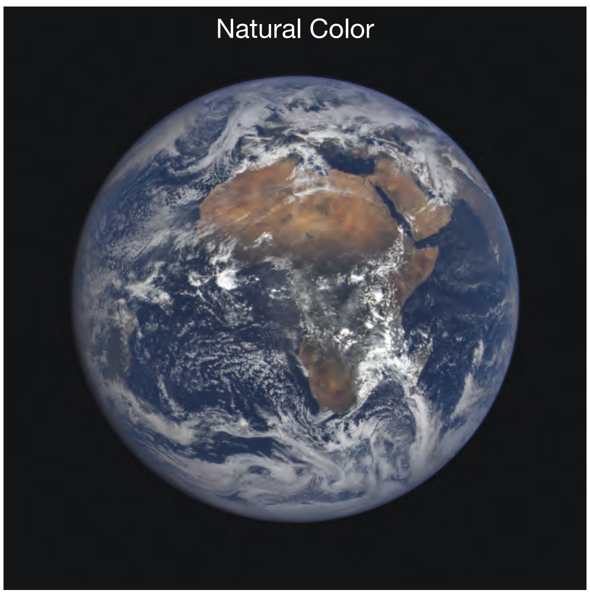
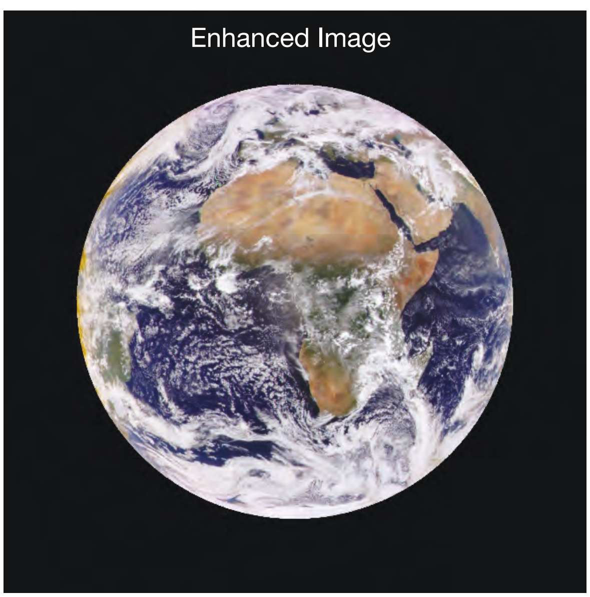
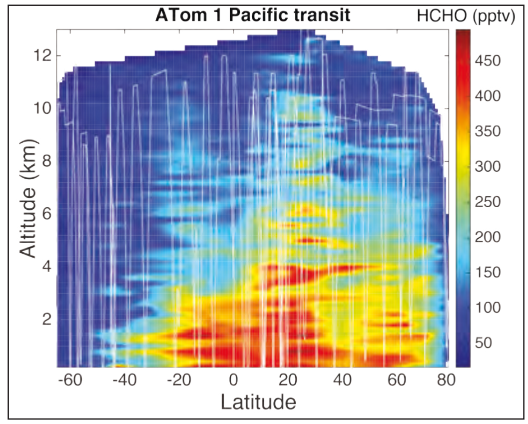
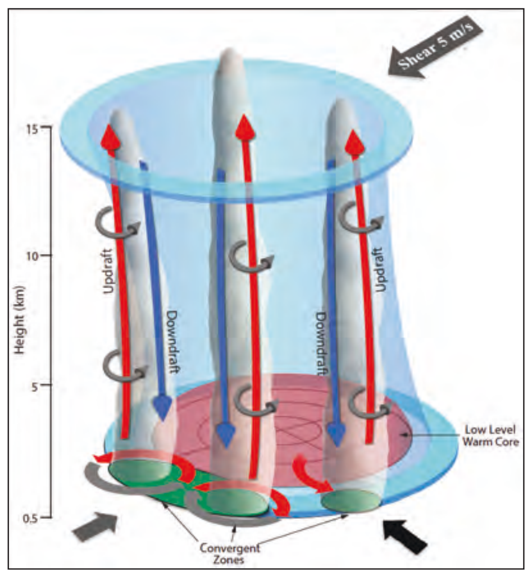
NASA/TM 2017-219020

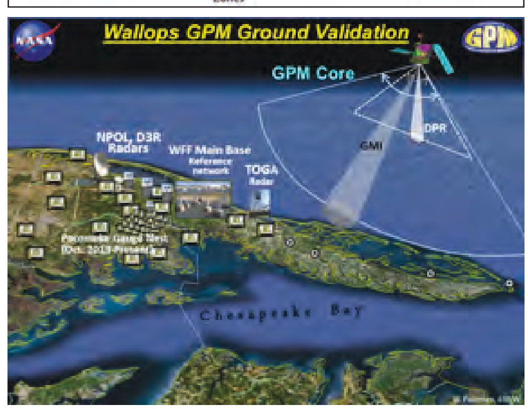
Atmospheric Research 2016 Technical Highlights











March 2017

Cover Photo Captions

LEFT, TOP AND BOTTOM

Yuekui used logarithmic transformation that replaces each pixel value with its logarithm. As a result of the transformation, low intensity pixel values of dark surfaces have been enhanced.

UPPER RIGHT

ATom field campaign provides a new perspective on tropospheric formaldehyde. Concentration of HCHO measured *in situ* from the NASA DC-8 with the ISAF instrument plotting versus latitude and altitude. The flights consisted of multiple vertical profiles that sampled the atmosphere at altitudes between 150 m and 12,000 m. The flights were designed to provide a representative slice of the atmosphere during the Northern Hemisphere summer. .

CENTER RIGHT

Convective bursts. A conceptual diagram summarizing the measurements and analysis from the rapid intensification of Karl. Red arrows denote the flow of air having anomalously warm characteristics. Green patches denote regions of convergence that form due to interaction between the mesovortex circulations and the larger scale vortex inflow.

BOTTOM RIGHT

GPM-WFF validation network. NASA has extended GPM/PMM ground validation (GV) activities through the development of a Wallops-based network of state-of-the-art GPM GV rain gauge, disdrometer, and multi-parameter radar measurements geared toward validating NASA precipitation products (spaceborne and combined ground and spaceborne retrieval algorithms and physics). .

Level of Review: This material has been technically reviewed by technical management.

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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:

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- 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.

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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:

- Access the NASA STI program home page at http://www.sti.nasa.gov

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National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

Dear Reader:

Welcome to the 2016 Atmospheric Research Highlights report, summarizing Earth atmospheric science highlights and communication/outreach accomplishments from NASA's Goddard Space Flight Center (GSFC). As in previous years, this report is intended for a broad audience, including colleagues within NASA, scientists outside the Agency, science graduate students, and members of the public.

Organizationally, the report covers research activities under the Office of Deputy Director for Atmospheres (Code 610AT), which is within Earth Sciences Division (610) in the Sciences and Exploration Directorate (600). Laboratories and office within 610AT include: Mesoscale Atmospheric Processes Laboratory (612), Climate and Radiation Laboratory (613), Atmospheric Chemistry and Dynamics Laboratory (614), and the Wallops Field Support Office (610.W).

While the report provides a comprehensive summary of 610AT activities, a few items of note are worth reporting here.

Satellite Observations: Early 2016 marked the spaceflight anniversaries of three recent 610AT-related projects. The Global Precipitation Measurement (GPM) mission entered its second year in orbit on February 27, while the Cloud-Aerosol Transport System (CATS) laser, installed on the International Space Stations (ISS) and DSCOVR/EPIC, completed their first year in orbit on January 10 and February 11, respectively. In addition, The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission was selected as the third NASA Earth Venture Instrument (EVI-3) in March 2016. Notable highlights:

- The GPM core observatory mission reached several significant milestones this year including product updates, recalibration of TRMM (previous precipitation mission) datasets, a highly successful conclusion to the OLYMPEX field campaign, new visualization tools, and a vigorous outreach and education effort.
- The CATS collects data to improve our understanding of aerosol and cloud interactions. Principal investigator (PI) Matthew McGill (610) and science lead John Yorks (612) have been actively collaborating with the scientific community to utilize measurement results. The CATS data and analysis team (612) includes Patrick Selmer, Andrew Kupchock, Dennis Hlavka, Steve Palm, and Edward Nowottnick.
- The Goddard Earth Polychromatic Imaging Camera (EPIC) is one of two NASA instruments on the DSCOVR mission that is observing our planet from the Lagrange-1, located about one million miles from Earth. From that vantage point, EPIC views the Earth disk from sunrise to sunset in 10 different wavelengths, ranging from ultraviolet to near-infrared. Jay Herman (614/UMBC), Sasha Marshak (613), and colleagues are now concentrating on deriving an accurate in-flight calibration for use in production algorithms to produce useful science products such as ozone, aerosols, and clouds.
- Scott Braun (GSFC/612) is the project scientist for the NASA TROPICS mission. With a constellation of 12 smallsats, TROPICS will provide rapid-refresh (21-minute median refresh rate) microwave measurements over the tropics for up to one year, observing the thermodynamic environment and precipitation structure of tropical cyclones over much of their lifecycle.

Suborbital Deployments: Many of our scientist were involved in major NASA suborbital (ground-based and aircraft) field campaigns during 2016.

