. This situation occurs frequently over the eastern South Atlantic

Ocean during austral winter when smoke from extensive biomass burning in southern Africa is transported westward over a region of persistent low stratocumulus cloud cover. If the layer of absorbing biomass burning aerosol attenuates the sunlight that is both incident on and reflected by the top of the cloud, then the radiance measured by the satellite will imply a weaker cloud reflectance than that of the true cloud. This bias in estimated reflectance can result in a low bias retrieval for cloud optical thickness, and for retrievals based on certain wavelength band combinations, a biased retrieval in effective radius as well.

[3] Haywood *et al.* [2004] computed the expected bias in the cloud property retrieval on the basis of a radiative transfer model and in-situ measurements of aerosol optical properties. They report a low bias of up to 30% in  $\tau$  for retrievals that depend on 0.63- or 0.86- $\mu\text{m}$  reflectance values. Biases in  $r_e$  were found to be less than 1  $\mu\text{m}$  for

<sup>1</sup>Climate and Radiation Branch, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

<sup>2</sup>Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, Indiana, USA.





## Variability of marine aerosol fine-mode fraction and estimates of anthropogenic aerosol component over cloud-free oceans from the Moderate Resolution Imaging Spectroradiometer (MODIS)

Hongbin Yu,<sup>1,2</sup> Mian Chin,<sup>2</sup> Lorraine A. Remer,<sup>2</sup> Richard G. Kleidman,<sup>2,3</sup> Nicolas Bellouin,<sup>4</sup> Huisheng Bian,<sup>1,2</sup> and Thomas Diehl<sup>1,2</sup>

Received 24 June 2008; revised 24 March 2009; accepted 30 March 2009; published 29 May 2009.

[1] In this study, we examine seasonal and geographical variability of marine aerosol fine-mode fraction ( $f_m$ ) and its impacts on deriving the anthropogenic component of aerosol optical depth ( $\tau_a$ ) and direct radiative forcing from multispectral satellite measurements. A proxy of  $f_m$ , empirically derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 5 data, shows large seasonal and geographical variations that are consistent with the Goddard Chemistry Aerosol Radiation Transport (GOCART) and Global Modeling Initiative (GMI) model simulations. The so-derived seasonally and spatially varying  $f_m$  is then implemented into a method of estimating  $\tau_a$  and direct radiative forcing from the MODIS measurements. It is found that the use of a constant value for  $f_m$  as in previous studies would have overestimated  $\tau_a$  by about 20% over global ocean, with the overestimation up to ~45% in some regions and seasons. The 7-year (2001–2007) global ocean average  $\tau_a$  is 0.035, with yearly average ranging from 0.031 to 0.039. Future improvement in measurements is needed to better separate anthropogenic aerosol from natural ones and to narrow down the wide range of aerosol direct radiative forcing.

**Citation:** Yu, H., M. Chin, L. A. Remer, R. G. Kleidman, N. Bellouin, H. Bian, and T. Diehl (2009), Variability of marine aerosol fine-mode fraction and estimates of anthropogenic aerosol component over cloud-free oceans from the Moderate Resolution Imaging Spectroradiometer (MODIS), *J. Geophys. Res.*, 114, D10206, doi:10.1029/2008JD010648.

### 1. Introduction

[2] With the implementation of multiwavelength, multi-angle, and polarization measuring capabilities, current satellite measurements can be used to categorize aerosol types in terms of microphysical properties, such as particle size and shape [e.g., Kahn *et al.*, 2001; Tanré *et al.*, 2001; Higurashi and Nakajima, 2002; Winker *et al.*, 2007]. For example, the fine-mode fraction, a measure of the contribution of fine-mode aerosols to the aerosol optical depth (AOD or  $\tau$ ), has been obtained from enhanced satellite sensors (e.g., the Moderate resolution Imaging Spectroradiometer (MODIS)) with improved data quality [Tanré *et al.*, 1997; Remer *et al.*, 2005]. Given that anthropogenic aerosols are predominately fine-mode or in the submicron range, the fine-mode fraction in conjunction with the total aerosol optical depth can be used as a tool for separating anthropogenic aerosol from dust [Kaufman *et al.*, 2002]. Kaufman *et al.* [2005a, 2005b]

further developed a quantitative method that uses MODIS over-ocean retrievals in a consistent way to estimate the anthropogenic component (e.g., originating from industrial and urban pollution and biomass burning smoke) of aerosol optical depth,  $\tau_a$ , as follows:

