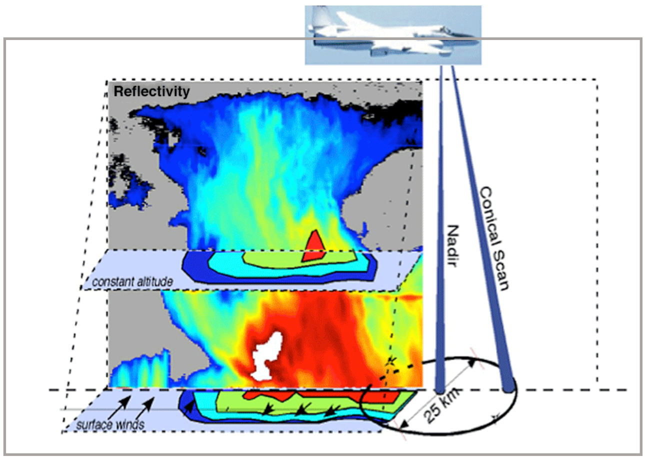
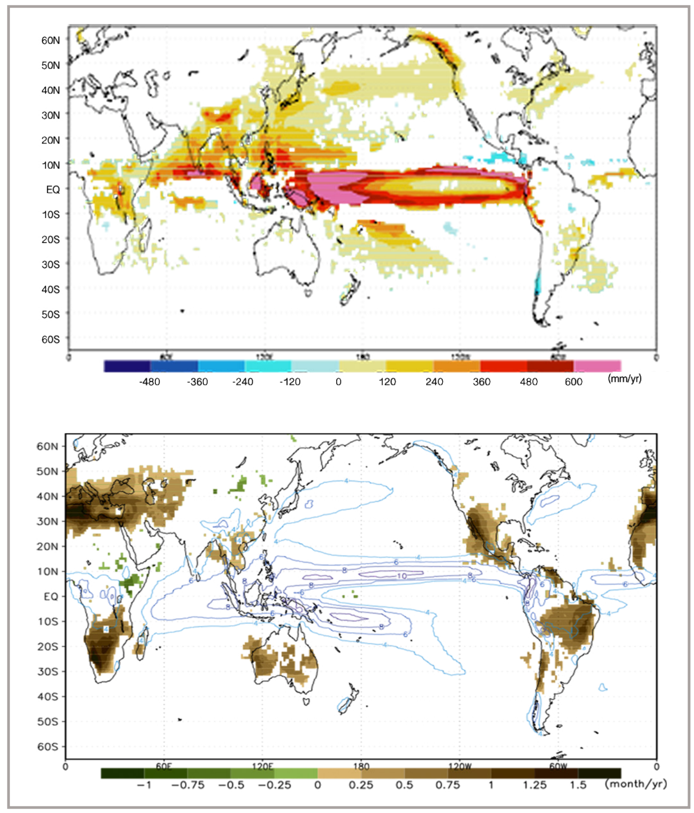
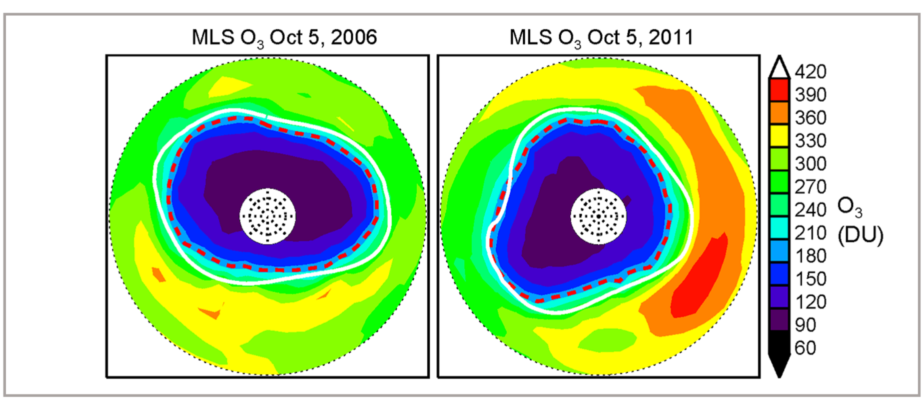
NASA/TM–2014-217517

Atmospheric Research 2013 Technical Highlights







May 2014

Cover Photo Captions

UPPER LEFT

ER-2 X-band Radar

The ER-2 X-band Radar (EXRAD) was installed on NASA ER-2 at NASA Dryden Flight Research Center. EXRAD is a dual-beam, X-band Doppler radar with one scanned beam (conical or cross-track) and the other beam fixed at nadir. It replaces the old EDOP radar, and it will be used for cloud- and precipitation-oriented field campaigns.

MIDDLE LEFT

New Radar Systems for GPM

A new operations site was secured near Wallops Flight Facility Main Base for the NASA Polarimetric (NPOL) radar and dual-frequency, dual-polarized doppler (D3R) radar to support Global Precipitation Measurement (GPM) ground validation activities, pre- and post-launch, when the radars and supporting instrument infrastructure is not field deployed.

UPPER RIGHT

Comparison of Intergovernmental Panel on Climate Change Models

An analysis of projections from 14 IPCC global climate models under a one-percent increase per year of CO_2 emission scenario found a robust, canonical global response in rainfall characteristics. The top panel shows the projected CO_2 global-rainfall anomalies for heavy rain, and the bottom panel shows prolonged drought. The contours indicate the model's climatological rainfall.

BOTTOM

Antarctic Ozone Hole Comparison

Aura Microwave Limb Sounder (MLS) measurements show that the Antarctic ozone (O_3) hole in 2011 appears similar to the 2006 O3 hole, the largest hole ever observed. But ClO, a reactive chlorine gas responsible for ozone depletion, was unexpectedly 20% lower in the O_3 hole in 2011 than in 2006. Temperatures were low in both years, and the small decrease expected in chlorofluorocarbons between 2006 and 2011 is too small to explain this result.

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NASA STI Program ... 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 plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and 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 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 co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, 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 also include organizing and publishing research results, distributing specialized research announcements and feeds, providing help desk and personal search support, and enabling data exchange services. For more information about the NASA STI program, see the following:

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Dear Reader:

Welcome to the Atmospheric Research 2013 Atmospheric Research Highlights report. This report, as before, 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 atmospheric research science highlights and summaries of our education and outreach accomplishments for calendar year 2013.

This report covers research activities from the Mesoscale Atmospheric Processes Laboratory, the Climate and Radiation Laboratory, the Atmospheric Chemistry and Dynamics Laboratory, and the Wallops Field Support Office under the Office of Deputy Director for Atmospheres (610AT), Earth Sciences Division in the Sciences and Exploration Directorate of NASA's Goddard Space Flight Center. The following are some noteworthy events that took place during 2013:

- GSFC scientists and engineers, led by Si-Chee Tsay, participated in the international field campaign, the Seven Southeast Asian Studies/Biomass-burning Aerosols and Stratocumulus Environment: Lifecycles and Interactions Experiment (7-SEAS/BASELInE), to study aerosol-cloud interaction along the "river of smoke aerosols" from near-source regions over northern Thailand-Laos-Vietnam to receptor areas of Hong Kong.
- Scott Braun and Paul Newman led another successful Hurricane and Severe Storm Sentinel (HS3) campaign during the 2013 hurricane season, collecting unprecedented data from the Global Hawk (GH) that will be used to improve understanding of the processes that control hurricane formation and intensity change.
- During May and June, Walt Petersen and scientists from the Iowa Flood Center, University of Iowa, carried out a successful field campaign, Iowa Flood Studies (IFloodS), in eastern Iowa to evaluate the accuracy of flood forecasting models and validate the GPM retrieval algorithms of precipitation measurements from space.

Code 610AT scientists also played key roles in numerous other field campaigns. These included: (1) the ER-2 Polarimeter Definition Experiment (PODEX) in Southern California, which evaluated and compared a new class of polarimeter instruments to measure aerosols and clouds; (2) the DISCOVER-AQ completed the third year of a four year campaign to make a series of flights with NASA aircraft over Houston and the San Joaquin Valley to measure gaseous and particulate pollution; (3) the DragonEye campaign flew an in-situ sulfur dioxide sensor package on NASA's small, unmanned aircraft system (sUAS) to study the chemical environment of the plume spewing from Turrialba Volcano, near San Jose, Costa Rica; (4) the Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC4RS) campaign over the Gulf of Mexico in August and September designed to better understand the coupling between pollution and deep convection; and (5) the Studying the Interactions Between Natural and Anthropogenic Emissions at the Nexus of Climate Change and Air Quality (SENEX) campaign to investigate the formation mechanism of organic aerosol over the southeastern United States.

Code 610AT scientists received many top professional honors and appointments during the year. PK Bhartia was awarded the American Meteorological Society (AMS) 2014 Remote Sensing Prize; Warren Wiscombe was elected a Fellow of the American Geophysical Union; Ginger Butcher, Edward Celarier, and Eric Nash won a 2013 Communicator Award for Excellence in Print and Design from the International Academy of the Visual Arts; Paul Newman co-chaired of the SAP (Scientific Assessment Panel) for the Montreal Protocol assessment of the ozone depletion; and Tiffany Moisan was featured in the 2013–2014 Women in Optics Annual Calendar in honor of her work in the remote sensing and laboratory research of ocean color properties as it relates to phytoplankton ecology. The second edition of the book entitled Intraseasonal Variability in the Atmosphere-Ocean Climate System by William Lau and Duane Waliser (JPL) [2012] made the list of the top 25-percent most downloaded eBooks in the relevant Springer Collection in 2013.

The year was a time to bid farewell to James Irons who served as the Deputy Associate Director of Atmospheric Sciences and became the new Deputy Director for Hydrospheric and Biospheric Sciences. Arthur Hou, Project Scientist for the Global Precipitation Measurement (GPM) mission, lost a long battle to pancreatic cancer. Arthur's presence, leadership, generous personality, and the example he set for all of us as a true team player will be greatly missed. He was selected, posthumously, as a fellow of the American Meteorological Society in 2013.

We also bid farewell to Robert Cahalan who retired after many years as Chief of the Climate and Radiation Laboratory, to David Starr who retired as Chief of the Mesoscale Atmospheric Processes Laboratory and who also served as validation scientist for the NASA Earth Observing System (EOS) Project Science Office, and to Warren Wiscombe who served as a senior scientist in the Climate and Radiation Laboratory following a research career in Earth radiation science. We also said farewell to Faye Richardson who retired after many years as a resource analyst for the Atmospheric Laboratories. We thank all of these retired employees for their years of service to NASA and Atmospheric Research programs and projects.

I am pleased to welcome civil servant scientists Kyu-Myong Kim (aerosol-climate interactions), Robert Levy (aerosol remote sensing), and Anne Thompson (atmospheric chemistry). We also welcome Carol Holcombe in her new position as resource analyst to replace Faye Richardson. The scientific and administrative expertise of all these new employees will help us continue to advance our science programs for many years.

This report is being published in two media: a printed version and an electronic version on our Atmospheric Science Research Portal 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.

William K.-M. Lau,

Deputy Director for Atmospheres

Earth Sciences Division, Code 610

April 2014

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1. INTRODUCTION

Atmospheric research in the Earth Sciences Division (Code 610) consists of research and technology development programs dedicated to advancing knowledge and understanding of the atmosphere and its interaction with the climate of Earth. The Division's goals are to improve understanding of the dynamics and physical properties of precipitation, clouds, and aerosols; atmospheric chemistry, including the role of natural and anthropogenic trace species on the ozone balance in the stratosphere and the troposphere; and the radiative properties of Earth's atmosphere and the influence of solar variability on the Earth's climate. Major research activities are carried out in the Mesoscale Atmospheric Processes Laboratory, the Climate and Radiation Laboratory, the Atmospheric Chemistry and Dynamics Laboratory, and the Wallops Field Support Office. The overall scope of the research covers an end-to-end process: starting with the identification of scientific problems, observation requirements for remote-sensing platforms, technology, and retrieval algorithm development; leading to flight projects and satellite missions; and eventually, resulting in data processing, analyses of measurements, and dissemination from flight projects and missions. Instrument scientists conceive, design, develop, and implement ultraviolet, infrared, optical, radar, laser, and lidar technology to remotely sense the atmosphere. Members of the various Laboratories 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 developing the next-generation Earth system models. Satellite missions, field campaigns, peer-reviewed publications, and successful proposals are essential at every stage of the research process to meeting our goals and maintaining leadership of the Earth Sciences Division in atmospheric science research. Figure 1.1 shows the 19-year record of peer-reviewed publications and proposals among the various Laboratories.

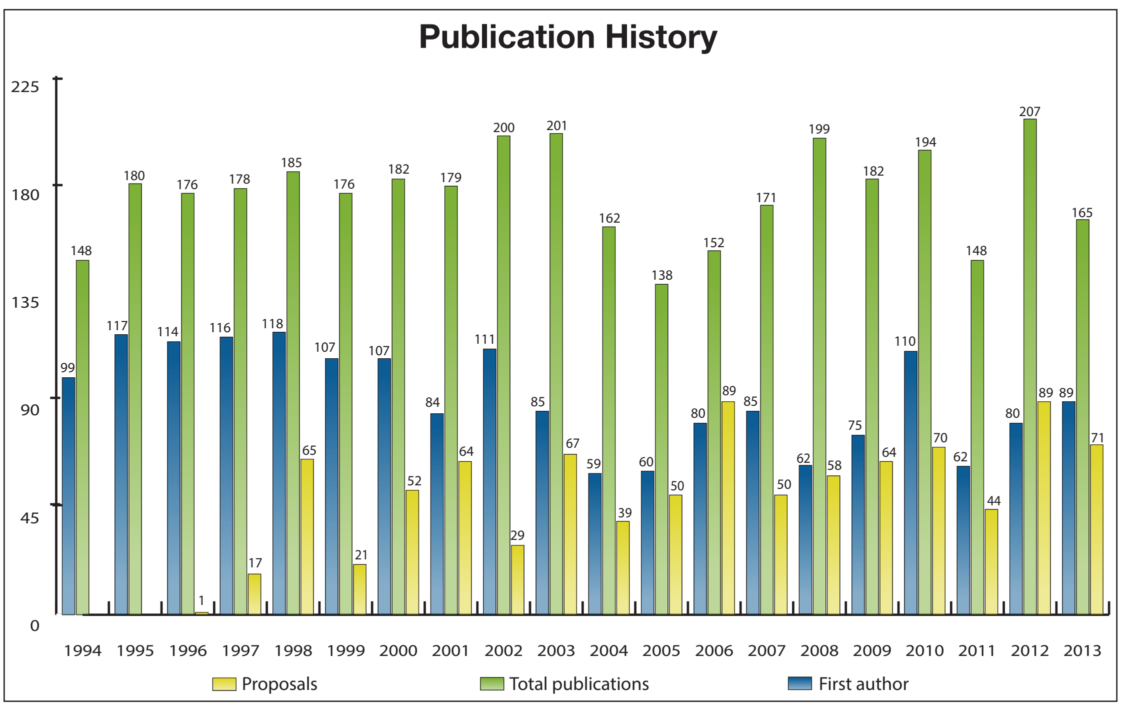

Figure 1.1: *Number of proposals and referred publications by Atmospheric Sciences members over the years. The green bars are the total number of publications and the blue bars the number of publications where a Laboratory member is first author. Proposals submitted are shown in yellow*

This data shows that the scientific work being conducted in the Laboratories is competitive with the work being done elsewhere in universities and other government agencies. The newly created office of Deputy Director for Atmospheric Research will strive to maintain this record by rigorously monitoring and promoting quality while emphasizing coordination and integration among atmospheric disciplines. Also, an appropriate balance will be maintained between the scientists' responsibility for large collabora tive projects and missions and their need to carry out active science research as a principal investigator. This balance allows members of the Laboratories to improve their scientific credentials, and develop leadership potentials.

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. Members of the Laboratories interact with the general public to support a wide range of interests in the atmospheric sciences. Among other activities, the Laboratories raise 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 Atmosphere Laboratories make substantial efforts to attract and recruit 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, provides highlights of our research scope and activities, and summarizes our scientists' major accomplishments during calendar year 2013. The composition of the organization is shown in Figure 1.2 for each code. This report is published in a printed version with an electronic version on our atmospheres Web site, http://atmospheres.gsfc.nasa.gov/.

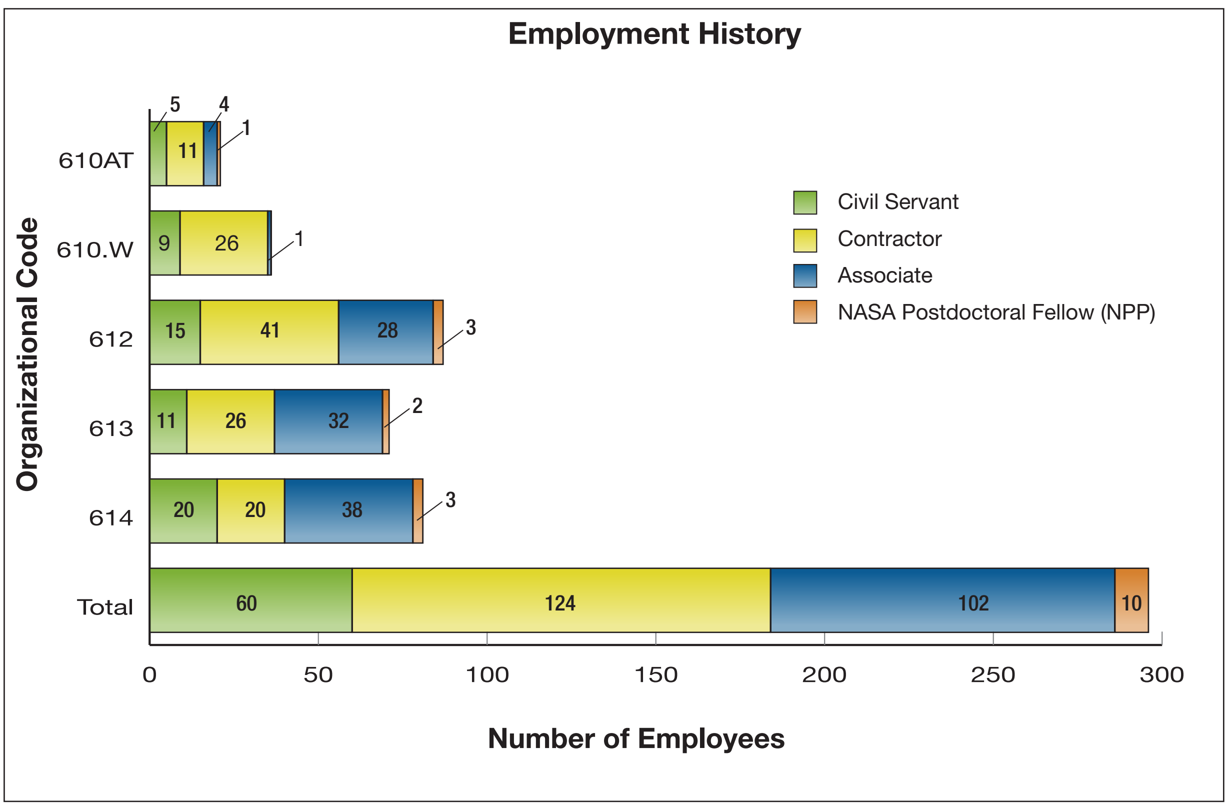

Figure 1.2: Employment composition of the members of Atmospheric Sciences.

2. SCIENTIFIC HIGHLIGHTS

Atmospheric research at Goddard has a long history, studying the atmospheres of both the Earth and the planets for more than 40 years. The early days of the TIROS and Nimbus satellites (1960s–1970s) emphasized ozone monitoring, Earth radiation, and weather forecasting. Planetary atmosphere research with the Explorer, Pioneer Venus Orbiter, and Galileo missions was carried out until around 2000. In recent years, EOS missions have provided an abundance of data and information to advance knowledge and understanding of atmospheric and climate processes. Basic and crosscutting research is carried out through observation, modeling, and analysis. Observation data is provided through satellite missions as well as *in situ* and remote-sensing data from field campaigns. Scientists also focus their efforts on satellite mission planning and instrument development. For example, feasibility studies and improvements in remote-sensing measurement design and technology are underway in preparation for the planned decadal mission recommendations made in the *Decadal Survey* by the National Academy of Sciences in 2007 (http://www.nap.edu/catalog.php?record_id=11820). The following sections summarize some of the scientific highlights for the year 2013. The individual contributors are named at the end of each summary. Additional highlights and other information may be found at the website: http://atmospheres.gsfc.nasa.gov.

2.1. ESD Atmospheres

AIRS Impact on Tropical Cyclone Forecasting in the GEOS-5

The representation of a tropical cyclone in global analysis is of paramount importance to the quality of the forecast. Tropical cyclone forecasting depends on the quality of the analysis, which relies on the initial conditions used to generate the forecast. Assimilation of AIRS clear-sky radiances, the procedure currently implemented in most operational centers, only makes use of channels unaffected by clouds. This poses a severe limitation to the spatial distribution of the data in proximity of tropical cyclones. The impact of AIRS retrievals and radiances has been investigated in a long series of experiments with the NASA GEOS-5 Data Assimilation and Forecast System. The experiments have shown that the impact of AIRS cloudy retrievals on global forecast skill is greater than that of clear sky radiances (e.g., Reale et al. 2012). In addition, a number of event-specific studies have shown a dramatic forecast-track improvement for the devastating tropical cyclone Nargis in the GEOS-5 (Reale et al. 2009), an improvement in precipitation produced by different tropical cyclones (Zhou et al. 2010), and a drastic improvement in the 7-day forecast of the extreme rainfall that contributed to the Pakistan floods of 2010 (Reale et al. 2012). This study shows that an available NASA product, the quality-controlled AIRS retrievals obtained in presence of clouds (now version 6), can substantially improve tropical cyclone forecasting. ***(Oreste Reale, William K. M. Lau, and Joel Susskind)***

2.2. Mesoscale Atmospheric Processes Laboratory

The Mesoscale Atmospheric Processes Laboratory seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. The Laboratory conducts research on the physical and dynamic properties, and on the structure and evolution of meteorological phenomena—ranging from synoptic scale down to microscales—with a strong focus on the initiation, development, and effects of cloud 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. The Laboratory also plays a key science leadership role in the Tropical Rainfall Measurement Mission

(TRMM), launched in 1997 and still operating, and in developing the Global Precipitation Measurement (GPM) mission concept. Another central focus is developing remote-sensing technology and methods to measure aerosols, clouds, precipitation, water vapor, and winds, especially using active remote sensing (lidar and radar).

Highlights of Laboratory research activities carried out during the year are summarized below. An electronic version of the full highlights may be found on the Mesoscale Atmospheric Processes Laboratory Web site, http://atmospheres.gsfc.nasa.gov/meso/science/index.php?year=2013.

The Hurricane and Severe Storm Sentinel (HS3)—Initial Findings From 2012

There is frequent debate within the hurricane research and operational communities about the impact of Saharan air, with some treating it as a major suppressor of hurricane formation and intensification and others holding that it is very difficult for the dry air to get into the circulation in such a way as to impact intensity. Observations needed to evaluate this process have been difficult to obtain previously, but the Global Hawk provides a new capability for mapping large regions of a storm and its environment. The goal of the HS3 mission is to improve understanding of the processes that control hurricane formation and intensity change and to determine better the relative roles of the large-scale environment and smaller-scale processes in the inner-core region of storms (i.e., the eyewall and rainbands).

Five flights were conducted in 2012 during Hurricane Nadine. All data are from the environmental Global Hawk carrying the Cloud Physics Lidar (GSFC) the Scanning High-resolution Interferometer Sounder (University of Wisconsin), and the Advanced Vertical Atmospheric Profiling System (NOAA/NCAR). Initial findings include: (1) while dry Saharan air was found in the immediate environment, there is no evidence that it penetrated the storm sufficiently to directly impact storm intensification, (2) Nadine maintained a well-defined warm core and upright vortex despite strong shear and cool sea-surface temperatures, and (3) when shear weakened, convection redeveloped and Nadine re-intensified into a hurricane. ***(Scott Braun)***

Improving Precipitation Forecasts with a New Data Assimilation System

It is a scientific challenge to effectively use remotely-sensed precipitation observations in numerical weather prediction (NWP) systems to improve precipitation forecasts and extend prediction capabilities in hydrological applications. In most current NWP systems, over 75% of satellite observations are not used due to complicated effects of clouds and precipitation to radiance signals. A state-of-the-art ensemble data assimilation system, the Goddard WRF-EDAS, has been developed with a focus on assimilation of precipitation-affected microwave radiances at cloud-resolving scales. This work establishes the viability of a cloud-scale ensemble data assimilation system capable of effectively assimilating precipitation-affected radiances with flow-dependent forecast error covariance, non-linear observation operators and microphysical variables in the control vector. Microwave radiances from TRMM, TMI, and AMSR-E were assimilated to evaluate system performance and assess the data impact on precipitation forecasts. Forecasts were validated against independent precipitation observations from a ground-based radar network. Ensemble assimilation of precipitation-affected radiances improved the quality of precipitation forecasts in terms of spatial distribution and intensity in accumulated surface rainfall in flooding regions. The ensemble provides a vehicle for optimal utilization of satellite precipitation information at cloud-resolving scales for climate reanalysis and hydrological applications. ***(Sara Q. Zhang, Arthur Y. Hou, and Xin Lin)***

Minimum Precipitation Rates Detectable By GPM

What is the minimum precipitation rate that NASA's Global Precipitation Measurement (GPM) satellite and constellation of sensors will be able to detect? To answer this question, we compared data from the

Department of Defense's Special Sensor Microwave Imager/Sounder (SSMIS) sensor, which has similar channels to GPM's microwave imager (GMI) and other constellation sensors, to NOAA's National Mosaic and Quantitative Precipitation Estimate (NMQ) ground radar-based precipitation product. Findings included:

- The minimum detectable rate varies by sensor and surface type, but is generally between 0.25 and 1 mm/hr.
- Oceans and bare ground have the smallest detectable rates, followed by snow-covered ground and coastlines.
- Detection can be improved if ancillary data regarding atmospheric temperature and water vapor profiles and snow cover status are used.

(S. Joseph Munchak and Gail Skofronick-Jackson)

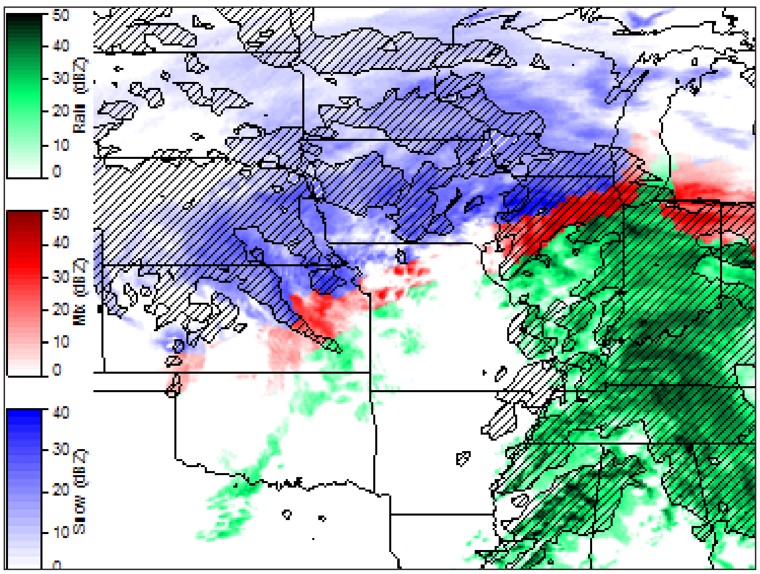

Figure 2.1: Ground mosaic surface reflectivity from a winter storm on December 8, 2009, is overlaid with precipitation detection (hatched area) from an SSMIS overpass. The contour overlay represents the precipitation detection threshold corresponding to a precipitation rate of 0.25 mm/hr. Some regions of snowfall over the upper Midwest are missed at this threshold, while some false detection (associated with snow covered ground) is evident over western Nebraska and North Dakota. Changing the threshold can result in detection of lighter precipitation rates, but at the expense of more false detections.

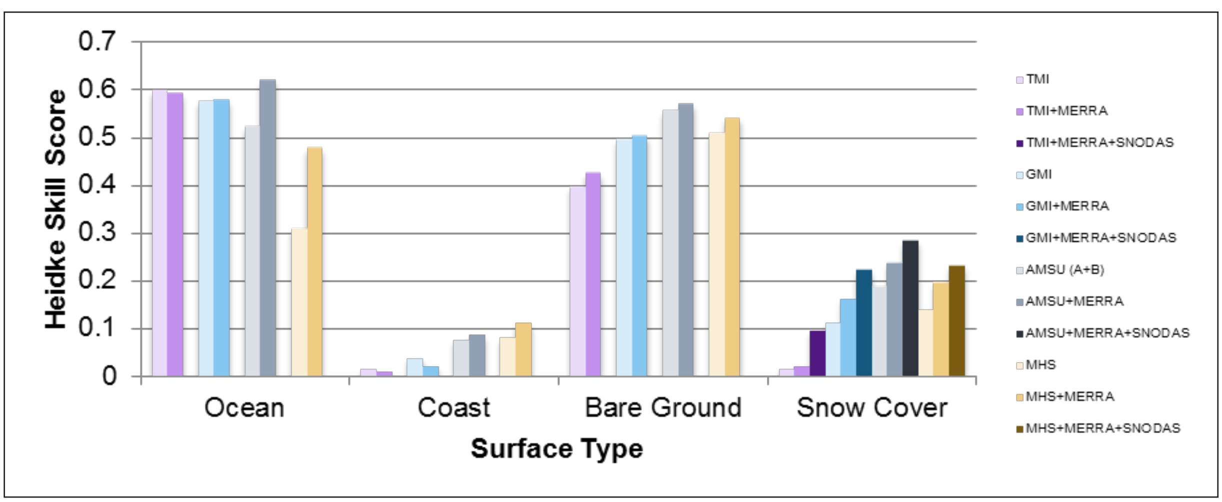

Figure 2.2: Relative precipitation detection skill over various surfaces and impact of ancillary data regarding atmospheric temperature and water vapor profiles (from MERRA reanalysis) and snow cover (from SNODAS) is shown for four passive microwave sensors: TMI, GMI, AMSU, and MHS.

First Flights of ER-2 X-band Radar—EXRAD

The ER-2 9.6 GHz X-band Doppler Radar (EXRAD) is a new radar that replaces the aging ER-2 Doppler Radar (EDOP) that has flown on the NASA ER-2 since 1992. EDOP has participated in numerous field campaigns for process studies and satellite validation, and EXRAD will carry on some of this activity. EXRAD has all the capabilities of EDOP, plus it has a conical or cross-track scanning beam in addition to a nadir beam. The characteristics of EXRAD make it ideal for studying all types of precipitation systems. EXRAD provides a unique capability to study weather events such as deep convection and hurricanes, or other types of weather such as frontal systems. Previous High-altitude Imaging and Rain Airborne Profiler (HIWRAP) measurements have already determined that attenuation and multiple scattering can be large in severe, land-based storms with hail. EXRAD will experience less attenuation in these cases and can therefore provide less ambiguous information than the GPM frequencies for these extreme events. EXRAD flies in the ER-2 nose and can be part of a multi-sensor process oriented field campaign. EXRAD will provide precipitation structure and wind measuremnts that are important for process-oriented field campaigns and for validation of satellite measurements. One example of the latter is the PACE Decadal Survey mission where the ER-2, along with EXRAD and a representative airborne radiometer, can provide empirical relationships between reflectivity or rain rate with millimeter-wave radiometer brightness temperatures. ***(Gerald Heymsfield)***

Exploring Local Land-Surface Feedbacks into Regional Circulation

General circulation models (GCM) are typically coupled to a single land-surface model (LSM). New versions of coupled modeling systems incorporate new physics in both models, making it difficult to isolate signals from the new LSM physics. We used the free-running Goddard Multi-Scale Modeling Framework (MMF) coupled with the multi-model Land Information System (LIS) to see if subtle changes to a LSM would feedback into the atmosphere at regional scales and how quickly that would happen. The Goddard MMF-LIS is a GCM with arrays of 2-D cloud-resolving models that replace moist physics parameterization, allowing true, global, cloud-resolving capability. The tested LSM is the NCAR Common Land Model (CLM) 2.0 and its update, the CLM 2.1. Both incorporate improvements in the soil-to-atmosphere heat transfer but not in other areas. By using both models in LIS, it is possible to have identical initial atmospheric conditions. Differences in regional pressure patterns due to local feedback among the shortwave radiation fluxes, land surface heat fluxes, and total cloud cover emerged after 10–14 days. Improved representation of the water and energy cycles is critical to global weather and climate simulation. The MMF-LIS explicitly accounts for kilometer-scale cloud and land-surface processes. This model framework concept shows promise for improving the simulation of global precipitation and thus atmospheric circulations at multiple scales without significant increases in computational overhead. ***(Karen Mohr, Jiun-Dar Chern, and Wei-Kuo Tao)***

What Surface Snow Rate Can be Detected from Space?