- Paul Newman and Tom Hanisco are members of NASA's Earth Venture Suborbital (EVS) Atmospheric Tomography Mission (ATom) science team. ATom deploys an extensive gas and aerosol payload on the NASA DC-8 aircraft for systematic, global-scale sampling of the atmosphere during four separate seasons. Its measurements of formaldehyde in August 2016 revealed a distinct pattern that provided new insights to the chemistry of the remote troposphere.
- Several teams from 610AT participated in the joint Korean-U.S. Air Quality (KORUS-AQ) campaign at the Taehwa Mountain Forest Research site located about 60 km southeast of Seoul, South Korea. PI Tom McGee (614) and coinvestigators John Sullivan (614/USRA), Laurence Twigg (614/SSAI), and Grant Sumnicht (614/SSAI) obtained TROPospheric Ozone (TROPOZ) differential absorption lidar measurements. Anne Thompson (610) and Ryan Stauffer (614/USRA) supported Tom McGee's lidar team by launching daily ozonesondes. The sonde profiles calibrated the TROPOZ lidar and provided comparisons for DC-8 spirals over the Taehwa site. Jay Herman (614/UMBC) and team installed a network of nine Pandora instruments.
- Steven Platnick and several 610 scientists were in Namibia in August–September 2016 participating in the EVS ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) campaign, focusing on the interaction of African biomass burning aerosol with the extensive marine boundary layer clouds off the coasts of Namibia and Angola. Platnick was the principal investigator for the eMAS imager flown on the NASA ER-2 high-altitude research aircraft during the campaign. Other 610AT scientists in the field included Kerry Meyer (613/USRA) and Tom Arnold (613/SSAI).
- Judd Welton (612), Sebastian Stewart (612/SSAI), and other MPLNET team members were Namibia in June to finalize the installation of a new MPLNET site located near Etosha National Park. The new site is located immediately downwind from the Etosha salt pan, a large dust source in Northern Namibia.
- Scott Braun (612) was the mission scientist for the NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) experiment flown out of Wallops Flight Facility (WFF). SHOUT used the NASA Global Hawk to conduct operational flights over Atlantic hurricanes to evaluate the impact of the airborne and sensor technologies in operational hurricane forecasts. Gerry Heymsfield (612) and the HIWRAP team collected data during Hurricane Matthew and Tropical Storm Hermine.
- On March 25, Anne Thompson (610) and Ryan Stauffer (614/USRA) launched the first ozonesonde from the Ascension Auxiliary Airfield since NASA and NOAA/National Weather Service (NWS) Ascension sonde operations ended in mid-2010. U.S. Air Force (USAF) contractors were trained to conduct weekly ozonesonde launches for the SHADOZ (Southern Hemisphere Additional Ozonesondes) network, as part of a new agreement between GSFC and USAF.

Kudos: As in previous years, 610AT scientists garnered professional honors and other recognition during 2016.

- Paul Newman (610) was elected as the Vice President of the International Ozone Commission. The International Ozone Commission is one of the special commissions of the International Union of Geodesy and Geophysics, who represent the entire community of geophysical scientists around the world.
- The TRMM team, headed by Scott Braun (612), was selected for the 2016 Group William T. Pecora Award. The Pecora Award is presented annually to individuals or groups that make outstanding contributions toward understanding the Earth by means of remote sensing.
- Agency Honor Awards were received by Alexander Marshak (613), Matthew DeLand (614/SSAI), and Kevin Ward (613/SSAI, Team Award). Robert H. Goddard Awards were received by Ralph Kahn (613) and Gerald Heymsfield (612, Team Award).

Organizational Changes: David Wolff (610.W) was selected as the new chief of the 610.W Field Support Office, effective April 17. The 610 Office is involved in several key projects (GPM cal/val, IceSat, Operation Ice Bridge, O_3 sondes, UAS capabilities) and science (PMM, ocean biology, and optics) activities. About 40 civil servants and contractor scientists, engineers, technicians, and administrative specialists work for the flight office. John Moisan (610.W) assumed the position of Assistant Chief of the Wallops Field Support Office, supporting David. Similarly, Charles Ichoku (613) assumed the position of Assistant Chief of the Climate and Radiation Laboratory, supporting Laboratory Chief Lazaros Oreopoulos (613).

Transitions: Change is ongoing, whether it be the excitement of a new hire, the celebration of retirement, or the ultimate sadness when we lose close colleagues.

- Piers Sellers, Director of the Earth Sciences Division (610), passed away December 23. We remember Piers as an exceptional scientist and leader, but most importantly as an inspiring human being. Piers' contributions to Earth science are beyond significant, and his enthusiasm and positive attitude will be missed by all.
- We were terribly saddened by the tragic loss of Tiffany Moisan (610.W). Her research focused on marine biology, optics, and remote sensing of the ocean. She was especially interested the remote sensing of ocean color and its implications relative to discernment of algal blooms and phytoplankton types, the basis of the ocean food chain. She will be greatly missed by her NASA family.
- Jose Rodriguez retired after 9 years of service. Jose was head of the Atmospheric Chemistry and Dynamics Laboratory (614) since September 2006 where he exhibited exceptional qualities of leadership and management. For the past 30 years, he was involved in modeling anthropogenic perturbations to the atmosphere. He was also a guest investigator under the Pioneer Venus Program and the Solar Mesospheric Explorer Program, and he was the principal investigator in numerous projects involving modeling support of aircraft campaigns, both in the stratosphere and in the troposphere. He was a member of NASA's Earth System Science and Applications Advisory Committee (ESSAAC) and served as project scientist for the Global Modeling Initiative (GMI) since its inception in 1994. He also held various leadership positions in international efforts.
- Ken Pickering retired after 11 years of service. Ken was an internationally known and highly respected scientist in the study of the effects of clouds on the distributions and budgets of tropospheric chemical species. He was closely aligned with the development of cloud system and mesoscale chemical transport models. His was primarily interested in the role of deep convection in vertical transport and redistribution of tropospheric trace gases and the subsequent consequences for upper tropospheric chemistry. Ken participated in numerous field experiments over the years and has led the use of data from convective events in cloud-scale modeling.
- Larry Wharton retired after 35 years of service. Larry made significant contributions to the understanding of Earth's atmosphere in his early years through analysis of measurements made from spacecraft such as the Dynamics Explorer (DE). He was the key scientist in developing the Wind and Temperature Spectrometer (WATS) instrument that flew on DE-2. He also made significant contributions to the improvement of the equations describing the Langmuir probes that flew on many satellites. In recent years, he oversaw IT security for the 613 Laboratory.
- We were pleased to welcome civil servant Yuekui Yang as a research physical scientist into Code 613 on December 27. Yang has expertise in atmospheric radiative transfer modeling and satellite remote-sensing. With leadership roles in several NASA-funded projects, Yang will be well-positioned to act as a liaison between the 613 Lab and other Goddard Earth Science Division organizations.

This report has been 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.

Steven Platnick

Deputy Director for Atmospheres

Earth Sciences Division, Code 610

March 2017

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1. INTRODUCTION

Atmospheric research in the Earth Sciences Division (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 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, leading to observation requirements for remote-sensing platforms, technology and retrieval algorithm development; followed by 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 22-year record of peer-reviewed publications and proposals among the various Laboratories.

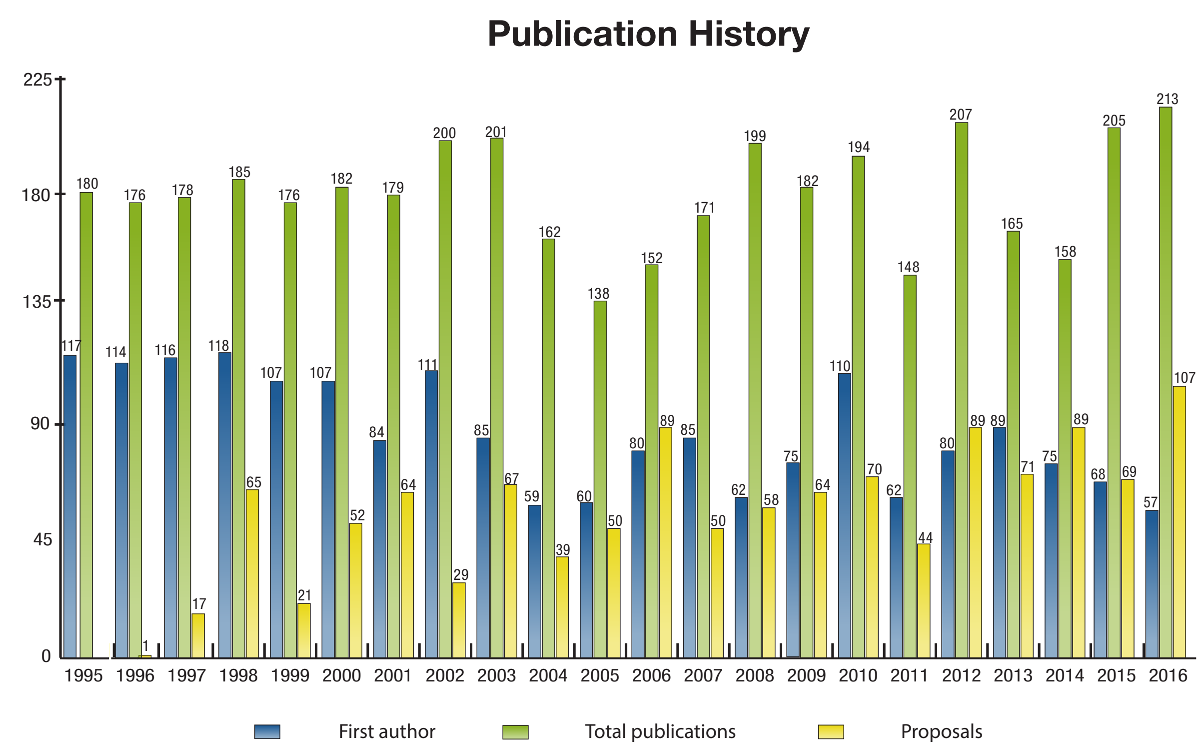


Figure 1.1: Number of proposals and referred publications by Atmospheric Sciences members over the years. The green bars are the total number of publications and the blue bars the number of publications where a Laboratory member is first author. Proposals submitted are shown in yellow.

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 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 collaborative 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 2016. 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/.