$$\tau_a = [(f - f_d)\tau - (f_m - f_d)\tau_m] / (f_a - f_d), \quad (1)$$

where  $\tau$  and  $f$  respectively represents total aerosol optical depth and fine-mode fraction retrieved directly from MODIS, both at 550 nm. Subscripts  $a$ ,  $d$ , and  $m$  denote anthropogenic, dust, and marine aerosol components, respectively. Marine aerosol optical depth  $\tau_m$  is empirically determined to be a constant of 0.06 [Kaufman *et al.*, 2005a] or a function of near-surface wind speed [Kaufman *et al.*, 2005b]. The fine-mode fractions for marine ( $f_m$ ), anthropogenic ( $f_a$ ), and dust ( $f_d$ ) aerosol were assumed to be constant, which were then derived from Terra MODIS Collection 4 measurements in selected regions where the specific aerosol type predominates and contributions of background aerosol are empirically accounted for [Kaufman *et al.*, 2005a]. Clearly this algorithm does not assume that all fine-mode AOD comes from anthropogenic contribution or anthropogenic AOD is exclusively fine-mode. Contributions from natural aerosols (dust and marine aerosol) to fine-mode AOD are empirically accounted for. The essence of this algorithm is that the

<sup>1</sup>Goddard Earth Science and Technology Center, University of Maryland at Baltimore County, Baltimore, Maryland, USA.

<sup>2</sup>Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

<sup>3</sup>Science System and Applications, Inc., Lanham, Maryland, USA.

<sup>4</sup>Met Office, Exeter, UK.

### Code 613.3 Highlighted Articles

---

Atmos. Chem. Phys., 9, 4239–4249, 2009  
 www.atmos-chem-phys.net/9/4239/2009/  
 © Author(s) 2009. This work is distributed  
 under the Creative Commons Attribution 3.0 License.

[Volumes and Issues](#) [Contents of Issue 13](#)

#### **Effects of the 2006 El Niño on tropospheric ozone and carbon monoxide: implications for dynamics and biomass burning**

**S. Chandra<sup>1,2</sup>, J. R. Ziemke<sup>1,2</sup>, B. N. Duncan<sup>1,2</sup>, T. L. Diehl<sup>1,2</sup>, N. J. Livesey<sup>3</sup>, and L. Froidevaux<sup>3</sup>**

<sup>1</sup>Goddard Earth Sciences and Technology Center, University of Maryland Baltimore County, Baltimore, MD, USA

<sup>2</sup>NASA Goddard Space Flight Center, Greenbelt, MD, USA

<sup>3</sup>NASA Jet Propulsion Laboratory, Pasadena, CA, USA

**Abstract.** We have studied the effects of the 2006 El Niño on tropospheric O<sub>3</sub> and CO at tropical and sub-tropical latitudes measured from the OMI and MLS instruments on the Aura satellite. The 2006 El Niño-induced drought caused forest fires (largely set to clear land) to burn out of control during October and November in the Indonesian region. The effects of these fires are clearly seen in the enhancement of CO concentration measured from the MLS instrument. We have used a global model of atmospheric chemistry and transport (GMI CTM) to quantify the relative importance of biomass burning and large scale transport in producing observed changes in tropospheric O<sub>3</sub> and CO. The model results show that during October and November biomass burning and meteorological changes contributed almost equally to the observed increase in tropospheric O<sub>3</sub> in the Indonesian region. The biomass component was 4–6 DU but it was limited to the Indonesian region where the fires were most intense. The dynamical component was 4–8 DU but it covered a much larger area in the Indian Ocean extending from South East Asia in the north to western Australia in the south. By December 2006, the effect of biomass burning was reduced to zero and the observed changes in tropospheric O<sub>3</sub> were mostly due to dynamical effects. The model results show an increase of 2–3% in the global burden of tropospheric ozone. In comparison, the global burden of CO increased by 8–12%.

[Final Revised Paper](#) (PDF, 955 KB) [Discussion Paper](#) (ACPD)

**Citation:** Chandra, S., Ziemke, J. R., Duncan, B. N., Diehl, T. L., Livesey, N. J., and Froidevaux, L.: Effects of the 2006 El Niño on tropospheric ozone and carbon monoxide: implications for dynamics and biomass burning, Atmos. Chem. Phys., 9, 4239–4249, 2009. [Bibtex](#) [EndNote](#) [Reference Manager](#) [XML](#)

Atmos. Chem. Phys., 9, 2207–2213, 2009  
www.atmos-chem-phys.net/9/2207/2009/  
© Author(s) 2009. This work is distributed  
under the Creative Commons Attribution 3.0 License.