The GPM core satellite, in conjunction with a constellation of microwave sensors from international partners, will provide instantaneous precipitation estimates over 90% of the globe with a 3-hour or less revisit time. This research provides information on what snow rates can be detected from the various passive channels on the GPM Core satellite as well as the constellation satellites. To address this problem, 2-D cloud resolving simulations of a lake effect and synoptic snow storm, modeling the brightness temperatures and reflectivities of GPM instruments was used. Methodologies were developed to estimate thresholds of detection and to convert columnar ice water path and surface ice water content to melted snow rates for 11 non-spherical snowflake shapes and various fall speeds. For GPM, detection of melted snow rates range from 0.5–1.0 mm h^{-1} with minimums to 0.1 mm h^{-1} under ideal assumptions. For future missions to capture the full spectrum of rain and snow rates, instrument specifications need to be examined and algorithm retrievals improved. ***(Gail Jackson)***

New Capabilities for Cloud and Aerosol Measurements—ACATS

Cloud and aerosol properties have a significant influence on the Earth's climate system. Obtaining an accurate assessment of cloud and aerosol properties and their influences on the atmospheric radiation budget remain a major challenge in understanding and predicting the climate system. The Airborne Cloud-Aerosol Transport System (ACATS) is a lidar system that is both a Doppler lidar and a high spectral resolution lidar (HSRL), allowing for simultaneous measurements of cloud and aerosol properties as well as particle motion. The ACATS data products have a large range of applications to significant climate system issues, such as examining cirrus optical properties and convective outflow in tropical storms, assessing dust and smoke transport, and investigating cloud-aerosol interactions and radiative effects. ACATS could contribute to future space-based missions by advancing component technologies and by producing an airborne instrument directly applicable to prototyping and validation for NASA's Cloud-Aerosol Transport System (CATS), Aerosol-Cloud-Ecosystem (ACE) and 3-D Winds missions. For example, the current algorithm development for ACATS data products will be used for algorithm development of the International Space Stations (ISS) CATS instrument. ***(John E. Yorks)***

Structure of Heavy Precipitation over California

The Global Precipitation Mission (GPM) will use a combination of active and passive remote-sensing techniques to study precipitation in mid-latitudes from space. This study uses data from Advanced Microwave Scanning Radiometer for EOS (AMSR-E), ground-based radars, and advanced numerical weather prediction and satellite simulator models to study the microphysical properties and vertical structure of precipitation over complex terrain in the western United States. The research addresses a key NASA Precipitation Measurement Missions science topic: to use advanced spaceborne sensors to gain physical insights into precipitation processes. Using both spaceborne and ground-based observations, we investigated the impact of four widely used microphysics schemes in WRF model on precipitation scattering signature, reflectivity, and Doppler velocity. We also obtained in-depth insights regarding assumptions related to particle size distribution, shape, fall velocity, and their relationship to remote sensing quantities for the four schemes in WRF. Methodologies developed to simulate those remote-sensing quantities could be contributed to a larger scientific community. The use of existing NASA satellites to evaluate the performance of a sophisticated numerical weather model will contribute to Agency's goal of improving weather prediction of extreme events. ***(Mei Han)***

Successful Forecasting of Propagating Precipitation Events by the NASA Unified-Weather Research and Forecasting Model

The diurnal variation of precipitation processes in the United States is well recognized but incompletely understood. A regional high-resolution model was used to conduct a series of real-time forecasts during the Midlatitude Continental Convective Clouds Experiment (MC3E) in 2011 over the Southern Great Plains (SGP). This study utilized a model dataset to investigate one type of diurnal precipitation variation generated by eastward-propagating MCSs, that are responsible for a majority of warm season precipitation in the central United States, from the lee side of the Rocky Mountains into the SGP. The study evaluated model simulations with regard to rainfall using observations and assessed the impact of microphysics, surface fluxes, radiation and terrain on the simulated diurnal rainfall variation. The model ably captured most heavy precipitation events. When all forecast days are composited, the mean forecast will depict accurate, propagating precipitation features and thus the overall diurnal variation. The results indicated that the high-resolution NASA Unified-Weather Research and Forecasting model (NU-WRF) is capable of simulating the diurnal variation of precipitation. The study also identified the key processes (e.g., microphysics) needed to improve rainfall forecasts. Statistical comparisons with ground measurements (e.g., radar and rain gauge) over the field campaign period (over a month) provided insights on evaluating the model physics and identifying biases and therefore on improving overall model predictability. ***(Wei-Kuo Tao)***

Predicting GPM Signals with the GPM Satellite Simulator

Global Precipitation Measurement (GPM) mission will detect rainfall rate globally approximately every three hours using an international constellation of satellites. Before its launch (February 2014), first generation GPM Core precipitation algorithms must be established, particularly for areas outside the current TRMM range. To support Core precipitation algorithm development, the Synthetic GPM Satellite Simulator integrates GPM Ground Validation (GV) observations, regional high-resolution storm simulations from cloud-resolving models, and GPM instrument simulators (forward modeling). The simulator can be utilized initially to construct virtual algorithm testbeds and simulated GPM orbital testbeds to diagnose the performance of pre-launch precipitation algorithms. It uses a comprehensive regional storm model with detailed microphysics, constrained by the best possible *in situ* and aircraft measurements from the GPM GV field campaigns. Precipitation process studies and the first generation of GPM Core Satellite precipitation algorithms are being generated from this unique combination of data and models. The simulated orbital data include detailed, retrieval-like geophysical parameters, such as rainfall rate, column water vapor, surface skin temperature, and moments of precipitation PSDs derived from the WRF-SBM. These geophysical parameters are then processed in the forward modeling with the same antenna convolution method in the GMI and DPR modules. Thus, the satellite sensor-observable signals and algorithm-retrievable geophysical parameters are sampled in identical footprints within the same dataset, allowing algorithm scientists to quickly assess their retrieval algorithm products. After the launch of the GPM core satellite, this software can be also used for data assimilation or radiance-based evaluation in cloud-precipitation process of mesoscale atmospheric models. ***(Toshi Matsui)***

Techniques for Improving Water Vapor Trend Detection Using Raman Lidar

As atmospheric temperatures increase due to increasing greenhouse gases, the atmospheric concentration of water vapor is expected to increase as well. These increases have already been reported in the literature. Given that water vapor is a more infrared active gas than carbon dioxide, this water vapor feedback exerts a larger radiative forcing than CO_2 itself. In fact, the IPCC reports that the contribution of water vapor feedbacks to anticipated warming is actually 50 percent of the total warming due to atmospheric gases. Two international networks are using Raman lidar as one of the techniques for monitoring atmospheric water vapor trends. Our recent research indicates the following: (1) to improve detection of trends in upper tropospheric (UT) water vapor, it is much more important to increase the frequency of measurement than to decrease the uncertainty of measurements; and (2) this result implies that Raman water vapor lidar is a viable tool for UT trend detection. There are two sources of systematic bias that significantly influence Raman water vapor lidar data and need correction with high accuracy: (1) a common wet bias that is observed in the UT and lower stratosphere, and (2) the temperature dependence of the Raman water vapor spectrum which introduces an altitude dependent bias in the Raman lidar water vapor measurements. Implementation of published corrections increases the accuracy of upper tropospheric Raman lidar water vapor measurements making them suitable for atmospheric trend detection purposes. ***(David N. Whiteman)***

Evaluating Light-Rain Drop-Size Estimates from Multi-Wavelength Micropulse Lidar Network Profiling

In the context of cloud-resolving models, raindrop size crucially affects the dynamics of the simulated systems and in particular the time scale of latent heating release. The latter is an essential component of the cumulus parameterizations used in large-scale circulation models. Previous multi-frequency, ground-based Doppler radar techniques have attempted to measure rain and drizzle droplets size. However, an ambiguity arises because the measured mean Doppler velocity has a significant contribution from the vertical velocity of the air, and rain rate and drop size retrieval are unambiguous only if the rain rate is known *a priori* to be greater than 6 mm/hr. This means that Doppler radars (even using three frequencies) cannot provide a sufficient accurate drop size measurement for light rain and drizzle. A new technique was developed to retrieve the size of light rain and drizzle drops using backscatter ratio measurements from dual wavelength lidar. The technique is based on a previously published method that was successful, but it required *a priori* knowledge of rain type (cold rain, warm rain, etc.) to initiate the algorithm and utilized a non-standard lidar wavelength pair in the near-infared. The new technique is applicable to both warm and cold rain processes, requires no a priori algorithm assignments, and utilizes standard YAG laser wavelengths (UV/VIS) available in many lidar instruments worldwide, thus applying to a greater number of existing lidar sites. ***(S. Lolli)***

MABEL Flights out of Langley Research Center Support ICESat-2 Algorithm Development

The Multiple Altimeter Beam Experimental Lidar (MABEL) instrument completed an extremely successful flight campaign over vegetation, water and calibration targets in Maryland, Virginia, and North Carolina. MABEL flew aboard the Scaled Composites Proteus aircraft using four science flights to collect over 20 hours of high-quality science data during September 2013. MABEL uses a multi-beam photon counting technique to measure elevation and surface brightness over vegetation canopies, the Chesapeake Bay, Ocean City, SERC, and WFF runways (calibration). The campaign was the first successful concentrated MABEL deployment designed to produce vegetation canopy data for algorithm development for ICESat-2. The signal acquired by the photon-counting technique to be employed by ICESat-2/ATLAS differs significantly from the signals acquired during ICESat/GLAS and so new analysis techniques and algorithms are required. MABEL closely simulates the data expected from the ICESat-2/ATLAS instrument in both spatial and temporal formats. During the next few years MABEL will be used for fundamental science associated with ice, snow, and perhaps vegetation in support of ICESat-2 and other missions. ***(William B. Cook)***

2.3. Climate and Radiation Laboratory

One of the most pressing issues humans 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 Laboratory. Accordingly, the Laboratory has 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 updated regularly on the Code 613 Laboratory Web site: http://atmospheres.gsfc.nasa.gov/climate/.

Key satellite observational efforts in the Laboratory include MODIS and MISR algorithm development and data analysis, SORCE solar irradiance (both total and spectral) data analysis and modeling, and TRMM and ISCCP data analysis. Leadership and participation in science and validation field campaigns provide key measurements as well as publications and presentations. Laboratory scientists serve in key leadership positions on international programs, panels, and committees, serve as project scientists on NASA missions and principal investigators on research studies and experiments, and make strides in many areas of science leadership, education, and outreach. Some of the Laboratory research highlights for the year 2013 are described below. These cover the areas aerosol-cloud-precipitation interactions, aerosol effects on climate, reflected solar radiation, land-atmosphere feedback, polar region variations, and hydrological cycle changes. The Laboratory also carries out an active program in mission concept developments, instrument concepts and systems development, and Global Climate Models (GCMs). The "Projects" link on the Climate and Radiation Laboratory Web site contains recent significant findings in these and other areas.

The study of aerosols is important to Laboratory scientists for many reasons: (1) Their direct and indirect effects on climate are complicated and not well-quantified; (2) Poor air quality due to high aerosol loadings in urban areas has adverse effects on human health; (3) Transported aerosols provide nutrients such as iron (from mineral dust and volcanic ash), important for fertilization of parts of the world's oceans and tropical rainforests; and (4) Knowledge of aerosol loading is important to determine the potential yield from the green solar energy sources.

Highlights of Laboratory research activities carried out during the year are summarized are below. An electronic version of the full highlight may be found on the Atmospheric Chemistry and Dynamics Laboratory Web site, http://atmospheres.gsfc.nasa.gov/acd/science/index.php?year=2013.

Discrimination of Biomass-Burning Smoke and Clouds in the MAIAC Algorithm

Current satellite retrievals from the multi-spectral pushbroom radiometers MODIS and VIIRS have very limited ability for the aerosol type discrimination and no skills to provide aerosol absorption information. In this work, we developed a "smoke" test which reliably detects aerosols absorbing in the visible part of spectrum, such as biomass-burning smoke and dust; bright smoke plumes from strong fires are often masked as clouds. The"smoke" test can reliably discriminate biomass-burning aerosols from clouds based on MODIS data (*Lyapustin et al.,* 2012). This test relies on a relative increase of aerosol absorption at MODIS wavelength 0.412 μm as compared to the 0.47–0.67 μm region due to multiple scattering and enhanced absorption by organic carbon released during combustion (e.g., *Russell et al*., 2010). The Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm makes aerosol retrievals from MODIS data at 1-km resolution. This information is required in different applications such as urban air quality analysis, aerosol source identification etc. This general principle has also been successfully used in the OMI detection of absorbing aerosols based on UV measurements (*Torres et al.*, 2007). Aerosol absorption is one of the most important and least known climate-forming factors. An accurate detection and characterization of the biomass burning aerosols is critical for improvement of our understanding of aerosol radiative and climate effects. The importance of studying this interaction is highlighted in the *Decadal Survey* and is a goal for the future NASA missions such as ACE. ***(A. Lyapustin, S. Korkin, Y. Wang, B. Quayle, and I. Laszlo)***

Hemispheric Impacts of Regional Anthropogenic Emissions of Aerosols

Aerosols can influence climate in several ways, but our current understanding is far from complete. An assessment as to how emission changes influence aerosol radiative forcing is therefore important. Compelling satellite evidence of aerosol intercontinental transport (ICT) suggests that regional emission reductions could have far reaching impacts on radiative forcing in downwind regions and continents. A task force on Hemispheric Transport of Air Pollution (HTAP) was established in 2005 by the United Nations. The task force organized a comprehensive international assessment activity on the ICT of air pollution in Northern Hemisphere that involved multiple modeling studies on source attribution and source-receptor relationships. An ensemble of 9 HTAP global models was used to assess the change of global and regional aerosol optical depth (AOD) and direct RF in response to the 20% reductions of anthropogenic emissions from four major polluted regions in the Northern Hemisphere and the role of ICT (Yu et al., 2013). Emissions for polluted regions exerted significant forcing on intercontinental and even hemispheric scales. Local emissions remain the main contributor in the four regions, but the import via ICT is significant. North America is substantially influenced by the import of black carbon from East Asia, while South Asia is substantially influenced by the import of sulfate from Europe. The result from this study shows that the import from intercontinental transport is significant, although local emissions remain the main contributor. ***(Hongbin Yu)***

Aerosol Indirect Effect on Tropospheric Ozone via Lightning

Human activity has increased the concentration of aerosols in the atmosphere. These tiny, airborne particles can act as cloud condensation nuclei, and changes in their concentration can therefore affect cloud development. In this study (Yuan et al., 2012) and a previous study (Yuan et al., 2011) we found unequivocal evidence that aerosols increase lightning activity of convective clouds. The rate at which lightning increases with aerosols is remarkable: lightning flash rates can increase up to 30 times per unit of aerosol optical depth. Lightning flash rate increases produce more ozone precursors such as nitrogen oxides (NO_x), particularly in the upper troposphere. Since NO_x in the upper troposphere is normally insufficient for active ozone production, lightning induced NO_x helps boost tropospheric ozone production in that part of the atmosphere, where ozone is a potent greenhouse gas. Thus, ultimately anthropogenic aerosol increase leads to more production of tropospheric ozone in the upper troposphere via increasing lightning. Using NASA satellite data and a NASA chemical transport model, we were able to demonstrate this chain reaction and show this new aerosol effect. The lightning increase due to aerosols can feedback to biomass burning since in the mid- to high- latitude regions wild fires are primarily initiated by lightning strikes from dry convection. Our results for the first time demonstrate that there is a link between aerosol, lightning, and tropospheric ozone via cloud microphysical processes. This link also has implications for lightning variability and future climate change. ***(Tianle Yuan, L. A. Remer, H. Bian, J. Ziemke, R. Albrecth, K. Pickering, L. Oreopoulos, S. Goodman, H. Yu, and D. Allen)***

Dust Shape Matters for Sedimentation and Vertical Structure

Dust aerosol has irregular shape, making its optical properties different from spherical aerosols. Does the particle shape also affect dust property variations along the altitude and their evolution during transport? Particles of more irregular shape experience more air-resistance; therefore their sedimentation may be slower, which may cause them stay at higher altitudes for a longer time as compared to spherical-like particles. Recent CALIPSO observations on vertical distribution of Saharan dust particulate depolarization ratio (noted as δ hereafter) over nine regions provide supportive evidence that dust shape does play an important role in sedimentation and, consequently, induces shape-dependent stratification during transport. This ratio is important as it can reveal particle irregularity. For example, while δ is close to zero for spherical particles, it is typically much larger for irregular dust particles. The larger δ values at higher altitudes and higher δ lapse-rate as dust leaves further away from its source clearly indicate the progressive preponderance of aspherical particles at higher altitudes during westward transport. By analyzing CALIPSO depolarization measurements, this study provides the first observational evidence that particle shape is a significant factor in the dust sedimentation process. Since the light-scattering properties of particles are strongly related to particle shape, our results imply that the dust optical properties are vertically inhomogeneous during transatlantic transport. Considering this stratification can help accurate estimations of dust radiative properties and radiative impacts. ***(W. Yang, A. Marshak, T. Várnai, and A. Kostinski)***

A Novel Technique to Retrieve Cloud Ice Water from Microwave Humidity Sounder

Ice water path (IWP) is a key variable to determine cloud radiative and thermodynamic properties in Earth climate systems. Substantial uncertainties remain among IWP measurements from satellite sensors, largely due to the different assumptions made about cloud microphysics in the retrievals. In this study, we develop an IWP retrieval algorithm from the Microwave Humidity Sounder (MHS) high-frequency channel radiances constrained by CloudSat Cloud-Profiling Radar cloud ice measurements. The retrieved IWP provides CloudSat-consistent measurements of ice water amount in thick, dense ice clouds and floating snows. The IWP retrieval from this empirical algorithm is consistent with CloudSat in terms of cloud ice map and normalized probability density distribution (PDF). Mesoscale model simulations suggest that MHS-observed IWP in the tropics is mostly precipitating ice, which can be used to infer floating snow precipitation in the future. This novel algorithm substitutes traditional 89 GHz channel with 183.3 GHz channels, the latter of which is not sensitive to water clouds and less sensitive to surface signals. Therefore, this algorithm is fast, reliable, and highly consistent with CloudSat measurements, yet out performs CloudSat because of its wide swath-width, long-time duration, and frequent daily sample rate. ***(Jie Gong and Dong L. Wu)***

Eyjafjallajökull Volcano Plume Particle-type Characterization From Space-based, Multi-angle Imaging

At any one time, about a dozen volcanoes are erupting somewhere on Earth. Although the ash particles and gases emitted can affect the local and regional environment as well as global climate, most active volcanoes are unmonitored, except by space-borne instruments. So extracting as much information as possible from satellite data is a priority. The NASA Earth Observing System's Multi-angle Imaging SpectroRadiometer (MISR) viewed Iceland's Eyjafjallajökull volcano during its spring 2010 activity, a series of eruptions that curtailed air traffic over Europe, and brought at least the immediate potential hazards of such events to public attention. Plume heights derived from MISR's stereo observations show particles injected to over 6 km at times during the five weeks of activity. The MISR INteractive eXplorer (MINX) software was used, a program that generates high-quality heights and wind vectors for any image features that can be identified in multiple, angular views (Figure 2.3).

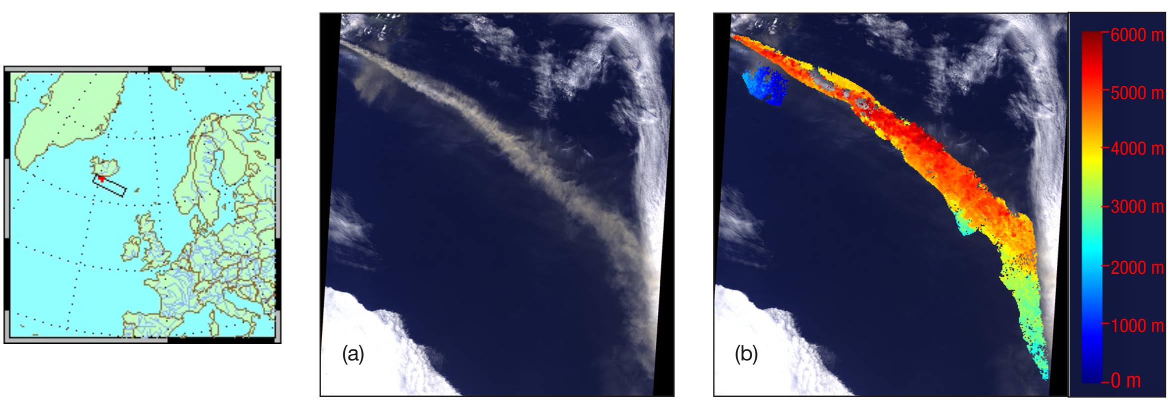

Figure 2.3: Map of the plume's location. (a) MISR true-color image of the Iceland volcanic plume on May 7, 2010, with map inset. (b) Plume height, in meters, derived from MISR multi-angle stereo imagery using the "MINX" algorithm. Note the near-surface (blue) plume of re-mobilized ash blown toward the southwest.

Maps of retrieved aerosol optical analogs, indicating that the volcanic plume contains much greater fractions of non-spherical and larger particles than the background aerosol are shown in Figure 2.4. Using the MISR Research Aerosol Retrieval algorithm, we pushed the information-content limits of the MISR data, demonstrating the ability to map detailed volcanic plume structure for several events. The plume particles are distinct from background – much more abundant, more angular, and larger in size. The analysis also provides some indication that the plume particles evolve as they age, becoming brighter and decreasing in average size. The MISR global data record extends over more than 13 years, offering the potential for systematic studies of volcano environmental impacts. This work is also relevant to future missions that aim to advance our ability to quantify aerosol impacts on climate, notably the ACE mission, but also CLARREO, GeoCAPE, and OCO-2, that must account for aerosols when retrieving carbon dioxide abundances. ***(Ralph Kahn)***

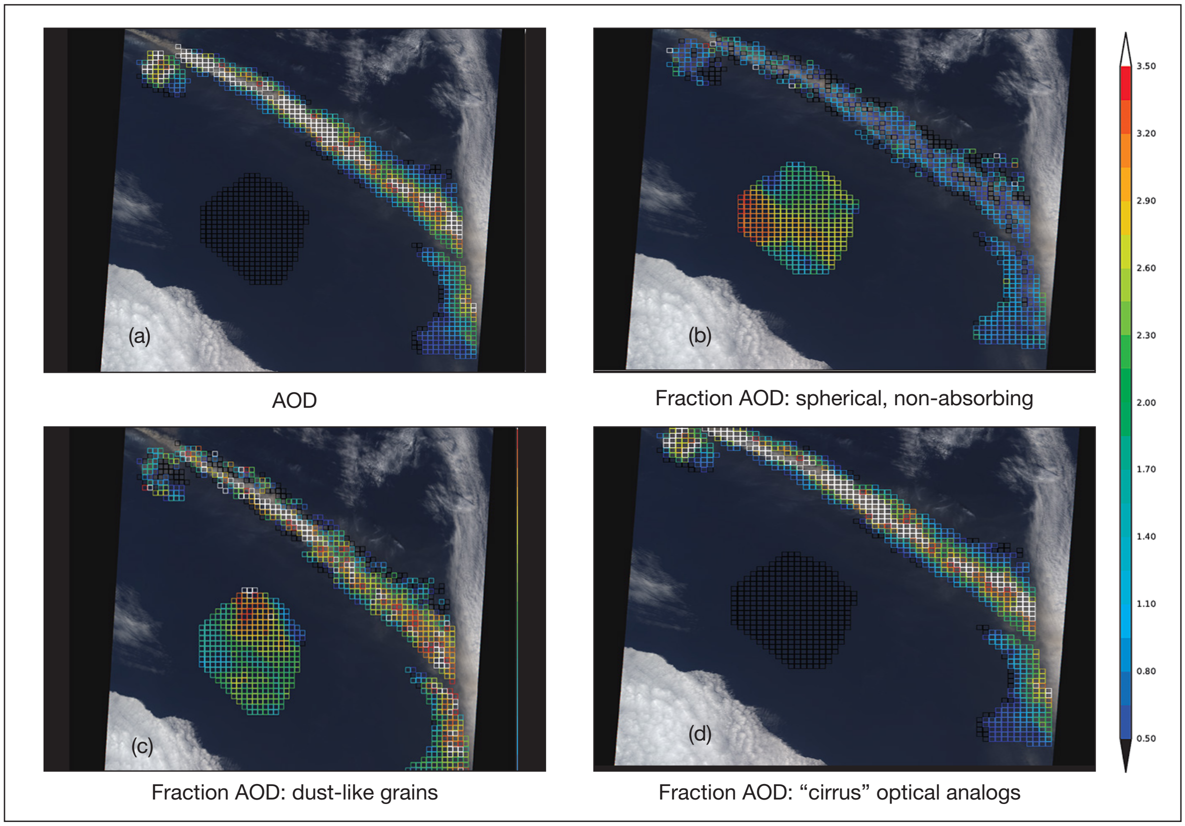

Figure 2.4: Four panels showing MISR particle property retrieval results for the May 7 plume: (a) Aerosol amount (AOD). Fraction AOD of: (b) spherical non-absorbing; (c) medium dust-like angular grains; and (d) large, non-spherical "cirrus" optical analogs.

Water Vapor Modulation by the Sun: Bottom-Up or Top-Down

Water vapor (H_2O) is a highly variable greenhouse gas. A ~10% decrease in stratospheric water vapor since 2000 was reported and thought as a potential contributing factor to climate change, slowing the increase in global surface temperature (Solomon et al., 2010). Discerning the influence of the solar forcing in atmospheric water vapor variations is an exciting task. Analysis of Microwave Limb Sounder (MLS) observation suggests an increase of stratospheric H_2O with solar cycle. MLS observations reveal a complex H_2O response. The "top-down" pathway starts with insolation increase in Lyman-α (121.6 nm), which decreases mesospheric H_2O by ~20% by photolysis (Zhou et al., 2013), and then descends down to the stratosphere via the wintertime polar vortex (Lee et al., 2013). In the "bottom-up" pathway, H_2O in the stratosphere originates from the troposphere, either directly or through methane oxidation, a principal source of stratospheric H_2O. Increased ozone and OH during solar maximum produce more than 8% of the H_2O enhancement via this reaction. An experiment with the Goddard Earth Observing System chemistry-climate model (GEOS CCM), using the Naval Research Laboratory (NRL) spectral solar irradiance model, simulates a consistent water vapor decrease in the mesosphere and an increase in the stratosphere, but with smaller amplitudes than those estimated from observations. Understanding the complex responses of the water vapor to solar variations is a challenging problem but essential to assess climate variability. The H_2O response pattern near the tropopause (10–20 km) shows a positive signal in the upper troposphere and negative signal in lower stratosphere, which is similar to that from El Niño Southern Oscillation (ENSO), and warrants further investigation of causes and effects. ***(Jae N. Lee)***

New MODIS 3-km Product Provides Insight about Urban Aerosol Retrieval Biases

The MODIS instruments aboard the Terra and Aqua satellites have provided a rich dataset of aerosol information at a 10-km spatial scale. However, routinely monitoring urban air quality remains a challenge, particularly in the developing world where *in situ* measurements are sparse or non-existent. The relatively coarse scale of AOD measurements does not adequately resolve small-scale sources of pollution. The MODIS 3-km product is a large step forward towards matching the scale of observations to the scale needed to measure aerosols for air quality applications. The 3-km product was evaluated over the Baltimore-Washington, D.C., corridor in the United States during the summer of 2011. Excellent agreement was observed between MODIS and AERONET AOD at sites outside the urban areas but an overestimation of AOD was observed in urban areas. There is evidence that a significant source of bias observed in the 3-km product results from improper characterization of urban surfaces. The poor performance is clearly a limitation in terms of air quality applications. Improved characterization of surface reflectance is required in urban areas and over moderately vegetated brighter surfaces. The VIIRS instrument aboard NPP slated for launch on JPSS can employ an algorithm that is very similar to MODIS to retrieve aerosols. This would provide an excellent opportunity for creating long-term data records, and monitoring change in aerosol over urban regions. ***(Leigh Munchak)***

Aerosol Observations under Thin Cirrus from MODIS

Aerosols are tiny particles suspended in the atmosphere and play a significant role in the Earth's energy budget (e.g. IPCC, 2007). These particles can reflect and absorb solar energy and act as cloud condensation nuclei. Due to their diverse sources (both natural and anthropogenic) and short lifetime (~few days), satellite observations with near or full daily global coverage are a priority for aerosol-climate studies. The Moderate Resolution Imaging Spectroradiometer (MODIS) has been providing information about aerosols over the globe for more than a decade. However, this information has been limited to cloud-free areas, hindering us from seeing more complete picture of aerosols including radiative forcing in the presence of clouds, particularly over Southeast Asia where the frequency of thin cirrus occurrence is as high as 50%. Recently, we have successfully performed aerosol retrievals under thin cirrus to help mitigate this limitation. The results apply over ocean areas, but this methodology can also be applied to land areas. This technique recovers the aerosol information under thin cirrus and reduces cloud contamination in aerosol retrievals compared to the original algorithm. Recent findings suggest that MODIS-like sensors can provide aerosol information above clouds, and this study adds information below transparent cirrus clouds, which can help to improve our understanding of the radiative forcing of aerosols. ***(Jaehwa Lee)***

Rain Characteristics and Large-Scale Environments of Extreme Wet Precipitation Systems from TRMM Measurements

One of the most fascinating characteristics of rainfall is the large scale range: the smallest precipitation features (PF) occupy less than a single satellite footprint or a few kilometers, while the largest ones span thousands of kilometers in space. Grouping contiguous satellite rainy footprints as independent PFs and then sorting out millions of them according to their total rain volume permitted a study of rain characteristics with different total rainfall during the 14-year TRMM period over the global tropics and subtropics. The results showed the statistical distribution, rain structure, and regional differences of PFs with extreme volumes of precipitation in tropical and subtropical land and oceans, and also illustrated their development stages and associated large-scale environments. The study illustrates important roles of large-scale moisture and dynamic conditions for occurrences of extreme precipitation. It has been widely accepted that increasing moisture in the atmosphere is a major mechanism for increasing extreme precipitation in a warming climate. This study shows a consistent increase of total rainfall volume with the increase of total precipitable water in the real world that confirms this connection. It further implies that more extreme precipitation events are likely to occur in a warmer climate when atmosphere moisture content is higher. ***(Yaping Zhou)***

How do Clouds Overlap? New Insights from Active Satellite Observations

Thin, high clouds and low boundary-layer clouds are two important cloud types for the Earth's radiation budget. Thin, high clouds trap outgoing thermal infrared (IR) radiation and thus exert a net warming effect since they have only a minor influence on solar radiation. Low boundary-layer clouds, on the other hand, strongly impact reflected solar radiation while only weakly changing the thermal IR radiation emitted to space, and therefore cool the planet. A variety of evidence suggests that these vertically well-separated cloud types often coexist in the same geographic area. In this type of high-over-low cloud overlap, the net radiative impact of the two cloud types as seen from space largely cancels out. Detecting multi-layer cloud systems from space is extremely difficult with passive radiometers measuring reflected solar radiation or emitted thermal infrared radiation. Active space sensors, namely lidars and cloud-precipitation radars are much more capable in discerning complex vertical cloud structures. In a recent paper the global features of high-over-low cloud overlap using observations from the CloudSat and CALIPSO satellites carrying radar and lidar instruments, respectively were studied. Near-global maps of cloud overlap rate can be produced and we found three major regimes of overlap that exhibit seasonal variations due to circulation shifts. Other intriguing results were also found and the results should be reproducible by Global Climate Models claiming good cloud simulations. ***(Tianle Yuan and Lazaros Oreopoulos)***

2.4. Atmospheric Chemistry and Dynamics Laboratory

The Laboratory 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. This 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. The Laboratory also is a leader in the integration and execution of the NPP mission, and is also providing leadership for the former NPOESS, now the newly reorganized Joint Polar Satellite System (JPSS). This group has also developed a state-of-the-are chemistry-climate model, in collaboration with the Goddard Modeling and Analysis Office (GMAO). This model has proved to be one of the best performers in a recent international chemistry-climate model evaluation for the stratosphere. Highlights of Laboratory research activities carried out during the year are summarized below.

Bay Breeze Circulations Magnify Surface Air Quality and Boundary Layer Venting

This study shows that bay breeze circulations are capable of transporting a significant amount of air pollution from the planetary boundary layer to the free troposphere, which has implications on climate and air quality. Observations during the DISCOVER-AQ field campaign and model simulations with the WRF meteorological and CMAQ air quality models showed an area where winds initiated on the western coastline of the bay created a strong temperature gradient between the relatively warm land and cool water surfaces called the bay breeze convergence zone. This strong surface convergence caused pollutant concentrations to accumulate and thus magnify air pollution to unhealthy levels. Strong vertical mixing allowed surface pollutants to be transported to the top of the boundary layer where they were horizontally advected toward a region with a shallower planetary boundary layer. Pollutants that enter the free troposphere gain a longer lifetime, are susceptible to long range transport, and can degrade air quality far away from the emissions sources after they subside back down into the planetary boundary layer. Future research will examine how these large spatial gradients impact deposition into terrestrial and aquatic ecosystems and spatial requirements for developing future satellites. ***(Christopher P. Loughner, Maria Tzortziou, Melanie Follette-Cook, and Kenneth E. Pickering)***

High Spatial Resolution Trace-gas Measurement Results from ACAM during DISCOVER-AQ

Current process understanding from satellite remote sensing is based on low earth orbit (LEO) measurements, which afford one sample per day at a given location in mid latitudes (often obscured by clouds). Key processes, however, occur on relatively short time scales: e.g., dispersal of point emissions, diurnal photochemistry, planetary boundary layer growth and decay that are not accessible from LEO observations. The Airborne Compact Atmospheric Mapper (ACAM) has recently flown onboard NASA's Langley Research Center's King Air aircraft in support of the DISCOVER-AQ program. The instrument views sunlight that is back-scattered from the atmosphere below the aircraft and can determine the abundance of trace-gas molecules in it's field of view by examining the absorption features in the measured spectrum. The high spatial resolution of the measurements allows us to correlate our values with both ground-based and other airborne "point" or *in situ* measurements, and larger area satellite-based mapping instruments. We have found that, particularly for NO_2, the satellite measurements can miss large horizontal gradients in the trace-gas distribution, which makes it difficult to validate those measurements against ground-based observations in polluted areas. However, by careful registration of the ACAM measurements to both the ground and satellite instruments, we can transfer the *in situ* measurements to the satellite. This work is most closely linked with future geostationary chemistry measurements needed to make the connection between local and global-scale processes. ***(Scott J. Janz)***

Evolution of the 2012 Antarctic Ozone Hole

Presently, we have a good understanding of the distribution and behavior of total column ozone. However, our knowledge of the vertical ozone distribution is limited, particularly in the lower stratosphere. The new OMPS Limb Profiler combines the high vertical resolution of occultation-type instruments with the high spatial coverage of nadir-type instruments. First results show the evolution of the 2012 Antarctic ozone hole. Total ozone near the center of the ozone hole declined throughout September of 2012 (Fig. 1a) as ozone values were depleted in the 15-km to 22-km layer to values less than 1 ppmv (Fig. 2.5). This depletion greatly sharpened the vertical ozone gradient at 22 km by October 1. The ozone concentration in the lower stratosphere reached a minimum about two weeks after the minimum in total column ozone. Total column ozone began to increase after October 1 because of the descent of high ozone concentrations to lower altitudes. These results demonstrate the ability of the OMPS Limb Profiler to detect strong variations in the ozone vertical distribution. The data will be used to continue monitoring the Earth's ozone layer and to improve understanding of the vertical ozone distribution, particularly in the lower stratosphere. Data from the OMPS Limb Profiler will advance our knowledge of the ozone vertical distribution and help to understand past trends in the vertical ozone profiles. As a result, the predictive capability of future ozone changes will be highly improved. ***(Natalya Kramarova)***

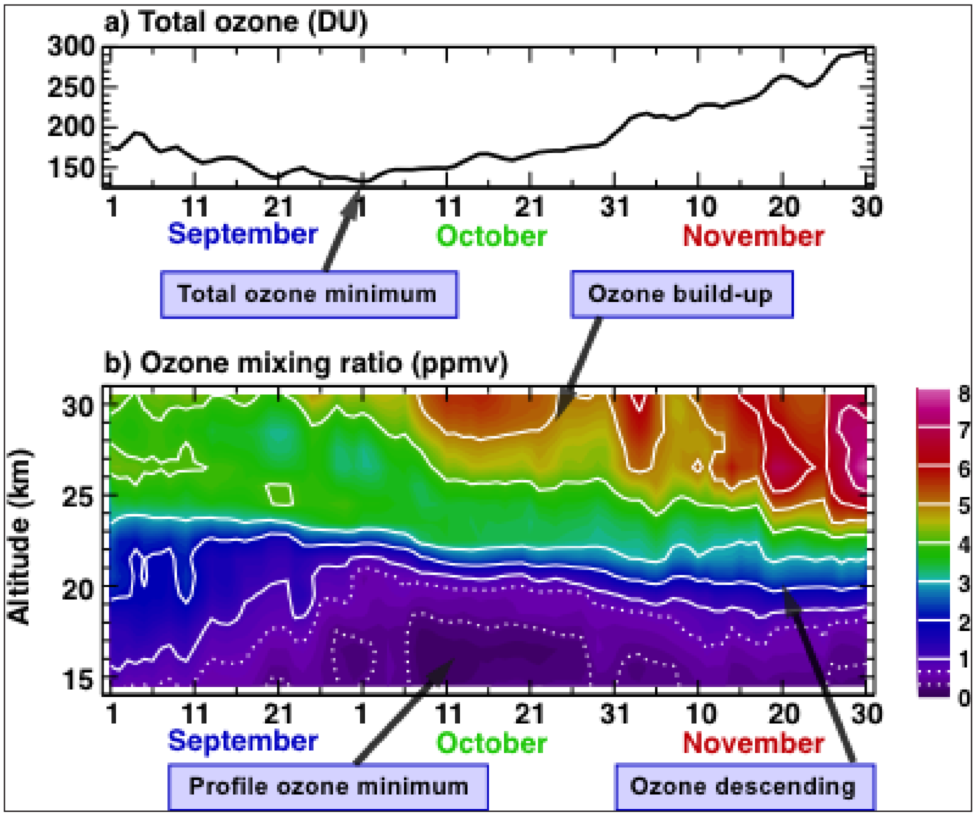

Figure 2.5: Daily time series of satellite ozone measurements near the center of the Antarctic ozone hole during the Southern Hemisphere spring of 2012 (September-November). Panel (a) is the time series of total ozone values (DU) observed by OMPS Total Column Mapper showing ozone depletion in September and its gradual recovery in October and November. Panel (b) shows the evolution of the ozone vertical distribution (ppmv) measured by the OMPS Limb Profiler in the middle and lower stratosphere. In October, while the ozone concentration in the lower stratosphere continues to decline, a strong ozone build-up occurs in the middle stratosphere. Sharp vertical gradients caused by the ozone loss are observed between 20 km and 25 km.