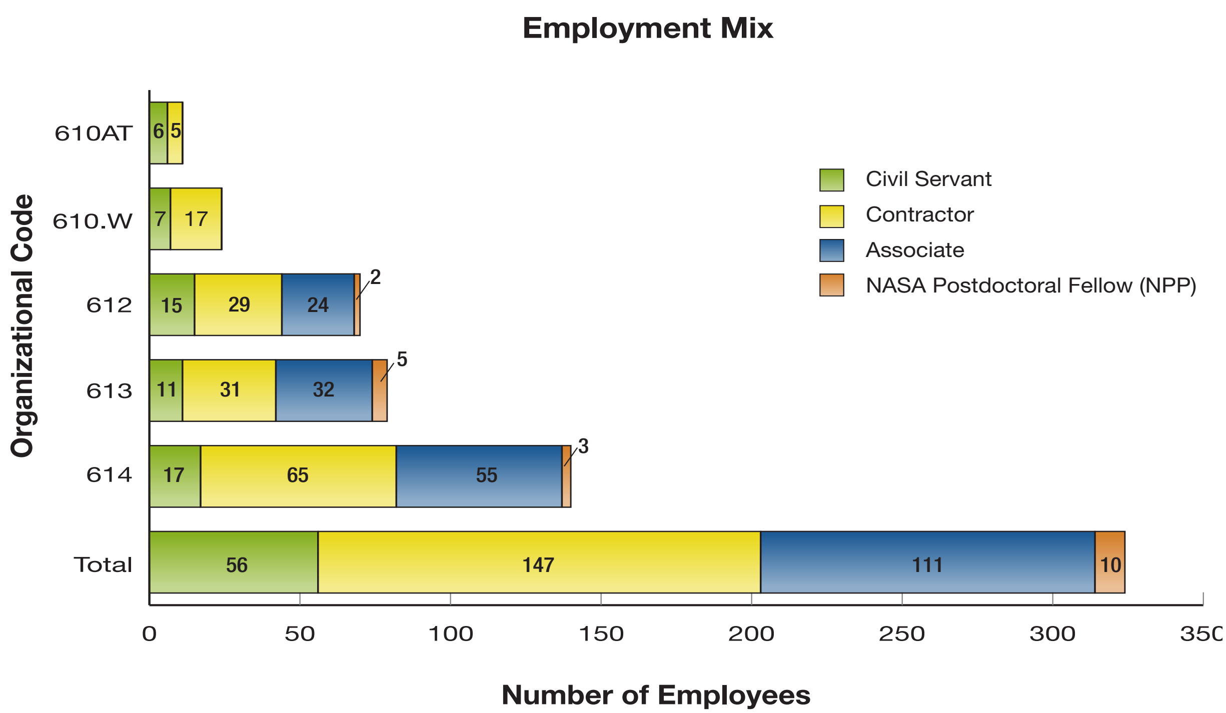


Figure 1.2: Breakdown of the organizational employee mix

2. SCIENCE HIGHLIGHTS

Atmospheric research at Goddard has a long history (more than 50 years) in Earth Science studying the atmospheres of both the Earth and the planets. The early days of the TIROS and Nimbus satellites (1960s–1970s) emphasized ozone monitoring, Earth radiation, and weather forecasting. Planetary atmospheric research with the Explorer, Pioneer Venus Orbiter and Galileo missions was carried out until around 2000. In the recent years, Earth Observing System (EOS) missions have provided an abundance of data and information to advance knowledge and understanding of atmospheric and climate processes. Basic and crosscutting research has been carried out through observations, modeling, and analysis. Observation data has been provided through satellite missions as well as *in situ* and remote-sensing data from field campaigns. Scientists are also focusing their efforts on satellite mission planning and instrument development. For example, feasibility studies, improvements in remote-sensing measurement design, modeling and technology are underway in preparation for the planned missions recommended in *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, The 2007 Decadal Survey* by the National Academy of Sciences (www.nap.edu/catalog/11820.html). The *2017–2027 Decadal Survey for Earth Science and Applications from Space* (ESAS) has updated priorities that will help shape science priorities and guide agency investments into the next decade. Many of our scientists are expected to contribute to surveys and other functions.

The following sections summarize some of the scientific highlights of each Laboratory and the Wallops Field Office for the year 2016. The individual contributors are named at the end of each summary. Additional highlights and other information may be found at the website: atmospheres.gsfc.nasa.gov.

2.1. Mesoscale Atmospheric Processes Laboratory

The Mesoscale Atmospheric Processes Laboratory (612) seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. The Laboratory conducts research on the physical and dynamic properties as well as the structure and evolution of meteorological phenomena—ranging from synoptic scale down to microscale—with an emphasis on the initiation, development, and effects of cloud and precipitation. Significant attention 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 played a key science leadership role in the Tropical Rainfall Measurement Mission (TRMM), launched in 1997, as well as in developing the Global Precipitation Measurement (GPM) mission concept and continuing to lead the scientific investigations. The Mesoscale Atmospheric Processes Laboratory is also 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 2016 are summarized below.

2.1.1. Uncertainties of GPM/DPR rain estimates caused by DSD parameterizations

The Ku- and Ka-band dual-frequency radar (DPR) is one of the instruments aboard the GPM satellite. One of its primary goals is to derive rain rate by estimating the rain's drop size distribution (DSD), which is often modeled by an analytical function with two or three unknown parameters. The inability of the modeled DSD to represent actual DSD spectra, as well as intrinsic variations of DSD in time and space, lead to uncertainties in the estimates of rainfall rate obtained from the DPR. Understanding the uncertainties in rain estimation that depend on DSD parameterizations is important in evaluating the overall performance of DPR rain-retrieval algorithms. DSD parameterization models have an impact not only on the radar reflectivity to rain-rate relationship but also on attenuation corrections needed to compensate for the loss of the radar signal caused by precipitation. Analysis of the uncertainties associated with the DSD model employed in the DPR rain estimation procedure also provides insight into the selection of DSD models adopted in the Ku- and Ka-band dual-wavelength radar rain-profiling algorithms. A large set of DSD measurement data (approximately 50,000 spectra averaged per minute), taken from 11 Parsivel disdrometers during the IFloodS field campaign, have been employed in this study to assess retrieval uncertainties in connection with the choice of DSD model within the context of dual-frequency retrievals.

L. Liao (612/Morgan State University), R. Meneghini (612), and A. Tokay (612/UMD/JCET)

2.1.2. Exploiting the full GPM constellation for the retrieval of precipitation

The GPM mission, launched in February 2014, has provided a greatly enhanced system for measuring precipitation on a global scale. Through improved instrumentation on the GPM Core Observatory, together with international partner satellites and sensors, observations can be generated globally every three hours more than 90% of the time, and ultimately 30-minute estimates can be obtained with the integration of infrared data. The team compared mean daily precipitation estimates from March 6, 2014, through March 5, 2015, generated by four different satellite sensors within the GPM mission constellation using the Advanced Microwave Scanning Radiometer-2 (AMSR2), GPM Microwave Imager (GMI) and Special Sensor Microwave Imager-Sounder (SSMIS). The mean daily rainfall derived from the cross-track Microwave Humidity Sounder (MHS) in Figure 2.1, lower left, illustrates the ability of the cross-track sensors to provide precipitation estimates similar to those derived from the conically-scanning sensors.

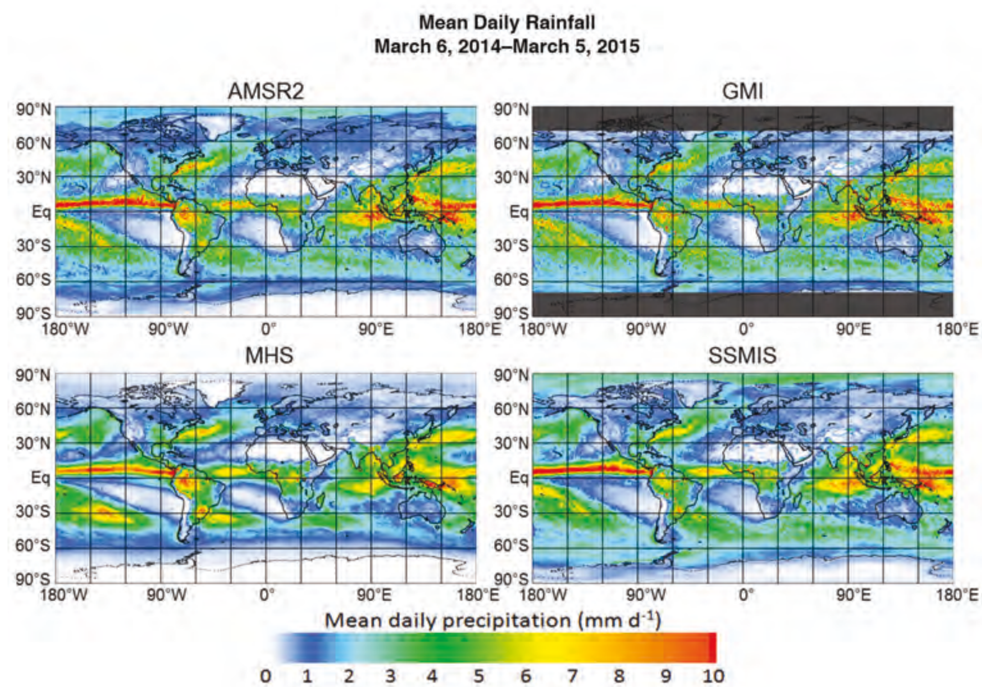


Figure 2.1: The exploitation of all GPM constellation sensors is critical to achieve accurate and timely precipitation estimates. Model-generated databases allow cross-track sensors to be fully utilized for global precipitation measurements.

Products derived from the conically-scanning sensors have formed the mainstay of satellite precipitation retrievals for the last 30 years. The ability to exploit observations from cross-track sensors is critical to achieve the temporal sampling needed for accurate precipitation retrievals. Historically the conically-scanning passive microwave radiometers (imagers) have been the mainstay of observations for precipitation estimates, but cross-track sensors (known as sounders) also have the capability to provide precipitation retrievals. The inclusion of the cross-track sensors within the GPM constellation is key to achieving the greater than 90-percent revisit time. Moreover, with the demise of the Tropical Rainfall Measuring Mission (TRMM) and the Defense Military Satellite Program (DMSP) F19 satellite, cross-track sensors now form the majority of precipitation-capable sensors. Unfortunately, no future launches of conically-scanning sensors are planned before that of the European Polar System-Second Generation (EPS-SG) MicroWave Imager (MWI) in 2023.

C. Kidd (612/UMD/ESSIC), T. Matsui (612/UMD/ESSIC), J. Chern (612/UMD/ESSIC), K. Mohr (610), C. Kummerow (Colorado State University) and D. Randel (Colorado State University)

2.1.3. Tropical convection and microphysics equilibrium

Microphysics and moist convection have been and unresolved physical processes—until now. These complex phenomena can be explained by a simple relationship using TRMM observations integrated over the entire tropics on the month-to-day scale. Namely, the spectrum shape of precipitation intensity and microphysics has virtually no change over time with extremely large samples over the entire tropics. When TRMM observation are integrated over the entire tropics, the precipitation particle-size distributions (microphysics) and precipitation intensity (convection) spectrum become equilibrium states on the month-to-daily time scale, regardless of variability of tropical meteorology. Shown in Figure 2.3, this study's data was acquired from TRMM Precipitation Radar (TRMM PR) attenuation-corrected echo profile from 2A25 and TRMM Microwave Imager (TMI) 89 GHz brightness temperature (Tb85) from 1B11. Precipitation intensity frequency were derived from merged precipitation data from (3B42). GPM precipitation microphysics was derived from GPM radar-radiometer combined retrievals (GPM 2A-CMB). All data were distributed by the NASA Precipitation Processing System.