[Volumes and Issues](#) [Contents of Issue 6](#)

## Stratospheric ozone in the post-CFC era

F. Li<sup>1</sup>, R. S. Stolarski<sup>2</sup>, and P. A. Newman<sup>2</sup>

<sup>1</sup>GEST, University of Maryland, Baltimore County, Baltimore, MD, USA

<sup>2</sup>Atmospheric Chemistry and Dynamics Branch, NASA GSFC, Greenbelt, MD, USA

**Abstract.** Vertical and latitudinal changes in the stratospheric ozone in the post-chlorofluorocarbon (CFC) era are investigated using simulations of the recent past and the 21st century with a coupled chemistry-climate model. Model results reveal that, in the 2060s when the stratospheric halogen loading is projected to return to its 1980 values, the extratropical column ozone is significantly higher than that in 1975–1984, but the tropical column ozone does not recover to 1980 values. Upper and lower stratospheric ozone changes in the post-CFC era have very different patterns. Above 15 hPa ozone increases almost latitudinally uniformly by 6 Dobson Unit (DU), whereas below 15 hPa ozone decreases in the tropics by 8 DU and increases in the extratropics by up to 16 DU. The upper stratospheric ozone increase is a photochemical response to greenhouse gas induced strong cooling, and the lower stratospheric ozone changes are consistent with enhanced mean advective transport due to a stronger Brewer-Dobson circulation. The model results suggest that the strengthening of the Brewer-Dobson circulation plays a crucial role in ozone recovery and ozone distributions in the post-CFC era.

[Final Revised Paper](#) (PDF, 705 KB) [Discussion Paper](#) (ACPD)

**Citation:** Li, F., Stolarski, R. S., and Newman, P. A.: Stratospheric ozone in the post-CFC era, Atmos. Chem. Phys., 9, 2207–2213, 2009. [Bibtex](#) [EndNote](#) [Reference Manager](#) [XML](#)



## Keywords

isoprene

## Index Terms

Atmospheric Composition and Structure: Troposphere: composition and chemistry

Atmospheric Composition and Structure: Troposphere: constituent transport and chemistry

Atmospheric Composition and Structure: Constituent sources and sinks

## Abstract

### Temperature dependence of factors controlling isoprene emissions

**Bryan N. Duncan**

Atmospheric Chemistry and Dynamics Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

**Yasuko Yoshida**

**Megan R. Damon**

Northrop Grumman TASC, Chantilly, Virginia, USA

**Anne R. Douglass**

Atmospheric Chemistry and Dynamics Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

**Jacquelyn C. Witte**

We investigated the relationship of variability in the formaldehyde (HCHO) columns measured by the Aura Ozone Monitoring Instrument (OMI) to isoprene emissions in the southeastern United States for 2005–2007. The data show that the inferred, regional-average isoprene emissions varied by about 22% during summer and are well correlated with temperature, which is known to influence emissions. Part of the correlation with temperature is likely associated with other causal factors that are temperature-dependent. We show that the variations in HCHO are convolved with the temperature dependence of surface ozone, which influences isoprene emissions, and the dependence of the HCHO column to mixed layer height as OMI's sensitivity to HCHO increases with altitude. Furthermore, we show that while there is an association of drought with the variation in HCHO, drought in the southeastern U.S. is convolved with temperature.

---

**Citation:** B. N. Duncan, Y. Yoshida, M. R. Damon, A. R. Douglass, and J. C. Witte (2009), Temperature dependence of factors controlling isoprene emissions, *Geophys. Res. Lett.*, 36, L05813, doi:10.1029/2008GL037090.

---

## Similar Articles

- [Constraining global isoprene emissions with Global Ozone Monitoring Experiment \(GOME\) formaldehyde column measurements](#)
- [Net ecosystem fluxes of isoprene over tropical South America inferred from Global Ozone Monitoring Experiment \(GOME\) observations of HCHO columns](#)
- [Formaldehyde distribution over North America: Implications for satellite retrievals of formaldehyde columns and isoprene emission](#)

**Keywords**

clouds  
ultraviolet  
reflectivity

**Index Terms**

Atmospheric Composition  
and Structure: Cloud optics  
  
Atmospheric Composition  
and Structure: Aerosols and  
particles  
  
Global Change: Remote  
sensing  
  
Atmospheric Processes:  
Clouds and aerosols  
  
Atmospheric Processes:  
Climate change and  
variability

**Abstract**

## Changes in cloud and aerosol cover (1980–2006) from reflectivity time series using SeaWiFS, N7-TOMS, EP-TOMS, SBUV-2, and OMI radiance data