Attribution of Sources of Pollution to the Western Arctic during the NASA ARCTAS Field Campaign

The Arctic is a region particularly sensitive to climate change. There is an urgent need to better understand changes in Arctic atmospheric composition and its feedback on climate; potential warming of the Arctic could reduce ice cover and release methane from permafrost, both of which would accelerate global warming. Most of pollutants found in Arctic air have been transported from middle latitudes, and a large fraction is attributable to anthropogenic and biomass burning emissions. We used DC-8 airborne measurements of CO from ARCTAS-A and ARCTAS-B in combination with tagged CO tracers simulations in GEOS-5 to investigate potential pollutant sources and their transport to and within the Western Arctic. About one-third of the mean of the Western Arctic CO in both campaign periods came from background CO produced by CH_4 oxidation. The remainder, in April, was impacted mostly by Asian Anthropogenic emissions, and biomass burning. In July, both Asian and boreal biomass burning had comparable contributions to the mean CO. We also found that European sources seldom made important contributions to the CO during the campaign domain and period. Studying the Arctic is challenging partially due to lack of measurements there from traditional passive instruments such as MODIS and MISR onboard NASA satellites. Lidar technology used in current satellite CALIPSO and a future satellite mission concept called ACE will fill this gap but the potential contamination due to the Arctic complex surface conditions needs to be addressed. ***(Huisheng Bian)***

DISCOVER-AQ San Joaquin Valley California Winter 2013 Campaign

DISCOVER-AQ completed its second deployment in a series of four airborne campaigns aimed at improving the use of satellite observations to diagnose near-surface air quality. The target was California's central valley during winter where cold, stagnant conditions encourage the accumulation of fine particles to reach unhealthy levels. Airborne sampling was conducted in coordination with ground monitoring sites operated by the state and local air pollution agencies. The NASA P-3B conducted spiral profiles for *in situ* aerosol and trace gas data collection over six of these sites and two additional missed-approach airport sites, each of which was outfitted with AERONET sun photometers for aerosol optical depth (AOD) measurements. The NASA King Air carried a High Spectral Resolution Lidar (HSRL) for observations of aerosol optical properties and their vertical distribution. The first five flights documented a period of pollution build-up as particulate levels in the southern end of the valley tripled. A second period of build-up was observed with the remaining flights. Similarity exists in the trends of the two measurements, which is encouraging for the applicability of observations of AOD from the satellite to surface air quality. An important factor in these intense pollution episodes was the shallowness of the polluted layer, which was almost always limited to the lowest 2000 feet above the surface. Statistical analyses of the data from the California campaign will more formally examine the linkage between surface and column observations, not only for aerosols, but also for the trace gases O_3, NO_2, and HCHO. These analyses will yield information on how well the column measurements from satellite represent surface air quality. ***(Ken Pickering)***

Breakthrough in the Retrieval of Terrestrial Chlorophyll Fluorescence from Space

Remote sensing of terrestrial vegetation fluorescence from space is of interest because it can potentially provide global coverage of the functional status of vegetation. For example, fluorescence observations may provide a means to detect vegetation stress before chlorophyll reductions take place. Although there have been many measurements of fluorescence from ground- and airborne-based instruments, there has been scant information available from satellites until our initial work with GOSAT. Since making the first global maps of terrestrial chlorophyll fluorescence in 2011, our group has pioneered a new approach to more accurately retrieve fluorescence with moderate spectral resolution instruments, here applied to the Global Monitoring Ozone Experiment (GOME-2) that flies on EUMETSAT's operational polar-orbiting weather satellites. In morning sunlight, fluorescence is correlated with photosynthesis. Fluorescence measurements provide estimates of instantaneous photosynthesis that are highly correlated with gross primary productivity (GPP). Fluorescence is thus complementary to the greenness signal from reflectance-based vegetation indices that are related to potential photosynthesis. Fluorescence shows declines in photosynthetic activity before reductions in greenness take place and is therefore of interest for precision farming, forestry, terrestrial ecosystem science, and carbon assessment. This work is an important step forward in demonstrating that the health of terrestrial ecosystems can be monitored from space. It will be possible to retrieve fluorescence using the NASA Orbiting Carbon Observatory-2 (OCO-2) to be launched in the next few years. ***(Joanna Joiner)***

The Observed Response of the Aura Ozone Monitoring Instrument: NO_2 Columns to NO_x Emissions over the United States: 2005–2011

In 2011, NASA's Applied Sciences Program created the Air Quality Applied Sciences Team, or AQAST, to serve the needs of American air quality management through the use of Earth science satellite data, suborbital data, and models. To comply with these regulations, emission control devices were installed on power plants, which create a natural experiment to assess the response of the satellite-observed tropospheric NO_2 column to a known change in a power plant's emissions. A study was conducted using Aura Ozone Monitoring Instrument (OMI) data (2005–2011) to understand this response for 55 facilities in the United States. We concluded that it is feasible for responsible government agencies to use OMI NO_2 data to assess changes of emissions from power plants and to demonstrate compliance with environmental regulations, though careful interpretation of the data is necessary. We identified issues that can muddle the facility's signal, such as the seasonal variation of the NO_x lifetime, proximity to other NO_x sources (e.g., urban areas), changes in the regional NO_2 levels, lack of statistical significance, and retrieval issues. Applied research, such as presented here, allows for the identification of deficiencies of the current satellite products for air quality applications, so as to identify future improvements needed to the retrieval and requirements for new satellite missions. ***(Bryan Duncan)***

A Long-Term Data Set of Ozone Measurements from Space

The ozone time series derived from satellites can now be used as far back as 1970. These data can now be used for model testing and for global long-term ozone trend analysis. The annual mean time series comparisons to an ensemble of ground stations show an agreement within ~1% over for almost the whole time period with the bias approaching zero over the last decade. The data set can now be used to assess the quality of individual ground instruments. Ozone has decreased by about 5% over the past 40 years, with most of the decrease occurring in the 1980s. This time series provides the best existing data for trend analysis and model validation. A careful multivariate analysis is being carried out to accurately determine long-term ozone trends and to separate the processes impacting the trends. A long-term, highly accurate series of measurements from space is important in order to establish a baseline to detect the recovery of the ozone layer and confirm model predictions. Data from the operational SBUV/2 instruments will be added to the existing ozone data record, which will allow continued monitoring of the state of the ozone layer. Ozone recovery due to decreasing ODS emissions is predicted to take decades and monitoring this recovery is critical to our understanding of the atmosphere. ***(Gordon Labow)***

Scaling Relationship for NO_2 Pollution and Urban Population Size: A Satellite Perspective

Concern is growing about the effects of urbanization on air pollution and health. Satellite-derived data provide a unique opportunity to investigate the dependence of ambient air pollutant concentration on urban population, and allow assessing population exposure to air pollution on a global scale. Nitrogen dioxide (NO_2), released primarily from combustion processes, is a short-lived atmospheric pollutant that serves as an air quality indicator, and is itself a health concern. The NO_2 data from the Aura Ozone Monitoring Instrument (OMI) are actually "columns", which is defined as the number of molecules of a gas between the satellite instrument and the Earth's surface. Model-simulated vertical distributions of NO_2 were used to derive how much NO_2 in the column is near the surface, or "nose-level". The OMI-derived surface NO_2 data are significantly correlated with independent surface measurements. The OMI-derived nose-level NO_2 concentrations were examined to determine how NO_2 columns, and bottom-up NO_x emission inventories relate to urban population. Surface NO_2 is significantly correlated with population for the three countries and one continent examined in this study. Urban NO_2 pollution, like other urban properties, is a power-law scaling function based on the population size: the NO_2 concentration increases proportionally to population raised to an exponent. The value of the exponent (β) varies by region (e.g., 0.36 for India to 0.66 for China) reflecting regional differences in industrial development and per capita emissions. ***(L.N. Lamsal)***

Unusually Low Chlorine Concentrations in the 2011 Antarctic Vortex

Aura Microwave Limb Sounder (MLS) measurements show that the Antarctic ozone (O_3) hole in 2011 appears similar to the 2006 O_3 hole, the largest hole ever observed. But ClO, a reactive chlorine gas responsible for ozone depletion, was unexpectedly 20% lower in the O_3 hole in 2011 than in 2006. Temperatures were low in both years and the small decrease expected in chlorofluorocarbons between 2006 and 2011 is too small to explain this. The GMI chemistry and transport model was used with MERRA meteorology to calculate how transport and chemistry contributed to the large 2011 O_3 hole. The calculations showed there was much less O_3 loss than in 2006, and that weak transport resulted in a lower O_3 column. Together, less chemical loss and less ozone transport made the 2011 O_3 hole appear deep. Previous research implied that the Montreal Protocol has led to the start of recovery of the ozone hole, but these results show that is not yet the case—the ozone hole depth varies for reasons beyond the removal of ozone-depleting gases emitted by humans. The new understanding of ozone hole dynamics suggests that the role of transport in the delivery of ozone to the Antarctic in winter and spring must be accounted for in the attribution of ozone hole recovery to declining ozone-depleting substances. ***(S.E. Strahan)***

New Algorithm Vastly Improves Measurements of SO_2 Pollution from Space

Sulfur dioxide (SO_2), predominantly emitted from man-made activities, can significantly impact air quality and climate. Advanced sensors including the Ozone Monitoring Instrument (OMI) flying on NASA's Aura spacecraft have been employed to measure SO_2 pollution. However existing algorithms often have substantial noise and biases owing to relatively weak signals and various interferences such as ozone absorption and stray light. We have developed a fundamentally different approach for retrieving SO_2 from satellites It utilizes hundreds of wavelengths available from OMI, and requires only 4–5 minutes to process an entire orbit on a single CPU, which is more than an order of magnitude faster than comparable methods that rely on on-line radiative transfer calculations. The reduced noise and low biases in SO_2 retrievals achieved in the new algorithm will allow SO_2 pollution to be monitored at much greater temporal resolution and will enable the detection of smaller emission sources. This can be particularly important in light of the recent reduction in SO_2 emissions in many regions around the world. The new algorithm has been proposed to reprocess data from the Aura OMI mission. It can be applied to NPP and future JPSS OMPS instruments to ensure SO_2 data continuity from the EOS era. It can also help extend satellite SO_2 data records if applied to other current and future NASA and European missions such as TEMPO, GEO-CAPE, TROPOMI, and GOME-2. ***(Can Li, Joanna Joiner, Nickolay A. Krotkov, Pawan K. Bhartia)***

2.5. Wallops Field Support Office

The Wallops Field Support Office (Code 610.W) supports the Earth science research activities of Code 600 scientists at the Wallops Flight Facility. The Office also conceives, builds, tests, and operates research sensors and instruments, both at Wallops and at remote sites. Scientists in the Office use radars, aircraft, balloons, and satellite platforms to participate in the full complement of Earth science research activities, including measurements, retrievals, data analysis, model simulations, calibration and validation. Office personnel collaborate with other scientists and engineers at Goddard Space Flight Center, other NASA centers, and at universities and other government agencies, both nationally and internationally.

The Office provided instrumentation and scientific research expertise to several NASA missions and field efforts in 2013. An example of radar data collected for use in physical validation of satellite-based precipitation retrievals is shown in Figure 2.6. The data in the figure was collected by the WFF Precipitation Research Facility during the Global Precipitation Measurement Mission (GPM) Iowa Flood Studies (IFloodS) ground validation campaign. IFloodS took place in near Waterloo, Iowa, during May–June 2013. In the right panel, the NPOL and D3R radars are shown as deployed in Traer, Iowa. In the center panel an NPOL plan view scan of returned echo power from the precipitation (i.e., radar reflectivity) is displayed for a storm producing a mix of rain and snow on May 2, 2013. The right-hand panel shows an accompanying range-height scan, or vertical "cut" of the reflectivity and the correlation coefficient from the D3R radar. Lower values of correlation coefficient at close ranges to the radar are observed where there are mixtures of rain, ice and snow occurring both in the cloud and extending to the surface. ***(Walt Petersen)***

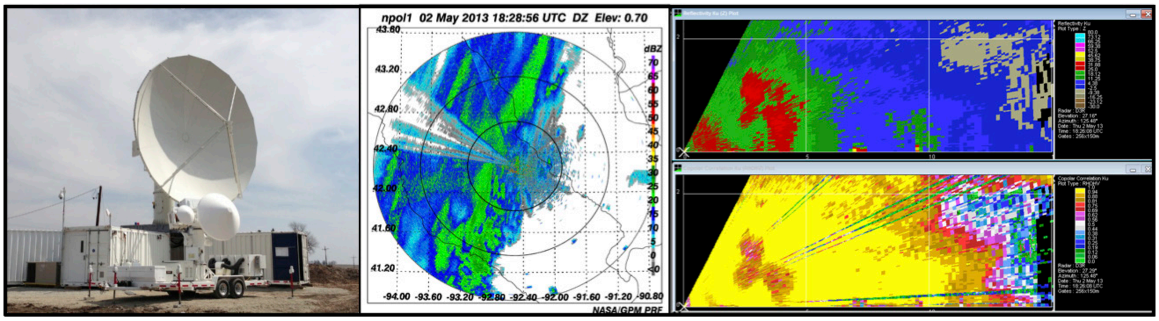

Figure 2.6: The NPOL and D3R radars are shown as deployed in Traer, Iowa.

Phytoplankton Biodiversity: Role in the Carbon Cycle and Climate Change

The link between climate change and biodiversity has long been established. Climate change is already having an impact on biodiversity, and is projected to become a progressively more significant threat in the coming decades. Loss of Arctic sea ice threatens biodiversity across an entire biome and beyond. The goal of this study was to develop algorithms for understanding the ocean's ecosystem with Ocean Color SeaWiFs and MODIS Data. This study describes how biodiversity plays an important role in the carbon cycle. Scientists have created the ability to describe biodiversity using marker pigments with ocean-color satellite remote-sensing data. Biodiversity boosts ecosystem productivity where each species, no matter how small, all have an important role to play. Rapid global warming can affect an ecosystem's chances to adapt naturally. Phytoplankton serves as the base of the food web in the ocean. Phytoplankton is responsible for approximately 50% of the total global photosynthesis. Understanding carbon linkages within the food web require a fundamental understanding of the ocean's dynamics. Understanding phytoplankton community structure is key to understanding climate and its effects on the ecosystem. A scientific paper by Tiffany Moisan, John Moisan, Matthew Linkswiler, and Rachel Steinhardt was published in the Journal of Continental Shelf Research in 2013. ***(Tiffany A. Moisan, John R. Moisan, Matthew Linkswiler, and Rachel Steinhardt)***

Wallops Precipitation Research Facility

Based at Wallops Flight Facility, the Wallops Precipitation Research Facility (WFF-PRF) is designed to provide multi-scale, referenced ground-based radar, disdrometer, and rain gauge-based measurements of hydrometeor properties including size, number concentration, shapes, fall speeds, and water contents for both liquid (e.g., rain) and frozen (e.g., snow) hydrometeors. The resultant PRF network supports fundamental NASA Precipitation Measurement Mission (PMM) science by providing ground-validation measurements of precipitation physical characteristics in the context of testing and improving Tropical Rainfall Measurement Mission (TRMM) and Global Precipitation Measurement Mission (GPM) precipitation remote sensing algorithms. PRF instrument assets include the NASA S-band dual-polarimetric radar (NPOL), the Dual-Frequency, Ka–Ku-band Dual-Polarized Doppler Radar (D3R; transferred to the PRF in late 2013), the TOGA C-band radar, a plethora of video, impact and laser disdrometers, high density autonomous rain gauge networks, a dual-pit gauge reference site located at Wallops, vertically-pointing micro rain radars (K-band; MRR), and snowfall particle imaging and liquid water content measurement systems. When not deployed in remote field campaigns, PRF instruments are stationed in a network around the WFF region as a means to support GPM ground validation, evaluate test instrumentation performance, develop new sampling methodologies, and conduct new PMM science.

During CY 2013, the PRF further developed its GPM ground validation capability by establishing a new NPOL and D3R radar operations site located approximately 40 km north of the Wallops Flight Facility near Newark, MD. When operated in coordinated scan modes the NPOL and D3R are able to conduct relatively unobstructed, triple frequency, flexible volumetric radar data collections over the WFF Main Base and adjacent Eastern Shore region where supporting PRF precipitation measurement networks are deployed. In addition to the Newark NPOL/D3R radar location and WFF main base instrumentation, a new, dense rain-gauge network consisting of 25 autonomously operating dual-rain-gauge platforms was transported northward from Nassawadox, VA, and installed in and around Pocomoke City, MD, to support radar operations and direct satellite validation. In 2014, the ACHIEVE 94-GHz cloud and X-BADGER (9.7 GHz) precipitation radars from GSFC, and a new micro-pulse lidar are expected to join the network and begin studies of coastal aerosol- and cloud-evolution impacts on precipitation. When combined, the datasets will help to connect the dots between precipitation characteristics measured at or from the ground, to cloud and precipitation processes occurring in the atmospheric column observed by the radars, and finally to remote sensing observations of clouds and precipitation made from spaceborne platforms such as GPM. Further information on site instruments, activities, and operations, including images of real-time NPOL data (when operating), or access to disdrometer and rain-gauge network data can be found at: http://wallops-prf.gsfc.nasa.gov/. For further information, please contact Walt ~~Peterson~~: walt.petersen@nasa.gov. ***(Walt Petersen and David Wolff)***

Iowa Flood Studies Field Campaign

During the months of April–June, 2013, the WFF PRF deployed its radar and ground instrumentation to central Iowa in support of the GPM Iowa Flood Studies Experiment (IFloodS). The IFloodS experiment was designed to provide spatially-distributed reference rainfall datasets from advanced rain gauge and multi-parameter radar networks to evaluate satellite-based estimates of rainfall with their associated uncertainties. The reference rainfall estimates function as a benchmark for assessing the utility of satellite products in the framework of multi-scale hydrologic modeling applications related to flood prediction. The PRF managed operations of the NPOL radar, a large suite of disdrometers, and multiple rain gauge networks. Here IFloodS ground-based disdrometers and gauge networks provide point verification of high resolution radar data, the radar data by virtue of its broad coverage providing a translation between point (gauge) measurements and a much broader regional domain suited to satellite validation and hydrologic applications. Data were collected in a wide variety of precipitation regimes ranging from snow to heavy rain associated with summer severe convective storms. Science products produced by the PRF from the combined radar and gauge networks include rainfall maps, grids of hydrometeor types and precipitation size distributions. These products will be used to satisfy GPM GV integrated and physical validation objectives. For further information, please contact Walt ~~Peterson~~: walt.petersen@nasa.gov. ***(Walt Petersen)***

Precipitation Imaging Package (GPM Ground Calibration and Validation)

The Precipitation Imaging Package (PIP) is an instrument that is being developed to enable measurement of frozen precipitation characteristics at field sites that support GPM Ground Calibration\Validation activities. During FY 2013, hardware were specified and purchased and extensive software was developed. Prototype systems are functional in that data is acquired during storms and data products are produced shortly thereafter—all by integrated software that requires no user intervention. A PIP uses a high-speed video camera (~400 fps) to acquire images of precipitation particles. A multi-core (6) PC enables simultaneous video input, logging, and computation of data products such as size distributions and fall speeds. PIP also generates user friendly video files for each minute that display particle motion. A patent application is in progress. In addition to the PIP at the Wallops GPM field site, six PIPs are deployed with collaborators in the United States, Canada, and Finland. For further information, please contact Larry Bilven: francis.l.bliven@nasa.gov. ***(Larry Bliven and Steven R. Long)***

SMART/ACHIEVE

A new calibration tower was constructed for the ACHIEVE 94 GHz radar at WFF in collaboration with the WFF Precipitation Research Facility. A 100-foot telescoping tower configured to carry frequency-appropriate corner reflectors was set up approximately 400 meters from the nominal operations site of the ACHIEVE 94 GHz radar when it is operated at WFF. Use of the tower for regular calibration exercises will support combined multi-frequency radar precipitation, cloud and aerosol interaction studies at WFF relative to assuring radar data quality, and will also support operations of the ACHIEVE facility in future remote field campaigns. For further information, please contact Walt Petersen: walt.petersen@nasa.gov or si-chee.tsay-1@nasa.gov. ***(Walt Petersen and Si-Chee Tsay)***

Airborne Topographic Mapper (ATM)

IceBridge

The ATM lidar instruments based at NASA's Wallops Flight Facility (WFF) have provided climate change scientists with accurate (<10 cm) surface elevation measurements of polar land and sea ice on an annual basis for more than 20 years. In CY 2013, the WFF Airborne Topographic Mapper flew 26 missions aboard the NASA P3B aircraft over Arctic land and sea ice regions. In November 2013, the ATM lidars were onboard the NASA P3 for the historic first P3 deployment to McMurdo Station (landing and taking off from the McMurdo sea ice runway), and successfully collected data during 6 Antarctic missions (the deployment was shortened due to the U.S. Government shutdown). The data from the 2013 Arctic deployment has been processed and uploaded to the National Snow and Ice Data Center (nsidc.org); the Antarctic campaign data is currently being processed. The ATM lidars have successfully collected data on 386 climate change missions since 1993 (including all 269 IceBridge missions since 2009). All ATM lidar data taken since 1993 (with the exception of the 2013 Antarctic data being processed) is available to the public at nsidc.org. For further information, please contact William Krabill: william.b.krabill@nasa.gov. ***(William Krabill and James Yungel)***

ICESat-2

The team at Wallops completed the detailed designs of the ICESat-2 Instrument Support Facility (ISF) hardware and software and the Science Investigator-led Processing System's (SIPS) ATLAS Science Algorithm Software (ASAS). The ISF and ASAS teams presented the detailed designs at the successful Ground System CDR (September 3–5, 2013). During CY 2013, the ASAS team worked with the ICESat-2 Science Development Team to plan the ATBD contents and delivery schedules and attended the reviews of the draft ATBDs. The team released ASAS V0 in December 2013. During the year, the team developed software to process MABEL data and support quick analysis of data from the MABEL science campaigns. As a prototype for ICESat-2, the team developed tools to efficiently develop HDF5 products of the ICESat-1 data. These tools were subsequently used by the Ice Bridge campaigns. During CY 2013, it was determined that the ISF will be located at GSFC in Building 33 SPOCC in the space currently used by LADEE. The

ISF team worked closely with the ATLAS I&T Team to develop specifications for ATLAS performance monitoring and commanding. For further information, please contact Peggy Jester: peggy.l.jester@nasa.gov. ***(Peggy Jester and David Hancock)***

NASA Wallops Wave Tank Facility

By the end of 2013, the NASA Air-Sea Interaction Facility (NASIRF) completed over 37 years in the research of air-sea interactions. The NASIRF Wave Tank and is now in the final stages of being packed into shipping containers for a move to its new home at the University of Washington in Seattle. The disassembly has been intricate due to much of the facility being built and assembled on site. The size of many of the components required an over-sized container for shipping the largest parts. During its operation at WFF, the wave tank produced data under controlled conditions that resulted in dozens of research articles, book chapters, NASA Patents, various awards, and contributions to several MS. and Ph.D. student theses. The move is expected to be finished in February 2014, with assembly beginning in the Harris Hydraulics Lab on the University of Washington campus shortly thereafter. For further information, please contact Steven Long: steven.r.long@nasa.gov. ***(Steven Long)***

Unmanned Aircraft Instrument Integration

Microspectrometer Instrument Suite

Instrument integration of the Wallops Microspectrometer Instrument Suite (MIS) was completed for the "Marginal Ice Zone Observations and Processes Experiment" (MIZOPEX/Maslanik, et al). This experiment was part of a series of unmanned aircraft-based missions aimed to capitalize on miniaturized instrumentation to explore the benefits of these new platforms, particularly for arctic research. The Wallops team created a complete payload package incorporating the MIS combined with instruments from the University of Colorado (BESST, CULPIS) and NOAA (AIS). Field support in Oliktok, AK, was provided by Matt Linkswiler. For further information, please contact Geoffrey Bland: geoffrey.l.bland@nasa.gov. ***(Geoff Bland, Ma tt Linkswiler, Kyle Krabill, Carl Shirtzinger, Ted Miles, and James Yungel)***

In situ Volcano Plume Observations

Three instrument systems were created for volcanic plume measurements of sulfur dioxide using the Dragon Eye, a small, unmanned aircraft provided by NASA's Ames Research Center. These instrument packages were flown as part of a field campaign at Turrialba, Costa Rica, which continued our efforts to compare *in situ* observations with spaceborne observations (e.g.; ASTER, Pieri, et al). The miniature instrument systems were the first new sensors to be integrated in the military surplus, electric-powered aircraft that are now accessible through the Airborne Science Program. For further information, please contact Geoffrey Bland: geoffrey.l.bland@nasa.gov. ***(Geoff Bland and Ted Miles)***

Advancing Earth Research Observation Kites and Tethered Systems (AEROKATS)

Development has continued of numerous instrumented Aeropods incorporating sensor systems for kite-based remote and *in situ* observations. Of particular note was adaptation of the sulfur dioxide instrument package used on the small Dragon Eye UAV to a kite-based configuration. The technique lends itself to tethered balloon-based observations as well. In addition to new instrumentation, new kite and line-handling systems were successfully deployed during the Turrialba, Costa Rica, campaign for *in situ* volcanic plume measurements (Pieri, et al). An effort for licensing of the AEROKATS/Aeropod technology for educational use is now underway with the GSFC Innovative Partnerships Program Office and potential customer. The subject of tethered systems also formed the foundation of the first-ever joint program for the American Institute of Aeronautics and Astronautics (AIAA) and the Association for Unmanned vehicle Systems International (AUVSI)—a special session held during the annual AUVSI conference in Washington, DC. For further information, please contact Geoffrey Bland: geoffrey.l.bland@nasa.gov. ***(Geoff Bland and Ted Miles)***

Remotely Operated Vehicle for Environmental Research (ROVER)

A second year of the Remotely Operated Vehicle for Environmental Research (ROVER) IRAD project enabled students and faculty at the University of Maryland Eastern Shore (UMES) to explore in-water measurements using novel platform systems. A multidisciplinary approach focused on specific coastal research objectives, engaging students and faculty with engineering, aviation sciences, biology, computer science, and technology interests. UMES "externs" were employed to capture details of fabrication and operation in an internet accessible format. Additionally, a significantly improved configuration incorporating lessons learned has been prototyped and tested. For further information, please contact Geoffrey Bland: geoffrey.l.bland@nasa.gov. ***(Geoff Bland and Ted Miles)***

Climate Adaptation Science Investigations

New climate adaptation work was initiated during 2013 as a result of NASA Climate Adaptation Science Investigations (CASI) proposal funding. The desired outcome of CASI work at WFF is to bring clear scientific evidence and insight into the decision making process for the WFF Master Plan and to disseminate these findings to the broader Eastern Shore community to support larger regional-scale climate change adaptation strategies. Scientists Tiffany A. Moisan (PI), Walt Petersen, John R. Moisan, and David Wolff have been working with the WFF master planner and decision makers to develop new strategies for protecting, maintaining, and building NASA WFF infrastructure in the coming years. Additional regional partners in the WFF CASI proposal originated from academic and government institutions to providing sound data towards formidable and creative solutions. The proposed work focuses on data collection, analysis, and modeling to assess and define the impacts of climate-induced changes in sea-level, storm frequency and intensity, and temperature on WFF infrastructure, operations, and coastal environment. For example, sea-level trends described in the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) were used as inputs to a coastal inundation model for assessing inundation risks and infrastructure vulnerabilities along the Wallops Island coastline. In the coming decades, the climate change signal associated with mean temperatures and mean sea-level is expected to dominate the climate variability term, leading to dramatic and policy-relevant shifts in the probability of extreme events. Long-term and risk-management planning can lessen negative outcomes of climate and increase positive outcomes. It is envisioned that results of this project will reveal the vulnerabilities and consequences of damage to NASA property that impose heavy costs on the agency. For further information, please contact Tiffany Moisan: tiffany.a.moisan@nasa.gov. ***(Tiffany Moisan)***

Upper Air Instrumentation Research Project (UAIRP)

Upper air observations continued for the longest sustained operational ozone measuring site at the Wallops Flight Facility. Fifty-two ozonesonde flight events for 6 "routine" weekly and 46 satellite overpass support observations were scheduled. Nine flights had to be rescheduled due to weather or range operations. Three backup sonde flights were required due to either primary or secondary flight system failures. Three scheduled flights were missed due to the furlough. Fifty-three actual balloon releases resulted in 47 successful (i.e., balloon termination altitude surpasses 13 hPa), 2 partially successful (i.e., balloon altitude surpasses the tropopause) flights producing vertical flight profile data sets, and 4 failed flights. Of the actual ascensions, 14 flights were routine observations, 19 supported the satellite A-Train (i.e., AURA, AQUA, TERRA), and 20 instruments supported the Suomi NPOESS Preparatory Project (NPP) satellite. The Ozone Research Facility (ORF) continued in operation with the Dobson spectrophotometer, the ground-based UV radiometer (GUV-51C), and the NovaLynx WS-16 weather station. The Dobson operated a total of 97 "acceptable sky days" for a total of 388 total column ozone measurements. Data acquisition and management continued for the NOAA National Geodetic Survey's Trimble NetRS GPS instrument for the Continuously Operating Reference Station (CORS) network's VAWI site at Wallops. The VAWI instrument sustained high data-rate collection for position and supplemental water vapor data without interruption, operating autonomously during the Federal shutdown. The NILU UV irradiance instrument remained out of service. In the last months of the year, data assessment indicated a failure of the wind speed sensor (cup anemometer) of the NovaLynx system. Operational and resupply planning was completed for a return-to-service of the Natal, Brazil, (Barra de Maxaranguape) ozone observing site, to resume weekly ozonesonde soundings in early 2014, operating under the joint NASA-INPE MOU. The existing support contract was modified to include logistics and processing support for the Natal station in addition to the ongoing Wallops site operation. For further information, please contact Larry Bliven: francis.l.bliven@nasa.gov. ***(Larry Bliven and Tom Northam)***

Ecosystem Modeling

In 2012, a project was jointly funded by NASA Headquarters and The Gordon and Betty Moore Foundation to develop a method of using genetic programming to model the microbial diversity of the ocean. This is a 3-year project to create an artificial intelligence capability that is able to evolve systems of coupled differential equations. Initial development of the code has been completed and is configured to carry out the initial "twin-experiments" necessary to validate the code's ability. This is a very abstract, large-payoff effort that can potentially be made use of for development of other NASA science needs, such as algorithm development. Presently, the effort has completed the initial twin-experiment model testing which demonstrated that ecosystem models can be developed using genetic programming code. Results from this will be presented at the February 2014 Ocean Color Meeting in Hawaii. In the coming year, the project will extend its effort into simulating real world ocean time series from Bermuda and Hawaii and finally extend into a global domain ocean microbial modeling effort. For further information, please contact John Moisan: john.r.moisan@nasa.gov. ***(John Moisan)***

3. MAJOR ACTIVITIES

3.1. Missions

Science plays a key role in the Earth Science Atmospheric Research Laboratories, which involves the interplay between science and engineering that leads to new opportunities for research through flight missions. Atmospheric research scientists actively participate in the formulation, planning, and execution of flight missions and related calibration and validation experiments. This includes the support rendered by a cadre of Project Scientists who are among the most active and experienced scientists in NASA. The following sections summarize mission support activities that play a significant role in defming and maintaining the broad and vigorous programs in Earth Science. As shown, the impact of atmospheric sciences on NASA missions is profound.

3.1.1. DECADAL SURVEY MISSIONS

3.1.1.1 ACE

The Aerosols, Clouds, and Ecosystems (ACE) mission is a Tier-2 mission recommended by the National Research Council (NRC) Decadal Survey for Earth Sciences (2007). Aerosols and clouds are major factors in modulating global climate change. ACE seeks to provide the necessary measurement capabilities to enable robust investigation of aerosols and clouds in global change during the 2020's, especially with regards to characterizing and understanding the processes that are occurring. 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 ecosystems. 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 aerosol effects via interactions with clouds and precipitation, and cloud processes. The current nominal plan is for a CY 2023 launch into low Earth orbit at an altitude of 400–450 km. The nominal ACE payload includes an advanced polarimeter for aerosol and cloud measurements, a nadir-pointing, 7-channel HSRL ($3\beta+2\alpha+2\delta$), and a dual frequency (w- and ka-band) Doppler radar with limited scanning capability. Broad-swath radiometers sensing in the infrared, microwave, and sub-millimeter spectral regions are also included in the mission concept.

A comprehensive report including detailed Science Traceability Matrices is availablefor review at: http://acemission.gsfc.nasa.gov/. Significant progress was reported in advancing TRL in FY 2013 for most of the instrument concepts, as well as maturing the associated science algorithms, especially polarimeter retrievals of aerosol properties and also including initiation of efforts to develop multi-sensor algorithms for clouds that are mission critical to advance the science. The Polarimeter Definition Experiment (PODEX) was successfully conducted over California in January through February2013. Analysis of data acquired during PODEX is proceeding. These data and their analysis directly support algorithm development and ultimately trade studies to resolve questions about the polarimeter concepts. PODEX was conducted in close coordination with DISCOVER-AQ. DISCOVER-AQ acquired highly valuable *in situ* and remote sensing validation data and also included HSRL-2, a simulator for the full $3\beta+2\alpha+2\delta$ system envisioned for ACE. Preliminary analysis indicates excellent data and target quality, and acquisition of a substantial subset of the desired scene types. For further information, please contact David Starr (david.starr@nasa.gov).

3.1.1.2 ASCENDS

The Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission, recommended by the NRC's 2007 Earth Science Decadal Survey, is considered the technological next step in measuring CO_2 from space following deployment of passive instruments such as the Japanese Greenhouse gases Observing Satellite (GOSAT, 2009) and the NASA Orbiting Carbon Observatory re-flight (OCO–2, expected in 2014). 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. The data from this mission will enable investigations of the climate-sensitive southern ocean and permafrost regions, produce insight into the diurnal cycle and plant respirations processes, and provide useful new constraints for global carbon cycle models. NASA currently plans for launch in the FY 2022–2023 timeframe. An ASCENDS mission white paper is in preparation.

The Atmospheric Chemistry and Dynamics Laboratory supports ASCENDS through technology development, analysis of airborne simulator data, instrument definition studies, and carbon cycle modeling and analysis. Lab members are engaged in CO_2 instrument development and participate on technology projects, led by the Laser Remote Sensing Laboratory, which target instrument and mission development for ASCENDS. They play a key role in radiative transfer modeling, retrieval algorithm development, instrument field deployment, and data analysis on a project to develop a laser spectrometric instrument for ASCENDS. 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 for ASCENDS. They also support the ASCENDS flight project by performing observing system simulations to establish science measurement requirements and to evaluate the impact of various mission technology options. For further information, please contact S. Randolph Kawa (stephan.r.kawa@nasa.gov) or see the NASA ASCENDS Web site: http://decadal.gsfc.nasa.gov/ascends.html.

3.1.1.3 GEO-CAPE

Geostationary Coastal and Air Pollution Events (GEO-CAPE) is one of the missions recommended by the National Research Council's 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. This is a Tier-2 mission, with expected deployment after 2020.

Scientists in Code 613 and 614 have been involved in GEO-CAPE atmospheric studies for a few years, including defining science objectives, measurement requirements, retrieval accuracy, etc. With the 2012 selection of an EVi mission, "Tropospheric Emissions: Monitoring of Pollution" (TEMPO, led by principal investigator Kelly Chance of the Harvard Smithsonian Astrophysical Observatory) that is expected to launch before 2020 on a commercial satellite, part of the GEO-CAPE atmospheric objective will be met by TEMPO. Therefore, in 2013 the GEO-CAPE atmospheric studies have been centered on assessing to what extent the GEO-CAPE atmospheric science objectives can be achieved by TEMPO and how additional synergistic efforts between TEMPO and other satellite programs may help fulfill the GEO-CAPE objectives. The GEO-CAPE Aerosol Working Group was reformed in 2013 with most members from Codes 613 and 614 to study (1) aerosol retrieval accuracy and product availability from TEMPO compared with GEO-CAPE requirements, (2) improving aerosol product accuracy and obtaining aerosol absorption and plume height by combining measurement capabilities from TEMPO and GOES-R (a NOAA satellite), (3) testing the retrievable information and accuracy from the joint retrieval of TEMPO and GOES-R by taking advantage of the "multi-angle view" from their different parking longitudes, and (4) testing sensitivity of retrieving aerosol height from oxygen-B and oxygen-gamma bands. The synergistic study will continue in FY 2014.