T. Matsui (612/UMD/ESSIC), W.-K. Tao (612), S. J. Munchak (612), M. Grecu (612/MSU/GESTAR), and G. J. Huffman (612)

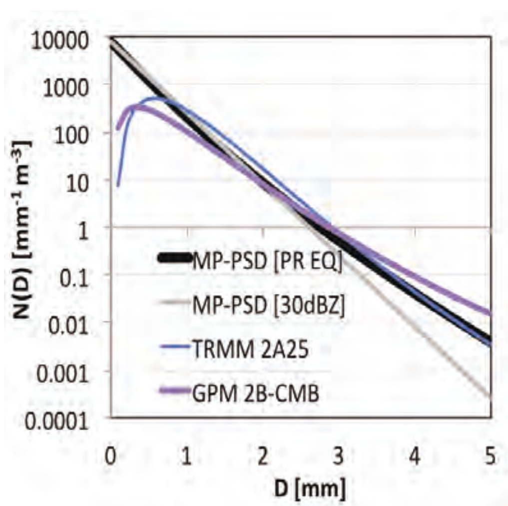


Figure 2.2: Tropics-integrated precipitation particle size distributions are estimated from the TRMM PR with Marshal-Palmer relationship, the TRMM PR algorithm (2A25), and the GPM combined algorithm (GPM 2A-CMB). These distribution shapes are invariant over time (i.e., equilibrium state). The equilibrium particle size distribution of GPM 2B-COMB is more broadly distributed than that from 2A25 due to different orbital patterns between TRMM and GPM satellites and also differences in the algorithm sophistications.

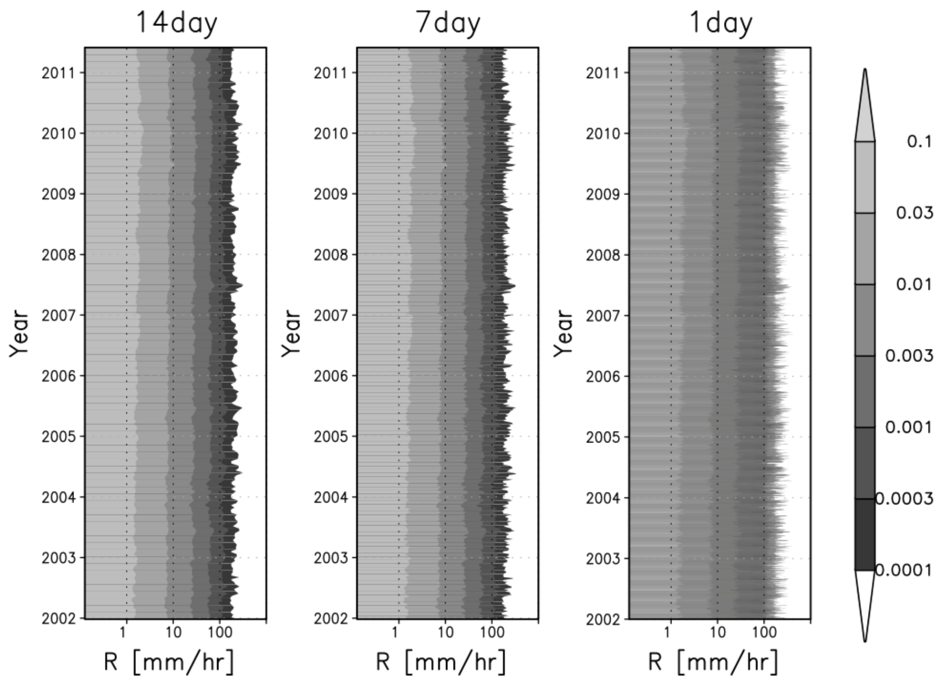


Figure 2.3: TRMM 3B42 datasets estimate precipitation using three measurements per hour on a 0.25°grid. With this, time series of the precipitation intensity frequencies are created by averaging for different time intervals (14 days, 7 days, and 1 day) over entire tropics to investigate equilibrium adjustment time. Comparing three averaging intervals, the time series of 1-day averaging is slightly noisier than 7-day, which is noisier than the 14-day composite; however, structures appears to be very similar between each other. This suggests that planetary-scale precipitation intensity (i.e., moist convection) spectrum could be equilibrium down to at least a 1-day time period.

2.1.4. A first look at X-BADGER data from the PECAN field campaign

Thunderstorms are most common after sunset across the Southern Great Plains in the summer and much of the resulting precipitation occurs from mesoscale convective systems (MCSs). Nocturnal MCSs can produce heavy rainfall, and their intensity is often correlated with the strength of a nocturnal low-level jet. The PECAN field campaign was a multi-agency project (NSF, NOAA, NASA, DOE) designed to advance the understanding and increased accuracy of predicting continental, nocturnal, warm-season precipitation. PECAN focused on nocturnal convection in conditions over the Southern Great Plains including convective initiation, mesoscale convective systems, bore/gravity waves, and the nocturnal low-level jets (NLLJ).

Multiple instruments (including a profiling radar, an interferometer, three lidars, and a tethersonde) were set up in Greensburg, Kansas, from June 1 through July 15, 2015, to study convection, which often occurs at night over the Great Plains region. Vertical profiles of radar reflectivity, Doppler velocity, and spectrum width were collected with the X-Band Atmospheric Doppler Ground-based Radar (X-BADGER) on June 25, 2015, during the PECAN field campaign. Data were collected over a period of nearly three hours where the continued descent of a cloud deck was observed. Rain finally began to fall from of the cloud base and was reported at the surface of the FP2 site in Greensburg, Kansas. The melting layer, positioned just above the bright band, is a feature commonly observed in stratiform precipitation. Approximately fifteen minutes after rain commenced at the surface, the cloud deck lifted back up and produced small wave-like undulations within the anvil (ice) cloud.

To date, accurate prediction and an in-depth understanding of elevated convection in this environment has remained an elusive goal for researchers. Case studies like these allow researchers to study large rain producing events that impact the Great Plains agricultural region in detail.

A. Emory (612), S. Nicholls (JCET), and M. Coon (555)

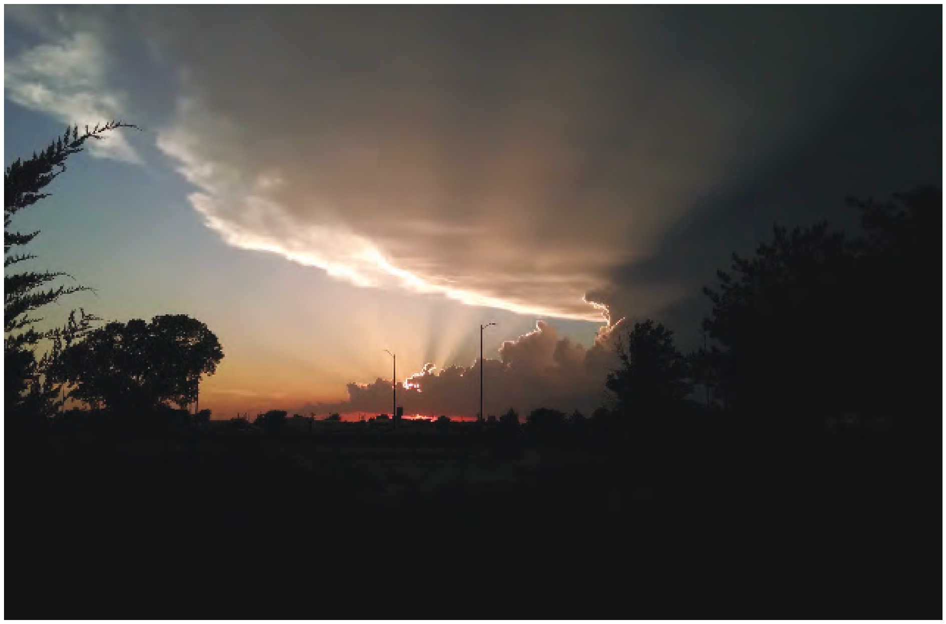


Figure 2.4: This is an image of one type of precipitation observed at the FP2 site. This photo was taken looking west from the FP2 site in Greensburg, Kansas, on June 18, 2015.

2.1.5. First remote-sensing observations of convective bursts in a rapidly intensifying hurricane from the Global Hawk platform

Understanding and predicting the rapid intensification of hurricanes is among the most challenging problems in atmospheric science due to the stochastic, turbulent nature of the primary forcing (convective clouds). In many cases, researchers require comprehensive observations from a variety of instruments to determine if there is some level of order in the chaotic evolution of convection. Using new NASA technologies, observations have indicated that deep convective clouds can be organized by mesoscale circulations at the eye/eyewall interface, which may provide some level of determinism for the predictive problem. During the NASA GRIP field experiment, scientists using GSFC's HIWRAP radar flying on the unmanned Global Hawk aircraft—with additional measurements from the Jet Propulsion Laboratory's (JPL) HAMSR radiometer and NOAA radars—obtained an unprecedented view of the rapid intensification of Hurricane Karl (2010) for approximately14 hours. Convective bursts formed in the hurricane through: (1) convergence generated from counter-rotating mesovortex circulations and the larger-scale vortex flow and (2) the turbulent transport of warm, buoyant air from the eye to the eyewall at low- to mid-levels. Figure 2.5 shows a conceptual diagram summarizing the measurements and analysis from the rapid intensification of Hurricane Karl. Red arrows denote the flow of air having anomalously warm characteristics. Green patches denote regions of convergence that formed due to the interaction between the mesovortex circulations and the larger scale vortex inflow.