**J. R. Herman**

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

**G. Labow**

Science Systems and Applications, Inc., Lanham, Maryland, USA

**N. C. Hsu**

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

**D. Larko**

Science Systems and Applications, Inc., Lanham, Maryland, USA

The amount of solar radiation reflected back to space or reaching the Earth's surface is primarily governed by the amount of cloud cover and, to a much lesser extent, by Rayleigh scattering, aerosols, and various absorbing gases (e.g., O<sub>3</sub>, NO<sub>2</sub>, H<sub>2</sub>O). A useful measure of the effect of cloud plus aerosol cover is given by the amount that the 331 nm Lambert Equivalent Reflectivity (LER) of a scene exceeds the surface reflectivity for snow/ice-free scenes after Rayleigh scattering has been removed. Twenty-eight years of reflectivity data are available by overlapping data from several satellites: N7 (Nimbus 7, TOMS; 331 nm) from 1979 to 1992, SBUV-2 series (Solar Backscatter Ultraviolet, NOAA; 331 nm) 1985 to 2007, EP (Earth-Probe, TOMS; 331 nm) 1997 to 2006, SW (SeaWiFS; 412 nm) 1998 to 2006, and OMI (Ozone Measuring Instrument; 331 nm) 2004–2007. Only N7 and SW have a sufficiently long data record, Sun-synchronous orbits, and are adequately calibrated for long-term reflectivity trend estimation. Reflectivity data derived from these instruments and the SBUV-2 series are compared during the overlapping years. Key issues in determining long-term reflectivity changes that have occurred during the N7 and SW operating periods are discussed. The largest reflectivity changes in the 412 nm SW LER and 331 nm EP LER are found to occur near the equator and are associated with a large El Niño–Southern Oscillation event. Most other changes that have occurred are regional, such as the apparent cloud decrease over northern Europe since 1998. The fractional occurrence (fraction of days) of high reflectivity values over Hudson Bay, Canada (snow/ice and clouds) appears to have decreased when comparing reflectivity data from 1980 to 1992 to 1997–2006, suggesting shorter duration of ice in Hudson Bay since 1980.

**Citation:** J. R. Herman, G. Labow, N. C. Hsu, and D. Larko (2009), Changes in cloud and aerosol cover (1980–2006) from reflectivity time series using SeaWiFS, N7-TOMS, EP-TOMS, SBUV-2, and OMI radiance data, *J. Geophys. Res.*, 114, D01201, doi:10.1029/2007JD009508.

**Similar Articles**

- [Determining the UV imaginary index of refraction of Saharan dust particles from Total Ozone Mapping Spectrometer data using a three-dimensional model of dust transport](#)
- [A study on the temporal and spatial variability of absorbing aerosols using Total Ozone Mapping Spectrometer and Ozone Monitoring Instrument Aerosol Index data](#)
- [The Meteor 3/total ozone mapping spectrometer version 7 data set: Calibration and analysis](#)

## Keywords

middle atmosphere  
solar proton event  
ozone

## Index Terms

Atmospheric Composition  
and Structure: Middle  
atmosphere: composition  
and chemistry  
Atmospheric Composition  
and Structure: Middle  
atmosphere: constituent  
transport and chemistry  
Atmospheric Composition  
and Structure: Middle  
atmosphere: energy  
deposition  
Global Change: Solar  
variability  
Solar Physics, Astrophysics,  
and Astronomy: Energetic  
particles