Other GEO-CAPE studies scientists in Code 613 and GMAO involved include the global and regional Observing System Simulation Experiment (OSSE) that use global and regional models to generate atmospheric state at high spatial and temporal resolution to test the GEO-CAPE retrieval sensitivities and methodology. For further information, please contact Mian Chin (mian.chin@nasa.gov).

3.1.1.4 Global 3D-Winds

The *NRC Decadal Survey for Earth Science* identified the Global Tropospheric 3D-Winds mission as one of the 15 priority missions recommended for NASA's Earth Science program. The 3D-Winds mission will use Doppler lidar technology to accurately measure (from space) the vertical structure of the global wind field from 0- to 20-km altitude in order to fill this important gap in the global observing system. The Decadal Survey panel recommended a two-phase approach to achieving an operational global wind measurement capability. First, the panel recommended that NASA develop and demonstrate the Doppler lidar technology and measurement concept and establish the performance standards for an operational wind mission. The second phase would develop and fly a space-based wind system based on this technology. In FY 2012, we made significant advances in the technological readiness of the direct-detection Doppler lidar approach leading towards space. Highlights of these advances include the October 2013 flights of the TWiLiTE Doppler lidar system, an airborne technology testbed for the space-based system, from NASA's ER-2 research aircraft. These flights yielded the first measured profiles of winds through the entire troposphere. These wind profiles, which extend from the aircraft altitude of 20 km to the surface with a vertical resolution of 250 m, demonstrate the data utility of the Doppler lidar wind system. Also in FY 2013 the TWiLiTE system was reconfigured to fly on the NASA Global Hawk as part of the Hurricane and Severe Storm Sentinel (HS3) Earth Venture Mission. We also continued to explore new technologies in collaboration with the Engineering Directorate by completing an ESTO-funded development program named the Hybrid Wind Lidar Transceiver (HWLT) telescope system. The HWLT utilizes a unique, all-composite structure that greatly reduces the weight, increases the stiffness, and decreases temperature sensitivity of the telescope system. Finally, space-based mission studies, sponsored by NASA Earth Science Technology Office, were carried out in the Goddard Integrated Design Center to explore the possibility of flying a Doppler lidar system on the ISS in the next several years. For further information, please contact Bruce Gentry (bruce.m.gentry@nasa.gov).

Table 3.1: Mission Study Scientists

Name	Mission
David Starr, Dong Wu	ACE Study Lead
Mian Chin, Omar Torres	GEO-Cape
Randy Kawa	ASCENDS
Bruce Gentry	Global 3D-Winds

3.1.2. NASA's Planned Missions

3.1.2.1 CATS

The Cloud-Aerosol Transport Lidar (CATS) is a light detection and ranging (LiDAR) remote sensing instrument designed to provide measurements of the particulate contents within the atmosphere including clouds and aerosols. The CATS instrument can function as both a standard backscatter lidar and a high spectral resolution lidar (HSRL). As an on-orbit demonstrations, the HSRL aspect of CATS will provide direct measurement of optical properties (e.g., extinction) without the assumptions normally required for backscatter lidar retrievals. The instrument uses a laser to provide data on the location, composition and distribution of atmospheric constituents that impact the climate on a global scale. Obtaining a better understanding of cloud and aerosol coverage and properties is critical for understanding and modeling of the Earth system and associated climate feedback processes.

CATS was originally designed for operation on high altitude aircraft to demonstrate the technology for future spaceborne missions, such as the proposed Aerosol-Cloud-Ecosystems (ACE) mission as well as to provide critical validation capability for future missions. The success of the system has enabled the transition to a spaceborne system. CATS will fly as an attached payload for the Japanese Experiment Module Exposed Facility, or JEM-EF, onboard the International Space Station (ISS). The CATS payload has successfully completed environmental testing and all safety reviews required by ISS. The CATS payload will undergo some additional calibration checks while waiting for a mid-2014 launch.

The CATS mission goals are: (1) to provide long-term (6 months to 3 years) operational science from ISS; (2) Provide near-real-time measurements of clouds and aerosols that can be assimilated into aerosol transport models; (3) provide on-orbit tech demo for high rep-rate laser, photon-counting detection, and 355-nm laser operation in space; and (4) provide risk reduction for future Earth Science missions. The cloud/aerosol products of layer boundaries, optical depth, and extinction are similar to the current Cloud Physics Lidar (CPL, http://cpl.gsfc.nasa.gov) data products. For further information, please contact Matt McGill (matthew.j.mcgill@nasa.gov) or http://cats.gsfc.nasa.gov.

3.1.2.2 DSCOVR

In 2013, Goddard's Atmospheric Research scientists are working on the finishing touches for two Earth-viewing instruments on board the Deep Space Climate Observatory (DSCOVR) spacecraft scheduled for a launch to the Lagrange-1 (L1) orbital point between the Earth and the Sun. These instruments are the National Institute of Standards (NIST) Advanced Radiometer (NISTAR), and the Earth Polychromatic Imaging Camera (EPIC). The four-channel radiometer, NISTAR, provides broadband measurements (UV to IR) of the whole sunlit Earth's reflected radiation. The 10-channel EPIC, measures spatially resolved radiances that can detect ozone levels, aerosol index, aerosol optical depth, scene reflectivity, cloud height, vegetation, and leaf area indices. The current goal is to provide calibrated radiances suitable for algorithm development based on future support direction from NASA.

DSCOVR will orbit the Sun–Earth L1 point 1.5 million kilometers upstream of Earth towards the Sun, simultaneously observing the entire sunlit Earth from sunrise to sunset. DSCOVR is scheduled for launch in January 2015 and will start taking data 6 months after launch. For further information, please contact Alexander Marshak (alexander.marshak@nasa.gov) or Jay Herman (jay.r.herman@nasa.gov).

3.1.2.3 GPM

The Global Precipitation Measurement (GPM) is an international satellite mission to provide next generation observations of rain and snow worldwide every three hours. NASA and the Japanese Aerospace Exploration Agency (JAXA) will launch a "Core" satellite in early 2014 carrying advanced instruments that will set a new standard for precipitation measurements from space. The data they provide will be used to unify precipitation measurements made by an international network of satellites provided by partners from the United States, Japan, France, India, and the European community to quantify when, where, and how much it rains or snows around the world. The GPM mission will advance our understanding of the water and energy cycles, and extend the use of precipitation data to directly benefit society.

In support of pre-launch precipitation retrieval algorithm development, GPM has been conducting a series of field campaigns with international and domestic partners in the past 5 years. In May and June of 2013 GPM jointly conducted the Iowa Flood Studies (IFloodS) campaign during which more than 10 inches of rain fell. Space and ground instruments were used to evaluate the accuracy of flood forecasting models and precipitation measurements from space. The data will be well suited to GPM retrieval algorithm physical validation, providing a 3D and high temporal resolution view of mixed phase precipitation microphysics at both dual polarization and the Ka-, Ku-, and S-band frequency triplet. The mission team held its 6th International Ground Validation Workshop on November 5–7, 2013. This mission critical workshop was hosted by the Italian National Research Council (CNR) and the Institute of Atmospheric Sciences and Climate (ISAC) and held in Rome, Italy. International science collaboration in GPM Ground Validation (GV) plays a vital role in refining remote sensing algorithms and in assessing the quality and utility of satellite precipitation products in different climate and geographic regimes. Under GPM programmatic leadership, GPM GV partners developed consensus plans for GV instrument calibration, tier infrastructures, and coordinated future GV campaigns through realtime technical discussions. A new NPOL and D3R radar operations site has been secured near Wallops to support GPM GV activities pre and post-launch when the radars are not field deployed.

Throughout the year a number of significant meetings and milestones were carried out to prepare for launch. In terms of milestones, GPM at-launch precipitation retrieval algorithms were delivered to the GPM Precipitation Processing System (PPS) and then integrated and tested by PPS. Among the meetings were: a Science Team meeting in March 2013 in Annapolis, a Cross-Calibration Meeting in May 2013 in France, several algorithm team meetings and ground validation meetings throughout the year. GPM science is prepared for the launch in early 2014. For further information, please contact: Gail Skofronick Jackson (gail.s.jackson@nasa.gov) or visit the GPM homepage at http://gpm.nasa.gov.

3.1.2.4 JPSS

As background, the National Polar Orbiting Environmental Satellite System (NPOESS) was 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. It was 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 President's FY 2011 budget contained a major restructuring of the NPOESS Program. Under the restructured system, NASA and NOAA will take primary responsibility for the afternoon orbit, and DoD will take primary responsibility for the early morning orbit. The agencies will continue to partner in those areas that have been successful in the past, such as a shared ground system. The NASA/NOAA portion was named the Joint Polar Satellite System (JPSS). The satellite system is a national priority—essential to meet both civil and military weather forecasting, and storm-tracking requirements, and contribute data to help answer climate change questions. In 2013, the JPSS program focused its near-term efforts on supporting the operations of Suomi NPP. The JPSS program provides three of the five instruments, the ground system, and post-launch satellite operations to the NPP mission. Suomi NPP observatory operations were successfully transferred from the JPSS program to the NOAA Office of Satellite and Product Operations in February 2013.

The future JPSS missions, J1 and J2, are currently scheduled for December 2016 and November 2021 launches. The J1 mission will be very similar to NPP, using the same spacecraft and instrument complement. The JPSS Program preliminary design review was held in March 2013 with the Program critical design review scheduled for early 2014. At the end of 2013, all the J1 instruments were in system-level test with calibration, characterization, and environmental testing to be completed in 2014. For further information, please contact James Gleason (james.gleason@nasa.gov).

3.1.2.5 JPSS Free Flyer (TSIS)

NASA, as part of the JPSS partnership with NOAA, is working to fly the Total and Spectral Solar Irradiance Sensors (TSIS) on the Free Flyer Mission. Free Flyer will also carry the climate sensors package. The TSIS sensor package's build has completed at University of Colorado, and was thoroughly tested during 2012, and delivered to NASA storage in 2013. Launch is planned for fall 2016. As SORCE is now 6 years beyond its original 5-year design life, and showing signs of its age especially in battery degradation, a new mission, the "TSI Calibration Transfer Experiment (TCTE)" launched in November 2013 as part of an Air Force payload on STPSat3, on a Minotaur out of Wallops Flight Facility. TCTE will serve as a "gap filler" for TSI only, not SSI, and is intended to ensure a continuous TSI record that connects the SORCE TIM record with the new TSI record from TSIS. TSIS will consist of two instrument sensors—a new Total Irradiance Monitor (TIM) and a new Spectral Irradiance Monitor (SIM)—both continuing the heritage of the first generation of TIM and SIM currently flying onboard SORCE.

The new TIM and SIM will each be fully traceable to the respective cryogenic radiometer facilities located at University of Colorado's Laboratory for Atmospheric and Space Physics (LASP.) These facilities are unique in the world, providing direct comparison in vacuum to cryogenic radiometers, using optical sources with power comparable to the Sun. The full characterization and traceability has been critical for meeting the required absolute accuracy. Equally important is the exacting degree of stability and precision met by these instruments, critical for any possible future direct determination of a decadal or longer trend in the Sun's variability. This will determine whether the Sun may be enhancing or reducing global warming that would otherwise occur if changes in atmospheric composition, due to greenhouse gases, volcanic or other aerosol emissions, or to natural atmosphere-ocean variations, were the only forcing mechanisms. Since the Sun's changing irradiance is the only well-established, external mechanism forcing the Earth's climate, it is critical to determine its sign and magnitude. For further information, please contact Robert Cahalan (robert.f.cahalan@nasa.gov).

3.1.3. NASA's Active Flight Missions

3.1.3.1 Aqua

The Aqua spacecraft, launched on May 4, 2002, carries six Earth-observing instruments: AIRS, AMSU, AMSR-E, CERES (two copies), HSB (no longer operating), and MODIS. In the latest report of the 2013 Senior Review panel for satellite missions in extended operations (available at http://nasascience.nasa.gov/earth-science/missions/operating/), Aqua received very high scores for scientific merit, scientific relevance, and scientific product maturity, and the highest overall score among all missions from the National Interests Panel. In addition to collecting data pertaining to Earth's water in all its phases, as highlighted in the name "Aqua," mission instruments also provide measurements (among others) about radiative energy flux, atmospheric temperature and composition, aerosols, cloud properties, land vegetation, phytoplankton and dissolved organic matter in the oceans, surface albedo, temperature, and emissivity. These measurements help scientists to quantify the state of the Earth system, validate climate models, address key science questions, and serve the applications community. Aqua Deputy Project Scientist, Lazaros Oreopoulos assists Project Scientist Claire Parkinson in a variety of activities that support the mission, and has the lead on budgetary matters and fund disbursement. For further information, please contact Lazaros Oreopoulos (lazaros.oreopoulos@nasa.gov).

3.1.3.2 Aura

The Aura spacecraft, which was launched July 15, 2004, carries 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 has addressed questions concerning the stratospheric ozone layer, air quality, and climate. It has now been more than eight years since launch, and two of the instruments continue to make daily measurements. HIRDLS suffered an anomaly and is no longer operational. TES shows signs of aging and presently makes limited measurements.

In 2013, Aura data revealed new aspects of the Earth composition while continuing to build a multiyear, global dataset reveals connections between chemistry and climate. Modelers from the world's major climate modeling centers are using MLS and TES observations to quantify realism of the simulated response of ozone and other constituents in the troposphere and stratosphere to El Niño/La Niña. OMI measurements of NO_2 and SO_2 are being used by scientists worldwide (including in developing countries) to estimate the emissions of these pollutants. TES measurements of ammonia demonstrate that emissions are under reported; this is important because ammonia is involved in the formation of the aerosol PM2.5, a pollutant with adverse health affects. Although HIRDLS is no longer operational, analysis of high vertical-resolution profiles had revealed the global statistics for occurrence of a "double tropopause." The composition and structure near the tropopause are important to the Earth radiative balance. More information on Aura science highlights can be found at http://aura.gsfc.nasa.gov/ or contact Anne Douglass (anne.r.douglass@nasa.gov).

3.1.3.3 GOES

NOAA's Geostationary Operational Environmental Satellites (GOES) are built, launched, and initialized by Goddard's GOES Flight Project Office under an inter-agency program hosted at Goddard. 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 project scientist from Goddard assures 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. During 2013, five new and improved instruments were under construction for the next generation of GOES satellites, which are expected to be launch-ready in 2015.

The project scientist also operates a popular 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. The GOES Project Science Web site (http://goes.gsfc.nasa.gov/) offers weather imagery and movies overlaid on a true-color background—an attractive and popular format. For example, in September 2013, the site served 158 GB/day to 237 thousand distinct guests at the average rate of 3 requests-per-second. During a hurricane, the Web server frequently hits its limit of 10 requests per second to 150 simultaneous guests. For further information, please contact Dennis Chesters (dennis.f.chesters@nasa.gov).

3.1.3.4 Terra

Launched on December 18, 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 American science team leader at JPL) provides a unique benefit to Terra's mission as a stereoscopic and high-resolution instrument used to measure and verify processes at fine spatial scales; (2) CERES (LaRC) investigates the critical role that 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 3D morphologies); (4) MODIS (GSFC) acquires daily, global, and comprehensive measurements of a broad spectrum of atmospheric, ocean, and land properties that 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 10 pressure levels; its gas correlation approach still produces the best data for studies of horizontal and vertical transport of this important trace gas. For more than 14 years, the Terra mission has been providing the worldwide scientific community with an unprecedented number of high-quality quantitative datasets making a significant contribution to all of NASA's Earth Science focus areas. Terra data will continue to support monitoring and relief efforts for natural and man-made disasters that involve U.S. interests. Terra also contributes to the Applications Focus Areas supporting the U.S. National Objectives for agriculture, air quality, climate, disaster management, ecological forecasting, public health, water resources, and weather. After 14 years of continuous operation, the project office coordinated closely with the science and engineering team to advocate that the EOS science to maintain a strong Terra program. For further information, please contact Si-Chee Tsay (si-chee.tsay-1@nasa.gov).

3.1.3.5 SORCE

By the time of the 11th anniversary SORCE Science Team meeting in Cocoa Beach in January 2014, SORCE will have circled Earth almost 60,000 times, for a total travel distance of about 2.6 billion miles. Along the way, SORCE has determined the Total Solar Irradiance (TSI), from which the Sun's Luminosity is found to be 3.827 x 10^{26} Watts, 0.5% lower than the current approximate value assumed by many astronomers. The new value is accurate to 0.035%. This new value has been used to correct all other space-based estimates back to 1978, showing that over the past 35 years the Sun's Luminosity has no significant trend. So the Sun cannot be causing the observed warming trend in Earth's global average surface air temperature. Though SORCE instruments have been turned off in the last half of 2013, they expect to return to daily operations in time for the cross calibration activities with TCTE, to begin in late December 2013.

Since its launch in January 2003, the Solar Radiation and Climate Experiment (SORCE) has achieved its goal of simultaneously measuring total solar irradiance (TSI) and solar spectral irradiance (SSI) in the 0.1–27-nm and 115–2400-nm wavelength ranges with unprecedented accuracy and precision. SORCE has successfully completed its 5-year core mission (January 2003 to January 2008) and is now beginning the sixth year of its extended mission. SORCE has accomplished unique new observations of the solar irradiance and has improved understanding of solar radiative forcing of Earth's climate and atmosphere during the descending phase of solar activity cycle 23, into the rising phase of solar cycle 24, and now beginning the descending phase of solar cycle 24.

Variations in the Sun's total and spectral irradiance impose key natural forcings on the climate system, and the solar ultraviolet (UV) radiation is a key driver for atmospheric photochemistry and composition. Accurate and precise long-term records of TSI and SSI are thus important components of NASA's Earth Science program (e.g. NASA Science Plan, 2010). Current TSI and SSI measurements by NASA SORCE, new TSI measurement by NASA TCTE (TSI Calibration Transfer Experiment), and planned TSI and SSI measurements by NOAA/NASA JPSS Free-Flyer-1 TSIS (Total and Spectral Solar Irradiance Sensor) are essential measurements for our national climate program as discussed in the *NRC Earth Science and Applications from Space Report* (2007).

Major accomplishments of the SORCE mission include accurate determination of TSI levels lower than previously thought, continuation of the 35-year TSI record, initiation of the first record of SSI in the visible and infrared (IR), and the construction of reference spectra spanning the entire wavelength domain of terrestrial relevance. Solar irradiance variability has been unequivocally detected across the electromagnetic spectrum, including during flares. Improved synergistic models of total and spectral irradiance variations based on direct SORCE observations have been extended to longer time scales with proxy indicators, and are facilitating an increasingly wide array of climate and atmospheric model studies.

A series of extensive radiometric laboratory and field measurements involving SORCE and other TSI instruments established that the most accurate measurement of TSI during the 2008 solar minimum period is 1360.8±0.5 W/m_{-2}, as measured by SORCE (Kopp and Lean, 2011). In 2010 new measurements by PREMOS/Picard were in close agreement with SORCE/TIM. Previous TSI values reported by ACRIM, and also those of SOHO/Virgo, have been revised downward, as a result of new understanding of scattered light revealed by the laboratory measurements. The composite TSI record has thus been improved and revised to reflect the new absolute value of TSI that SORCE has established.

SORCE's SSI observations suggest that solar cycle variations at some visible and near infrared wavelengths, in contrast to TSI, are out of phase with solar activity, i.e, the sunspot numbers in Figure 3.3 (Harder et al., 2009). While observed short-term solar rotational (27-day) variability results are consistent with understanding of solar sunspot and facular influences, these new SORCE spectral irradiance results challenge this understanding for solar cycle variability. SORCE-sponsored workshops involving NIST calibration experts and the broader SSI community were held in 2012 and 2013 to better understand SSI instrument degradation processes and trends. Progress is significant but the SORCE SSI results still require additional understanding or validation, which is in progress.

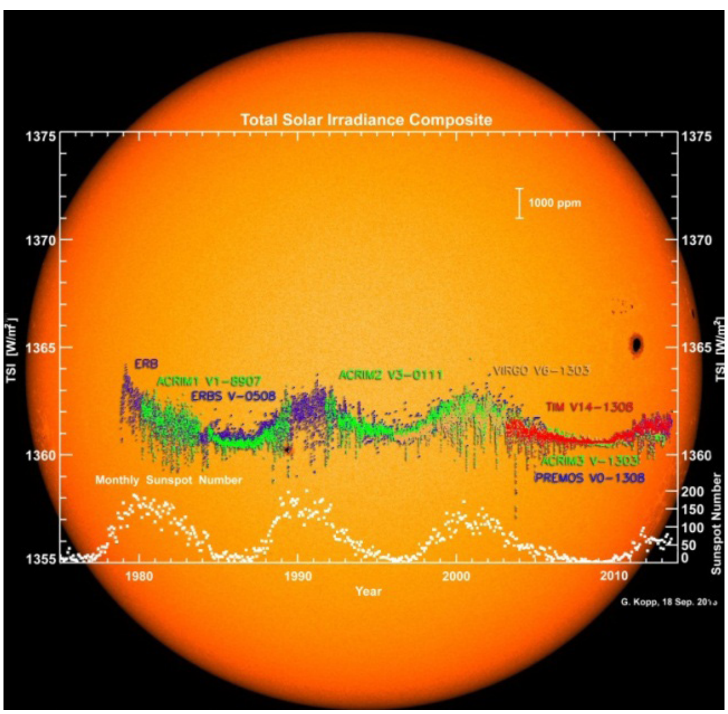

Figure 3.3: Solar Irradiance Composite

The SORCE SSI measurements continue the UV irradiance record and the magnesium index implemented by SBUV, SME, and UARS instruments. SORCE's data are the critical elements in a new solar spectra reference throughout the X-ray, UV, visible, and IR ranges (e.g Woods et al., 2009).

Models of solar irradiance variations have been improved by the SORCE TSI and SSI observations, which provided insight into physical sources of solar variability and enabled investigations for studying solar influence on climate and atmosphere changes (Kopp and Lean, 2011; Haigh et al., 2010; Cahalan et al., 2010).

During the extended mission in 2014 to 2015, approved by NASA/HQ in 2013, solar activity will be near the maximum levels of cycle 24, but the amplitude of the cycle maximum is trending a factor of two lower than that of cycle 23 and possibly lower than all prior 16 cycles. SORCE's extended mission has three primary objectives tailored to investigate this current "peculiar" state of solar activity, while aligned overall with SORCE's original mission objectives.

Key to achieving the first objective is the continuation of SORCE TSI measurements during solar cycle 24 maximum, and overlap with new TSI measurements to be made by the NOAA-NASA TSI Calibration Transfer Experiment (TCTE) aboard the Air Force STPSat-3 (launched onboard STPSat-3, November 19, 2013, at Wallops Flight Facility) and JPSS Total Solar Irradiance Sensors (TSIS) mission (launch planned in 2016). The second objective focuses on extensive, quantitative validation and interpretation of SORCE's SSI results, in addition to continuing the new SSI record. The third objective is better understanding, specification and modeling of instrument degradation that impacts all space-based radiometers, important for Earth Science missions and advancing understanding of Sun-climate relationships.

The next few years will provide a natural laboratory to critically study terrestrial responses in a period of low solar activity, as compared with the higher cycles that have dominated the space era. The maximum of solar cycle 24 in 2013–2014 offers a unique opportunity to contrast solar cycle irradiance variability of a low cycle maximum that is almost a factor of two lower in amplitude than the recent solar cycle 23 maximum. This uniquely low cycle 24 follows a long solar activity minimum in 2008–2009, and may herald the onset of regular low cycles such as during the Gleissburg Cycle Minimum in the early 1900s, or the Dalton Minimum in the early 1800s (Russell et al., 2010).

All of the SORCE instruments have remained in functional good health and are expected to perform well during the extended mission. Because of instrument redundancies SORCE has successfully acquired a full set of solar irradiance data records over the entire SORCE mission, and this is expected to continue during the extended mission. Data processing algorithms to convert raw instrument signals into irradiances are very mature; however, significant data analysis of instrument degradation trends is still needed to maintain the most accurate irradiance products during the extended mission phase.

The SORCE spacecraft is a robust Orbital spacecraft with a redundant set of subsystems except for the battery. Degradation of the battery performance that began in 2009 has in 2013 led to instruments being powered on only during short eclipse periods. The SORCE mission operations team consists of LASP (lead), Orbital, and GSFC. They have worked closely on the spacecraft anomalies to understand the technical issues, to change operations and flight software to mitigate the risks, and to minimize the impact on the science observations. The battery degradation has continued steadily since the first cell anomaly, and the life of the SORCE mission is possibly limited to about two years because of the declining battery voltage level. All instruments are now power-cycled off during orbit eclipse. The instruments have wider temperature variations in this power-cycling mode, thus SORCE irradiance data quality has degraded some, but remains high enough for SORCE extended observations to continue providing high quality TSI and SSI climate records. For further information, please contact Robert Cahalan (robert.f.cahalan@nasa.gov).

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Richard (2009). Solar Irradiance Reference Spectra (SIRS) for the 2008 “Whole Heliosphere Interval (WHI), Geophys. Res. Lett., 36, LOllOl. doi: 10.1029/2008GL036373.

3.1.3.6 Suomi NPP

The Suomi National Polar-orbiting Partnership (NPP) satellite was launched on October 28, 2011. NPP’s advanced visible, infrared, and microwave imagers and sounders are designed to improve the accuracy of climate observations and enhance weather forecasting capabilities for the nation’s civil and military users of satellite data. NPP instruments include the Advanced Technology Microwave Sounder (ATMS), the Cross-track Infrared Sounder (CrIS), the Ozone Mapping and Profiler Suite (OMPS), the Cloud and Earth Radiant Energy System (CERES), and the Visible Infrared Imaging Radiometer Suite (VIIRS). The five sensors onboard Suomi NPP operate routinely, and the publically available products are available from the NOAA CLASS archive, www.class.noaa.gov.

Suomi NPP is on track to extend and improve upon the Earth system data records established by NASA’s Earth Observing System (EOS) fleet of satellites that have provided critical insights into the dynamics of the entire Earth system: clouds, oceans, vegetation, ice, solid Earth, and atmosphere. Data from the Suomi NPP mission will provide a continuation of the EOS record of climate-quality observations after EOS Terra, Aqua, and Aura.

Since launch, Suomi NPP’s instruments have been in nominal operations. Suomi NPP’s Level 1 instrument data and all the higher-level data products have been publicly released and are available from the archive.

In August 2013, CrIS radiance data was added to the ATMS radiance data being ingested into operational numerical weather prediction models used by the National Weather Service. NOAA has been using VIIRS Imagery data from the SNPP direct broadcast data in the Advanced Weather Interactive Processing System (AWIPS) for weather forecasting in Alaska.

The product evaluation and test elements (PEATE) are doing an excellent job in supporting the science team’s analysis. The existing Interface Data Processing Segment (IDPS) instrument operational collaboration is working well. The Science Team has determined that the Suomi NPP instruments and the Level 1 data quality is sufficient and is to create data continuity products. A re-competition of the

Suomi NPP Science Team was announced in the Research Opportunities in Space and Earth Sciences (ROSES) – 2013 with proposals due in March 2014. For further information, please contact James Gleason (james.f.gleason@nasa.gov).

Suggested S-NPP Earth Observatory features for images:

Tracking the Chelyabinsk Meteor Plume
http://earthobservatory.nasa.gov/IOTD/view.php?id=81844
http://www.nasa.gov/content/goddard/around-the-world-in-4-days-nasa-tracks-chelyabinsk-meteor-plume/

Tracking Dust Across the Atlantic
http://earthobservatory.nasa.gov/IOTD/view.php?id=81864
http://www.nasa.gov/content/goddard/tracking-saharan-dust-across-the-atlantic/

Gas Drilling in North Dakota
http://earthobservatory.nasa.gov/IOTD/view.php?id=79810

Auroras Light up the Antarctic Night
http://earthobservatory.nasa.gov/IOTD/view.php?id=79750

Extensive Ice Fractures in the Beaufort Sea
http://earthobservatory.nasa.gov/IOTD/view.php?id=80752

Early February Blizzard Buries Northeastern United States
http://www.earthobservatory.nasa.gov/NaturalHazards/view.php?id=80399

Cloud Plume with a Cold War Twist
http://earthobservatory.nasa.gov/IOTD/view.php?id=82213

NASA Reveals New Results From Inside the Ozone Hole
http://www.nasa.gov/content/goddard/new-results-from-inside-the-ozone-hole/

3.1.3.7 TRMM

The Tropical Rainfall Measuring Mission (TRMM) launched in late 1997 as a joint mission between NASA and JAXA, the Japanese space agency. The first-time use of both active and passive microwave instruments and the processing, low-inclination orbit have made TRMM the world's foremost satellite for the study of precipitation and associated storms and climate processes in the tropics. TRMM instruments include the first and only precipitation radar (PR) in space, the TRMM microwave imager (TMI), a visible and infrared scanner (VIRS), and a lightning-imaging sensor (LIS). Originally, TRMM's goal was to advance our understanding of the mean distribution of tropical rainfall and its relation to the global water and energy cycles. As the TRMM mission has entered into its 17th year, the science objectives have extended beyond just determining the mean precipitation distribution and have evolved toward determining the time and space varying characteristics of tropical rainfall, convective systems, and storms and how these characteristics are related to variations in the global water and energy cycles.

TRMM fuel levels are sufficient for continued operations until at least early 2014. Given uncertainties in the amount of remaining fuel and future solar activity (which causes drag on the satellite), fuel depletion could occur as late as mid-2016. TRMM successfully completed its fifth senior review. TRMM rated very high in science merit, relevance, product maturity, and product utility. The launch of GPM in 2014 will provide an excellent opportunity for comparisons with TRMM for a period potentially lasting up to two years before TRMM fuel is depleted.

The TRMM Web site (http://pmm.nasa.gov/TRMM) provides near-real-time precipitation estimates every three hours, with daily and weekly accumulations, as well as flood potential maps. A brief synopsis of most major hurricanes, typhoons, and flood events around the globe with attendant images of accumulated precipitation or precipitation structure can be found at http://trmm.gsfc.nasa.gov/publications_dir/extreme_events.html/. For further information, please contact Scott Braun (scott.a.braun@nasa.gov).

3.2. Project Scientists

Project scientists serve as advocates, communicators, and advisors in the liaison between the project manager and the community of scientific investigators on each mission. The position is one of the highest operational roles to which a scientist can aspire in NASA Table 3.2 lists project and deputy scientists for current and planned missions. Table 3.3 lists the validation and mission scientists and major participants in field campaigns.

Table 3.2: Atmospheres Project and Deputy Project Scientist

Project Scientists		Deputy Project Scientists	
Name	**Project**	**Name**	**Project**
Charles Jackman	AIM	Lazaros Oreopoulos	Aqua
Anne Douglass	Aura	Bryan Duncan	Aura
Steve Platnick	EOS	Joanna Joiner	Aura
Dennis Chesters	GOES	Alex Marshak	DSCOVR
Arthur Hou, Gail Skofronick Jackson	GPM	Gail Skofronick Jackson	GPM
James Gleason	JPSS/NPP	Christina Hsu	NPP
James Irons	LDCM	Si-Chee Tsay	Terra
Pawan K. Bhartia	OMI		
Robert Cahalan	SORCE and TSIS		
Scott Braun	TRMM		

Table 3.3: Atmospheres Validation, Instrument and Mission Scientists

Validation Scientists		Instrument Scientist	
Name	**Mission**	**Name**	**Campaign**
David Starr	EOS	Kenneth Pickering	DISCOVER-AQ
Ralph Kahn	EOS/MISR	Walter Petersen	GPM GV
Matthew McGill	ISS/JEM-EF/CATS	Scott Braun	HS3
Robert Cahalan, Dong Wu, Jae Lee, Charles Ickoku	TCTE/PFF (U.S.A.F.)	Walter Petersen	iFLoodS
		Judd Welton	MPLNET
		William Krabill	Operation IceBridge
		Walter Petersen	MC3E

		Judd Welton, Si-Chee Tsay	7 SEAS
		David Starr	PODEX
		Walter Petersen	Dragon Eye
		Tom Hanisco	SEAC4RS, SENEX

4. 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 Global Hawks, 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 2013, atmospheric research personnel supported activities in the planning and coordination phases as scientific investigators or as mission participants.

4.1. DISCOVER-AQ

DISCOVER-AQ is a five-year campaign to improve the use of satellites to monitor air quality for public health and environmental benefit. Through targeted airborne and ground-based observations, DISCOVER-AQ will enable more effective use of current and future satellites to diagnose ground level conditions influencing air quality. The campaign employed NASA aircraft to make a series of flights, with scientific instruments on board to measure gaseous and particulate pollution, beginning in 2011. The series of flights commenced over Baltimore-Washington, D.C. in 2011. Other deployments included Houston (September 2013); San Joaquin Valley (January–February 2013); and a final site in 2014 in the Denver area. The measurements are taken in concert with ground observations in order to shed light on how satellites could be used to make similar, consistent measurements over time, with the ultimate goal of putting better data in the hands of policymakers and elected officials.

In January and February 2013 DISCOVER-AQ completed its second deployment. The target was California's central valley during winter where cold, stagnant conditions encourage the accumulation of fine particles to reach unhealthy levels. The first five flights documented a period of pollution build-up as particulate levels in the southern end of the valley tripled. A second period of build-up was observed with the remaining flights. Similarity in the trends of surface particulate matter less than 2.5 micrometers in diameter and of aerosol optical depth (AOD) is encouraging for applicability of observations of AOD from satellite for surface air quality. An important factor in these intense pollution episodes was the shallowness of the polluted layer which was almost always limited to the lowest 2000 feet above the surface, which made the "missed approaches" at six airports in the valley a vital piece of the flight plans. They allowed the P-3B aircraft to come within ~30m of the ground. Several flights were performed in collaboration with the ER-2 flights of PODEX over the San Joaquin Valley and over the stratocumulus clouds off the Pacific coast.

The Houston, Texas, deployment ended on September 29, 2013. The deployment was highly successful with nine flight days having air quality conditions for ozone ranging from very clean to strongly polluted An 8-hour average ozone mixing ratio of 124 ppbv occurred at one of these sites, which was tied for the highest ozone seen in the Houston area since 2006, far exceeding the National Ambient Air Quality Standard of 75 ppbv. One the primary objectives of DISCOVER-AQ is to investigate the relationships between surface pollution and the column amounts aloft that a satellite would observe. The P-3B data will be valuable for this purpose. Planning is underway for the fourth deployment, which will occur in Summer 2014 in the Denver area. For further information, please contact Ken Pickering (kenneth.e.pickering@nasa.gov).

4.2. Dragon Eye

An *in situ* sulfur dioxide sensor package was completed, integrated and flown on NASA's Dragon Eye small, unmanned aircraft system (sUAS). The instrument package was completed by Ted Miles (569) and Geoff Bland and weighs approximately one half pound, including instrument power and data system. This package represents a first step in developing small instrument systems for these platforms, which are potentially suitable for a wide variety of *in situ* measurements. The Dragon Eye is a military surplus platform with electric propulsion, weighing 5.9 pounds, having a 3.75-foot wingspan and twin electric engines that can carry a one-pound instrument payload for up to an hour. Three such vehicles were used to study the chemical environment of the plume spewing from Turrialba Volcano, near San Jose, Costa Rica. The study, called "In Situ Validation and Calibration of Remotely Sensed Volcanic Emission Data and Models," launched 10 flights between March 11–14, 2013, into the volcanic plume and along the rim of the Turrialba summit crater approximately 10,500 feet above sea level (ASL). The launch site was located at 8,900 feet ASL, and flights ranged up to 12,500 feet ASL, more than 2,000 feet above the Turrialba summit. Project objectives included improving satellite data research products, such as maps of concentration and distribution of volcanic gases, and transport-pathway models of volcanic plumes. A long-term project goal is to develop the means to sample drifting ash and gas in volcanic plumes up to 30,000 feet ASL, that result from large explosive eruptions such as those that crippled aviation traffic in Iceland and Europe in the spring of 2010. The research project was funded by the NASA Science Mission Directorate's Earth Science Solicitation from the Earth Surface and Interior Focus Area. The project was a collaborative effort between three NASA centers, the Jet Propulsion Laboratory (lead), Goddard Space Flight Center's Wallops Flight Facility, Ames Research Center, and several international and commercial partners, including the University of Costa Rica. NASA investigators were especially appreciative of the kind hospitality and superb technical support of the Costa Rican hosts. For further information, please contact Walt Petersen (walt.petersen@nasa.gov).