S. Guimond (612/UMD/ESSIC) and G. Heymsfield (612)

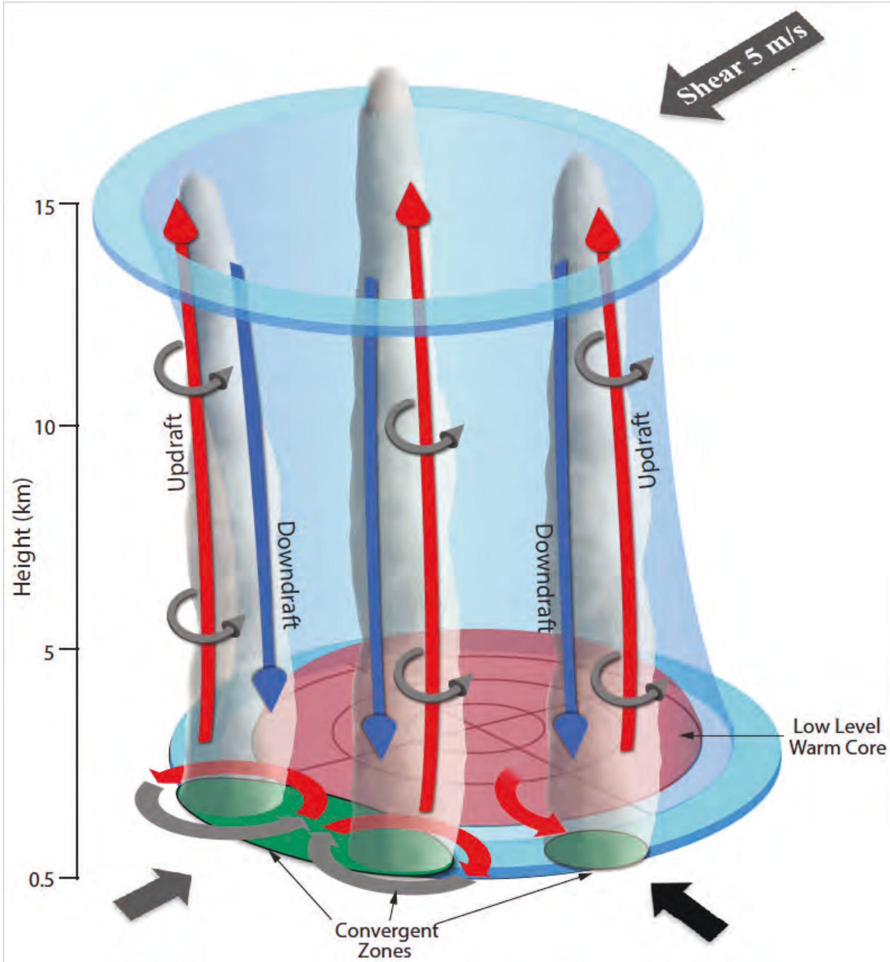


Figure 2.5: A conceptual diagram summarizing the measurements and analysis from the rapid intensification of Karl. Red arrows denote the flow of air having anomalously warm characteristics. Green patches denote regions of convergence that form due to the interaction between the mesovortex circulations and the larger scale vortex inflow.

2.1.6. Engaging audiences about rain, snow and storms: GPM's Rain EnGAUGE

The GPM education and communication team developed the Rain EnGAUGE project to make resources easily accessible for others to plan their own outreach events and further spread information about the mission and precipitation science, ultimately magnifying the effect of the small GPM core team. Rain EnGAUGE was intended to share the scientific information from the GPM mission in a way that is understandable to students, teachers, and the general public, rather than furthering the science itself. The program provides free precipitation education activities and resources available online (https://pmm.nasa.gov/education/rain-engauge). Thousands of people have learned about NASA Earth science generally and GPM specifically in events sponsored by or known to the GPM team. Other events may have used Rain EnGAUGE resources without any assistance from GPM. The concept of the program, best practices, and lessons learned have been shared with other NASA missions to help spread their own science messages.

K. Weaver(612/USRA/GESTAR), D. Janney (612/ADNET Systems), and H. Davis (Tech for Learning, Inc.)

2.1.7. Nonspherical ice particle models for precipitation remote sensing

At higher latitudes (greater than 40°N and less than 40°S), snow contributes a significant proportion of the net precipitation at the Earth's surface, making it an important component of the global water cycle and a key climate indicator at those latitudes. The GPM Core Satellite Observatory is fitted with a downward-looking weather radar and passive microwave radiometer. These multichannel instruments were designed to work synergistically to estimate surface precipitation and precipitation vertical structure over the 65°S to 65°N latitude range.

Snow affects both spaceborne radar and microwave radiometer observations. Kuo et al. (2016) and other recent studies have begun to quantify the impact of snow particle shape on both radar reflectivities and the scattering of microwave radiances. Snow particles generally have irregular, nonspherical shapes; Kuo et al. simulated snow particles (2016) and computed their radiative properties. Although the nonsphericity of snow particles has an influence on radar reflectivities at GPM channel frequencies, it has its greatest impact on higher-frequency microwave radiances sensed by the GPM radiometer, such as those at 89 GHz and 166 GHz. This impact on microwave radiances is mainly due to less forward scattering by nonspherical particles relative to spheres of the same mass, leading to lower upwelling radiances at the higher frequencies. Therefore, the proper interpretation of the higher-frequency microwave channel data from GPM, as well as other microwave sensors such as SSMIS and AMSR2, depends on models of the atmosphere containing nonspherical snow particles. Proposed satellite missions such as ACE and CaPPM plan to utilize higher-frequency radar and passive microwave channels to interpret cloud and precipitation distributions. Further research into the structural and radiative properties of snow particles will be needed to better quantify their impact on remote-sensing observations.

K.-S. Kuo (612/UMD/ESSIC), W. Olson (612/UMBC/JCET), B. Johnson (612/UMBC/JCET), M. Grecu (612/MSU/GESTAR), L. Tian (612/MSU/GESTAR), T. Clune (610.1), B. van Aartsen (606/SSAI), A. Heymsfield (NCAR/UCAR), L. Liao (612/MSU/GESTAR), and R. Meneghini (612)

2.1.8. Validation of ice particle models using airborne observations

At higher latitudes (greater than 40°N or less than 40°S), snow contributes a significant proportion of the net precipitation at the Earth's surface, making it an important component of the global water cycle and a key climate indicator at those latitudes. The responses of the Ku/Ka band radar and multichannel microwave radiometer of the GPM mission to snow particles must be properly modeled so that GPM measurements can be used to accurately quantify snowfall rates. In this study, the scattering properties of snow particle models are evaluated using field campaign measurements from airborne HIWRAP and CoSMIR observations. The objective is to determine how well different snow particle models can be used to simultaneously explain radar and radiometer observations from GPM-like instruments. Nonspherical snow models produce simulated radiances at 89 and 166 GHz that are consistent with CoSMIR observations, while simpler, spherical snow particle models do not. The proper interpretation of the higher-frequency microwave channel data from GPM, as well as other microwave sensors such as SSMIS and AMSR2, therefore depends on models of the atmosphere containing nonspherical snow particles. Proposed satellite missions such as ACE and CaPPM will utilize higher-frequency radar and passive microwave channels to interpret cloud and precipitation distributions, and so further research on the properties of snow particles will be needed to better quantify their impact on remote-sensing observations.

W. Olson (612/UMBC/JCET), L. Tian (612/MSU/GESTAR), M. Grecu (612/MSU/GESTAR), K.-S. Kuo (612/UMD/ESSIC), B. Johnson (612/UMBC/JCET), A. Heymsfield (NCAR/UCAR), A. Bansemer (NCAR/UCAR), G. Heymsfield (612), J. Wang, R. Meneghini (612)

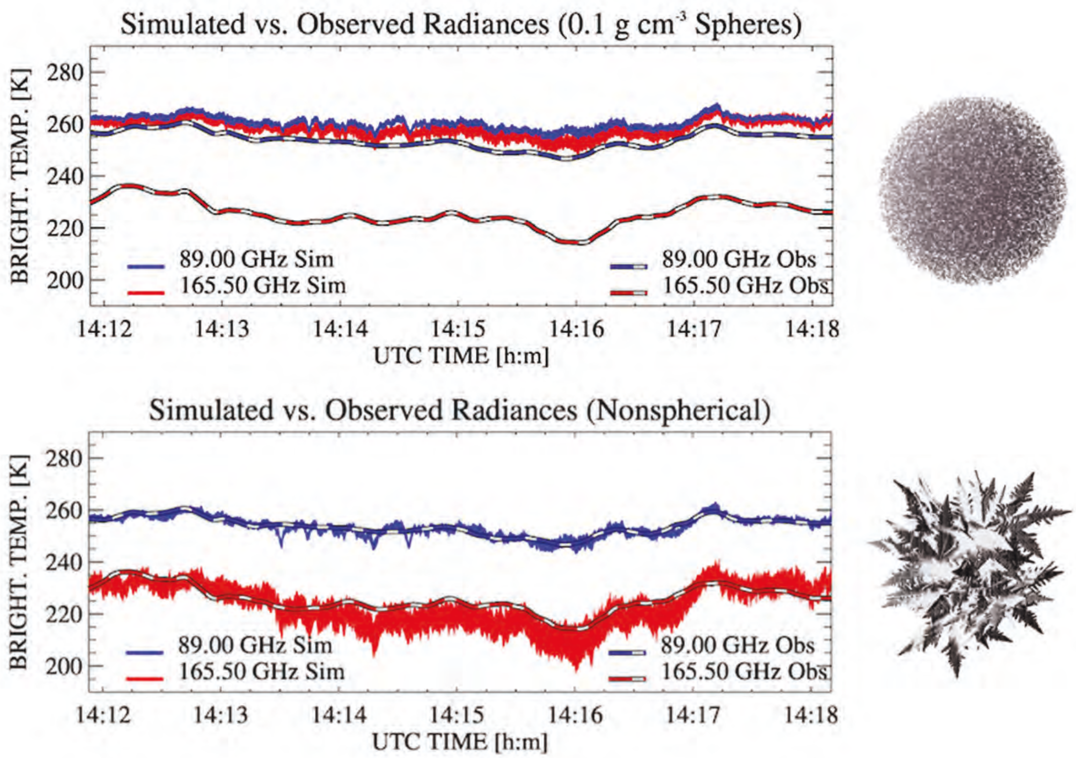


Figure 2.6: Microwave radiances at 89 GHz (solid blue) and 166 GHz (solid red) simulated from the estimated precipitation profiles from HIWRAP, using spherical (upper panel) and nonspherical (lower panel) ice particle models. Width of curves indicates uncertainties due to humidity and precipitation size distribution variability. CoSMIR-observed radiances at 89 GHz (dashed blue) and 166 GHz (dashed red) are shown for comparison.

2.1.9. Improved cirrus cloud retrievals from new MPLNET algorithm

Information about cloud height, thickness, occurrence, and amount are critical inputs for a host of numerical applications involving climate research. Therefore, it is important to have highly accurate and quantitative data records of cloud properties that span several years and geographic regions. A new Version 3 algorithm has been developed to detect clouds from the Micropulse Lidar Network (MPLNET). When compared to Version 2, the Version 3 algorithm improves the ability to detect clouds at high altitudes (i.e. cirrus) and provides, for the first time, information about cloud phase and cloud optical depth (COD). The new algorithm increases the quality of detection for cirrus clouds, which is significant for studies of radiative forcing because cirrus are known to both warm and cool the atmosphere depending on their varying physical properties. Autonomous lidar monitoring projects, like MPLNET and CALIOP aboard the CALIPSO satellite, have already demonstrated that optically thin cirrus clouds are the most common cloud type in the earth–atmosphere system. Long-term ground-based datasets from MPLNET continue to provide crucial diurnal information to complement NASA satellite missions.