## Abstract

### Long-term middle atmospheric influence of very large solar proton events

**Charles H. Jackman**

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

**Daniel R. Marsh**

Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, Colorado, USA

**Francis M. Vitt**

Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, Colorado, USA

**Rolando R. Garcia**

Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, Colorado, USA

**Cora E. Randall**

Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado, USA

**Eric L. Fleming**

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

**Stacey M. Frith**

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

The Whole Atmosphere Community Climate Model (WACCM3) has been used to study the long-term (more than a few months) effects of solar proton events (SPEs). Extremely large solar proton events occurred in 1972, 1989, 2000, 2001, and 2003 and caused some longer-lasting atmospheric changes. The highly energetic solar protons produced odd hydrogen (HOx) and odd nitrogen (NOy), which then led to ozone variations. Some statistically significant long-term effects on mesospheric ozone were caused by the HOx increases due to a very active time period for SPEs (years 2000–2004), even though the HOx increases were short-lived (days). The long-term stratospheric ozone effects were caused by the NOy enhancements. Very large NOy enhancements lasted for months in the middle and lower stratosphere after a few of the largest SPEs. SPE-caused NOy increases computed with WACCM3 were statistically significant at the 95% level throughout much of the polar stratosphere and mesosphere in the recent solar maximum 5-year period (2000–2004). WACCM3-computed SPE-caused polar stratospheric ozone decreases of >10% continued for up to 5 months past the largest events; however, statistically significant ozone decreases were computed for only a relatively small fraction of this time in relatively limited altitudes in the lower mesosphere and upper stratosphere. Annually averaged model output showed statistically significant (to 95%) stratospheric ozone loss in the polar Northern Hemisphere for years 2000–2002. The computed annually averaged temperature and total ozone change in these years were not statistically significant.

**Citation:** C. H. Jackman, D. R. Marsh, F. M. Vitt, R. R. Garcia, C. E. Randall, E. L. Fleming, and S. M. Frith (2009), Long-term middle atmospheric influence of very large solar proton events, *J. Geophys. Res.*, 114, D11304, doi:10.1029/2008JD011415.

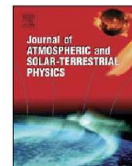
## Similar Articles

- [Dynamics of the middle atmosphere as simulated by the Whole Atmosphere Community Climate Model, version 3 \(WACCM3\)](#)
- [Evaluation of heterogeneous processes in the polar lower stratosphere in the Whole Atmosphere Community Climate Model](#)
- [Simulation of secular trends in the middle atmosphere, 1950–2003](#)



Contents lists available at ScienceDirect

# Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: [www.elsevier.com/locate/jastp](http://www.elsevier.com/locate/jastp)

## Intra-seasonal monthly oscillations in stratospheric NCEP data and model results

H.G. Mayr<sup>a,\*</sup>, J.G. Mengel<sup>b,1</sup>, F.T. Huang<sup>c</sup>, E.R. Nash<sup>b</sup><sup>a</sup> NASA, Goddard Space Flight Center, Laboratory for Atmospheres, Code 613.3, 8800 Greenbelt Road, Greenbelt, MD 20771, USA<sup>b</sup> Science Systems and Applications Inc., Lanham, MD, USA<sup>c</sup> University of Maryland, Baltimore, MD, USA

### ARTICLE INFO

#### Article history:

Received 1 March 2009

Received in revised form

24 April 2009

Accepted 6 May 2009

Available online 10 May 2009

#### Keywords:

Intra-seasonal oscillations (ISO)

Sudden stratospheric warmings (SSW)

NCEP data analysis

Stratosphere dynamics

Theoretical modeling

### ABSTRACT

Intra-seasonal oscillations (ISO) are observed in the zonal-mean of mesospheric wind and temperature measurements—and the numerical spectral model (NSM) generates such oscillations. Relatively large temperature ISO are evident also in stratospheric CPC (NCEP) data at high latitudes, where the NSM produces amplitudes around 3 K at 30 km. Analyzing the NCEP data for the years 1996–2006, we find in Fourier spectra signatures of oscillations with periods between 1.7 and 3 months. With statistical confidence levels exceeding 70%, the spectral features are induced by nonlinear interactions involving the annual and semi-annual variations. The synthesized data show for the 10-year average that the temperature ISO peak in winter, having amplitudes close to 4 K. The synthesized complete spectrum for periods around 2 months produces oscillations, varying from year to year, which can reach peak amplitudes of 15 and 5 K respectively at northern and southern polar latitudes.

© 2009 Elsevier Ltd. All rights reserved.

### 1. Introduction

Zonal-mean intra-seasonal oscillations (ISO) with periods around 2 months have been observed in the mesosphere. Eckermann and Vincent (1994) and Eckermann et al. (1997) reported such oscillations in zonal and meridional winds, and in the gravity wave activity inferred from medium frequency radar measurements at equatorial latitudes in the upper mesosphere and lower thermosphere. Lieberman (1998), Huang and Reber (2003), and Huang et al. (2005) reported similar oscillations seen in wind measurements on the Upper Atmospheric Research Satellite (UARS), and Huang et al. (2005, 2006) inferred such ISO from the temperature measurements on the UARS and on the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) spacecraft. The polar mesospheric clouds (PMC), which are sensitive to temperature variations, reveal zonal-mean ISO structures with periods around one month, as shown by Bailey et al. (2005) based on measurements with the Student Nitric Oxide Explorer (SNOE).