4.3. EXRAD

The ER-2 X-band Radar (EXRAD) was installed on NASA ER-2 at NASA's Dryden Flight Research Center. EXRAD is a dual-beam X-band Doppler radar with one scanned beam (conical or cross-track) and the other beam fixed at nadir. It replaces the old EDOP radar and it will be used for cloud and precipitation-oriented field campaigns. EXRAD was initially funded by IRAD, and then by ESTO AITT with L. Li (555) as P.I. and G. Heymsfield (612) as Co.I. EXRAD is capable of providing high-resolution 3D radar reflectivity and wind measurements from clouds and precipitation as well as ocean surface winds. Three sucessful test flights were flown on the ER-2 while at Dryden. The last flight was a 6.5-hour flight over the northwest coast near Seattle. The ocean return measured by EXRAD was as expected and further analysis will determine whether any precipitation was measured since it was very light and spotty. This readies EXRAD for future flights and proposed activities. EXRAD was supported under a NASA AITT with Lihua Li as P.I. and G. Heymsfield (612) as Co.I. Other team members include M. Mclinden and M. Coon of 555, M. Perrine of 567, and J. Cervantes of SSAI. For further information, please contact Gerry Heymsfield (gerald.m.heymsfield@nsas.gov).

4.4. GPM IFloodS Ground Validation

From May 1 to June 15, 2013, scientists from the NASA Global Precipitation Measurement (GPM) Mission and the Iowa Flood Center (IFC; University of Iowa), led a field campaign to measure rainfall in eastern Iowa with ground instruments and satellites as part of the Iowa Flood Studies (IFloodS) experiment. The team collected ground-based reference datasets to evaluate spaceborne precipitation estimates and their use in water resource management and flood prediction. The experiment was led by Walt Petersen, the NASA GPM Ground Validation Science Manager, and David Wolff, a scientist with NASA's Wallops Flight Facility (WFF). The NASA WFF GPM Precipitation Research group lead by Petersen and David Wolff deployed and operated the NPOL S-band dual-polarimetric radar, the D3R radar (Ka–Ku-band), 4 Micro Rain Radars, 22 disdrometers, and a plethora of rain gauges in support of IFloodS. The NPOL radar operated 24/7 and performed exceptionally well, conducting the first-ever coordinated triple frequency scanning with the D3R radar (Ka–Ku Bands) along a unique reference ray of disdrometer nodes. The IFC deployed a total of four X-band radars, numerous rain gauges and provided streamflow data over the experiment domain in support of the effort.

Precipitation in the form of snow, mixtures of rain and snow, stratiform rain, and heavy convective rain were observed by NPOL, D3R and IFC radars in concert with frequent stream and river flooding in eastern Iowa. Indeed, during the first week of the experiment the NPOL and D3R radars sampled a "record setting" mixed rain and snow event in central Iowa. The event provided a mixed-bag of precipitation types over a 2.5 day period with up to 11 inches of snow falling in northwestern Iowa (new record) and 2 to 4 inches of rain and snow falling over the remainder of central Iowa and the IFloodS domain. As the experiment progressed, larger convective systems with associated widespread heavy rainfall, several severe storms, and an outbreak of tornadic supercell thunderstorms were also sampled by the NPOL and IFC X-band radars at relatively close range.

The IFloodS experiment conducted a robust education and outreach program while in the field. During the experiment over 100 elementary and middle school students, local television networks, and local newspapers were hosted at the NPOL/D3R radar site. Scientists contributed to a NASA Earth Observatory Web Blog site for IFloodS and conducted online seminars (e.g., Google+ Hangout) from the NPOL science cabin while conducting radar operations.

The collective dataset will be well suited to GPM retrieval algorithm integrated and physical validation, providing a high temporal and spatial resolution view of regional rainfall, and 3-D radar sampling of mixed phase precipitation microphysics at dual polarization and multiple radar frequencies (Ka-, Ku-, X-, and S-band), all under numerous satellite overpasses. More information can be found at: http://earthobservatory.nasa.gov/blogs/fromthefield/category/iowa-flood-studies/.

4.5. HS3

The 2013 HS3 EV-1 campaign took place between August 20 and September 23, 2013. HS3 used two of NASA's unmanned Global Hawk (GH) aircraft to study Atlantic hurricanes during the deployment at the Wallops Flight Facility. The mission's goal is to improve understanding of the processes that control hurricane formation and intensity change and to better determine the relative roles of the large-scale environment and smaller-scale processes in the inner-core region of storms (i.e., the eyewall and rainbands). One GH, designated the environmental GH (AV-6), is designed to sample temperature, humidity, winds, and Saharan dust in the storm environment while the other, designated the over-storm GH (AV-1), is focused on measuring winds and precipitation within the storm.

HS3 conducted seven flights with the environmental GH and two with the over-storm GH. The first flight (August 20–21, AV-6) was over the remnants of Tropical Storm (TS) Erin, which had dissipated two days prior to flight. Power to the dropsonde system was lost shortly after getting on-station, but S-HIS and CPL obtained information on the movement of a major Saharan Air Layer (SAL) outbreak over the low-level remnants of Erin. On August 24–25, AV-6 obtained detailed measurements of an intense SAL outbreak.

The next four flights (3 with AV-6, 1 with AV-1) over the period of August 29–September 8 examined the pre-Gabrielle disturbance, its formation into a tropical storm, and its later potential for redevelopment. An AV-1 flight on September 15–16 obtained two overpasses of Hurricane Ingrid in the Gulf of Mexico before cold fuel temperatures required a return to base. A September 16–17 AV-6 flight examined the reformation of Tropical Storm Humberto, revealing a hybrid tropical/extratropical storm structure. The final science flight, on September 19–20, used AV-6 to examine the potential genesis of a disturbance in the Gulf of Mexico. While this storm failed to develop, the HS3 data should provide valuable information on the factors that prevented its genesis.

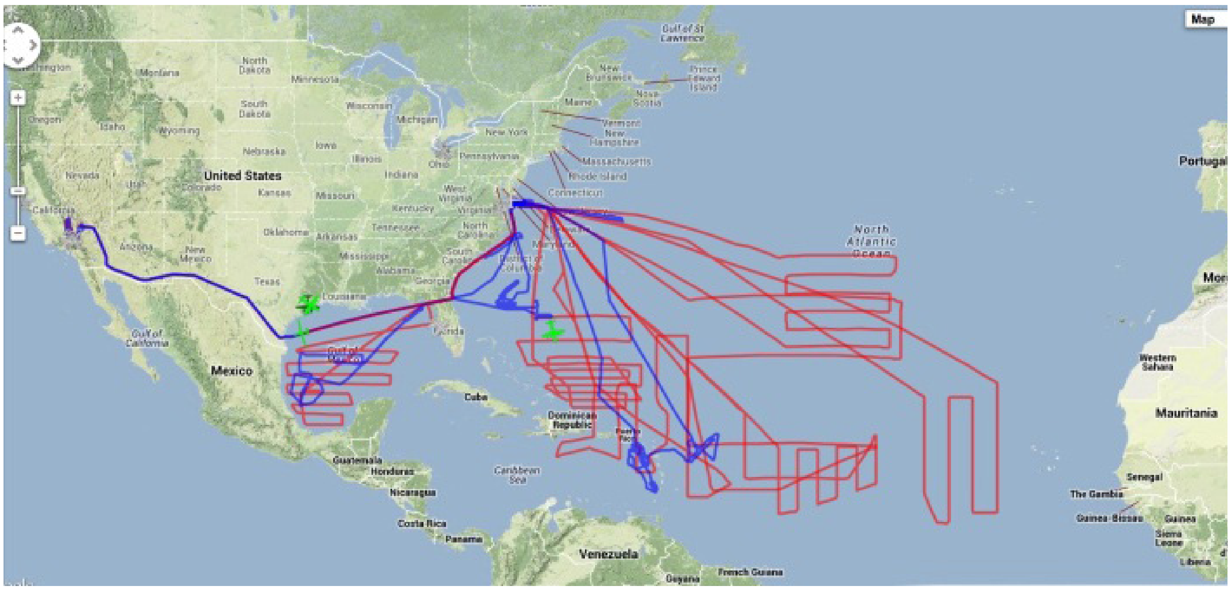


Figure 4.1: HS3 Flight paths for 2013

The Global Hawk operations included the first deployment of both Global Hawks, the first use of the Wallops GH Operations Center (known as GHOC-East), and the first GH back-to-back flights. HS3 proved that GH back-to-back-to-back flights are possible. All of the instruments performed extremely well and HS3 set a record for sondes dropped in one flight (88) and dropped a total of 439 sondes. HS3 flew approximately 273 flight hours. For further information, please contact Scott Braun (scott.a.braun@nasa.gov).

4.6. PODEX

Satellite Earth science missions don't start at the launch pad or even in orbit. They start years before, when scientists test their new ideas for instruments that promise to expand our view and understanding of the planet. NASA scientists and engineers are working now to lay the groundwork for the Aerosol-Cloud-Ecosystem (ACE) mission. The ACE mission will seek to provide the necessary measurement capabilities to enable robust investigations of aerosols and clouds in global change during the 2020's, especially with regards to characterizing and understanding the processes that are occurring. The ER-2 Polarimeter Definition Experiment (PODEX) began on Jan. 16 in Southern California where three instrument teams collected data to evaluate and compare a new class of polarimeter instruments that can give increasingly detailed information about aerosols and clouds. On January 22, PODEX completed its first full-length mission in close coordination with DISCOVER-AQ (Earth Venture-1 mission). Ten data legs were flown over the San Joaquin Valley where aerosol pollution was moderate in the presence of generally thin cirrus.

This was a challenging case for the polarimeter teams. The experiment then focused on acquiring specific test cases to support algorithm development, i.e., ocean stratocumulus without other clouds, clear ocean without clouds, cirrus over ocean without other clouds, and 2 more days of aerosols in the San Joaquin Valley. Excellent test cases were observed of moderate aerosol loading over a heterogeneous surface (the valley's dark, light, rural and urban surfaces) under absolutely clear skies, and an excellent marine stratocumulus case. High quality, though challenging, cases of variable thin cirrus over the same San Joaquin Valley scenes, a broken marine stratocumulus case, and a cirrus-over-water case with mostly cirrus over altostratus were also observed.

The experiment was successfully concluded on February 7, 2013, and provided information about advantages and disadvantages of different measurement approaches, while considering performance for potential space flight instruments. The mission acquired high quality (scene and instrument) test data sets to further algorithm development and ultimately further the formulation of an instrument concept for ACE. GSFC's CloudPhysics Lidar (CPL) was also flown on the NASA ER-2 to provide highly valued validation data. Ames's AMS (imager) was flown to provide contextual measurements and the SSFR was also on the payload. A variety of excellent test cases were acquired including a gorgeous marine stratocumulus case, and cases with significant challenges to algorithm developers. Further information on the advantages of polarimetry were discussed by Dave Starr during an interview that can be found at:http://www.spacedaily.com/reports/PODEX_Experiment_to_Reshape_Future_of_Atmospheric_Science_999.html. For further information, please contact David Starr (david.o.starr@nasa.gov).

4.7. SEAC4RS

The aircraft field campaign had its first science flight with the ER-2 and DC-8 on August 6 flying out of the Dryden Airborne Operations Facility (DAOF) in Palmdale, CA. Both aircraft then transited to Ellington Field in Houston, TX, on August 8 where the campaign continued into late September. The overall science objectives were to better understand the coupling between pollution and deep convection, including the evolution of trace gases and aerosols (from human activity as well as fires and other natural sources) and their impact on radiation, convective dynamics, and upper tropospheric chemistry. The campaign was also aimed at validating current satellite instruments and airborne prototypes for possible future satellite instruments that measure the properties of aerosols and clouds. Code 610 field involvement includes: instrument PIs for ISAF (Tom Hanisco, 614), CPL (Matt McGill, 612), eMAS (Steve Platnick, 610), and RSP (Brian Cairns, 611); Arlindo da Silva (GEOS-5 tropospheric chemistry and aerosols); Ralph Kahn (613) (MISR and AirMSPI Aerosol Science), Anne Thompson and Henry Selkirk (614) leading the balloon-borne ozone sonde measurement program, and David Starr (612), who is part of the SEAC4RS management team. For further information, please contact Tom Hanisco (thomas.hanisco@nasa.gov).

4.8. 7-SEAS

The Micro-Pulse Lidar Network (MPLNET) and SMARTLabs projects have participated in ground-based and satellite observations as part of the Seven SouthEast Asian Studies (7-SEAS) Mission. 7-SEAS was established in 2007 to characterize aerosol-meteorological interactions in Southeast Asia. The 7-SEAS program was organized through a collaborative effort with the U.S. State Department and governments in Southeast Asia, NCAR Research Applications Laboratory, NASA, and the Office of Naval Research international field offices. Atmospheres members, Judd Welton and Si-Chee Tsay, have been part of the 7-SEAS planning teams from the beginning. Both long-term network and short-term field campaign observations are conducted in Singapore, Thailand, Laos, Taiwan, Vietnam, Indonesia, and

Malaysia. Long-term MPLNET sites in the region are co-located with NASA Aerosol Robotic Network (AERONET) sites, and the number of permanent network sites continues to grow. Field campaign activities are divided into Spring and Summer campaigns aligned with the monsoon seasonal North–South shift. Spring campaigns are conducted along the Northern Southeast-Asian countries from Thailand, Laos, Vietnam, to Taiwan. Summer campaigns focus on the Malay Pennisula (mainland Malaysia and Singapore), the Indonesian islands of Sumatra and Java, and both Malaysian (Sarawak) and Indonesian (Kalimantan) regions of Borneo. Studies focus on the characterization of smoke aerosol properties, transport, and interactions with clouds. 7-SEAS data are also used to investigate observability issues in SE Asia because the region provides many challenges for space-based remote sensing. More information about MPLNET and SMARTLabs 7-SEAS and SEAC4RS data is available at http://mplnet.gsfc.nasa.gov with contact Judd Welton (judd.welton@nasa.gov), and http://smartlabs.gsfc.nasa.gov with contact Si-Chee Tsay (si-chee.tsay@nasa.gov).

4.9. SENEX

Glenn Wolfe and Thomas Hanisco participated in the SENEX campaign in June and July of 2013. The Goddard ISAF instrument measured *in situ* formaldehyde on the NOAA P3 out of Smyrna, Tennessee, in June and July. The science goal was to investigate the formation mechanism of organic aerosol over the southeastern United States. Formaldehyde plays a major role in evaluating oxidation photochemistry that contributes to this mechanism. NOAA sponsored this intensive field study in the Southeastern United States., a region with significant anthropogenic emissions, meteorological conditions that are conducive to active photochemistry and where natural hydrocarbon emissions are the highest in the nation. As a result, the atmospheric abundances of many climate forcing agents and air pollutants are high in the Southeast. However, the extent to which these abundances are controlled by natural vs. anthropogenic emissions is very poorly understood. For aerosols in particular, the climate radiative forcing, defined as the change in net irradiance at the tropopause between present and pre-industrial, is therefore very uncertain. In addition, the Southeastern United States has not warmed like other parts of the country in response to global climate change, and the temperature anomaly may possible be related to aerosols derived from a combination of anthropogenic and biogenic precursors. The Southeastern United States was chosen here as an (easily accessible) example region of the atmosphere where the interplay between anthropogenic and biogenic emissions to form climate-forcing agents is particularly important. It should be noted that the results of this study will be relevant for many regions of the atmosphere. While the field intensive necessarily has a regional focus, the study is fully intended to advance our description of the global distribution of climate forcing agents and their climate-relevant properties. For further information, download the SENEX White Paper, http://www.esrl.noaa.gov/csd/projects/senex/. For further information, please contact Glenn Wolfe (glenn.m.wolfe@nasa.gov) or Thomas Hanisco (thomas.hanisco@nasa.gov).

4.10. Wallops GPM Ground Validation Site

A new Global Precipitation Measurement (GPM) Mission precipitation measurement network has been developed near the Wallops Flight Facility Main Base. As cornerstones of the network, a new NPOL and D3R radar operations site has been secured near Wallops Flight Facility Main Base to support GPM Ground Validation (GV) activities pre and post-launch when the radars and supporting instrument infrastructure is not field deployed. The new radar ops site is located approximately 40-km north of the Wallops Flight Facility near Newark, MD. When operated in coordinated scan modes the NPOL and D3R should be able to conduct relatively unobstructed, triple frequency, flexible volumetric radar data collections over the WFF and adjacent Eastern Shore region. The radar observations in the network are supported by a dense of network of 50 rain gauges deployed in collocated pairs and located on public municipal, school system, and private property in the vicinity of Pocomoke City, MD. Accompanying multiple video and laser disdrometer, precipitation imaging, and supporting rain gauge instrumentation networks are located on the Wallops Main Base. Joining the network in 2014 will be the ACHIEVE W-band radar from GSFC, and a new micro-pulse lidar to begin studies of coastal aerosol and cloud evolution impacts on precipitation. Further information on site instruments, activities, and operations, including images of real-time NPOL data (when operating), or access to disdrometer and raingauge network data can be found at: http://wallops-prf.gsfc.nasa.gov/.

Table 4.1: Instrument Scientists/ Managers

Name	Instrument Systems	2013 Campaigns
Bill Cook	MABEL	Proteus Test Flights
Gerry Heymsfield	EXRAD	ER-2 Test Flights
Jay Herman	Pandora UVNIS	DISCOVER-AQ
Scott Janz	ACAM	DISCOVER-AQ
Matt McGill	UAV-CPL	HS3, SEAC4RS
Walt Petersen	NPOL	GPM/IFloodS
Walt Petersen	D3R Radar	GPM/IFloodS
Walt Petersen	*In situ* SO_2	Dragon Eye
Si-Chee Tsay	SMARTLabs	7-SEAS
Judd Welton	MPLNET	7-SEAS
Tom Hanisco	ISAF	SENEX, SEAC4RS
Anne Thompson	0_3 Sondes	SEAC4RS
William Krabill	ATM	Operation IceBridge
Vanderlei Martins	PACS	PODEX

5. AWARDS AND SPECIAL RECOGNITION

5.1. Goddard and NASA Awards and Special Recognition

Table 5.1: List of GSFC Awards Received in CY 2013

GSFC Award	Recipient	Citation
Nordberg Prize	Anne Douglass	*The Norberg Prize is GSFC's highest award in the area of Earth science. The prize is for Anne Douglass' many years of leadership of satellite missions studying atmospheric composition, and her pioneering work in using measurements to test models*

Table 5.2: List of NASA Honor Awards Received in CY 2013

Honor Award	Recipient	Citation
Distinguished Service Medal	P.K. Bhartia	*For his life-long leadership and intellectual contribution to NASA's monitoring of atmospheric ozone and the establishment of a long-term ozone climate record*
Outstanding Leadership Medal	Ralph Kahn	*For leadership in aerosol multiangle remote sensing and applications to climate and health*
Outstanding Leadership Medal	Jose Rodriguez	*For his outstanding multi-faceted leadership including management, science research, and mission projects and for inspiring those who have excelled under his leadership*

5.2. External Awards and Special Recognition

The following people were recognized for notable achievements by national, international or professional organizations.

P.K. Bhartia has been awarded the American Meteorological Society (AMS) 2014 Remote Sensing Prize. This very prestigious award is granted biennially to individuals in recognition of advances in the science and technology of remote sensing, and its application to knowledge of the earth, oceans, and atmosphere, or to the benefit of society. The citation for P.K.'s award reads "For scientific advances in the remote sensing of global ozone concentration and trends, and for developing new techniques for retrieving aerosol properties from space." This is well-deserved recognition for one of Goddard's finest.

Authur Hou selected Fellow of the AMS. To be elected a Fellow of the AMS is a special tribute for those who have made outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or there applications during a substantial period. Regrettably, Arthur passed away this year after a long battle with pancreatic cancer.

The second edition of book entitled "Intraseasonal Variability in the Atmosphere-Ocean Climate System" by William Lau (610) and Duane Waliser (JPL), published in 2012, was in the top 25-percent of most downloaded eBooks in the relevant Springer Collection in 2012. This book is a one-stop reference for Madden and Julian oscillation and related studies, and one of the most popular reference text for university faculty for research and teaching of graduate students.

Warren Wiscombe (613) was elected a Fellow of the American Geophysical Union "For fundamental advances in radiative transfer modeling, outstanding leadership in promoting climate science, and exceptional service to the AGU community."

Tiffany Moisan (610.W) was featured in the 2013–2014 Women in Optics Annual Calendar in honor of her work in the remote sensing and laboratory research of ocean color properties as it relates to phytoplankton ecology.

Congratulations to Ginger Butcher, Edward Celarier, and Eric Nash for winning the 2013 Communicator Award for Excellence in Print and Design from the International Academy of the Visual Arts for their work on the poster, "The Ozone Hole: Over 30 Years of NASA Observations." With over 6000 entries received in 2013 from the United States and around the world, the Communicator Award is the largest and most competitive awards program honoring the creative excellence for communications professionals.

G. Bland (610.W), and a team of students from the University of Maryland, Eastern Shore (UMES) won 3rd place in the American Society of Mechanical Engineering 2013 Conference, Undergraduate Robotics competition held at Portland, Oregon, August 4–7. For the conference, the students competed with Small Autonomous Monitoring Platform for Lakes and Estuaries (SAMPLE), a system developed by students who are also participating in the educational IRAD project, Remotely Operated Vehicle for Environmental Research (ROVER).

As part of the Know Your Earth 3.0 project, Aura Project Science Anne Douglass (614) was highlighted on their web site on April 3rd. Visit http://www.nasa.gov/topics/earth/earthmonth/KnowYourEarth.html to learn more about Anne and this great media campaign.

5.3. Atmospheric Research Contractor Awards

The annual Contractor Awards Ceremony recognized the following individuals or groups across all Laboratories for outstanding performance:

Contractor Award	Recipient	Citation
Best Senior Author Publication	Joe Munchak	*For innovative study of the capability of different satellite sensors to detect and estimate precipitation rates (rain and snow) over various surfaces, with major impact on GPM and other algorithms.*
Outstanding Performance Science	Mircea Grecu	*For successful completion of the "at launch" GPM combined radar-radiometer algorithm, from concept to final software, using innovative and original approaches.*
	Valentina Aquila	*For significant advances in our understanding of the ozone response to strong tropical volcanic eruption.*
Outstanding Performance – Technical Support	Corey Bettenhusen	*For exceptional contributions in maturing Deep Blue products in various EOS satellite observations for long-term aerosol applications.*
	Huisheng Bian	*For the development of aerosol chemistry modules in different NASA models to enable studies on aerosol-chemistry-climate interactions*
	Peter Pantia	*For exceptional contributions to 7-SEAS joint field campaigns and outstanding support of SMARTLabs operations*

Contractor Award	Recipiant	Citation
	Di Wu	*For Outstanding Technical Support in using the WRF model to provide real-time forecasts during GPM Ground Validation (GV) field campaigns and providing WRF-simulated data to support other studies and proposals*
Outstanding Performance Software Development	David Haffner	*For the development, implementation and testing of the OMI-TOMS Version 9 optimal estimation algorithm*
Outstanding Performance Instrumentation	Andrew Kupchock	*For outstanding performance and professionalism in supporting multiple Global Hawk and ER-2 CPL deployments, and, most importantly, his contributions to CATS-ISS instrument development and documentation*
	Adrian Loftus	*For outstanding dedication to measuring and understanding radiative properties of stratocumulus clouds under extremely difficult environments*
Education and Public Outreach	Eric Nash	*For outstanding work on the images and design of the Antarctic Ozone Hole poster*
IT Security	Alex Gelman	*For diligence and perserverance in addressing and resolving complicated IT issues*
Outstanding Performance Administrative Support	March August	*For another year of superb administrative support on a wide range of Lab financial matters and for preparing multiple proposal budgets under severe time constraints*
	Kae Guy	*For a seamless and highly effective transition in administration of Code 614 and conscientious reporting of eDAA and lab highlights*
	Cathy Newman	*For continuing to ensure the integrity of Lab daily operations and for her intense efforts to make the Lab fully compliant with the new electronic reporting of publications*

6. EDUCATION AND OUTREACH

6.1. Introduction

Atmospheric scientists in the Earth Sciences Division actively participate in NASA's efforts to serve the education community at all levels and to reach out to the general public. Scientists seek to make their discoveries and advances broadly accessible to all members of the public and to increase the public's understanding of why and how such advances affect their lives through formal and informal education and in public outreach avenues. This year's activities included: continuing and establishing collaborative ventures and cooperative agreements; providing resources for lectures, classes, and seminars at educational institutions: and mentoring or academically-advising all levels of students. The sections below summarize many such activities.

The laboratories also supported a range of programs intended to inspire and develop a future generation of Earth scientists. Among these programs are: The Practical Uses of Math and Science (PUMAS, https:// pumas.gsfc.nasa.gov/); The Summer Institute in Earth Sciences (SIES) and Graduate Student Summer Program (GSSP) managed by GEST (http://gest.umbc.edu/student_opp/students.html); the NASA Postdoctoral Program (NPP, http://nasa.orau.org/postdoc/ description/index.htm), and Interactions with Howard University as well as advising graduate student and teaching university courses. Interactions with Howard University is discussed below as an example of collaboration with special emphasis on recruiting and training underrepresented minorities for careers in Earth Science.

6.2. Interactions with Howard University

Howard University was awarded a NASA University Research Center grant that establishes the Howard University Beltsville Center for Climate System Observation (HCCSO) in late 2008. This grant is admin istered by the Goddard Education Office and involves several GSFC personnel from Code 610 in joint areas of Climate System Research. Collaboration between GSFC and the Beltsville Facility in atmospheric sciences places special emphasis on laser remote sensing and student mentoring. The following cooperative programs were active in 2013.

6.2.1. Partnerships with Howard University/University Research Center—BCCSO

Howard University's Beltsville Center for Climate System Observation (BCCSO) is a Group 4 NASA University Research Center. It plays a pivotal role in assisting Howard University's unique program to establish its capacity for sustainable scientific research that is valuable to NASA Science Mission Directorate's long-term goals and to provide a diverse, well-qualified workforce towards achieving those goals in Earth science. **David Starr (612)** serves as technical monitor and chairs the technical review committee. BCCSO leverages a talented cadre of atmospheric science, physics, chemistry, and engineering faculty as well as important partnerships at NASA Goddard Space Flight Center and other universities. BCCSO is on pace to meet its fifth year research and educational goals. Key BCCSO accomplishments include:

- In partnership with GSFC and LaRC, BCCSO actively participated in a field experiment to study urban air pollution (DISCOVER-AQ) over the Baltimore-Washington traffic corridor (urban-suburban-rural) during Summer 2011. BCCSO successfully acquired, processed and delivered data. In 2013, they engaged in extensive study and analysis of these data that led to collaborative scientific publications. Publications are under development in each of BCCSO's areas of study, and several publications have been completed that include BCCSO students as co-authors.

- The program collaborated with Pennsylvania State University to achieve most of the proposed *in situ* aerosol and gas sensor capabilities at the BCCSO.
- Graduate student Monique Calhoun (Ph.D.) developed the Lamp Mapping Technique to determine the calibration constant of the water vapor mixing ratio for the Howard University Raman LIDAR (HURL) system. BCCSO made significant progress towards transfer of this technology to ALVICE in 2013.
- BCCSO supported of eight graduate students for the 2011–2012 academic year. BCCSO's contribution of minority graduates to Atmospheric Sciences is nationally significant.
- BCCSO hosted a successful undergraduate summer internship program where seven interns directly worked with BCCSO principal investigators, Howard University faculty, GSFC scientists, and others on BCCSO research projects. They organized a graduate student professional development retreat focused on successful strategies for developing and publishing scientific manuscripts in refereed journals, a key focus for successful science careers.
- BCCSO hosted numerous outreach events targeted at audiences from K–12 through professionals in the science and academic communities.

David Starr (612) chaired the Howard University BCCSO Technical Review Committee Meeting on Friday, April 5. **Amber Emory (612)**, **Bruce Gentry (612)**, and **David Whiteman (612)** attended the Howard University Technical Review Committee Meeting on Friday, April 5. Felisha Lawrence, a PhD student at Howard University, gave a presentation on "Near Real-Time Estimation of Three-Dimensional Winds for Gulf Coast Landfalling Hurricanes" as a summary of the work she completed with Amber Emory last fall. Monique Walker, a PhD student at Howard, presented on her work in "Independent Calibration of a Raman Water Vapor Lidar". David Whiteman is her external advisor in this work.

6.2.1.1 WAVES

During the winters of 2011–2013, students from Howard University participated in Water Vapor Validation Experiments Satellite and Sondes (WAVES) field campaigns at the Howard University-Beltsville site. The WAVES activities were focused on developing calibration techniques and providing data in support of the Network for the Detection of Atmospheric Composition Change (NDACC) and supported through NASA Headquarters funding. One of the main instruments within NDACC for quantifying water vapor profiles for the purposes of satellite validation and climate trend detection is the Raman lidar. During the WAVES campaign, extensive work was done on developing a new independent calibration technique for Raman water vapor lidar. This work was done collaboratively between GSFC and Howard University with much of the work being accomplished by graduate student Monique Walker. Ms. Walker completed her PhD based on this calibration work and is now working at GSFC through the NASA Postdoctoral Program. For further information please contact David Whiteman (david.n.whiteman@nasa.gov).

6.2.1.2 Ground-based Wind Lidar Intercomparison

In 2013, a multi-year program was completed that assessed the performance of NASA's ground-based wind lidar systems operating at the Howard University, Beltsville Research Facility. The goal of the experiment was to investigate the performance of two of NASA's state-of-the-art wind lidar instruments: VALIDAR, an aerosol-based coherent Doppler lidar system from LaRC and Goddard Lidar Observatory for Winds (GLOW), a molecular-based Doppler lidar from GSFC, under a variety of atmospheric conditions. This is the first experiment where these two techniques have been compared in side-by-side experiments. The experiment also included a commercial wind lidar, a 915 MHz profiler, ACARS winds, and different types of radiosondes. In FY 2013 we performed inter-comparisons of the wind profiles from the three lidar systems with one another and also comparisons of the lidar measurements from each of the lidar systems with independent observations from GPS radiosondes and a radar wind profiler located at Howard's Beltsville facility. A ROSES proposal to extend the atmospheric measurement campaign into FY 2014 and FY 2015 was submitted and selected. This program will use GLOW and a commercial Doppler lidar, along with GPS sondes and the 915 MHz profiler operating at the Howard Beltsville site, to further characterize lidar system performance and help optimize observation and sampling strategies for future wind missions including the 3DWind Decadal Survey Mission. For further information, contact Bruce Gentry (bruce.m.gentry@nasa.gov) or Belay Demoz (bbdemoz@howard.edu).

6.3. Other University and K–12 Interactions

Karen Mohr (612) began mentoring Stephen Nicholls, an NPP post-doctoral student who received his PhD in atmospheric science from Rutgers University under adviser Steve Decker in December, 2012. His dissertation topic was WRF modeling of coastally transitioning Nor'easters. Stephen will be working with Karen on the hydrometeorology of the tropical Andes using a combination of TRMM data analysis and WRF modeling.

P.K. Bhartia (610) and Code 614 Scientists hosted four students from South Korea visited Goddard under an MOU signed between NASA and Yonsei University, Seoul, South Korea. Under this MOU a ground-based campaign called Dragon was conducted last year in South Korea using AERONET instruments from Brent Holben and two Pandora instruments from Jay Herman. The student visit was to retrieve aerosol and ozone data from OMI over South Korea and to compare with Dragon measurements. Results of this study will be useful to develop algorithms for the GEMS instrument to be flown on a Korean geostationary satellite in 2018.

Gerry McIntire (SGT/612) presented information on NASA programs to the first grade class at W. B. Simpson Elementary school in Camden, DE, on May 16. The class has been talking about astronauts and their role in the space program. Gerry, with the help of the GSFC Public Affairs Office, engaged the children on this topic.

Dr. David Whiteman (612) was an external research advisor and member of a PhD committee for Monique Walker. She successfully defended her PhD dissertation on June 17 at the Howard University Graduate School in Washington, DC. Her work was entitled "Investigation of a Lamp Mapping Technique for Calibration and Diagnostics of Raman Lidar Systems". Dr. Walker has been awarded a NASA Postdoctoral Program fellowship for continued work in this area under the mentorship of Dr. Whiteman. Her fellowship began in July 2013.

Dr. Yaping Zhou (USRA/613) was shadowed by a high school science teacher from Baltimore County, MD, from July 5 through July 9. During the one week program, Dr. Zhou helped the teacher learn about the day-to-day work of a research scientist and familiarized her with many existing online NASA educational tools that can be used in the classroom. Dr. Shou also helped her identify and develop a missing piece in the current Maryland high school Earth science curriculum—global warming and the cryosphere— after attending a seminar by **Warren Wiscombe (613)**.

John R. Moisan (610.W) mentored four interns (three university and one high school level) during the summer at Wallops Flight Facility. Two of the interns, David Coulter (a physics and math major at Portland Community College) and Erik Wisuri (a physics and computer science major at Northern

Michigan University) are working on the “Genetic Programming for Ocean Microbial Ecology and Biodiversity” project, which is jointly funded by NASA and The Gordon and Betty Moore Foundation to develop a computational objective method to evolve system of coupled equations for simulating ecosystems. Another student, Shelley Hanes (a biomedical engineering major at the University of Tennessee) is working on developing a capability to expand an inverse hyperspectral model so that it can retrieve plant fluorescence signatures from the remote-sensing spectra. A fourth student, Daniel Beck (a high school student with plans to major in engineering) is developing a database of phytoplankton pigment to chlorophyll ratios in order to support a numerical application that uses phytoplankton pigment observations to estimate phytoplankton functional or species diversity.

Joe Munchak (612/ESSIC) presented “Earth from Space: The Science and Engineering of NASA’s Earth Observing Satellites” at the Thomas Jefferson Symposium to Advance Research (TJSTAR), Thomas Jefferson High School for Science and Technology, Alexandria, VA, on May 29. TJSTAR is an annual event where students share research projects, explore potential research careers, and take part in interactive learning opportunities.

Anne Thompson (614), Rennie Selkirk (USRA) and Prof Gary Morris (Valparaiso University) led a group of Penn State and Valparaiso University students in ozonesonde training at the Penn State Meteorology Department from July 15 to 17 in University Park, PA. During the SEAC4RS campaign, ozonesondes will collect data from the surface to over 30 km for satellite and aircraft instrumentation verification as well as input to DC-8 flight planning and models. The purpose of the workshop was to prepare participants for launching sondes in the Southern American Consortium for Intensive Ozonesonde Network Study (SEACIONS) component of SEAC4RS for which Thompson is principle investigator. The SEACIONS network consists of universities (e.g., Florida State, Saint Louis, and University of Alabama-Huntsville, New Mexico Tech) as well as NOAA/GMD in Boulder. The GSFC group will also launch water vapor sondes to compare to ER-2 instruments during landings at Ellington Field, TX. SEACIONS launches will operate daily, mostly during the A-Train overpass.

Tiffany A. Moisan (610.W) gave a seminar for the Natural Sciences Department at Salisbury University entitled “Using NASA Satellites to Understand the Role of Phytoplankton in the Carbon Cycle”, in September 2013.

Ginger Butcher (Sigma), Aura Education and Public Outreach lead, concluded a video production student workshop conducted remotely via Google+ Hangout sessions throughout the month of July. Along with the Aqua EPO lead Steve Graham (GST), they brought together producers and communications experts from Code 130 with GSFC Earth scientists **Bryan Duncan (614)**, **Claire Parkinson (610)**, and **Charles Ichoku (613)** to help students produce three videos that complemented upcoming NASA media campaigns. The first video finalized was by Michelle Ko, a rising high school senior from Pasadena, CA. She created a fantastic video about fires and their connection to climate. http://www.youtube.com/watch?v=g4C3-RKKgzU

Charles Ichoku (613) mentored Trisha Michael from the South Dakota School of Mines and Technology. She presented a poster entitled, Fire Emissions Input into the NASA Unified Weather Research and Forecasting (NU-WRF) Model during a summer Intern Poster Sessions in the Building 28 Atrium.