J. Lewis (612/UMBC/JCET), E. Welton (612), S. Stewart (612/SSAI), P. Haftings (612/SSAI), J. Campbell (NRL Monterey)

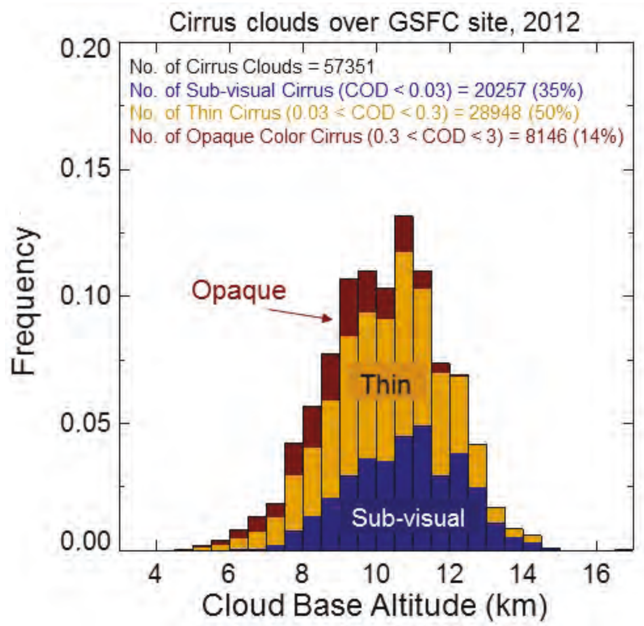


Figure 2.7: Distribution of cloud base heights for cirrus clouds observed over the GSFC site during 2012. The colors indicate the cirrus type based on the estimated cloud optical depth (blue for sub-visual, yellow for thin, and red for opaque color) using an effective extinction-to-backscatter ratio of 30 sr. The combination of sub-visual and thin cirrus clouds accounts for over 85 percent of the sample, which is significant because these clouds are the most difficult to detect using passive remote-sensing methods. However, it is noted that the limit to which the cirrus cloud optical depth could be reliably estimated occurs between of 0.5 and 0.8.

2.2. 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 (613). 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 observational satellite 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 influential leadership positions on international programs, panels, and committees, serve as project scientists on NASA missions and PI's 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 are described below. They 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 2016 are summarized below.

2.2.1. GPS radio occultation valuable for polar boundary layer studies

This study describes a unique GPS radio occultation (RO) refractivity-based algorithm to derive boundary layer properties (viz., inversion height and surface-based inversion frequency) for the dry polar atmosphere (total precipitable water ≤ 3.6 mm). The retrieval method is applied to multiyear GPS/Constellation Navigation Observing System (COSMIC) RO data over the remote Arctic Ocean during the cold season (November–April). For the ice-covered Arctic Ocean, the retrieved inversion height is found to be sensitive to the surface air temperature. An irregular peak in the RO-derived inversion height reflects the anomalous warming in the central polar ice pack during January 2012 (evidenced by higher-than-average surface air temperatures and below-average sea ice fraction). The refractivity-based retrieval method thus enables an independent evaluation of model and observations. It can also be used to investigate the boundary layer response to surface warming and to monitor the multiyear variability in polar climate. Changes to the Arctic Ocean and Greenland ice sheet have implications for the global population and should be monitored closely for geopolitical and climatic reasons.

This work was supported by NASA's Constellation Observing System for Meteorology, Ionosphere, and Climate (GNSS) Remote-Sensing and Interdisciplinary Research in Earth Science programs. Given the promise for polar climate monitoring, GPS RO should be considered as a measurement capability in the portfolio of future NASA missions.

M. Ganeshan (613/GESTAR/USRA) and D. L. Wu (613)

2.2.2. A stable, high-quality aerosol data record from MODIS Terra Deep Blue

The calibration efforts by the MODIS Characterization Support Team and Ocean Biology Processing Group have resulted in high quality measurements by the Terra MODIS instrument going back to its launch in 2000. As a result, the new Collection 6 MODIS Terra Deep Blue time series is highly consistent with its MODIS Aqua (launched 2002) counterpart, without the strong divergence exhibited in MODIS Collection 5. Well-understood, accurate, and stable calibration of a satellite sensor is a requirement before attempting to detect trends in derived data sets such as aerosol loading or others. Sensors with calibration drift can falsely mask or magnify real changes in the Earth system. The present study illustrates and confirms the potential of MODIS Terra Collection 6 data for scientific analyses of trend studies. To understand the long-term behaviour of the Earth system, stable records from historical, current, and future space-based sensors must be obtained and stitched together to move towards a long-term climate data record. One of the goals of the Deep Blue aerosol project is to achieve this by applying the same basic approach to monitor aerosols from sensors including (at present) SeaWiFS (1997–2010), MODIS Terra (2000 onwards), MODIS Aqua (2002 onwards), and S-NPP VIIRS (2012 onwards).

A. M. Sayer (613/GESTAR/USRA), N. C. Hsu (613), C. Bettenhausen (613/SSAI), M. J. Jeong (Gangneung-Wonju National University, Korea), and G. Meister (616)

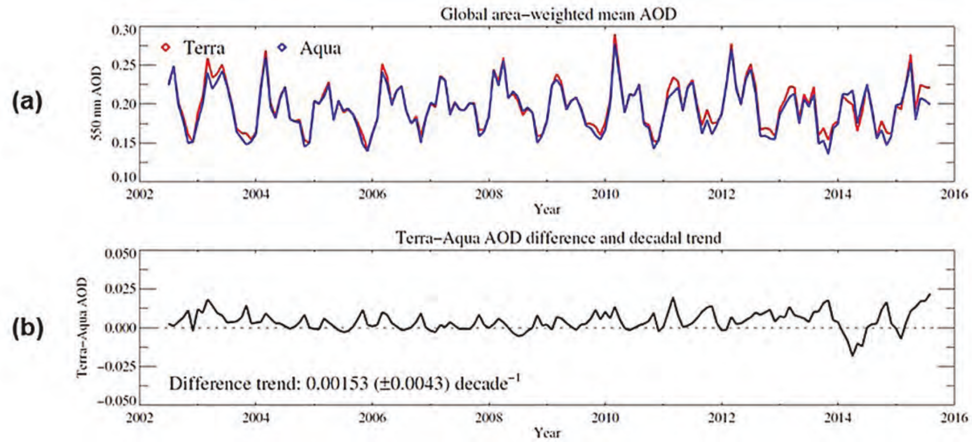


Figure 2.8: This figure shows the global over land-area–weighted time series of Deep Blue (a) AOD from MODIS Terra (red) and Aqua (blue), and (b) the time series and decadal trend in the Terra-Aqua AOD difference.

2.2.3. Aircraft observations help quantify smoke microphysical impacts on Arctic and subarctic clouds

The Arctic is experiencing a series of rapid environmental changes. Currently, our ability to predict future changes is hampered, in part, by a poor understanding of Arctic cloud-aerosol interactions, which affect the radiation budget. At the same time, Arctic and subarctic wildfires are increasing due to the changing climate, and might double or triple by the end of the century. Smoke is believed to have a large effect on cloud lifetime, albedo, and precipitation. However, the interactions between smoke particles and clouds remain poorly quantified due to confounding meteorological influences, remote-sensing limitations and biases (which are particularly high in the Arctic), and limited *in situ* observations. Here, we gathered data from multiple historic aircraft campaigns in the Arctic and subarctic to reduce these uncertainties. Smoke halved median cloud droplet radius in liquid clouds. In certain low-albedo conditions during the summer, we estimate that smoke-driven cloud indirect effects may decrease surface shortwave fluxes by 2 to 4 Wm-2 or more. These findings will be useful input for radiative transfer models and for constraining the energy balance in a changing Arctic. Moreover, they will enhance the utility of remote-sensing observations, which show trends in clouds very well, but which, without context from *in situ* studies, can underestimate cloud albedo effects. Information from our study highlights the need to continue improvements to satellite retrievals of aerosol and cloud properties in polar regions.

L. Zamora (613/GESTAR/USRA) and R. Kahn (613)

2.2.4. The missing tropical arm of the Atlantic Multidecadal Oscillation

In the current generation of global climate models, the tropical arm of the Atlantic Multidecadal Oscillation (AMO) is often absent. Using many years of satellite observations, we show that positive feedbacks from low clouds and dust are critical. However, models fail to produce these feedbacks because of missing both physics and a key coupled atmosphere-ocean teleconnection between high and low latitudes. This is the first study that highlights the connection between mid- to low-latitude SST anomalies in the North Atlantic and discovers the positive feedbacks from dust and low clouds. Our analysis reveals the common weakness in current global climate models that fail to simulate the tropical arm of AMO that is an important source of predictability at decadal time scale, an important new research area. The study also underscores that for low frequency climatic oscillations like the AMO long time series of satellite data are essential for understanding the nature and behavior of the processes involved.