Mayr et al. (2003) demonstrated with the Numerical Spectral Model (NSM) that meridional wind oscillations with periods of about 2 months are generated by the momentum deposition from small-scale gravity waves (GW) propagating north/south. The underlying wave-driven dynamical process is intrinsically non-

linear, similar to that generating the quasi-biennial oscillation (QBO) of the zonal winds, except that the meridional momentum source is involved. Stimulated by the observed variations of PMC, Mayr et al. (2009, hereafter MetAI) applied the NSM to explore the temperature environment of the mesopause region. The model generates temperature oscillations with periods around 1.5 months, which can reach peak amplitudes close to 10 K in the polar regions during summer. The ISO are generated by the meridional winds that peak around the equator but extend to high latitudes, where they converge/diverge to produce the vertical winds that cause dynamical heating and cooling in the polar regions. Spectral analysis shows that the annual oscillation (AO) and semi-annual oscillation (SAO) induce (stimulate) the ISO through nonlinear interactions. The oscillations are apparently amplified by meridional wave mean flow interactions owing to GW and planetary waves in the 3D version of the NSM (MetAI).

In the present paper, our focus is the stratosphere. We present the ISO that are generated by the NSM. We then discuss the large temperature oscillations that are seen at high latitudes in the data supplied by the National Centers for Environmental Prediction (NCEP). As the reviewers pointed out, the inferred ISO appear to be related to observed sudden stratospheric warmings (SSW).

### 2. Intra-seasonal oscillations in a 3D model

The global-scale Numerical Spectral Model (NSM) extends from the Earth's surface into the thermosphere, and its numerical

\* Corresponding author.

E-mail address: [hans.g.mayr@nasa.gov](mailto:hans.g.mayr@nasa.gov) (H.G. Mayr).<sup>1</sup> Deceased.



Atmos. Chem. Phys., 9, 2113-2128, 2009  
 www.atmos-chem-phys.net/9/2113/2009/  
 © Author(s) 2009. This work is distributed  
 under the Creative Commons Attribution 3.0 License.

### What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated?

**P. A. Newman<sup>1</sup>, L. D. Oman<sup>2</sup>, A. R. Douglass<sup>1</sup>, E. L. Fleming<sup>3</sup>, S. M. Frith<sup>3</sup>, M. M. Hurwitz<sup>4</sup>, S. R. Kawa<sup>1</sup>, C. H. Jackman<sup>1</sup>, N. A. Krotkov<sup>5</sup>, E. R. Nash<sup>3</sup>, J. E. Nielsen<sup>3</sup>, S. Pawson<sup>1</sup>, R. S. Stolarski<sup>1</sup>, and G. J. M. Velders<sup>6</sup>**

<sup>1</sup>NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

<sup>2</sup>Johns Hopkins University, Baltimore, Maryland, USA

<sup>3</sup>Science Systems and Applications, Inc., Lanham, Maryland, USA

<sup>4</sup>NASA Postdoctoral Program, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

<sup>5</sup>Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, Maryland, USA

<sup>6</sup>Netherlands Environmental Assessment Agency, Bilthoven, The Netherlands

**Abstract.** Ozone depletion by chlorofluorocarbons (CFCs) was first proposed by Molina and Rowland in their 1974 Nature paper. Since that time, the scientific connection between ozone losses and CFCs and other ozone depleting substances (ODSs) has been firmly established with laboratory measurements, atmospheric observations, and modeling studies. This science research led to the implementation of international agreements that largely stopped the production of ODSs. In this study we use a fully-coupled radiation-chemical-dynamical model to simulate a future world where ODSs were never regulated and ODS production grew at an annual rate of 3%. In this "world avoided" simulation, 17% of the globally-averaged column ozone is destroyed by 2020, and 67% is destroyed by 2065 in comparison to 1980. Large ozone depletions in the polar region become year-round rather than just seasonal as is currently observed in the Antarctic ozone hole. Very large temperature decreases are observed in response to circulation changes and decreased shortwave radiation absorption by ozone. Ozone levels in the tropical lower stratosphere remain constant until about 2053 and then collapse to near zero by 2058 as a result of heterogeneous chemical processes (as currently observed in the Antarctic ozone hole). The tropical cooling that triggers the ozone collapse is caused by an increase of the tropical upwelling. In response to ozone changes, ultraviolet radiation increases, more than doubling the erythemal radiation in the northern summer midlatitudes by 2060.