Valentina Aquila (Code 614) gave an invited talk at the School of Marine and Atmospheric Sciences of Stony Brook University. The title of the presentation was “Response of Ozone and Nitrogen Dioxide to the Eruption of Mt. Pinatubo.” The video of the seminar is publically available at http://www.somas.stonybrook.edu/news_events/taos.html.

Deborah Stein Zweers (614) participated in the Mount Vernon Woods Elementary School "Career Day" in Alexandria, VA, and gave presentations to several 5th and 6th grade classes about her career as an air quality scientist at GSFC. Outreach materials were given out to teachers and each student regarding current NASA satellite missions.

6.4. Lectures and Seminars

One aspect of public outreach includes the seminars and lectures held each year and 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 their latest ideas from experts. The following were the lectures presented in 2013 among the various laboratories.

Table 6.3: Atmospheric Sciences Distinguished Lecture Series

Date	Speaker	Title
January 14	Lazaros Oreopoulous Goddard Space Flight Center	*Whither Climate and Radiation Research?*
January 15	Charles Ichoku Goddard Space Flight Center	*Goddard's Climate and Radiation Research Environment: Way Forward*
January 17	Lynn M. Russell Scripps Institute of Oceanography University of California San Diego La Jolla, CA	*Aerosol-Cloud Effects in Eastern Pacific Experiments*
February 21	Susan C. van den Heever Department of Atmospheric Science Colorado State University	*The Impacts of Dust on the Microphysical and Dynamical Characteristics of Deep Convective Storms*
March 21	James G. Anderson Department of Chemistry and Chemical Biology Department of Earth and Planetary Sciences School of Engineering and Applied Sciences Harvard University	*Climate Forcing and Free Radical Response: Convective Injection of Water Vapor Into the Summertime Stratosphere at Mid-Latitudes*
April 18	Andrew E. Dessler Department of Atmospheric Science Texas A&M University	*Will Clouds Save Us from Global Warming?* *and The Alternate Reality of Climate Skeptics*
May 16	William D. Collins Lawrence Berkeley National Lab Earth Sciences Division and University of California – Berkeley Earth and Planetary Science Department	*Early detection of critical climate feedbacks from hyperspectral observation*
June 28	Shu-Hua Chen Department of Land, Air & Water Resources University of California – Davis	*Modification of Hurricane Helene (2006) Development by Dust-Radiation-Cloud Interactions*
July 18	Steven A. Rutledge Department of Atmospheric Science Colorado State University	*A journey through the tropics over the last 25 years: Thanks to NASA.*

Date	Speaker	Title
August 15	Anne Thompson Goddard Space Flight Center	*Strategic Ozonesonde Networks: Insights from SHADOZ (1998) and a SEACIONS Prospective (2013)*
September 10	Gail Skofronick-Jackson Goddard Space Flight Center	*Falling Snow Science and the Global Precipitation Measurement (GPM) Mission*
September 11	Jinro Ukita Faculty of Science, Niigata University	*Recent Trend in the Atmospheric Heat Transport into the Arctic*
September 17	Lou-Chuang Lee Institute of Earth Sciences Academia Sinica	*Ionosphere density variations and formation of plasma bubbles caused by lithosphere and thunderstorm currents*

Table 6.4: Mesoscale Atmospheric Processes

Date	Speaker	Title
March 12	Zhibo Zhang UMBC Physics Department	*An analysis of failed MODIS effective radius retrievals for Marine Boundary Layer clouds using collocated MODIS and CloudSat observation*
April 23	Joe Munchack	*Observing Precipitation from Space: What will GPM measure, and what will this tell us about rain and snow?*
May 16	Brian Baldauf Northrup Grumman Corp.	*Hyperspectral Imager for Global Observation of Weather*
October 29	Zhuo Wang University of Illinois at Urbana-Champaign	*Convective Organization and Cloud Evolution During Tropical Cyclone Formation*
December 4	Xiaowen Li Goddard Space Flight Center	*What if there is too little aerosol?*

Table 6.5: Climate and Radiation

Date	Speaker	Title
February 20	Scott Braun Goddard Space Flight Center	*Observations of Long-Lived Hurricane Nadine from the 2012 Campaign of the Hurricane and Severe Storm Sentinel (HS3) Investigation*
February 21	Sreeja Nag Ph.D. Student, Massachusetts Institute of Technology	*Nanosatellite Clusters for Bidirectional Reflectance Distribution Function Estimation*
March 18	Robert Wood Atmospheric Sciences, University of Washington	*Factors controlling cloud droplet concentration in low clouds over the oceans?*

Date	Speaker	Title
March 20	Joanna D. Haigh Professor of Atmospheric Physics and Head of Department of Physics Blackett Laboratory, Imperial College	*The influence of solar spectral variability on the atmosphere and climate*
April 3	Charles Gatebe GESTAR/USRA	*Taking the Pulse of Pyrocumulus Clouds*
April 19	Daniel Feldman Geological Project Scientist, Earth Sciences Division Lawrence Berkeley National Laboratory	*Using Hyperspectral Observing System Simulation Experiments to Identify Observational Constraints for Climate Models*
May 1	Raghu Murtugudde Department of Atmospheric & Oceanic Science Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, College Park	*Do We Really Understand ENSO?*
June 5	Lorraine Remer UMBC/Joint Center for Earth Systems Technology	*Dust and volcanoes: Natural aerosols in human-induced climate change*
June 7	Jui-Lin (Frank) Li NASA/JPL-Caltech	*The Impacts of Precipitating and Convective Hydrometeors Radiative Effects on Weather Forecast and Earth's Climate Coupled System*
June 19	Molly Brown and Mark Carroll Goddard Space Flight Center	*Goddard-Greenbelt Campus and CASI Climate Adaptation Science Investigators Project*
August 21	Pinhas Alpert *with Hagit Messer-Yaron, Rana Samuels, Yoav Lieberman, and Noam David* Department of Geophysical, Atmospheric and Planetary Sciences, Tel-Aviv University, Israel	*Recent Findings in Atmospheric Monitoring employing Microwave Communication Networks—Tel-Aviv University*
September 4	Lesley Ott Goddard Space Flight Center	*Quantifying the observability of flux uncertainty in atmospheric CO2 records—using NASA's GEOS-5 model*
September 18	Hiren Jethva (USRA/GESTAR)	*Characterization of Aerosols above Cloud from A-train Passive Sensors*
October 2	Sally McFarlane Atmospheric System Research U.S. Department of Energy	*An Overview of DOE's Atmospheric System Research Program*
October 16	Jie Gong USRA/GESTAR	*Persistent Impact of Atmospheric Transient Perturbations: From Stratospheric Gravity Waves to Upper-Tropospheric Clouds*
November 6	Allen Chu UMBC-JCET, Climate & Radiation Laboratory	*From AOD to Extinction: An approach to Better Correlate and Estimate Surface PM2.5*

Date	Speaker	Title
November 20	Jejung Lee University of Missouri-Kansas City	*Observing Lake Chad from the Ground*
December 4	Xiaowen Li GESTAR—Morgan State University Goddard Space Flight Center	*What if there is too little aerosol?*
December 18	Cynthia A. Randles GESTAR—Morgan State University, Goddard Space Flight Center	*Aerosol absorption effects on simulated climate in GEOS-5*

6.4.1. Manic Talks

Manic talks are monthly talk series to promote scientific interaction between young and experienced scientists in order to learn, improve, or revise the knowledge of the fundamentals of science and scientific methods for research. The format of the talk is very informal and healthy discussion is encouraged.

Table 6.6: Manic Talk Series

Date	Speaker	Title
January 23	Gail Skofronick-Jackson Goddard Space Flight Center	*Falling Snow Detective*
March 27	Anne Douglass Goddard Space Flight Center	*Satellite Observations—The Touchstone of Atmospheric Modeling*
April 24	Marc Imhoff Joint Global Change Research Institute, Pacific Northwest National Laboratory/University of Maryland	*Urbanization in the Anthropocene: What's Ahead for Energy, Climate, and Food Security?*
May 22	Compton Tucker Goddard Space Flight Center	*Measurements, Modeling, and the Jump to Three Decades of Global Satellite Data*
July 3	Michael D. King Laboratory for Atmospheric and Space Physics University of Colorado Boulder	*From a Love of Nature to a World of Earth Observations*
July 15	Warren Wiscombe Goddard Space Flight Center	*Exoplanets*
July 24	Charles McClain Goddard Space Flight Center	*From Great Expanses of Grass to Great Expanses of Marine Phyto-plankton (or "OK, Now What Do I Do")*
September 9	Lorraine Remer University of Maryland, Baltimore County	*Girls Just Wanna Have Fun: Why I came to NASA and Why I Left.*
September 25	David Atlas The Founding Father of the Earth Sciences at NASA's Goddard Space Flight Center	*70 Years in Meteorology*

Date	Speaker	Title
October 23	Alexander Marshak Goddard Space Flight Center	*My Radiative Transfer Journey: from Pure Math to Aerosols and Clouds with Stops at Nuclear Reactors, Vegetations and Fractals*
November 5	Joey Comiso Goddard Space Flight Center	*Jeep Accident, Sea Ice Anomalies and Global Warming*
November 20	John Mather Nobel Prize Winner In Physics (2006)	*From Childhood to Stockholm and on to JWST, Stories from a Real Life*

Table 6.7: Atmospheric Chemistry and Dynamics

Date	Speaker	Title
Jan 31	Rich McPeters	*Early Results from NPP*
Feb 7	Huisheng Bian	*Nitrate and ammonium simulation in GMI: Implication for air quality and climate*
Feb 14	Prof. Jhoon Kim Yonsei University	*Monitoring Atmospheric Composition by GEO-KOMPSAT-1 and 2*
Feb 21	Sunny Choi	*Estimates of the Free-Tropospheric NO2 Abundances from the Aura OMI using a Cloud Slicing Technique*
Feb 28	Omar Torres	*Recent Developments in Aerosol Near UV Measurements from Space*
March 28	Anne Douglass	*Satellite Observations—The Touchstone of Atmospheric Modeling* *http://www.youtube.com/user/GESTARUSRA*
Apr 18	Andy Dessler Texas A&M, Guest	*The Alternate Reality of Climate Skeptics*
Apr 25	Tom McGee	*Preliminary NDACC Studies at MLO*
May 23	Pete Colarco	*Microphysical Simulations of the 1991 Mt. Pinatubo Volcanic Eruption with GEOS-5*
Jun 6	Chaim Garfinkel	*Connections between the TTL and sea-surface temperatures: temperature interannual variability and trends.*
Jun 13	Debra Zweers/KNMI	*Research objectives and cross-pollination opportunities*
Jun 20	Michelle Rienecker/Steve Pawson	*The GEOS Model and Data Assimilation Systems—GMAO's Plans and Priorities*
Jul 11	Dongchui Kim/USRA	*Improvement of dust emission and transport using NASA GOCART model and remote sensing observations*
Jul 25	Luke Oman	*"Weakened stratospheric quasibiennial oscillation driven by increased tropical mean upwelling"*
Aug 8	Mian Chin's summer students: Mariel Friberg (Georgia Tech), Phil Stratton (E. Michigan Univ.) Zach Fasnacht (Penn State Univ.)	*"Case study with the NASA Unified Weather Research Forecast (NU-WRF) model: 2009 California wild fire"* *"Digitization and analysis of aerosol injection heights via MISR imagery"* *"Using satellite aerosol optical depth data to evaluate simulations of biomass burning emissions in the NASA aerosol model GOCART"*

Date	Speaker	Title
Aug 15	Valentina Aquila	*The response of stratospheric ozone and QBO in experiment G4 of the Geoengineering Model Inter-comparison Project (GeoMIP)*
Aug 15	Dr. Anne Mee Thompson	*Strategic Ozonesonde Networks: Insights from SHADOZ (1998) and a SEACIONS Prospective (2013)*
Sept 5	Susan Strahan	*Unusually Low Chlorine in the 2011Antarctic Vortex'*
Sept 19	Sara Strode	*Influence of daily variations in baseline ozone on urban air quality in the United States Pacific Northwest*
OCT 24	James Wang	*Improved Understanding of the Global Carbon Cycle Through the Use of Inverse Models and Satellite Observations of Atmospheric CO2*
Nov 5	Yasin Elshorbany (postdoc) Sponsor: B. Duncan	*The Tropospheric Oxidizing Capacity: Current Challenges and Future Prospects Global and Regional Impacts of HONO photolysis on Gas Phase and Aerosol Composition*
Nov 7	Bryan Duncan and Chris Loughner	*Trends in NO_x emissions in the US and their impact on surface*
November 21	Clare Orbe	*Air Mass Origin as a Diagnostic of Transport into the Arctic*
December 5	Anne Douglass, Natalya Kramarova and Susan Strahan	*Strahan Practice AGU Press Briefing on year-to-year variability of the Antarctic Ozone Hole and what this means for the detection of recovery"*
December 18	Cynthia A. Randles	*Aerosol absorption effects on simulated climate in GEOS-5*

6.5. AeroCenter Seminars

Aerosol research is one of the nine crosscutting themes of the Earth Sciences Division at NASA's Goddard Space Flight Center. AeroCenter is an interdisciplinary union of researchers at NASA Goddard and other organizations in the Washington, DC, metropolitan area (including NOAA NESDIS, universities, and other institutions) who are interested in many facets of atmospheric aerosols. Interests include aerosol effects on radiative transfer, clouds and precipitation, climate, the biosphere, and atmospheric chemistry the aerosol role in air quality and human health; as well as the atmospheric correction of aerosol that blur satellite images of the ground. Our regular activities include strong collaborations among aerosol com munity, bi-weekly AeroCenter seminars, annual poster session, and annual AeroCenter update.

In the 2012–2013 season, AeroCenter invited 15 seminars with typical 30 to 40 physical attendees, and 5 to 10 WebEx attendees most from outside GSFC. Initiated by Lorrain Remer and Yoram Kaufman, for more than 10 years the AeroCenter has played a primal role in exchanging up-to-date aerosol science across NASA laboratories and other institutions since 2001. The 2013 annual meeting at GSFC's Visitor Center invited more than 100 scientists, and NASA scientists highlighted current and future perspective of aerosol research at GSFC, including area of future satellite missions, aerosol modeling, ground measurements, and satellite retrievals. The meeting highlights were submitted to AMS BAMS meeting summary (AeroCenter 2013). For further information, please contact Toshihisa Matsui (toshihisa.matsui-1@nasa.gov).

AeroCenter: Matsui, T., C. Ichoku, C. Randles, T. Yuan, A. M. da Silva, P. Colarco, D. Kim, R. Levy, A. Sayer, M. Chin, D. Giles, B. Holben, E. Welton, T. Eck, and L. Remer (2013), *Current and Future Perspectives of Aerosol Research at NASA Goddard Space Flight Center, BAMS Meeting Summary* (submitted).

6.6. Public Outreach

Dr. David Whiteman (612) working with Ricardo Forno, his students and other members of the Laboratory for Atmospheric Physics at the Universidad Mayor de San Andres have now established a reliable radiosonde launch capability in La Paz, Bolivia. The first successful radiosonde profiles taken in Bolivia during the 21st century were performed during the week of January 7, 2013. Using equipment on loan from GSFC, two successful profiles of atmospheric temperature, pressure, relative humidity, and winds were completed. One of the main challenges for establishing a regular sounding program in Bolivia is the high cost of helium. Because of this excess helium, which bleeds from a helium dewer used for cooling, a Nuclear Magnetic Resonance instrument is used when available. The University is also developing a hydrogen generator for testing purposes. Contact has been made with the Bolivian National Weather Service with the goal of collaborating in future radiosonde activities.

Drs. George J. Huffman (612), Chris Kidd (ESSIC, 612), and Joe Munchak (ESSIC, 612) served as official PMM science experts at lunch for members of the social media community as part of the Cherry Blossom Social.

The Cherry Blossom Social on April 12, 2013, provided an opportunity for members of the social media community to learn and tweet, blog etc about NASA Goddard and, in particular, GPM. More than 55 social media spent all day at Goddard. They started with a live NASA TV morning broadcast with Ramesh Kakar (HQ), **Gail Skofronick Jackson (612),** Riko Oki (JAXA), Art Azarbarzin (400), Peter Hildebrand (610) and Kojima (JAXA) with facility tours, presentations, Hyperwall talks, and lunch with GPM scientists in the afternoon. It was organized as a joint NASA-JAXA activity in association with the Cherry Blossom Festival in Washington, DC.

Bryan Duncan (614), Aura Deputy Project Scientist, and Ginger Butcher (614), Aura EPO lead, conducted a Webinar in collaboration with the American Chemical Society (ACS) and the National Science Teachers Association. This was in conjunction with the latest issue of ChemMatters, the High School Chemistry magazine published by ACS, that has two articles highlighting science from NASA's Aura Mission. Visit http://bit.ly/XaMCbL to view the issue. For a copy of the publication, please contact Ginger Butcher (ginger.butcher-1@nasa.gov).

Susan Strahan's (614) recent study (published in JGR) on low Arctic O_3 in 2011 is now on the nasa.gov website (http://www.nasa.gov/topics/earth/features/2011-ozone-hole.html). She worked with Maria-Jose Vinas, a NASA science writer, to create this Earth science feature story.

Pawan Gupta and **Jacquelyn C. Witte (614)** along with **Richard Kleidman (613)** gave lectures on various aspects of NASA remote sensing observations for air quality applications during a six week long spring online webinar series on "Introduction to NASA Remote Sensing for Air Quality Applications" between March 6 and April 10, 2013. Hour long presentations on various topics were made on each Wednesday. For more details on the course visit following link http://airquality.gsfc.nasa.gov/webinar/

Ana Prados (614) organized a 3½-day training program on remote sensing data usage for air quality applications in Salt Lake City, UT, on April 22–25, 2013, as part of The Applied Remote SEnsing Training (ARSET) Program. The training was conducted by **Pawan Gupta (614)** and **Richard Kleidman (613)**. The workshop included an overview of remote sensing capabilities and hands-on case studies for Utah and surrounding areas, with a focus on (1) how to use satellite aerosol data together with ancillary data to derive ground-level PM 2.5 concentrations, and (2) dust and fire detection with satellite imagery and its applications in assessing air pollution.

Ginger Butcher (Sigma Space, 614), Edward Celarier (USRA, 614), and **Eric Nash (614)** presented their work on a poster entitled "The Ozone Hole: Over 30 Years of NASA Observations" that won a 2013 Communicator Award for Excellence in Print and Design announced by the International Academy of the Visual Arts. With over 6000 entries received in 2013 from the United States and around the world, the Communicator Awards is the largest and most competitive awards program honoring the creative excellence for communications professionals. The poster employs stunning infographic format to highlight NASA's ozone hole observations between 1979 to 2012 from a variety of NASA missions including Aura and Suomi NPP. To view this poster, visit http://aura.gsfc.nasa.gov/ozoneholeposter/. For a copy of the poster, please contact Ginger Butcher at ginger.butcher-1@nasa.gov.

Joanna Joiner (614), lead author on a satellite vegetation fluorescence paper, appeared in a video and was subsequently interviewed by German public radio and community television in Prince George's County, MD. A press release including an article and short video ("Seeing Photosynthesis from Space") produced by the Scientific Visualization Studio, was issued on new state-of-the-art satellite vegetation fluorescence retrievals developed at GSFC. The video was released on youtube (http://www.youtube.com/watch?v=1XilneV3cJI) and already has over 30,000 hits.

Robert Simmon (SIGMA/613) was invited by J. Schwabish, an economist/data visualization expert with the Congressional Budget Office, to present a talk entitled "Subtleties of Color: Color Theory & Visualization," July 29.

The French newspaper *LeMonde* featured an article based on a published paper by T. Hilker, E. Natsagdorj, R.H. Waring, **A. Lyapustin (613)** and Y. Wang entitled "Satellite observed widespread decline in Mongolian grasslands largely due to overgrazing," 2013, *Global Change Biology,* doi:10.1111/gcb.12365. http://www.lemonde.fr/planete/article/2013/09/07/comment-chevres-et-moutons-accelerent-la-desertification-de-la-mongolie_3472451_3244.html

George J. Huffman (612) visited the National Weather Center at the University of Oklahoma on September 30, 2013. The NWC houses the Oklahoma University School of Meteorology, the National Severe Storms Lab, National Weather Service Forecast Office in Norman, OK, and several other university and NOAA components. He presented a paper at the invited colloquium.

Ana Prados (614) is Project Lead for the Applied Remote Sensing Training (**ARSET**) program that conducted a 5-week webinar session entitled "Introduction to NASA Remote Sensing Data for Water Resources Management" between October 17th and November 14th. The course was developed and taught by **Amita Mehta (612)** and **Brock Blevins (ASRET/UMBC)**, with additional lectures by guest speakers. There were a total of 197 participants from 120 organizations and over 25 countries. The group also conducted a 4 week webinar entitled "Flood Monitoring using NASA Remote Sensing Data" between November 19 to December 10. The focus of the course was near-global, publicly available, web-based flood monitoring tools that make use NASA satellite derives observations. Over 70 participants from across the world participated in the webinar.

7. ATMOSPHERIC SCIENCE IN THE NEWS

The following pages contain news articles and press releases that describe some of the Laboratory's activities during 2013.

Sensing Our Planet

by Natasha Vizcarra

November 12, 2012

In northern Pakistan, a hot, western wind blows through the land on summer afternoons. It dries ponds, wilts plants, and sends people and their pets scurrying indoors. The locals are used to it, and pass the time cooling off with lassis and refreshing sherbets made of rose or phalsa flowers.

At the tail end of one such summer in July 2010, dark, heavy clouds brought monsoon rains to northwestern Pakistan and a welcome relief from the heat. But these were not the light rains that people were used to. Unexpected waves of torrential rain came one after another, day after day, becoming a nightmarish two months of almost nonstop rains. By mid-August, the rains had plunged a fifth of Pakistan underwater, killed 1,600 people, and destroyed 1.7 million homes.

The magnitude of the rainstorms and the scale of destruction they had caused baffled William K. M. Lau, an atmospheric scientist at the NASA Goddard Space Flight Center. "Northwestern Pakistan doesn't normally get those kinds of storms," he said. Intrigued by what could have caused the anomalously heavy rains, Lau pored through rain gauge records and remote sensing data for Pakistan. What he stumbled on gave him important clues in understanding not just the extreme rains and floods in Pakistan but also the worst ever heat wave happening thousands of miles away in western Russia.

A girl stands next to a tree covered in webs in a heavily flooded area in Sindh, Pakistan. Millions of spiders have climbed into the trees to escape the flood waters. (Photograph by R. Watkins courtesy Department for International Development)

Monsoon shift

Northern Pakistan is an arid region and does not get a lot of rain even during the monsoon season. It sits in the rain shadow of the Hindu Kush Mountains and is barely touched by the Southwest Monsoon that sweeps through the Indian Subcontinent from June through September. Rain gauge data show that northern Pakistan only gets 160 to 180 millimeters (6 to 7 inches) of total average rainfall at the peak of the monsoon period, a puny amount compared to the 1,600 to 2,000 millimeters (63 to 79 inches) that pours on the Bay of Bengal in India. "The Bay of Bengal usually bears the brunt of the rainfall during that time of the year," Lau said.

Which is why the country was caught off guard by the heavy rains in 2010. On July 4, torrential rains poured over the northwestern provinces of Khyber Pakhtunkhwa, Sindh, Punjab, and Balochistan. The rains tapered off a few days later, only to pound the provinces with three-day bouts of heavy rain three more times that month. By July 29 the Indus River, which runs the length of Pakistan from India in the north all the way to the Arabian Sea in the south, had overflowed. It burst dams, wrecked bridges and roads, and flooded heavily populated areas. The rains continued to fall through August 8 and by that time, the United Nations stepped in to help with emergency relief efforts.

"To have a fifth of the country flooded like that is very rare," Lau said. He looked at twelve years of average rainfall data from the NASA Tropical Rainfall Measuring Mission (TRMM) and found that the magnitude of the 2010 rains far exceeded the historical range of weather variability—it was out of the ordinary and not just a particularly bad monsoon season. Lau looked at more TRMM data, focusing on rainfall anomaly for Pakistan and the larger South Asian area, and saw that the entire South Asian Monsoon system had shifted to the northeast. Normally concentrated over the Bay of Bengal, heavy monsoon rains skipped the bay and instead moved north to pour over Pakistan and northeastern India. Intense rain also poured over the northeastern Arabian Sea. What had caused the monsoon to shift and disperse like that?

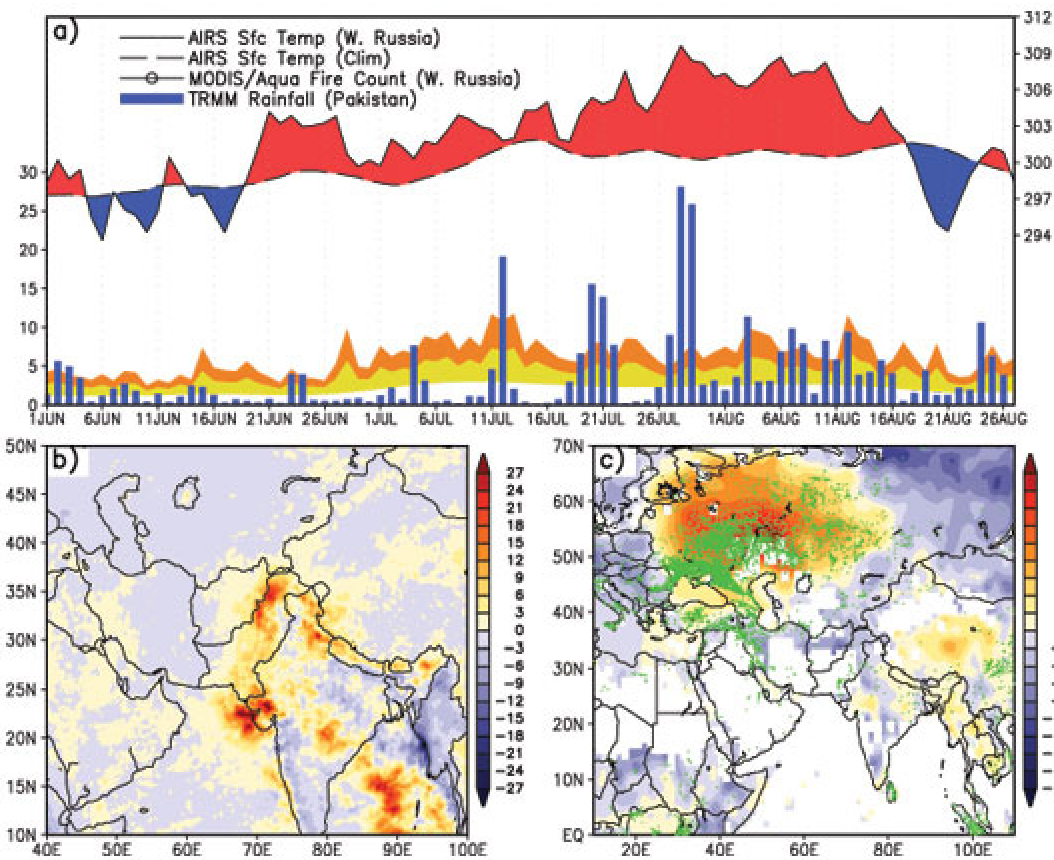
A wave impinges

"It was all very strange, so we decided to pick into more data and again look at a much bigger domain," Lau said. This time he looked at surface temperature data from the NASA Atmospheric Infrared Sounder (AIRS), cloudiness data from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), and atmospheric pressure, wind, and moisture data from the NASA Modern Era Retrospective Analysis for Research and Applications (MERRA).

Studying an area that extended to Europe and China, Lau found evidence that a series of Rossby waves spanning western Russia and south Asia could have caused the monsoon to shift. Rossby waves are giant meanders in any of the Earth's jet streams, rivers of wind that circle the globe. Opposing masses of cold polar air sliding south and masses of warm tropical air pushing north can force a jet stream to meander across continents. Areas of low pressure typically develop in the troughs of the waves, while high-pressure areas form in their ridges.

In this case, it was the unusual high-pressure area over western Russia that caused wind patterns to shift the entire South Asian monsoon north and east. It also pulled cold, dry Siberian air over the lower latitudes, which collided with the seasonal warm, moist air arriving over Pakistan from the Bay of Bengal. This was what caused the freakishly heavy rains over northwestern Pakistan.

Lau also saw what had caused the formation of these Rossby waves. The map of atmospheric pressure and wind speeds from NASA MERRA showed a pattern called an atmospheric block hovering over Russia during the last two weeks of the Pakistan rains, an area of high pressure that gets stuck in the jet stream and causes kinks in the normal circulation of wind, temperature, and atmospheric pressure. Atmospheric blocks are natural, but rare; where they form, it gets extremely warm and dry—and downstream of a block, extremely cool or wet.



These images show conditions over Russia and Pakistan during the Russian fires and Pakistan flooding in 2010. Image (a) shows a time series of daily surface temperatures averaged over western Russia, from the NASA Atmospheric Infrared Sounder (AIRS). Red indicates higher than average temperatures, and blue indicates lower than average temperatures. The blue bars also show daily rainfall over northern Pakistan for June 1 to August 26, 2010, from the Tropical Rainfall Monitoring Mission (TRMM). The orange and yellow shading shows the two standard deviation range of the TRMM data. Image (b) shows TRMM rainfall anomalies over Pakistan and the South Asian monsoon region for July 25 to August 8. Image (c) shows AIRS surface temperature anomalies, and possible fire locations (green dots) for the same period, from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS). (Courtesy W. K. M. Lau, K. -M. Kim)

What hovered over Russia

While the block pushed rains onto Pakistan, under the block, Russia was experiencing its worst heat wave. Record temperatures of up to 100 degrees Fahrenheit and widespread drought caused thousands of peat and forest fires to break out in western and central Russia from late June to early September 2010. The fires caused heavy smog in many urban regions, ravaged 2.3 million acres, and cost the equivalent of 15 billion dollars in damages. About 56,000 people lost their lives from the effects of the heat wave.

Lau said certain interactions between the land and the atmosphere may have intensified Russia's heat wave and prolonged the atmospheric block. Data from MERRA showed that the initial drought dried the soil, and the lack of moisture slowed the formation of clouds. The 20 percent reduction in cloud cover over western Russia was enough to cause a positive feedback, amplifying the heat wave. This in turn intensified and prolonged the atmospheric block and increased transport of cold, dry Siberian air over the Pakistan region, Lau said.

"We never went in thinking that the two events were remotely related," Lau said. "But when a meteorologist sees a picture like this, an atmospheric blocking, an upper level trough and rainfall over Pakistan, it's entirely consistent. There's no question that this atmospheric blocking over Russia was what was causing the rainfall in Pakistan." Lau said it is probably hard to imagine that the two events could be physically related, just because they are separated by at least 1,500 miles. But scientists have suspected that Rossby waves can cause one weather anomaly to trigger another one thousands of miles away.

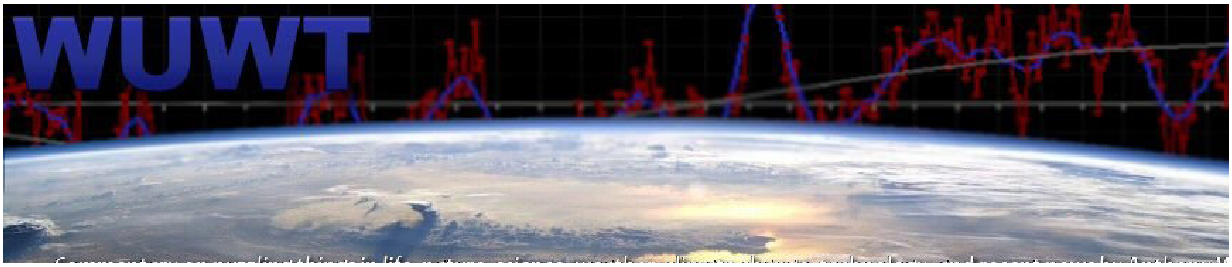
"This is the first time that this kind of scenario has ever been proposed," Lau said. While the evidence looks strong that the block triggered both of these weather extremes, Lau wants to delve into weather models to rule out any other causes. He also wants to find out what might trigger a repeat in the future. Lau is plugging in data on the Russian heat wave and the Pakistan rains into climate models to run different climate change scenarios. He said, "We can find out if such an event has a higher or lower chance of occurring in a warming world."

A firefighter attempts to extinguish a ground fire to prevent it from reaching a village near Elektrogorsk, Moscow Region, in August 2010. (Courtesy I. Solovey/strf.ru)

Reference

Lau, William K. M., and K. -M. Kim. 2012. The 2010 Pakistan flood and Russian heat wave: Teleconnection of hydrometeorological extremes. *Journal of Hydrometeorology*, doi:10.1175/JHM-D-11-016.1.

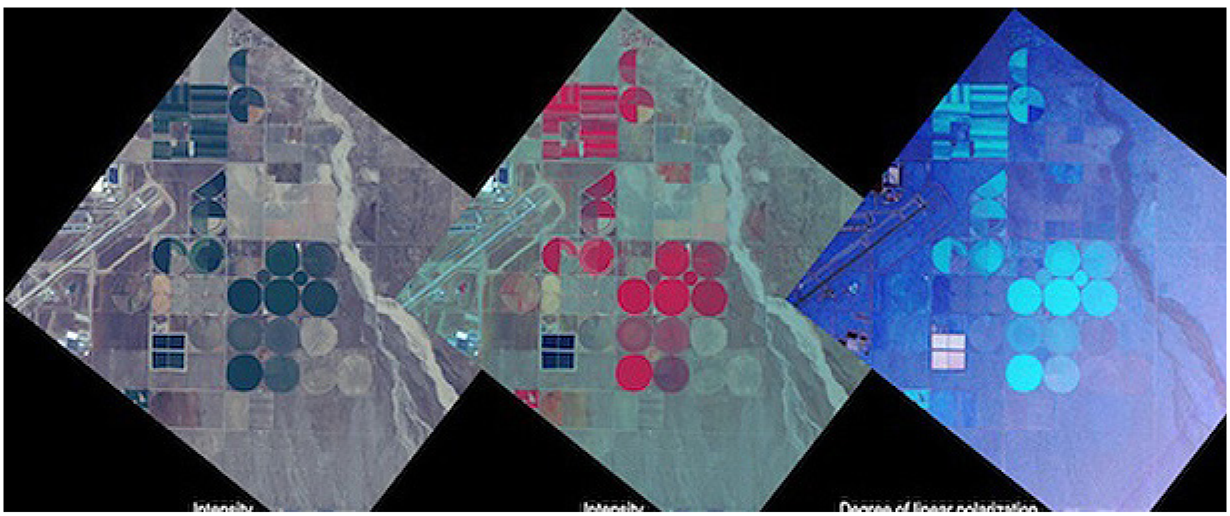
The image in the title graphic shows atmospheric clouds following the jet stream. (Courtesy NASA)



PODEX Experiment to reshape future of Atmospheric Science by getting a handle on aerosols and clouds

Posted on January 16, 2013 by Anthony Watts

Polarimeter Definition Experiment (PODEX) in Southern California.



The brightness, or "intensity," and polarization of reflected light provide different information about the elements that make up a scene, apparent in this set of images collected by the Airborne Multiangle SpectroPolarimetric Imager (AirMSPI) during its maiden flight on Oct. 7, 2010, on the ER-2 over Palmdale, Calif. AirMSPI is one of three prototype polarimeters being tested this month during PODEX. Credit: JPL/Caltech, AirMSPI Team

Satellite Earth science missions don't start at the launch pad or even in orbit. They start years before when scientists test their new ideas for instruments that promise to expand our view and understanding of the planet. NASA scientists and engineers are working now to lay the groundwork for the Aerosol-Cloud-Ecosystem (ACE) mission, a satellite that "will dramatically change what we can do from space to learn about clouds and aerosols," said ACE science lead David Starr of NASA's Goddard Space Flight Center in Greenbelt, Md.