T. Yuan (613/UMBC/JCET), L. Oreopoulos (613), H. Yu (613/UMD/ESSIC), M. Chin (614), S. Platnick (610), K. Meyer (613/GESTAR/USRA)

2.2.5. DSCOVR[ing] EPIC's utility for cloud retrievals

The Deep Space Climate Observatory (DSCOVR) satellite was launched on February 11, 2015, and in June 2015 began making observations of both the Earth and the Sun from its Lissajous orbit about the Earth's L1 Lagrange point, a gravity neutral position near the Sun-Earth line 1.5 million km from the planet. The DSCOVR payload includes the Earth Polychromatic Imaging Camera (EPIC) that views the entire sunlit half of the Earth continuously at near backscatter directions (scattering angle between 164° and 176°) at a native spatial resolution of 8 km at nadir. Numerous geophysical products will be derived from EPIC observations at 10 spectral channels ranging from the ultraviolet to the near-infrared that are sensitive to various atmospheric and surface components, and can provide information on ozone, aerosol, cloud, and vegetation properties. NASA's EPIC cloud products will include cloud detection, cloud optical thickness (COT), and cloud effective height derived from the oxygen (O_2) A- and B-band observations. The EPIC COT product will be produced with the same core algorithms as those used by the operational MODerate-resolution Imaging Spectroradiometer (MODIS) cloud optical and microphysical property product (MOD06/MYD06 for Terra/Aqua) that provides cloud-top pressure, temperature, and height retrievals, as well as simultaneous two-channel retrievals of COT and cloud effective particle radius (CER) and cloud phase retrievals using a variety of spectral tests. However, because the EPIC spectral channel set does not extend to wavelengths longer than near-infrared, COT retrievals will be performed using a single-channel approach similar to that of the International Satellite Cloud Climatology Project (ISCCP) and the Multi-angle Imaging SpectroRadiometer (MISR) mission, assuming fixed values for CER. Since COT can be dependent on CER, single-channel COT retrievals are prone to errors larger than those of the two-channel COT-CER retrievals. Cloud thermodynamic phase will be inferred by imposing thresholds on cloud temperature converted from O_2 A-band cloud effective height retrievals, an approach different from MOD06 that relies on measurements in infrared window and CO_2 absorption channels. Here, the team degraded the 1-km Aqua MODIS observations to 25-km spatial resolution to investigate the impacts of EPIC's coarser spatial resolution and limited spectral channel set on retrievals of cloud thermodynamic phase and COT, as well as their aggregated statistics. Results show that EPIC can provide COT retrievals mostly within 10 percent uncertainty for liquid phase clouds, and within 2 percent for ice phase clouds.

K. Meyer (613/GESTAR/USRA), Y. Yang (613/GESTAR/USRA), and S. Platnick (610)

2.2.6. A new method to quantify smoke and dust aerosols above clouds

Light-absorbing smoke and mineral-dust aerosols above clouds (AAC) are omitted from most passive space-based aerosol optical depth (AOD) data sets. We developed a method to determine above-cloud AOD and liquid cloud optical depth (COD) from MODIS and similar sensors, for incorporation into the NASA Deep Blue AOD data set.

Most existing satellite AOD retrieval algorithms determine the total column AOD only for clear-sky pixels. In cloudy conditions, no retrieval is performed. This leads to significant data gaps in the derived satellite AOD records, which is doubly unfortunate because some of the large-scale recurring absorbing aerosol features, such as from springtime biomass burning in southeastern Asia, occur in very cloudy environments. Extending the coverage of these data sets to include cases of AAC renders them more useful for monitoring aerosol transport or evaluating climate model output. These techniques can be applied directly to multiple past, present, and future NASA and international Earth-orbiting satellite data, providing a means to decrease coverage gaps in these data sets.

Two MODIS scenes with AAC were analyzed using NASA Ames Airborne Tracking Sun photometer (AATS) data as a truth AOD and Angström exponent (ANG) data source, demonstrating the validity of the technique with real observations.

A. M. Sayer (613/GESTAR/USRA), N. C. Hsu (613), C. Bettenhausen (612/SSAI), and J. Lee (612/UMD/ESSIC)

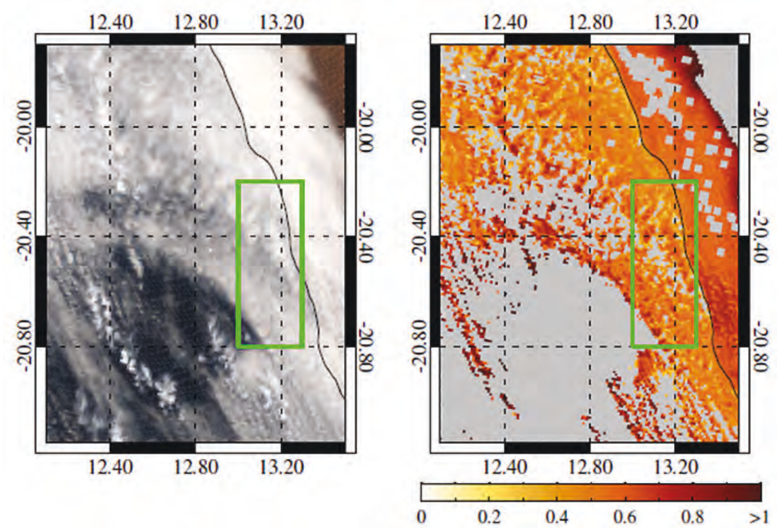


Figure 2.9: A MODIS true-color image from September 13, 2000, of smoke-laden clouds off the African coast (left), and mid-visible AOD above these clouds determined using the new algorithm developed in this study (right). The green box indicates the region of a same-day flight of the University of Washington's Convair-580 aircraft, upon which the AATS instrument was mounted.

2.2.7. Effects of DSCOVR temporal sampling frequency quantified with GEOS-5 Nature Run

Orbiting around the Earth's L1 Lagrange point, the DSCOVR satellite always stays near the Sun-Earth line. At this location, which lies around 1.5 million km away from the Earth, DSCOVR can view the entire daytime hemisphere continuously. Observations from the two Earth-observing instruments onboard, the National Institute of Standards and Technology Advanced Radiometer (NISTAR) and the Earth Polychromatic Imaging Camera (EPIC), are being used to derive information about the Earth's radiation budget, cloud, aerosol, ozone, and vegetation. We investigate how subsampling affects the calculated mean and how close the sampled time series is to the truth using GEOS-5 Nature Run data.

DSCOVR sampling of global radiation and cloud cover is simulated using high spatial resolution output from NASA's GEOS-5 model. We find that the less frequent the sampling, the worse the correlation between the subsample and the original time series, as expected. On the other hand, more frequent sampling is not as beneficial as expected due to errors in the global monthly, seasonal, and annual means. For example, the uncertainty in the Figure below is larger for 6-hour sampling than for 7, 9, 10 and 11 hours.

This is due to the Earth's 24-hour rotation cycle. Using sampling frequencies that are a factor of 24 result in repeatedly capturing specific parts of the cycle, introducing a bias. As shown by DSCOVR, satellites located at the L1 point has the unique advantage in observing the climate system. In the future, should a DSCOVR follow-up be planned, this study could provide general guidance in the sampling strategy.

D. Holdaway (610.1/GESTAR/USRA) and Y. Yang (613/GESTAR/USRA)

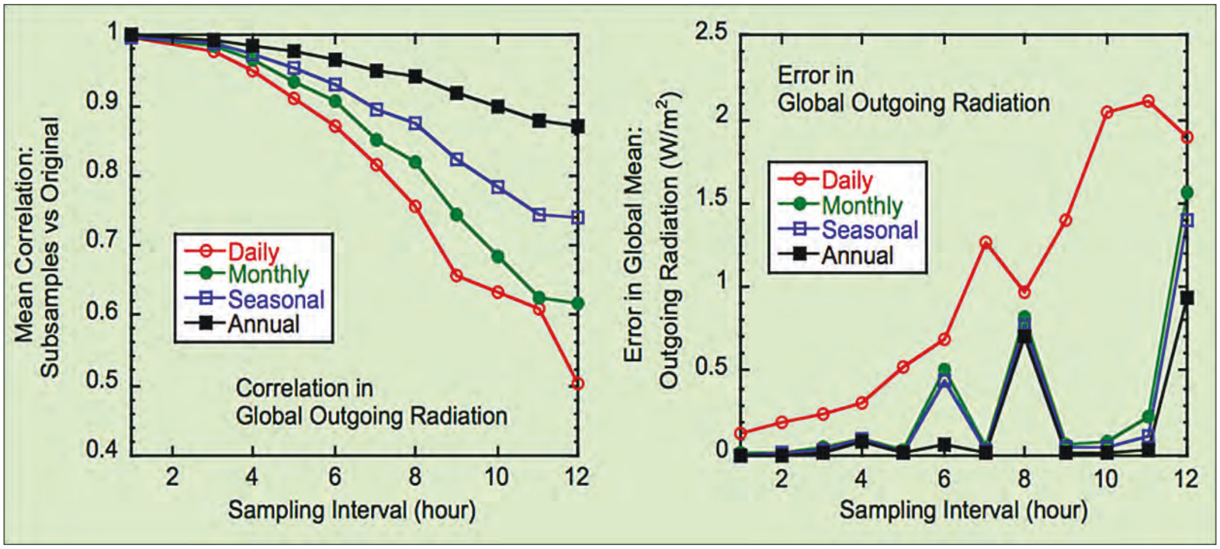


Figure 2.10: Left: Mean of the correlation coefficients between the original and subsampled global total outgoing radiation time series as a function of temporal sampling frequency. The different curves represent different time scales. Right: The error in the global mean total outgoing radiation derived from the subsampled time series as a function of temporal sampling frequency.

2.2.8. Alaska, Greenland, Iceland, and Patagonia are active dust producing regions

Scientists expect high-latitude glaciers and ice sheets to retreat during the 21st century. Dust activity can occur during cold, dry conditions in these environments. An international, multidisciplinary collaboration assessed the state of knowledge and current understanding of contemporary dust activity of high-latitude dust sources. Possible impacts (some of them already observed) include changes in air quality and snow/ ice albedo, and nutrient deficient marine ecosystems. Under contemporary environmental conditions, 80–100 Tg yr-1 of dust is contributed to the global dust cycle from high-latitude sources; this very rough estimate represents up to five percent of the global dust budget. However, with receding glaciers and ice fields as well as expansion of human settlements towards high latitudes, it is expected that air quality issues and regional aerosol direct effects will become more apparent. In addition, Aeolian deposition of glacier silt will increase over nutrients deficient marine ecosystems with unknown biogeochemical impacts. Understanding current high-latitude dust in the Earth system, even at relatively small scales, requires a multidisciplinary approach combining expertise in geomorphology, glaciology, meteorology, oceanography, sedimentology, atmospheric sciences, and other specializations. It also requires the use of a range of research tools including fieldwork, experimentation, observational networks, modeling, and especially remote sensing.