[Final Revised Paper](#) (PDF, 3453 KB) [Discussion Paper](#) (ACPD)

**Citation:** Newman, P. A., Oman, L. D., Douglass, A. R., Fleming, E. L., Frith, S. M., Hurwitz, M. M., Kawa, S. R., Jackman, C. H., Krotkov, N. A., Nash, E. R., Nielsen, J. E., Pawson, S., Stolarski, R. S., and Velders, G. J. M.: What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated?, Atmos. Chem. Phys., 9, 2113-2128, 2009. [Bibtex](#) [EndNote](#) [Reference Manager](#) [XML](#)

**Keywords**

stratosphere  
mean age  
climate change

**Index Terms**

Global Change: Atmosphere  
Global Change: Impacts of  
global change  
Global Change: Climate  
dynamics  
Atmospheric Composition  
and Structure: Middle  
atmosphere: constituent  
transport and chemistry  
Global Change: Global  
climate models

**Abstract**

## On the influence of anthropogenic forcings on changes in the stratospheric mean age

**Luke Oman**

Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, Maryland, USA

**Darryn W. Waugh**

Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, Maryland, USA

**Steven Pawson**

Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

**Richard S. Stolarski**

Atmospheric Chemistry and Dynamics Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

**Paul A. Newman**

Atmospheric Chemistry and Dynamics Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

A common feature of stratospheric simulations of the past or future is an increase in tropical upwelling and a decrease in mean age. Possible causes of these changes include (1) increases in tropical sea surface temperatures (SSTs) driven by increases in well-mixed greenhouse gases (WMGHGs), (2) the direct radiative effect of increases in WMGHGs, and (3) changes in ozone. Here we examine a suite of simulations from the Goddard Earth Observing System chemistry-climate model (GEOS CCM) to isolate the relative role of these three factors. Our analysis indicates that all three factors cause changes in the mean age, but the relative impact of each factor depends on the time period analyzed. Over the past 30–40 years ozone depletion is the major factor causing the decrease in mean age, with negligible changes due to direct radiative impact of WMGHGs. However, ozone is predicted to recover back to 1970 levels during the next 50–60 years, and this causes an increase in the mean age, whereas the continued increase in SSTs from increased levels of WMGHGs and the direct radiative impact of WMGHGs will still cause a decrease in the mean age. The net impact of these factors will still result in a decreasing mean age although the rate will be smaller than that of the past. The decreases in mean age are primarily caused by increases in upwelling in the tropical lower stratosphere. The increased upwelling from both increased tropical SSTs and polar ozone loss appears to be related to changes in zonal winds and increases in wave activity propagating into the stratosphere. The different contributions of changes in SSTs, WMGHGs, and ozone to the circulation of the stratosphere may help explain the large spread in the rate of change of tropical upwelling seen in previous studies.

**Citation:** L. Oman, D. W. Waugh, S. Pawson, R. S. Stolarski, and P. A. Newman (2009), On the influence of anthropogenic forcings on changes in the stratospheric mean age, *J. Geophys. Res.*, 114, D03105, doi:10.1029/2008JD010378.

**Similar Articles**

- [Potential effects of regional pumpage on groundwater age distribution](#)
- [AGE OF STRATOSPHERIC AIR: THEORY, OBSERVATIONS, AND MODELS](#)
- [A comparison of the lower stratospheric age spectra derived from a general circulation model and two data assimilation systems](#)

Atmos. Chem. Phys., 9, 2471–2480, 2009  
www.atmos-chem-phys.net/9/2471/2009/  
© Author(s) 2009. This work is distributed  
under the Creative Commons Attribution 3.0 License.

### The impact of tropical recirculation on polar composition

S. E. Strahan<sup>1</sup>, M. R. Schoeberl<sup>2</sup>, and S. D. Steenrod<sup>1</sup>

<sup>1</sup>Goddard Earth Science and Technology Center, University of Maryland, Baltimore County, Baltimore, MD, USA

<sup>2</sup>NASA Goddard Space Flight Center, Greenbelt, MD, USA

**Abstract.** We derive the tropical modal age of air from an analysis of the water vapor tape recorder. We combine the observationally derived modal age with mean age of air from CO<sub>2</sub> and SF<sub>6</sub> to create diagnostics for the independent evaluation of the vertical transport rate and horizontal recirculation into the tropics between 16–32 km. These diagnostics are applied to two Global Modeling Initiative (GMI) chemistry and transport model (CTM) age tracer simulations to give new insights into the tropical transport characteristics of the meteorological fields from the GEOS4-GCM and the GEOS4-DAS. Both simulations are found to have modal ages that are in reasonable agreement with the empirically derived age (i.e., transit times) over the entire altitude range. Both simulations show too little horizontal recirculation into the tropics above 22 km, with the GEOS4-DAS fields having greater recirculation. Using CH<sub>4</sub> as a proxy for mean age, comparisons between HALOE and model CH<sub>4</sub> in the Antarctic demonstrate how the strength of tropical recirculation affects polar composition in both CTM experiments. Better tropical recirculation tends to improve the CH<sub>4</sub> simulation in the Antarctic. However, mean age in the Antarctic lower stratosphere can be compromised by poor representation of tropical ascent, tropical recirculation, or vortex barrier strength. The connection between polar and tropical composition shown in this study demonstrates the importance of diagnosing each of these processes separately in order to verify the adequate representation of the processes contributing to polar composition in models.