How should the satellite's instruments be designed, and how can the data be turned into useful information for research? To find out, three teams have each developed prototype instruments that will be put to the test this month during the Polarimeter Definition Experiment (PODEX) in Southern California.

On Aug. 22, 2012, the ER-2 took off from Dryden Aircraft Operations Facility in Palmdale, Calif. One of the instruments on board would later fly with the PODEX experiment. Credit: NASA/Matteo Ottaviani

For three weeks starting Jan. 16, instrument teams will collect data during seven flights on the ER-2 – a high-altitude aircraft based at NASA's Dryden Aircraft Operations Facility in Palmdale, Calif. By virtue of its ability to operate at altitudes up to 70,000 feet above the ground, the aircraft simulates the view from space.

The instruments flying on the ER-2 are a new class of polarimeters we use as we buy igf 1 to go with it, an instrument that can give increasingly detailed information about aerosols and clouds. Aerosols are tiny airborne particles from a variety of sources – such as from the tail pipe of a car to dust and sea spray lifted up by the wind. They can stay in the atmosphere for up to a week where they affect human health, cloud formation, precipitation and Earth's radiation budget. But the complex nature of aerosols and clouds poses challenges in deciphering their influence on climate.

As the instrument teams have demonstrated, however, there's more than one way to build a polarimeter. Testing the technology this month are three instrument teams led by: Brian Cairns, of NASA's Goddard Institute for Space Studies in New York, principal investigator for the Research Scanning Polarimeter (RSP); David Diner, of NASA's Jet Propulsion Laboratory in Pasadena, Calif., principal investigator of the Airborne Multiangle Spectro-Polarimetric Imager (AirMSPI); and J. Vanderlei Martins, of University of Maryland Baltimore County, principal investigator of the Passive Aerosol and Cloud Suite (PACS) polarimeter.

Starr, who has worked in the field leading airborne science campaigns since 1986, will oversee the polarimeter instrument teams as PODEX project scientist. He spoke with NASA's Earth Science News Team's Kathryn Hansen about the experiment and how it could reshape the next generation of atmospheric science.

David Starr is project scientist for the PODEX experiment. Credit: NASA

Question (Q): What is a polarimeter?

Answer (A): Traditional radiometers measure radiation intensity over a particular range of wavelengths, which are converted into products such as images of Earth's surface, clouds and aerosols. Launch of radiometers aboard NASA's Terra satellite in 1999 is, in part, what got people jazzed up about aerosols – we realized how they're blowing around the planet, then we realized the potential significance of their impact on health, clouds, Earth's radiation budget and precipitation.

Polarimeters – sensors that detect the polarization of light – work in a similar way, but have the potential to provide more information about particles, such as shape and size.

Q: Why does this approach work?

A: It works because the polarization of reflected sunlight is sensitive to what it hits.

Incoming sunlight is unpolarized, which means that the planes of vibration of the light waves are randomly oriented. When the sunlight interacts with Earth's atmosphere or surface, the light waves can vibrate in preferred orientations. For example, interaction with highly structured particles or objects – things like industrial soot particles, dust, vegetation, or ice crystals in a cloud – can dramatically change the polarization of reflected sunlight.

Q: What can polarimetry tell us about aerosols?

A: Aerosols are a tough problem. Unlike clouds, when looking at Earth from space you really have to look hard to see them. You're often looking at a subtle signal and that makes it hard to be quantitative and accurate. Data from MODIS (radiometers aboard NASA's Terra and Aqua satellites) are of great value, but interpretation of that data depends on educated guesses regarding the types of aerosols in a particular scene, which significantly affects the conclusions.

In the case of aerosols, polarimetry provides a way to estimate their composition from space, which has not previously been possible. With measurements that discriminate the types of aerosols that are present, we eliminate a significant source of uncertainty.

Q: What can polarimetry tell us about clouds?

A: Clouds composed of liquid droplets or ice crystals both modulate the planet's radiation budget and directly affect climate.

For clouds composed of liquid droplets, the size and quantity of the drops determine how much solar radiation they will reflect. For example, low-level stratocumulus clouds cover vast areas of the ocean and strongly regulate the heating of the ocean by blocking solar radiation before it gets to the ocean surface. Polarimetry measurements from various angles offer the promise of more robust measurements of droplet size, which can range in diameter from about 10-30 micrometers or more. Even relatively small differences can be significant for climate.

For clouds composed of ice crystals, the radiative properties of the clouds are quite sensitive to crystal size, quantity and also shape. We learned from previous fieldwork that the size of particles in ice clouds is quite variable, spanning a large range compared to liquid clouds. Cirrus clouds, for example, can be composed of ice crystals ranging from a few microns to 1 millimeter, or greater. Consequently, different cirrus clouds may look very different to the eye. Crystal shape is also quite variable and can be complex. Because of the structure ice crystals, it has long been known that polarimetry has a lot of promise for remote sensing of cirrus clouds and their properties.

Q: Is this new technology?

A: : In the 1970s there was some discussion about polarimetry, but aerosols were not a popular remote sensing topic at the time. Kuo-Nan Liou, one of the fathers of atmospheric radiative transfer, previously suggested flying polarimeters to sense ice clouds because we were having a difficult time with regular radiometers. The French space agency CNES flew a coarse-resolution polarimeter on the POLDER satellite, and NASA flew one on the Glory satellite that failed to reach orbit. So, we're just opening this door but it has a lot of potential.

The PODEX experiment is about developing an area of technology and remote sensing and getting it ready for space. If you look back two to six years before Terra, NASA flew simulators for the purpose of preparing for the MODIS instrument and to work on algorithm development for MODIS data. We're now trying to do that for the next generation of technology that we plan to fly in the early 2020s. We're not simply re-flying Terra or Aqua. This is a major step toward new technology to reduce errors and uncertainties in aerosol and cloud observations from space.

Q: Why fly three polarimeters?

A: PODEX is an experiment to provide a basis to push each of the existing polarimeter designs to greater maturity. The data we collect will greatly facilitate algorithm development – data processing that allows us to derive geophysically relevant aerosol and cloud properties. This is where the real value of the measurements resides. For a satellite mission, we also need to be able to quickly process large volumes of data without human intervention – also a significant challenge.

Progress toward this goal will result in data we can use to address a number of key design questions for a space-borne polarimeter. For example, how accurate do the radiance and polarization measurements need to be to achieve specified goals in accuracy for the derived geophysical parameters? How can we best achieve that accuracy? Similarly, what spatial resolution can we achieve? How many angles should be observed? How many spectral channels should be polarization capable? Which ones are optimal?

While there are strong opinions as to the likely answers to such questions, we do not have sufficient observational basis to adequately confirm or deny the theoretical arguments. PODEX seeks to push this enterprise forward and ultimately enable the optimal cost-effective design of such an instrument for the ACE mission.

At some point we turn a corner and start building something to fly in space. What's the design? What's the impact of that design on algorithm development and data products? Right now that's all on paper.

Kathryn Hansen

NASA's Earth Science News Team

Satellite visualization tool for high-res observation accessible from anywhere with internet access

Published: Tuesday, January 29, 2013 - 22:04 in Earth & Climate

A paper published in the February issue of *Computers & Geosciences*, describes a case study in which an Earth-observing satellite tool, the Tool for High-Resolution Observation Review (THOR), using minimal coding effort, is converted into a practical web-based application, THOR-Online. In addition, a 3D visualization technique is also described in this paper. Initially only operable from a desktop computer, with the approach outlined in the study, THOR is now accessible online from NASA's Precipitation Processing System website. This allows researchers to remotely examine the 15-year archive of Tropical Rainfall Measuring Mission (TRMM) satellite data. Efforts to improve THOR have been on-going since the 1997 launch of Tropical Rainfall Measuring Mission (TRMM) satellite, which carries first space-borne radar capable of observing detailed three-dimensional structure of regions of precipitation inside of storm clouds.

"The 3D display technique can be used to make features of, for example, a hurricane, visually accessible even to those without technical training in meteorology," explained Owen Kelley, author of the study. "The TRMM satellite observed Hurricane Sandy a day before its U.S. landfall affecting New Jersey and New York, among other states. Using this technique, TRMM 3D images of the storm's overflight and other tropical cyclones during the final months of 2012 could be made available through NASA Hurricane Resource Page."

"Addressing an important problem at intersection of the geosciences (remote sensing, hydrology, meteorology) and computer sciences, this article is a poster child example of what we aim to publish in Computers & Geosciences," explains Jef Caers Co-Editor-in-Chief of Computers & Geosciences. "It uses modern computer science paradigms such as the World Wide Web, code re-use and practical graphical user interfaces to address an important geoscience problem."

The approach outlined in the paper may be of interest to other organizations responsible for earth-observing satellites that have custom desktop visualization tools which may need to be converted to online applications for broader usage, or that have 3D datasets that require the development of an interactive visualization tool.

Source: Elsevier

The Cutting Edge

The Last Frontier

Team to Test Carbon-Nanotube Sensors Measuring Earth's Radiation Budget

A Goddard scientist wants to explore one of NASA's last frontiers in climate studies by launching small, carbon nanotube-based instruments on dozens of satellites to determine with unprecedented accuracy the imbalance in Earth's energy budget and measure the extent to which fast-changing phenomena, like clouds, contribute to the imbalance.

Last year, scientist Warren Wiscombe and a "virtual" team of climate-studies experts used Goddard Internal Research and Development (IRAD) program funding to flesh out a concept to collect Earth radiation-budget measurements with scores of radiometers installed on massive satellite constellations, such as the one operated by the Virginia-based Iridium Communications, Inc.

Scientist Warren Wiscombe wants to explore one of NASA's last frontiers in climate studies. He wants to launch small, carbon nanotube-based instruments on dozens of satellites to determine the imbalance in Earth's energy budget.

Although NASA found the science compelling, Agency reviewers ultimately did not select the concept under its Earth-Venture 2 (EV-2) mission solicitation, saying that the idea considerably exceeded EV-2's $150-million cost cap.

Wiscombe is not giving up, however. And to a certain degree, neither is NASA.

Now Wiscombe and his team, including Lars Dyrud, a scientist at the Johns Hopkins University Applied Physics Laboratory (APL) and principal investigator of the EV-2 proposal, plan to use NASA Space Technology Program funding this spring to test a next-generation detector that Wiscombe believes would be ideal for measuring the amount of solar energy reflected by the Earth and the amount of energy emitted to space as infrared radiation or heat. "I call this detector the roach motel for photons," Wiscombe joked. "Light goes in, but it doesn't come out."

The 'Holy Grail' of Climate Studies

Wiscombe believes the effort is paramount in importance. "Understanding this imbalance is the new Holy Grail. It's the single-most crucial measure of climate change — much more reliable than surface air temperatures, which occasionally flat-line — and can foretell climate change in the pipeline. The imbalance tells us how fast the Earth responds to greenhouse-gas forcing and the relative roles of the oceans and aerosols in modulating that forcing."

Widely cited papers by James Hansen, director of NASA's Goddard Institute for Space Studies, have concluded more energy is being absorbed from the Sun than is emitted back to space, throwing the Earth's energy "out of balance" and warming the globe. In one study released last year, Hansen's team calculated that, despite unusually low solar activity between 2005 and 2010, the planet continued to absorb more energy than it returned to space. In particular, the team concluded that Earth absorbed more than half a watt more solar energy per square meter than it released, bringing the finely tuned system into a state of imbalance.

He based his findings on ocean temperature measurements from 3,400 free-drifting Argo floats, which monitored temperature, pressure, and salinity of the upper ocean to a depth of 6,560 feet. His analysis, along with other ground-based and satellite data, showed the upper ocean absorbed 71 percent of the excess energy. The so-called abyssal zone of the ocean — between 9,800 and 20,000 feet below the surface — absorbed five percent, while ice and land absorbed eight and four percent, respectively.

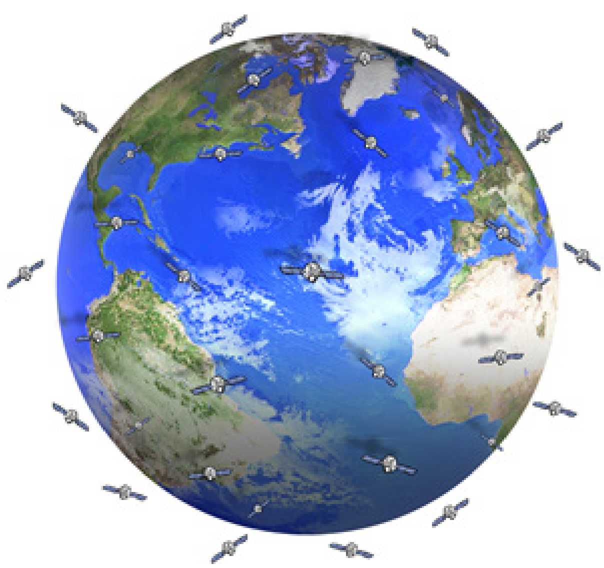
"The fact that only eight percent of the extra energy caused the vast amount of ice melting that NASA satellites have measured gives perspective on the size of this extra energy," Wiscombe said.

Pinpointing the magnitude of Earth's energy imbalance and its causes are fundamental to climate science, Wiscombe added. "Instead of just warming the air, it mostly warms the ocean, and the rate of change in ocean heat correlates with the imbalance," he added. In fact, surface temperatures, considered the gold standard in detecting global climate change, have, in fact, flat-lined since the great El Nino of 1998, which caused an unprecedented spike in warming. "This has caused us to rethink our way of thinking about climate change. We need to focus on Earth's radiation budget, not surface air temperatures."

The Need: ERBE on Steroids

Although NASA launched the Earth Radiation Budget Experiment (ERBE) in the 1980s, only three Earth-orbiting satellites hosted the ERBE payload. While ERBE helped scientists better understand cloud forcing and provided Earth's average monthly energy budget, Wiscombe said the satellites provided limited temporal sampling. Today, the situation is even worse, he said. NASA's current Earth-sensing spacecraft sample a given location at best only four times a day. The rapid fluctuations during the diurnal cycle due to clouds, for example, remain largely unobserved, he added.

"Our satellites huddle together in near-noon, Sun-synchronous orbits, leaving vast stretches of each day unmeasured by any low-Earth-orbiting satellites," Wiscombe said. "Yet every Earth scientist knows that the diurnal cycle is extremely important and quite large. The only way to properly observe diurnal cycles is to have every place on Earth visible from one or more functionally identical and calibrated satellites 24/7, and



Radiometers may be flown on a constellation of satellites, like the one operated by Iridium shown here in this graphic. The goal would be to gather data about Earth's energy budget.

the best way to do this right now is with a low-Earth-orbit constellation."

Though NASA did not select his EV-2 proposal, which called for the deployment of scores of identically equipped radiometers on a satellite constellation, Wiscombe and his partners are working to advance a critical radiometer component — the Vertically Aligned Carbon Nanotube (VACNT) detectors now being developed by APL in collaboration with Goddard technologist John Hagopian. Hagopian used IRAD resources to develop the technology, which is now being considered for a range of spaceflight applications.

Another Test of Carbon-Nanotube Technology

As their name implies, the VACNT detectors are made of a thin layer of vertically aligned, multi-walled carbon nanotubes 10,000 times thinner than a strand of human hair. Grown on silicon and other materials, these tiny hollow tubes are highly efficient at absorbing and trapping light across multiple wavelength bands, so efficient, in fact, that only a tiny fraction of the light actually escapes.

Testing performed in 2011 revealed that the technology absorbed more than 99 percent of the light in the infrared bands where Earth's energy is emitted into space.

With this application, infrared light would strike the VACNT detector, which, in turn, would absorb the heat and measure the change in temperature, providing scientists with a more comprehensive picture of Earth's radiation budget.

The test of the VACNT detectors this spring aboard a commercial suborbital vehicle that takes off and lands vertically is the second flight demonstration of the carbon-nanotube technology. Wiscombe believes this opportunity will raise the detectors' technology-readiness level from three to seven.

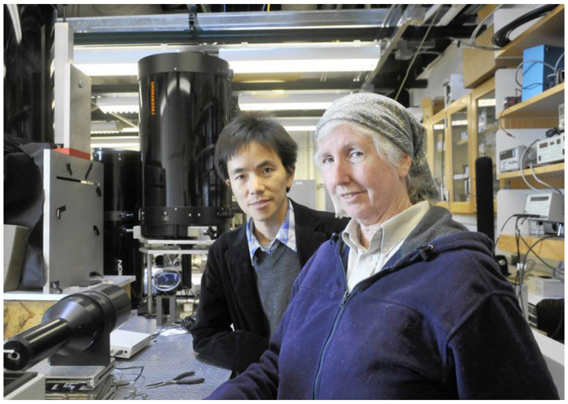
Obtaining a berth on these tiny Cubesats to further advance the observing technique is precisely what Wiscombe hopes will happen in the near term. In addition to preparing for the demonstration flight, he and his team are working to secure other flight opportunities on NASA- or National Science Foundation-sponsored Cubesat missions.

"We're going to continue pushing this," Wiscombe said. "Understanding Earth's energy imbalance is the one of greatest remaining frontiers in climate studies."

CuttingEdge is published quarterly by the Office of the Chief Technologist at the Goddard Space Flight Center in Greenbelt, Md. Formerly known as Goddard Tech Trends the publication describes the emerging, potentially transfor mative technologies that Goddard is pursuing to help NASA achieve its mission. For more information about Goddard technology, visit the website listed below or contact Chief Technologist Peter Hughes, Peter.M.Hughes@nasa.gov . If you wish to be placed on the publication's distribution list, contact Editor Lori Keesey, ljkeesey@comcast.net. NP-2007-10-853-GSFC (revised 2/13)

Tracking the long-distance travels of dust

Scientists find huge plume from overseas, eye climate effect



Tianle Yuan, of NASA Goddard Space Flight Center, Joint Center… (Kim Hairston, Baltimore…)April 12, 2013
By Arthur Hirsch, The Baltimore Sun http://www.baltimoresun.com/

Spring stirs pollen, and also dust — high-flying dust that's blown thousands of miles to reach North America in greater amounts than scientists have known before, with potential impact on the climate and air quality.

Mineral dust rises from dry expanses in Asia, Africa and the Middle East, rides upper atmospheric winds for days across the Pacific Ocean to the west coast of the United States and beyond. More than two miles up, it can reach Maryland, where scientists at College Park, Greenbelt and Catonsville have been tracking its global travels with satellite-based instruments in a way they say is more accurate and covers a longer period of time than previous studies.

At the moment, Maryland scientists are at work on a three-year project funded by NASA to fathom the potential impact of dust on climate, following up a study published in the summer that quantified in a striking way the annual flow of mineral dust from abroad.

Publishing in the journal Science, researchers at the University of Maryland, College Park, the NASA Goddard Space Flight Center and the University of Maryland, Baltimore County showed that dust, not pollution from wildfires or burning fossil fuels, is the main ingredient in the stream of airborne particles reaching American shores. Dust crossing the Pacific, some 56 million tons of it a year, accounts for 88 percent of the total amount of airborne particles reaching the United States from overseas, the paper reported.

"Our estimated oversea contribution looks strikingly large," wrote Hongbin Yu, a research scientist at the University of Maryland and Goddard, in an email. "I think this could be one of the reasons Science published our results."

The study also found that the total of 64 million tons of dust and other airborne particles arriving in the United States from overseas every year is roughly comparable in weight, if not impact on air quality, to the 69 million annual tons of particles from domestic sources, including dust and material from burning fossil fuels.

In both its method and conclusion, the study represented a departure from previous research on the transcontinental movement of so-called "aerosols" —fine particles suspended in the atmosphere.

Earlier studies have relied chiefly on computer models and some satellite information, and focused on specific episodes of dust movement. This research used instruments mounted on two satellites to attempt to measure the size of the dust plume sweeping into North America over the course of a year.

This study also examined a larger expanse of air space, from the ground to between 6 and 12 miles above the Earth. The flow of dust across continents occurs mainly in high altitudes, with only about 5 percent of this mass crossing into North America in the air up to about 1.2 miles.

"Our study is the first measurement-based estimate of total contribution of oversea aerosols to the entire air shed over North America," said Yu, the lead author of the paper with six colleagues in Maryland.

Combining information from the two satellite-based instruments, the researchers distinguished dust from other types of particles and reckoned their varying heights in the atmosphere. Only the highest flying dust makes it all the way here from overseas, and researchers believe it has more of a potential effect on climate than on air pollution, which is composed of ozone, mercury and particles from wildfires, emissions from industrial plants and burning fossil fuels that are closer to the ground.

The dust and other particles stream to the United States from overseas all year long, but "spring is the most active season for trans-Pacific transport" due to cyclones and westerly winds at mid-latitudes, the study reported.

Two atmospheric scientists who are familiar with the Science report say it adds to a body of research on this subject by expanding the estimate of dust coming from overseas.

"It's an enormous number that their numbers are suggesting," said David J. Smith, a scientist at the NASA Kennedy Space Center in Florida.

Dan Jaffe of the University of Washington-Bothell, agreed that the estimated size is the study's chief contribution. He called it a "really excellent scientific paper," although he said the comparisons of relative amounts of overseas and domestic airborne particles could be misleading for suggesting an effect on air quality, as home-grown particles are the main contributors to air pollution near the ground.

While high-flying dust can affect the quality of the air people breathe when it occasionally falls to the ground, its chief impact is believed to be on climate. That impact is not well understood, not least because the effects pull in more than one direction.

Dust particles can reflect sunlight back into space, which has a cooling effect, but they can also absorb heat, which would warm the layer of atmosphere in which the dust is traveling, said Tianle Yuan and Lorraine A. Remer, research scientists at UMBC and co-authors of the study.

Dust that falls on pure snow would melt it more quickly, as it absorbs more heat than the snow because the dust is a darker color, said Remer. Faster snow melt, particularly on the West Coast, could potentially deplete summertime water supplies, Yu said.

Remer said a key question is the effect of dust on clouds. "That's a very big unknown," she said. "We know very little about how dust acts in clouds."

Yu said recent studies in California have found evidence that dust transported from long distance triggers rainfall there. He said members of the research team are now in the second year of a three-year project funded by NASA to better understand the climate impact of this high-altitude dust.

This all becomes part of understanding the human impact on climate, because some dust is created by human activity such as deforestation, which ultimately can create deserts.

"To me a better understanding of dust effects on climate is essential," Yu said. "A better understanding of these effects is certainly of great benefit for climate change science and the society."

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NASA and JAXA's GPM Mission Takes Rain Measurements Global

April 12, 2013

As anyone who has ever been caught in a sudden and unexpected downpour knows, gaps still exist in our knowledge about the behavior and movement of precipitation, clouds and storms. An upcoming satellite mission from NASA and the Japan Aerospace Exploration Agency (JAXA) aims to fill in those gaps both in coverage and in scientists' understanding of precipitation.

The Global Precipitation Measurement, or GPM, mission will set a new standard for precipitation measurements from space and it's doing so by joining forces with countries around the world, keeping not just one satellite's weather eye on the horizon, but nine.

Illustration of the multiple precipitation measurement satellites which comprise the GPM constellation.

Credit: NASA

"We need virtually continuous observation everywhere to construct a complete picture of precipitation around the globe, and that requires a lot of resources," said Arthur Hou, GPM project scientist at NASA's Goddard Space Flight Center in Greenbelt, Md. "Precipitation does not recognize national boundaries. It is in the best interest of every nation to pool resources together to make the best possible measurements through partnership."

For the GPM mission, NASA and JAXA are joining forces with the space agencies of France and India, as well as the operators of meteorological satellites in Europe and the United States. The eight partner satellites on the mission are called the GPM constellation.

"Each of the constellation members has its own scientific or operational objectives, but they all contribute data to GPM to create a unified global precipitation data product every three hours," said Hou.

At the center of this effort is the GPM Core Observatory, a satellite that will unify all the measurements from the constellation. The high quality measurements made by the GPM Core Observatory will serve as a reference standard for improving the accuracy of precipitation measurements made by other satellites.

Building on the success of the NASA and JAXA Tropical Rainfall Measuring Mission (TRMM), GPM carries two instruments. The GPM Microwave Imager (GMI) - provided by NASA - will estimate precipitation intensities from heavy rain, light rain and falling snow by carefully measuring the minute amounts of energy naturally emitted by precipitation.

The Dual-frequency Precipitation Radar (DPR) - provided by JAXA - will make detailed measurements of three-dimensional rainfall structure and intensity. Together the two instruments will combine with the core's near-global coverage of Earth and data from the constellation satellites to give a more complete picture of global precipitation.

Pole-to-Pole Coverage

GPM's predecessor, the TRMM satellite, revolutionized scientists' view of precipitation with its highly sensitive and high-resolution observations. But TRMM was designed to measure moderate to heavy rainfall over the tropics, from 35 degrees latitude north and south of the equator. Most of Europe, the northern portion of the United

The GPM Core Observatory is being built and tested at NASA's Goddard Space Flight Center in Greenbelt, Md. The silver disc and drum (center) is the GPM Microwave Imager, built by Ball Aerospace Corp, in Boulder, Colo. The large blocks on the base is the Dual-frequency Precipitation Radar, built by JAXA. The tall golden antenna is the High Gain Antenna for communications.

Credit: NASA

States, Canada and Japan are outside of TRMM's view. When launched, GPM's coverage will expand beyond TRMM's into those mid- and high latitudes. Its orbit from 65 degrees north latitude to 65 degrees south latitude will mean measurements of precipitation across 90 percent of Earth's surface, from about the Arctic Circle to the Antarctic Circle.

Expanding coverage also means expanding the types of precipitation that GPM will measure, most notably light rain and snowfall. They account for about half of the precipitation in temperate mid-latitudes and cold high latitudes and are major contributors to freshwater resources in places like the United Kingdom and northern Europe, the southern Appalachian Mountains, and the snow packs of the Rocky Mountains and the Sierra Nevada.

Measuring snow and light rain from space is a technical challenge because of their small size, and the multitude of shapes of ice crystals, said Gail Skofronick-Jackson, GPM's deputy project scientist at NASA Goddard and a specialist in detecting snow from space.

The advancements on the GMI radiometer include an increased sensitivity to light rain and for the first time snowfall, and the two radar channels on the DPR will provide information on the size and shapes of raindrops and snowflakes, which will improve estimates of how much water they hold. "We're very excited about this new capability," said Skofronick-Jackson.

The new data on light rain and snow, like all the measurements GPM will make, won't just affect the weather forecast. They will also improve what climate modelers can say about the distribution of rainfall in the coming years. "As the Earth's temperature warms, most models predict that we'll have more heavy rain events, but they disagree on whether we'll have more or less light rain," said Hou. "GPM data will help us to clarify that."

A Song of Water and Heat

As part of Earth's climate system, precipitation tells us about the ways energy moves around the planet. Hou says energy and precipitation are connected through the process of how water vapor in the atmosphere is converted into liquid or ice particles that make up clouds, rain and snow.

This process releases heat energy, called latent heat, into the atmosphere. You can see this happening in thunderstorm clouds: The release of heat causes air masses to rise and grow upward in a tall, billowing shape. This vertical movement of air masses creates pressure changes and wind - ultimately influencing how large-scale winds circulate and transport heat around the globe, which then affects local climate.

Precipitation at Earth's surface is the signature of the total latent heat released throughout an atmospheric column above it. Scientists will use the combined moisture information from the GMI with the DPR's three-dimensional images of precipitation to get a better understanding of the mechanisms and behavior of latent heat structures that evolve with clouds and precipitation.

Now Presenting: Rain in 3-D

Studying latent heat in storms dovetails with the direct need to study storm behavior, especially of hurricanes and tropical cyclones that can have devastating effects in terms of flooding, landslides, economic damage and loss of life.

Storms over the cloud radars during the Mid-latitude Continental Convective Clouds Experiment. This experiment from April 22 to June 11 was part of the GPM missions ground validation program, where teams of scientists take very detailed measurements of rainfall and storm systems on the ground and compare them to measurements made by radars and radiometers similar to those that will fly on the Core Observatory.

Credit: DOE/ARM/Scott Collis

The first space-borne precipitation radar on the TRMM satellite changed the way scientists understood storms. Its single radar frequency provided a new three-dimensional view of how systems like hurricanes grow and intensify as they move through the tropics. When the GPM Core Observatory satellite launches, its DPR will have a second radar frequency that will not only add precision, but will also give scientists the ability to infer the microphysical processes that govern rain droplets and snowflakes within storm systems, including the process of condensation that produces latent heat. Additional heat accumulating high up in a storm is one of the signs that it's about to intensify, which is valuable information for forecasters.

Even more valuable will be the ability to continue to observe intense storms, like Superstorm Sandy, which devastated the New Jersey and New York coasts in October of 2012, as they move north or south into the middle and higher latitudes. The GPM Core's expanded coverage will give scientists a window into understanding how individual storms like Sandy intensify and change over the course of their entire life cycles.

"Satellite data are already being used operationally to improve weather forecasts," said Hou. "GPM data will be of much higher quality and that will enable the operational agencies to continue to improve their forecast products."

GPM will also be used to improve other computer models, including those for understanding and predicting climate, floods, watershed hydrology and crop forecasting. One of the moving parts they each depend on is accurate and frequent observations of rain, sleet, hail, snow and other forms of precipitation. Global GPM data will be part of fitting the puzzle pieces together.

"When most people start a puzzle, they do the edge pieces first. Other satellites have started that, but the GPM Core is really poised to complete the boundaries so we can understand how liquid rain and frozen precipitation fall out of clouds," said Skofronick-Jackson. The constellation observations fill in the rest of that puzzle, she said, "so that we have a complete understanding both scientifically and structurally of precipitation so we can apply it to all sorts of applications."

The GPM Core Observatory, the largest satellite to be built and tested at Goddard, will be transported from Maryland to Tanegashima Island in Japan, where it will launch on a Japanese H-IIA rocket in early 2014.

Ellen Gray

NASA's Goddard Space Flight Center, Greenbelt, Md.

NASA, University of Iowa Ground Measurement Campaign to Improve Flood Forecasting

April 30, 2013

GREENBELT, Md. - Ground data now being collected in northeastern Iowa by the Iowa Flood Studies experiment will evaluate how well NASA's Global Precipitation Measurement (GPM) mission satellite rainfall data can be used for flood forecasting.

GPM is an international satellite mission that will set a new standard for precipitation measurements from space, providing worldwide estimates of precipitation approximately every three hours. The GPM Core Observatory, provided by NASA and mission partner the Japan Aerospace Exploration Agency, will launch in early 2014. Scientists are already at work, however, developing the methods for turning satellite observations into meaningful data by measuring rainfall with existing satellites and rain gauges in the field, and then using that data for societal applications, such as flood forecasting and monitoring of water resources

NASA and Iowa Flood Center staff install instrumentation in eastern Iowa for the IFloodS campaign.

Image Credit: Aneta Goska / Iowa Flood Center

"We're trying to figure out how well our satellites estimate rainfall," said Walt Petersen, GPM ground validation scientist at NASA's Wallops Flight Facility in Virginia. "This study is unique in that it takes space-borne observations, it takes ground-based observations, and it brings those things into a modeling framework that should further our ability to predict flooding."

With rainfall estimates in hand, the science teams input them into flood prediction computer models and then evaluate how the rain estimates and their uncertainties affect the outcome of the flood forecast, said Petersen. Rainfall estimates of water content and intensity are vital inputs for forecasters who need that information to determine whether or not streams and rivers will flood and impact people living in the floodplain.

The field campaign, which is taking place from May 1 to June 15, is a partnership between NASA and the Iowa Flood Center at the University of Iowa, Iowa City. The Iowa Flood Center was established after the unprecedented flooding, particularly of Cedar Rapids, in 2008, said Witold Krajewski, the Center's director. Since then, the Center has improved field monitoring of stream and river height and developed a 'library' of flood inundation maps of where flooding may occur for some of Iowa's most vulnerable communities.

Many variables go into flood prediction, said Krajewski, including soil type and moisture, stream and river geography, and land use. Some variables are difficult to measure, such as how water flows underground after it soaks into the ground. Rainfall, while challenging, is one of the easier variables to measure because we can see it, he said.

The field campaign, called the Iowa Flood Studies experiment, or IFloodS, will collect data from a vast network of ground instruments as well as instruments on satellites passing overhead. The ground instruments include rain gauges; instruments to measure soil moisture and temperature; disdrometers, which measure raindrop numbers, sizes and shapes as they reach the surface; and advanced precipitation radars, which measure the characteristics of rain as is falls.

The advanced NASA Polarimetric (NPOL) precipitation radar being deployed just south of Waterloo, Iowa, will look at rainfall above a line of ground instruments stretching toward Iowa City. The NPOL radar scans a volume

The NASA NPOL (left) and D3R (right) precipitation radars deployed south of Waterloo, Iowa, for the Iowa Flood Studies ground measurement campaign.

Image Credit: Matt Schwaller / NASA

of the atmosphere as it transmits pulses oriented in two directions, horizontal and vertical, returning three-dimensional images that provide information for distinguishing the size, shape and distribution of raindrops within rainclouds. This view will help scientists understand the physics of rainfall, essentially where ice, rain and sleet occur in clouds, how precipitation particles form, grow and interact, and how the distribution of raindrops changes as a function of height, said Petersen.

"The physics in the air column, all the way to the top of the cloud, affect how that rain forms and falls and how much rain you get at the surface," he said. Better understanding of the physics will improve rainfall estimates from space.

A second NASA ground radar, called the Dual-Frequency, Dual-Polarimetric Doppler Radar (D3R), will collect data at similar frequencies to the Dual-frequency Precipitation Radar that will fly on the upcoming GPM Core Observatory. The orbiting satellites that will collect data as they pass over Iowa each carry an instrument called a microwave radiometer, the same type of instrument as the Core's second instrument, the GPM Microwave Imager.

The satellite data used during the campaign will be from NASA's Tropical Rainfall Measuring Mission (TRMM), CloudSat, and Suomi National Polar Partnership (NPP) satellites; NOAA's 16, 18, and 19 weather satellites; the Defense Satellite Monitoring Program (DSMP) satellites; JAXA's Global Change Observation Mission-Water (GCOM-W1) satellite; and the European Union's METOP A and B weather satellites. In addition, the geosynchronous GOES satellite products will be analyzed.

"Here in Iowa, we have basins of varied sizes that are well instrumented compared to some other parts of the country," said Krajewski. That's one reason that NASA chose Iowa for its field campaign, according to Petersen. Krajewski added, however, that with the additional instruments from NASA, "collectively we will be gathering data that will be without precedent."

The GPM and IFloodS science teams will first use the ground radar and gauge data to develop a reference for how much rain is actually falling out of the sky, said Petersen. They can then compare the ground reference to those of the satellite estimates of rainfall. Secondly, both sets of data are fed into flood forecasting models for the Cedar and Iowa rivers. The ground rain data alone goes into a reference model experiment that creates a flood forecast. Then the researchers will see how well the other flood forecasts that include data from satellites and even other weather prediction models do in comparison.

For the GPM mission, the results of these comparisons mean a better interpretation of the raw rain data and improved understanding of the rainfall estimates the new satellite will provide from space. For the Iowa Flood Center, Krajewski said, the benefit could be closer to home: "Our hope is that with all that information, we can really improve our flood forecasting models."

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THE VERGE

Rain will get more extreme thanks to global warming, says NASA study

By Carl Franzen on May 4, 2013 06:31 am Email @carlfranzen 188Comments

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The forecast for the future of rainfall on Earth is in: over the next hundred years, areas that receive lots of precipitation right now are only going to get wetter, and dry areas will go for longer periods without seeing a drop, according to a new NASA-led study on global warming. "We looked at rainfall of different types," said William Lau, NASA's deputy director of atmospheric studies and the lead author of the study, in a phone interview with *The Verge*.

"The extreme heavy rain end the prolonged drought side both increase drastically and are also connected physically."

"The new part is looking at the entire global rainfall system."

The NASA rainfall study, which is due to be published in an upcoming edition of the journal Geophysical Research Letters, examined data from 14 different leading global climate models. Although each one previously predicted rainfall increases in rain-prone areas such as the tropics, and droughts in drier regions including the American Southwest, the study by Lau and his colleagues is said to be the first to look at rainfall from a global perspective, including over unpopulated areas like the middle of the oceans. "The new part is looking at the entire global rainfall system from a basic science perspective, and what we're finding is amazing" Lau said.