[Final Revised Paper](#) (PDF, 504 KB) [Discussion Paper](#) (ACPD)

**Citation:** Strahan, S. E., Schoeberl, M. R., and Steenrod, S. D.: The impact of tropical recirculation on polar composition, Atmos. Chem. Phys., 9, 2471–2480, 2009. [Bibtex](#) [EndNote](#) [Reference Manager](#) [XML](#)



## AGU: Geophysical Research Letters

## Keywords

tropospheric ozone  
 biomass burning  
 aerosol index

## Index Terms

Atmospheric Composition and Structure: Constituent sources and sinks  
 Atmospheric Composition and Structure: Troposphere: composition and chemistry  
 Atmospheric Composition and Structure: Troposphere: constituent transport and chemistry  
 Atmospheric Composition and Structure: Aerosols and particles  
 Atmospheric Processes: Boundary layer processes

## Abstract

## Recent biomass burning in the tropics and related changes in tropospheric ozone

J. R. Ziemke

S. Chandra

B. N. Duncan

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

M. R. Schoeberl

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

O. Torres

NASA Langley Research Center, Hampton, Virginia, USA

M. R. Damon

Northrup Grumman/TASC, Chantilly, Virginia, USA

P. K. Bhartia

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

Biomass burning in the tropics is set intentionally during dry season each year to destroy agricultural waste and clear land for human expansion. These burning activities cause pollution including atmospheric particulates and trace gases which are harmful to human health. Measurements from the Aura Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) from October 2004–November 2008 are used to evaluate the effects of biomass burning on tropical tropospheric ozone in the context of the Global Modeling Initiative (GMI) chemical transport model. The impact of biomass burning on ozone is significant within and near the burning regions with increases of ~10–25% in tropospheric column ozone relative to average background concentrations. Globally the model indicates increases of ~4–5% in ozone, ~7–9% in NO<sub>x</sub> (NO + NO<sub>2</sub>), and ~30–40% in CO.

**Citation:** J. R. Ziemke, S. Chandra, B. N. Duncan, M. R. Schoeberl, O. Torres, M. R. Damon, and P. K. Bhartia (2009), Recent biomass burning in the tropics and related changes in tropospheric ozone, *Geophys. Res. Lett.*, 36, L15819, doi:10.1029/2009GL039303.

## Similar Articles

- [Tropospheric ozone determined from Aura OMI and MLS: Evaluation of measurements and comparison with the Global Modeling Initiative's Chemical Transport Model](#)
- [Evaluating the credibility of transport processes in simulations of ozone recovery using the Global Modeling Initiative three-dimensional model](#)
- [A trajectory-based estimate of the tropospheric ozone column using the residual method](#)



REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p>					
1. REPORT DATE (DD-MM-YYYY) 28-07-2010		2. REPORT TYPE Technical Memorandum		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE  Laboratory for Atmospheres 2009 Technical Highlights				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)  Laboratory for Atmospheres				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Goddard Space Flight Center Greenbelt, MD 20771				8. PERFORMING ORGANIZATION REPORT NUMBER  2010-00866	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING/MONITOR'S ACRONYM(S)	
				11. SPONSORING/MONITORING REPORT NUMBER NASA-TM-2010-215851	
12. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified-Unlimited, Subject Category: 42, 47, 48 Report available from the NASA Center for Aerospace Information, 7115 Standard Drive, Hanover, MD 21076. (443)757-5802					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT  The 2009 Technical Highlights describes the efforts of all members of the Laboratory for Atmospheres. Their dedication to advancing Earth Science through conducting research, developing and running models, designing instruments, managing projects, running field campaigns, and numerous other activities, is highlighted in this report.					
15. SUBJECT TERMS  Technical Highlights, Laboratory for Atmospheres, Atmospheric Research					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  Unclassified	18. NUMBER OF PAGES  170	19a. NAME OF RESPONSIBLE PERSON William Lau
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) (301) 614-6332