Specifically, the new study found that although the 14 climate models differ when it comes to the amount of rainfall in individual locations such as cities, over larger areas, they all point to the same average picture. That is, for every single degree Fahrenheit the global average temperature climbs, heavy rainfall will increase in wet areas by 3.9 percent, while dry areas will experience a 2.6 percent increase in time periods without any rainfall.

"The projected Mediterranean and southwestern US droughts forced by CO2 [carbon dioxide] increases alone exceed Dust Bowl levels by the end of the century," said Dargan Frierson, associate professor of atmospheric sciences at the University of Washington, who was not involved in the study. The reason for the shift is thought to be due to the fact that as the globe warms, the atmosphere is able to hold more water vapor as moisture, but this moisture clusters in the already wet areas, depriving the dry areas of moisture and exacerbating their droughts. Just how quickly the change happens depends on how much CO2 gets pumped into the atmosphere, but Lau said his study was applicable to the next century.

- **Source** NASA http://www.theverge.com/

NASA Study Projects Warming-Driven Changes in Global Rainfall

05.03.13

A NASA-led modeling study provides new evidence that global warming may increase the risk for extreme rainfall and drought.

The study shows for the first time how rising carbon dioxide concentrations could affect the entire range of rainfall types on Earth.

Analysis of computer simulations from 14 climate models indicates wet regions of the world, such as the equatorial Pacific Ocean and Asian monsoon regions, will see increases in heavy precipitation because of warming resulting from projected increases in carbon dioxide levels. Arid land areas outside the tropics and many regions with moderate rainfall could become drier.

The analysis provides a new assessment of global warming's impacts on precipitation patterns around the world. The study was accepted for publication in the American Geophysical Union journal Geophysical Research Letters.

"In response to carbon dioxide-induced warming, the global water cycle undergoes a gigantic competition for moisture resulting in a global pattern of increased heavy rain, decreased moderate rain, and prolonged droughts in certain regions," said William Lau of NASA's Goddard Space Flight Center in Greenbelt, Md., and lead author of the study.

The models project for every 1 degree Fahrenheit of carbon dioxide-induced warming, heavy rainfall will increase globally by 3.9 percent and light rain will increase globally by 1 percent. However, total global rainfall is not projected to change much because moderate rainfall will decrease globally by 1.4 percent.

Heavy rainfall is defined as months that receive an average of more than about 0.35 of an inch per day. Light rain is defined as months that receive an average of less than 0.01 of an inch per day. Moderate rainfall is defined as months that receive an average of between about 0.04 to 0.09 of an inch per day.

Areas projected to see the most significant increase in heavy rainfall are in the tropical zones around the equator, particularly in the Pacific Ocean and Asian monsoon regions.

Some regions outside the tropics may have no rainfall at all. The models also projected for every degree Fahrenheit of warming, the length of periods with no rain will increase globally by 2.6 percent. In the Northern Hemisphere, areas most likely to be affected include the deserts and arid regions of the southwest United States, Mexico, North Africa, the Middle East, Pakistan, and northwestern China. In the Southern Hemisphere, drought becomes more likely in South Africa, northwestern Australia, coastal Central America and northeastern Brazil.

"Large changes in moderate rainfall, as well as prolonged no-rain events, can have the most impact on society because they occur in regions where most people live," Lau said. "Ironically, the regions of heavier rainfall, except for the Asian monsoon, may have the smallest societal impact because they usually occur over the ocean."

Lau and colleagues based their analysis on the outputs of 14 climate models in simulations of 140-year periods. The simulations began with carbon dioxide concentrations at about 280 parts per million -- similar to pre-industrial levels and well below the current level of almost 400 parts per million -- and then increased by 1 percent per year. The rate of increase is consistent with a "business as usual" trajectory of the greenhouse gas as described by the United Nations' Intergovernmental Panel on Climate Change.

Analyzing the model results, Lau and his co-authors calculated statistics on the rainfall responses for a 27-year control period at the beginning of the simulation, and also for 27-year periods around the time of doubling and tripling of carbon dioxide concentrations. They conclude the model predictions of how much rain will fall at any one location as the climate warms are not very reliable.

"But if we look at the entire spectrum of rainfall types we see all the models agree in a very fundamental way -- projecting more heavy rain, less moderate rain events, and prolonged droughts," Lau said.

Kathryn Hansen

NASA Goddard Space Flight Center, Greenbelt, Md.

ENVIRONMENTAL monitor

Ground mission helps NASA's space-based flood forecasts

By Daniel Kelly on May 14, 2013

Top Image: NASA Dual-Frequency Dual-Polarized Doppler Radar (smaller radar with two dishes in front) and the NASA NPOL dual-polarimetric radar (large radar)

Credit: NASA

Changing to a local television station for weather or flood forecasts is easy, but the work behind predicted weather patterns is far more complicated. NASA scientists working with the University of Iowa's Flood Center know just how difficult it can be.

From May 1 to June 15, the researchers are conducting a field campaign – the Iowa Flood Studies experiment – that will assist in long-term efforts to measure flooding from space. With ground data collected in Iowa and future locations, NASA will be testing and further developing algorithms to reliably predict flooding using satellite data. The collective efforts are part of NASA's global precipitation measurement mission (GPM).

Accurate flood forecasts are vital to minimizing property damage, which can cost state and local governments millions. As the prediction models become more accurate, fewer ground measurements will likely be needed, saving resources used to keep ground-based stream gauges up and running.

"We chose Iowa for this campaign because we wanted to start with something that was topographically easy," said Walt Petersen, GPM ground validation scientist at NASA.

Much of the United States is flat, said Petersen, which makes Iowa a good starting point. Beginning there also lets the team leverage some of the expertise from the Flood Center.

To conduct the field study, Petersen and others are comparing ground-based measurements taken with a variety of sensors to readings from numerous NASA, NOAA and even European satellites. The NASA

Tropical Rainfall Measuring Mission, CloudSat, and NASA/NOAA Suomi National Polar Partnership satellites are a few examples.

Suites of disdrometers, which measure rain droplet size and concentration, and rain gauges are deployed every 5, 15, 25, 45 and 70 kilometers from NASA's two radars deployed just south of Waterloo, Iowa. The first radar is the Polarimetric precipitation radar and the second is the Dual-Frequency, Dual-Polarimetric Doppler radar.

Several watersheds, including the Turkey, Cedar, South Fork, and Clear Creek basins are also instrumented with numerous rain gauges and soil moisture and temperature instruments. The gauge, disdrometer and soil moisture readings are all transmitted back to researchers via cellular telemetry. The two NASA radars track the characteristics of rain as it falls.

"The radar takes us up into the atmosphere. We can scan upward and better understand how rainfall is made," said Petersen. "Every three minutes or less we take measurements in the horizontal around a 360 degree circle centered on the radar, and then we also do special vertical cross-sections of the storms to map the distribution of raindrops in a vertical profile."

The collected ground measurements are compared to those taken by satellites. The team makes estimates of rainfall from space using a combination of microwave, visible and infrared imaging. Petersen said the combination of all the different techniques helps pinpoint locations of rainfall.

This isn't the first to work toward estimating flooding from space. Past missions have made key findings for the current research.

"The (Tropical Rainfall Measuring Mission) satellite was launched in 1997, and it's still in orbit," said Petersen. "We got our feet wet using radar and measurements from space, then worked into hurricane forecasting, and GPM is the next level. Each mission builds on the previous one, and we're really standing on the shoulders of previous researchers."

Future field missions are slated for areas near Asheville, N.C. and the Appalachian region in 2014, where Petersen said the mountains cause numerous types of clouds and a greater challenge for satellite measurements. In 2015, the GPM team is planning to head to Washington State's Olympic peninsula, where the Pacific Ocean's cold surface and frequent Pacific storms lead to large amounts of rain, sleet and snow.

NASA is partnering with the Japan Aerospace Exploration Agency (JAXA) to launch the GPM Core observatory satellite for the global precipitation mission in 2014. The current field studies are just the first step toward that goal.

"The GPM is an international mission. The GPM core satellite will carry a cutting edge dual-frequency radar built by JAXA and a NASA multi-frequency microwave radiometer," said Petersen. "Approximately eight other satellites will occasionally orbit under or over the GPM core satellite, and the GPM Core will then serve as a reference for all the other ones to give a constant calibration. The entire constellation of satellites then provides calibrated estimates of precipitation every 1 to 3 hours over the globe."

NASA's HS3 Mission May Target Cape Verde Island Hurricanes in 2013

May 29, 2013

Credit: NASA Goddard MODIS Rapid Response Team

Credit: NASA

On Dec. 21, 2012, at 1515 UTC (10:15 a.m. EST) the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Aqua satellite captured a clear view of the Cape Verde islands from its orbit in space that clearly showed all 10 islands in the group. The Cape Verde Islands are located about 350 miles (570 km) from Africa's west coast. The 10 islands cover approximately 1,500 square miles (4,000 square km).

During the Hurricane & Severe Storm Sentinel (HS3) mission, NASA's Global Hawk performed a grid flight pattern over Tropical Storm Nadine on Sept. 26 and 27, 2012. This image shows the flight pattern as the Global Hawk was flying back to its deployment base at NASA's Wallops Flight Facility on Sept. 27. The Cape Verde Islands off the coast of western Africa are well-known to hurricane scientists because that's a region where a number of tropical cyclones form during the Atlantic hurricane season. NASA's multi-year Hurricane and Severe Storms Sentinel, or HS3, mission may explore tropical cyclones of Cape Verde origins when it takes to the skies again this August.

HS3 returns this summer after several successful flights in 2012 by one of NASA's unmanned Global Hawk aircraft gathered data from hurricanes Leslie and Nadine. This year NASA will be sending two Global Hawks above stormy skies to help researchers and forecasters uncover information about hurricane formation and intensity changes. HS3 will use the two aircraft carrying an array of instruments this summer, flying from a base of operations at NASA's Wallops Flight Facility in Wallops Island, Va.

The tropical cyclones HS3 will explore may include Cape Verde storms, like Hurricane Nadine in 2012. For more information about how the HS3 mission explored Nadine during the 2012 mission, visit NASA's Hurricane Nadine web page.

According to the National Oceanic and Atmospheric Administration (NOAA), Cape Verde-type hurricanes are those Atlantic basin tropical cyclones that develop into tropical storms fairly close (600 miles, or less than 1,000 km) to the Cape

Verde Islands and then become hurricanes before reaching the Caribbean. This type of storm typically occurs in August and September, but in rare years there may be some in late July or early October. The number of this type of storm ranges from none up to five per year - with an average of around two.

NASA conducted a Cape Verde hurricane research campaign in 2006. The two-month research project known as NAMMA-06 (short for NASA African Monsoon Multidisciplinary Activities) flew NASA's DC-8 aircraft into small disturbances in the eastern Atlantic that had the potential to become Cape Verde hurricanes. NAMMA was NASA's contribution to the European- and African-led African Monsoon Multidisciplinary Activities (AMMA) experiment carried out in and near West Africa in 2006.

The HS3 campaign constitutes a significant advance over the earlier NAMMA, given the ability of the Global Hawk aircraft to loiter over the Cape Verde/East Atlantic region for much longer periods of time than the DC-8 could.

"The DC-8 data in NAMMA were very limited and we had to rely more on satellite data and NOAA G-IV data," said Scott Braun, HS3 principal investigator and research meteorologist at NASA's Goddard Space Flight Center in Greenbelt, Md. "With the HS3 mission, we hope to obtain a more complete data set that can better answer some of the questions raised in that study."

The Atlantic hurricane season runs primarily from June 1 through Nov. 30, peaking in mid-September.

The HS3 mission is supported by several NASA centers including Wallops; Goddard; Dryden Flight Research Center in Edwards, Calif.; Ames Research Center in Moffett Field, Calif.; Marshall Space Flight Center in Huntsville, Ala.; and the Jet Propulsion Laboratory in Pasadena, Calif. HS3 also has collaborations with partners from government agencies and academia.

HS3 is an Earth Venture mission funded by NASA's Science Mission Directorate in Washington. Earth Venture missions are managed by NASA's Earth System Science Pathfinder Program at the agency's Langley Research Center in Hampton, Va. The HS3 mission is managed by the Earth Science Project Office at Ames.

Source: NASA

CATS Eye View Of Pollution, Aerosols And Clouds

July 24, 2013

This is a photo showing how payloads attach to the Exposed Facility of the Japanese Experiment Module on the International Space Station. The laser will always fire directly down from the space station into the atmosphere. Credit: NASA

NASA

Quick looks by a special CATS-eye attached to the International Space Station will help scientists catalog and track particles in Earth's atmosphere and act as a pathfinder for a new satellite planned for 2021.

"We're going to do operational Earth science that's new, looking at aerosols, pollution and clouds and real-time inputs to global climate models," said Matthew McGill, principal investigator for the Cloud-Aerosol Transport System (CATS) at NASA's Goddard Space Flight Center in Greenbelt, Md. "CATS will also help show NASA how to do low-cost, fast-turnaround payloads on station."

The approach is similar to low-cost Hitchhiker payloads — small studies that "hitched" a ride into orbit with larger investigations — that NASA flew on the space shuttle during 1984-2003. "The International Space Station Program looked at our airborne Cloud Physics Lidar (CPL) instrument and its 15-year heritage flying near the edge of space [on the ER-2 aircraft] and asked, 'Can you put that in a box?'" McGill said. "In other words, could we take this proven, autonomous aircraft instrument and transfer the design to be space station compatible, and

CATS was born."

Weather satellites do a phenomenal job of monitoring clouds, air temperatures, moisture and other factors. But measuring aerosols, whose role in weather and climate is a significant mystery, requires probing the air by using light in a manner similar to radar. This will be the job of the CATS investigation.

Aerosol means particles or droplets dissolved in air. The term is a century old, but humans have always been around them in the form of clouds, fog, smoke rising from a fire, exhaust from a car, spray from a sneeze, and even some emissions from plants. Aerosols come in all shapes, sizes, populations, masses and other factors, making them a challenge for scientists trying to understand their impact on weather and climate.

"[Computer] models need to know if there is a layer of stuff in the atmosphere, its altitude — because that matters a lot — how thick that layer is, and what it is made of," McGill explained. "The fundamental data from CATS will tell us if something is there, and then take ratios of different readings to tell us if it's ice, water or aerosols, and if it is an aerosol, is it dust, smoke or pollution."

Knowing what is where is important to understanding how energy is transported in the atmosphere. Particulates can absorb different quantities of sunlight or heat from surrounding air, and carry that energy to be released elsewhere.

Researchers also need to know how aerosol populations change during the day. Most Earth observing satellites are in polar orbits that cross the equator at the same local time. That ensures an apples-to-apples comparison of data taken by multiple instruments across the years. But this also keeps them from observing the faster ebb and flow of some events in the atmosphere during the day or night. The space station's orbit will provide that coverage.

CATS will be the fourth space-based lidar — light detection and ranging — designed to probe atmospheric aerosols by using a laser light like a radar. The Lidar In-space Technology Experiment (LITE), which flew on the space shuttle STS-64 mission in 1994, demonstrated that the concept is sound. The Geoscience Laser Altimeter System (GLAS) instrument on ICESat only operated for two months in 2003. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite has made more than 3 billion soundings of the atmosphere since 2006. CATS will provide continuity for CALIPSO data and help bridge the gap until the 2021 launch of the Aerosol-Cloud-Ecosystems (ACE) mission.

Lidar works much like its namesake, radar. A signal is emitted â€" radio waves for radar, light for lidar — and electronics capture and analyze the reflection.

Two factors make lasers essential to this kind of work. First, they emit on a very narrow wavelength band. That makes it easier to measure changes caused by particles that reflect the incident light. Second, because the band is so narrow the light beam itself can be narrowly focused, like a needle probing tiny spots. CATS will be able to detect single photons returning from the scanned area.

Distance is the first measurement, giving the height and thickness of aerosol layers. Other factors, including how the signal is extinguished within a layer and polarization (similar to polarizing sunglasses), carry clues about the sizes and distribution of particles.

CATS uses a three-in-one laser that simultaneously produces near-infrared, green and ultraviolet light. "Some people expect to see a green light saber coming from station," McGill said. "That is absolutely not the case."

CATS will flash 5,000 times a second in pulses that spread out to a circle more than 14 feet wide and move as fast as the station. Putting CATS aboard the space station has a significant advantages over conventional remote sensing satellites in that it is far less expensive than building and launching a dedicated platform.

Work is underway to get CATS ready for its future flight. "We're uncovering a lot of places where we have to make new rules," McGill added, referring to building for space station.

When it launches, CATS will be as close to plug-n-play as space experiment can get. It will attach to the Exposed

Facility on the Japanese Experiment Module (JEM-EF) after delivery by Japan's HTV in 2014.

McGill and his colleagues hope to operate the instrument for at least three years. That's more than 400 billion blinks of a CATS's eye to help diagnose the health of Earth's atmosphere.

Source: Dave Dooling, International Space Station Program Science Office

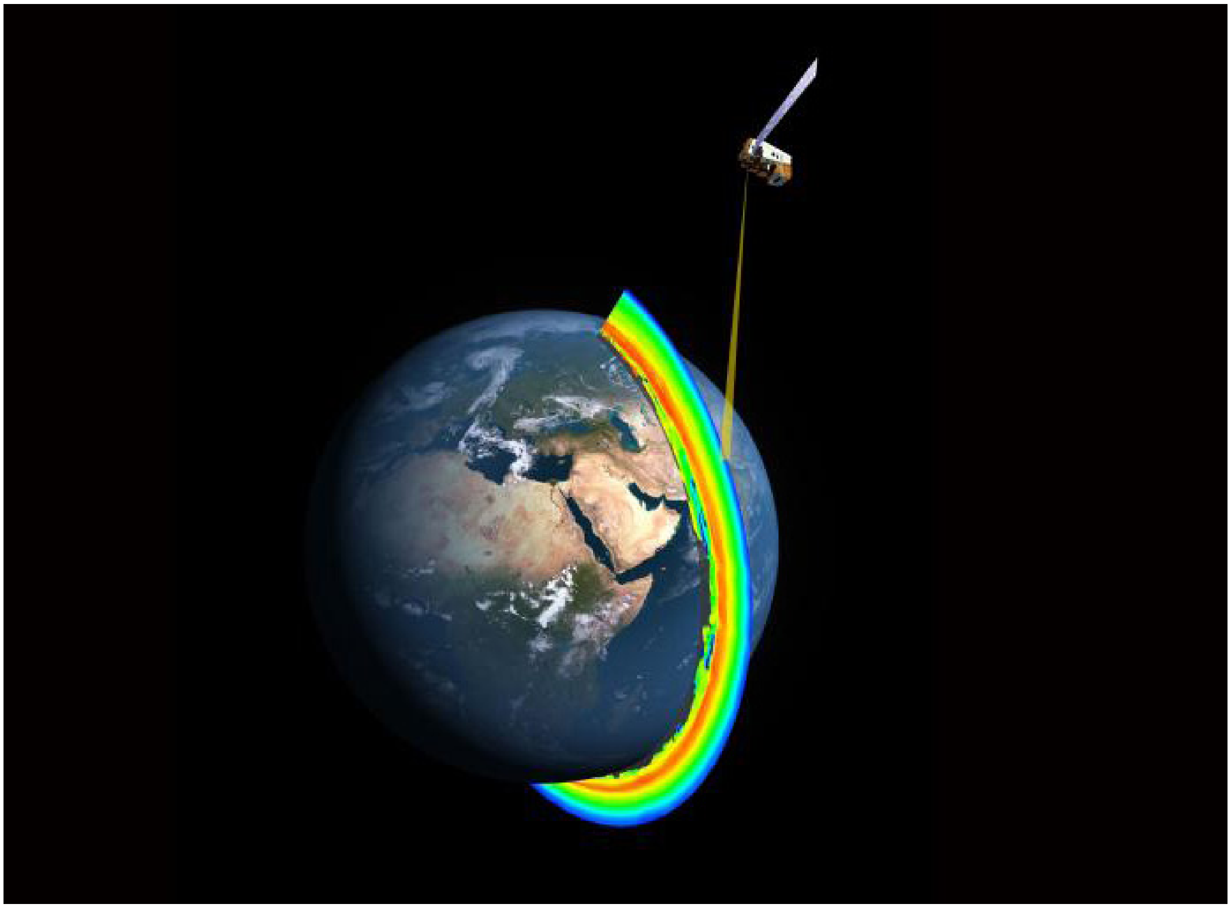
Topics: Environment, Earth, Spaceflight, Spacecraft, French space program, Robotic sensing, Aerosol science, STS-64, CALIPSO, Particulates, ICESat, LIDAR, Aerosol, Matthew McGill, National Aeronautics and Space Administration

Read more at http://www.redorbit.com/news/space/1112905921/cats-eye-view-pollution-aerosols-clouds-072413/#T8Gp0dmLDD58O2S7.99

INTERNATIONAL BUSINESS TIMES http://www.ibtimes.com/

NASA Reveals New Details About Ozone Hole, Says No Signs Of Recovery Yet

By Kukil Bora on December 12 2013 2:33 AM



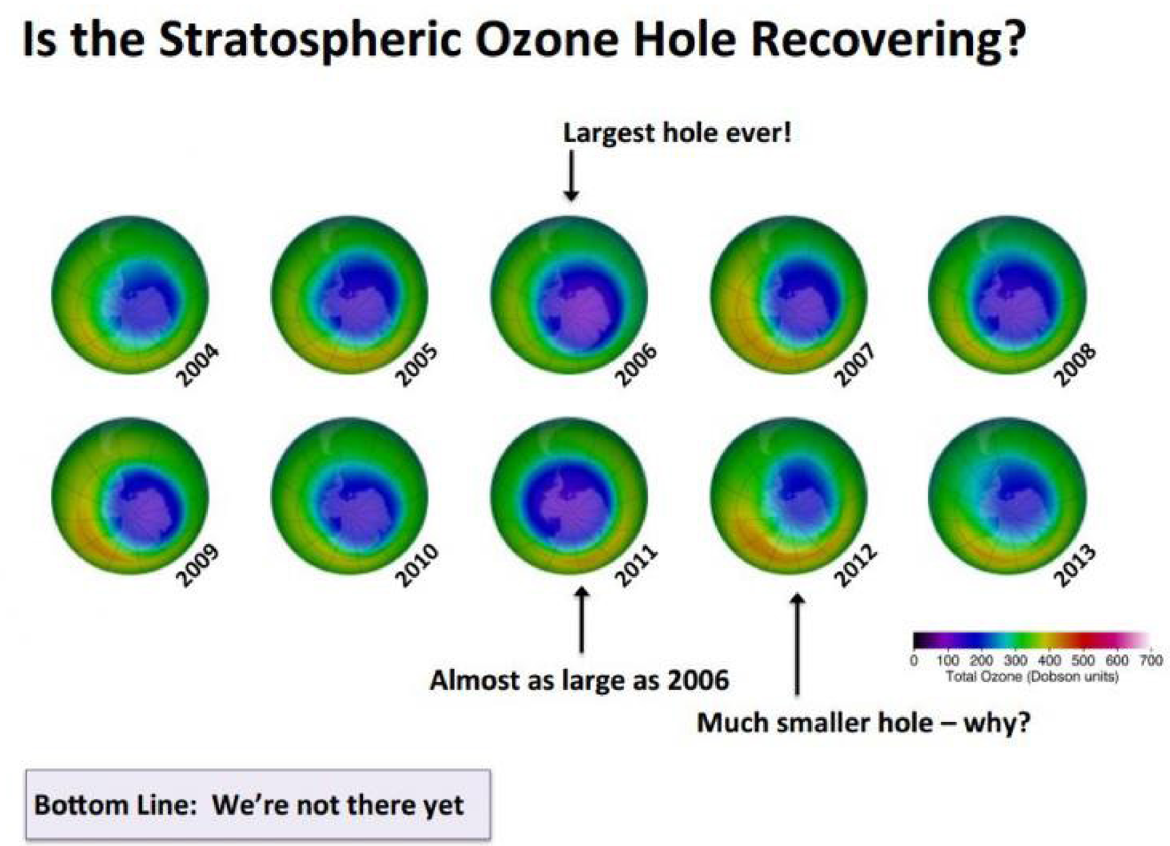
A cross-section of Earth's ozone layer as measured by the limb profiler, part of the Ozone Mapper Profiler Suite that's aboard the Suomi NPP satellite. NASA/NOAA

Revealing new details about the inner workings of the ozone hole, the annual thinning of the protective ozone layer in Earth's stratosphere over Antarctica, scientists at NASA said on Wednesday that the declining amount of chlorine in the stratosphere has not yet caused a recovery of the seasonal depletion of ozone in the region.

It has been more than 20 years since the Montreal Protocol agreement limited human emissions of ozone-depleting substances. And, although satellites have monitored the area of the annual ozone hole and watched it stabilizing and ceasing to grow larger, two new studies have shown that conclusive signs of recovery of the ozone hole have not yet been found.

"Ozone holes with smaller areas and a larger total amount of ozone are not necessarily evidence of recovery attributable to the expected chlorine decline," Susan Strahan of NASA's Goddard Space Flight Center in Greenbelt, Md., said in a statement. "That assumption is like trying to understand what's wrong with your car's engine without lifting the hood."

Strahan and Natalya Kramarova of NASA Goddard used satellite data to examine the 2012 ozone hole, the second-smallest hole since the mid 1980s, to find out what caused the hole's diminutive area. The scientists eventually converted the data into a map, which revealed that the 2012 ozone hole was more complex than previously thought.



NASA tackled the ozone holes of 2006 and 2011 -- two of the largest and deepest holes in the past decade. NASA

According to NASA, the classic metrics suggest that the ozone hole has improved as a result of the Montreal Protocol but in reality, weather was responsible for the increased ozone and the resulting smaller hole, as ozone-depleting substances in 2012 were still elevated.

Another research led by Strahan tackled the ozone holes of 2006 and 2011 -- two of the largest and deepest holes in the past decade -- and showed that they became that way for very different reasons.

Strahan used satellite data to track the amount of nitrous oxide, a tracer gas related to the amount of ozone-depleting chlorine. The researchers were surprised to find that the holes of 2006 and 2011 contained different amounts of ozone-depleting chlorine -- a finding that led them to question how the two holes could be equally severe.

Further analysis revealed that in 2011, there was less ozone destruction than in 2006 because the winds transported less ozone to the Antarctic. This was a meteorological effect and not a chemical one. In contrast, winds blew more ozone to the Antarctic in 2006, which led to greater destruction of the ozone.

According to NASA, the second study shows that the severity of the ozone hole, as measured by classic measurements, does not reveal the significant annual variations in the two factors that control ozone -- the winds that bring ozone to the Antarctic and the effect of chlorine on the ozone hole.

Scientists said that chlorine levels in the lower stratosphere are expected to decline below early 1990s levels only by 2030, and will thus become the primary factor in determining the size of the ozone hole.

ACRONYMS

Acronyms defined and used only once in the text may not be included in this list. GMI has dual definitions. Its meaning will be clear from context in this report.

3D	Three Dimensional
7-SEAS	Seven SouthEast Asian Studies
ACE	Aerosols, Clouds, and Ecology
ACRIM	Active Cavity Radiometer Irradiance Monitor
AEROKATS	Advancing Earth Research Observation Kites And Tether Systems
AERONET	Aerosol Robotic Network
AETD	Applied Engineering and Technology Directorate
AIRS	Atmospheric InfraRed Sounder
AlVICE	Atmospheric Lindar for Validation, Interagency Collaboration and Education
AMA	Academy of Model Aeronautics
AMS	American Meteorlogical Society
AMSR-E	Advanced Microwave Scanning Radiometer–Earth Observing System
AMSU	Advanced Microwave Sounding Unit
AOD	Aerosol Optical Depth
AOT	Aerosol Optical Thickness
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
ARM	Atmospheric Radiation Measurement
ASCENDS	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
ASIF	Air Sea Interaction Facility
ASR	Atmospheric System Research
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATM	Airborne Topographic Mapper
ATMS	Advanced Technology Microwave Sounder
BC	Black Carbon
BESS	Beaufort and East Siberian Sea
BEST	Beginning Engineering Science and Technology
BMKG	Meteorological Climatological and Geophysical Agency
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAR	Cloud Absorption Radiometer
CCM	Chemistry-climate model
CCMVal	Chemistry Climate Model Evaluation
CCNY	City College of New York
CERES	Cloud and Earth Radiant Energy System

CF	Central Facility
CINDY	Cooperative Indian Ocean experiment on intraseasonal variability
CIRC	Continual Intercomparison of Radiation Codes
CLEO	Conference on Lasers and Electro-Optics
CO	Carbon Monoxide
CoSMIR	Conical Scanning Millimeter-wave Imaging Radiometer
CPL	Cloud Physics Lidar
CrIS	Cross-track Infrared Sounder
CRM	Cloud-resolving Models
CRS	Cloud Radar System
DB-SAR	Digital Beam-forming SAR
DISC	Data and Information Services Center
DISCOVER-AQ	Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DOD	Department of Defense
DOE	Department of Energy
DPR	Dual-frequency Precipitation Radar
DSCOVR	Deep Space Climate Observatory
DYNAMO	Dynamics of the Madden-Julian Oscillation
EC	Environment Canada
ECO-3D	Exploring the Third Dimension of Forest Carbon
ENSO	El Niño Southern Oscillation
EOF	Empirical Orthogonal Function
EOS	Earth Observing System
EPIC	Earth Polychromatic Imaging Camera
ESA	European Space Agency
ESSIC	Earth System Science Interdisciplinary Center
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FMI	Finnish Meteorological Institute
FV	Finite Volume
GCE	Goddard Cumulus Ensemble
GCM	Global Climate Model
GCPEX	GPM Cold Season Precipitation Experiment
GEMS	Geostationary Environmental Monitoring Sensor
GEO-CAPE	Geostationary Coastal and Air Pollution Events
GEOS	Goddard Earth Observing System
GES	Goddard Earth Sciences

GEST	Goddard Earth Sciences and Technology Center
GESTAR	Goddard Earth Sciences Technology Center and Research
G-IV	Gulfstream IV
GLOPAC	Global Hawk Pacific Missions
GMAO	Goddard Modeling and Analysis Office
GMI	GPM Microwave Imager
GMI	Global Modeling Initiative
GOES	Geostationary Operational Environmental Satellites
GOES-R	Geostationary Operational Environmental Satellite – R Series
GOSAT	Greenhouse gases Observing Satellite
GPCEX	GPM Cold Season Precipitation Experiment
GPM	Global Precipitation Measurement
GRIP	Genesis and Rapid Intensification Processes
GSFC	Goddard Space Flight Center
GUV	Global UltraViolet
GV	Ground Validation
HAMSR	High Altitude Monolithic Microwave Integrated Circuit Sounding Radiometer
HBSSS	Hydrospheric and Biospheric Sciences Support Services
HIRDLS	High Resolution Dynamics Limb Sounder
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
HOPE	Hyperspectral Ocean Phytoplankton Exploration
HS3	Hurricane and Severe Storm Sentinel
HSB	Humidity Sounder for Brazil
I3RC	Intercomparison of 3D Radiation Codes
IAMAS	International Association of Meteorology and Atmospheric Sciences
IASI	Infrared Atmospheric Sounding Interferometer
ICAP	International Cooperative for Aerosol Prediction
ICCARS	Investigating Climate Change and Remote Sensing
ICESat	Ice, Cloud, and land Elevation Satellite
IIP	Instrument Incubator Program
INPE	National Institute for Space Research (Brazil)
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IRAD	Internal Research and Development
IRC	International Radiation Commission
ITCZ	Intertropical Convergence Zone
IUGG	International Union of Geodesy and Geophysics

JAXA	Japanese Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JWST	James Webb Space Telescope
LaRC	Langley Research Center
LASP	Laboratory for Atmospheric and Space Physics
LDCM	Landsat Data Continuity Mission
LDSD	Low Density Sonic Decelerator program
LIS	Lightning Imaging Sensor
LIS	Land Information System
LPVEx	Light Precipitation Validation Experiment
LRRP	The Laser Risk Reduction Program
MABEL	Multiple Altimeter Beam Experimental Lidar
MAIAC	Multi-Angle Implementation of Atmospheric Correction
MC3E	Mid-latitude Continental Convective Clouds Experiment
MISR	Multi-angle Imaging Spectroradiometer
MJO	Madden-Julian Oscillation
MLS	Microwave Limb Sounder
MMF	Multi-scale Modeling Framework
MMF-LIS	Multi-scale Modeling Framework Land Information System
MODIS	Moderate Resolution Imaging Spectroradiometer
MoE	Ministry of Environment
MOHAVE	Measurement of Humidity in the Atmosphere and Validation Experiment
MOPITT	Measurement of Pollution in the Troposphere
MPLNET	Micro Pulse Lidar Network
MSU	Morgan State University
NCAR	National Center for Atmospheric Research
NCTAF	National Commission on Teaching and America's Future
NEO	NASA Earth Observations
NIST	National Institute of Standards
NISTAR	Advanced Radiometer
NLDAS-2	North American Land Data Assimilation System
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar Orbiting Environmental Satellite System
NPOL	Naval Physical and Oceanographic Laboratory
NPP	National Polar-orbiting Partnership

NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSTA	National Science Teachers Association
OASIS	Ocean Ambient Sound Instrument System
OCO-2	Orbiting Carbon Observatory
ODSs	Ozone Depleting Substances
OEI	Ozone ENSO Index
OLI	Operational Land Imager
OMI	Ozone Monitoring Instrument
OMPS	Ozone Monitoring and Profiling Suite
OMPS	Ozone Mapping and Profiler Suite
PACE	Pre-Aerosols, Clouds, and Ecology
PI	Principal Investigator
PR	Precipitation Radar
PSCs	Polar Stratospheric Clouds
PUMAS	Practical Uses of Math and Science
PVI	Perpendicular Vegetation Index
RESA	Regional Education Service Agency
ROMS	Regional Ocean Modeling System
ROSES	Research Opportunities in Space and Earth Sciences
RSESTeP	Remote Sensing Earth Science Teacher Program
RSIF	Rain-Sea Interaction Facility
SAF	Satellite Application Facility
SAIC	Science Applications International Corporation
SDC	Science Director's Council
SEAC4RS	Southeast Asia Composition, Cloud, Climate Coupling Regional Study
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SGP	South Great Plains
SHADOZ	Southern Hemisphere Additional Ozonesondes
S-HIS	Scanning High-Resolution Interferometer Sounder
SIM	Spectral Irradiance Monitor
SIMPL	Swath Imaging Multi-polarization Photon-counting Lidar
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SORCE	Solar Radiation and Climate Experiment
SPARRO	Self-Piloted Aircraft Rescuing Remotely Over Wilderness

SPE	Solar Proton Event
SSA	Single Scattering Albedo
SSAI	Science Systems Applications, Inc.
SSI	Solar Spectral Irradiance
SST	Sea Surface Temperature
STEM	Science, Technology, Engineering, and Mathematics
SWOT	Surface Water Ocean Topography
TES	Tropospheric Emission Spectrometer
TIM	Total Irradiance Monitor
TIROS	Television Infrared Observation Satellite Program
TIRS	Thermal Infrared Sensor
TJSTAR	Thomas Jefferson Symposium To Advance Research
TMI	TRMM Microwave Imager
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measurement Mission
TROPOMI	Troposhere Ozone Monitoring Instrument
TSI	Total Solar Irradiance
TSIS	Total Spectral Solar Irradiance Sensor
TWiLiTE	Tropospheric Wind Lidar Technology Experiment
UARS	Upper Atmosphere Research Satellite
UAVs	Unmanned Aerial Vehicles
UMBC	University of Maryland, Baltimore County
UMSA	Universidad Mayor San Andres
USGS	United States Geological Survey
USRA	Universities Space Research Associates
UTLS	Upper Troposphere and Lower Stratosphere
UV	Ultraviolet
VIIRS	Visible Infrared Imaging Radiometer Suite
VIRS	Visible and Infrared Scanner
WAVES	Water Vapor Validation Experiments Satellite and sondes
WFF	Wallops Flight Facility

APPENDIX 1. REFEREED ARTICLES

Laboratory members' names are in boldface.

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