S. Gassó, (613/MSU/GESTAR)

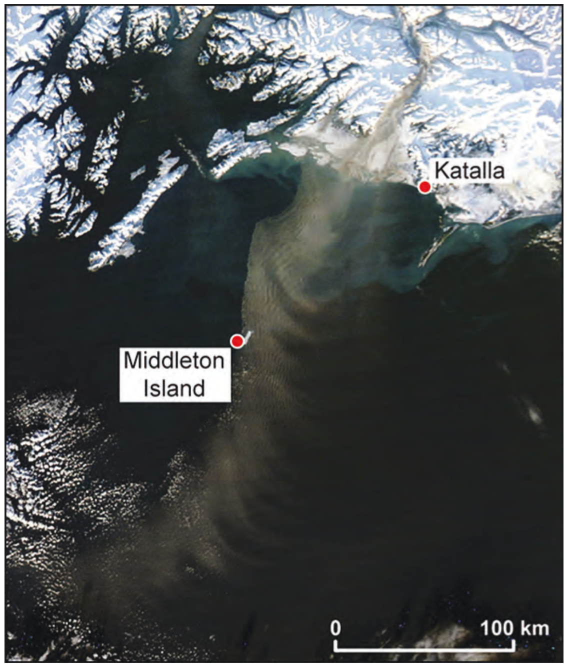


Figure 2.11: MODIS Aqua image on December 4, 2012, showing a major dust plume originating from the Copper River Valley and extending >200 km over the Gulf of Alaska. The dust cloud reaches a region known to be deficient of the micronutrient iron.

2.2.9. Advancements in observing and modeling coupled aerosol-cloud systems

The inaugural deployment of GSFC's SMARTLabs-ACHIEVE mobile laboratory, in conjunction with ground-based cloud radar monitored for the first time the evolution of pre-monsoon continental stratocumulus in the presence of biomass-burning aerosols. Such detailed observations are critical for improving models simulating aerosol-cloud-precipitation processes and for validating future spaceborne cloud measurements.

Ground-based cloud radar measurements, though spatially limited, provide detailed information on low-level stratocumulus cloud properties currently not attainable from much coarser resolution spaceborne radar systems—which also suffer from surface clutter and signal attenuation. Such data can be used to both constrain and evaluate models that simulate the potential impacts of these coupled aerosol-cloud systems on local and regional weather and air quality. Because microphysical processes and cloud radiative properties depend on the cloud/raindrop size distribution (CDSD), accurate CDSD prediction is critical.

The modeling portion of this study employed a new triple-moment (3M) bulk microphysics scheme for fully prognostic CDSDs as an efficient alternative to computationally expensive size-resolving (bin) microphysics schemes. Deployable ground-based cloud radar provided critical measurements of cloud properties in regions with strong aerosol-cloud interaction signals that will aid the design of future spaceborne cloud measurements (e.g., a NASA ACE-like mission). Systematic model simulations, utilizing the GCE with 3M microphysics, and a larger-scale regional model (e.g., NU-WRF) equipped with a detailed aerosol module, can bridge the gap between *in situ* and remote measurements at field campaigns and collocated satellite measurements for understanding the physical processes involved in aerosol-cloud interactions.

A. Loftus (613/UMD/ESSIC) and S.-C.Tsay (613)

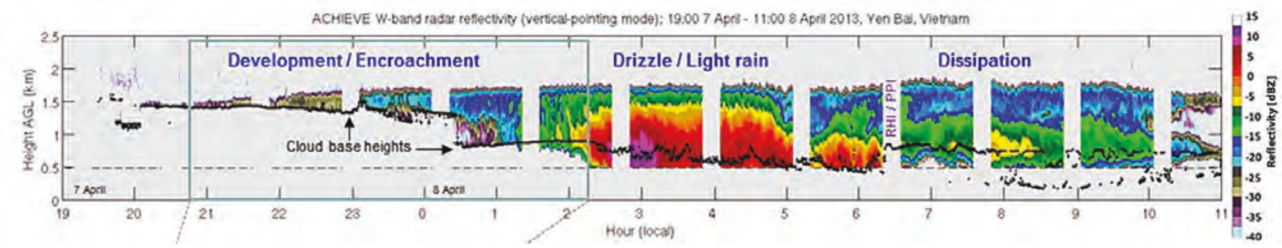


Figure 2.12: Time series of radar reflectivity showing in unprecedented detail the nighttime development/ encroachment of a stratocumulus deck and evolution into a lightly precipitating system (after ~02:00 local time) on April 7–8, 2013, over Yen Bai, Vietnam during the Seven Southeast Asian Studies/Biomass-burning Aerosols and Stratocumulus Environment: Lifecycles and Interactions Experiment (7-SEAS/BASELInE) campaign. Breaks in reflectivity time series coincide with radar scans in range height indicator and plan position indicator modes.

2.2.10. Fire-induced land conversion to cropland is increasing in middle Africa

Northern Sub-Saharan Africa (NSSA) accounts for 20 to 25 percent of the global carbon emissions from biomass burning. Widespread burning that peaked in 2006 influences land-cover changes that result in a net conversion of 0.28 percent/year of the total land area to cropland, with the majority (0.18 percent/year) coming from savanna. Over the last decade, the trend is increasing from savanna, forest, and wetlands to cropland. Given such overwhelming occurrence of biomass burning in this region and its inherent potential to affect vegetation changes, land degradation, deforestation, surface albedo, aerosol emissions, and surface evapotranspiration, it is reasonable to hypothesize that biomass burning, directly or indirectly, exerts significant impact on NSSA's environmental dynamics and water cycle across different spatial and temporal scales. These results provide observational evidence of changes in land-cover that are consistent with feedbacks from biomass burning in NSSA and encourage more synergistic modeling and observational studies (including field campaigns) that can elaborate this feedback mechanism and its wider ramifications

C. Ichoku (613) and L. Ellison (613/SSAI)

2.2.11. Diurnal cycle and evolution of tracked cold-cloud clusters

Storms are a major contributor to natural hazards, so understanding how and when cloud development occurs is important for storm prediction. Tracking clouds using overlapping clusters between satellite images allows scientists to study their trajectories. By analyzing millions of clouds in this manner, we can determine the time of day that major storm phases occur. Our results show that during their life cycle, cloud clusters typically undergo distinct life cycle stages. However, the clusters with longer and shorter lifetimes mature differently: Long-lasting clusters tend to achieve their temperature maturity before size maturity, thereby prolonging this stage. Timing wise, afternoon development is more likely over land, while over the ocean there are two peaks in activity: one in the early morning and one in the afternoon. This study provides the first big picture survey of cold-cloud cluster evolution, characteristics, and daily cycle.

R. Esmaili (613/USRA/ESSIC), Y. Tian (617/USRA/ESSIC), and K.-M. Kim (618/USRA/ESSIC)

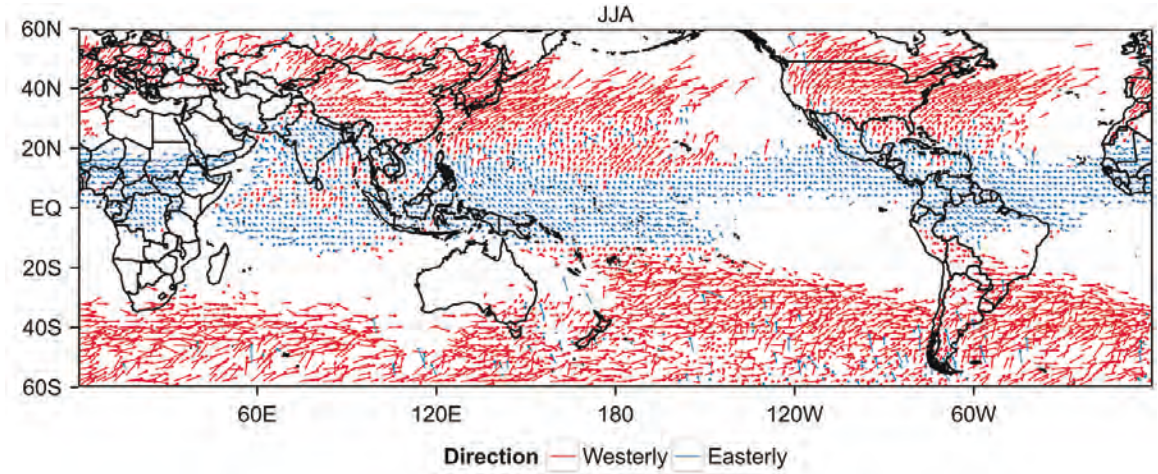


Figure 2.13: Climatology of cloud cluster trajectories acquired January to August 2002–2012, with 6- to 9-hour lifetimes binned at 2° x 2°. Lines show average displacement of all cloud clusters that initiated at the same point over the 11-year period studied. Coloring indicates net zonal movement of clusters. Grid boxes with fewer than five initiations were not displayed.

2.3. Atmospheric Chemistry and Dynamics Laboratory

The Atmospheric Chemistry and Dynamics Laboratory (614) 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 Ozone Monitoring Instrument (OMI) instrument U.S. Science team come from this group. The Laboratory also is a leader in the integration and execution of the NPOESS Preparatory Mission (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-art 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. Dry deposition of NO_2 and SO_2 contributes excess nitrogen and sulfur to vegetation, soil, and water. Deposited nitrogen can cause eutrophication, leading to a loss of biodiversity. Deposited nitrogen and sulfur both have the potential to acidify soil and water, and may influence climate by perturbing the carbon uptake of an ecosystem. Measurements of NO_2 and SO_2 columns from OMI in combination with the GEOS-Chem chemical transport model have provided the first global budgets and estimates of spatial patterns of NO_2 and SO_2 dry deposition. These results have potential applications in a range of fields, from atmospheric chemistry to ecology. The upcoming NASA Earth venture mission called Tropospheric Emissions: Monitoring of Pollution (TEMPO) will allow dry deposition to be quantified at very high spatial and temporal resolution.

2.3.1. Total ozone comparison between SNPP/OMPS and DSCVR/EPIC

We have obtained estimates for the calibration coefficients K (317.5), K (325 nm), and K (340 nm) that yielded an improved (right) ozone retrieval that has been compared with the same day as observed from Suomi/ Ozone Mapping and Profile Suite (OMPS) (Figure 2.14, left). The calibration estimates will be improved with a goal of two percent ozone accuracy (currently at five percent). The native spatial resolution from EPIC 20 x 20 km^2 has been reduced to approximate the 50 x 50 km^2 resolution from OMPS. While the agreement appears to be quite good, there are issues at high solar zenith and view angles in both the latitude and longitude directions that are not present in the nadir viewing OMPS data. Additional work is required developing retrieval algorithms incorporating improved spherical geometry calculations and improved calibration coefficients K for each wavelength.

Based on the results obtained with the preliminary retrieval algorithm, a production algorithm for calculating ozone, must be developed for the special geometry needed for analysis of EPIC data. The derived EPIC data must be compared extensively with results from well-established results from OMI and OMPS obtained at 13:30 local time. Most interestingly, the EPIC ozone "movies" we obtained show the motions of ozone during the day, especially the rotation of the Antarctic Ozone Hole as it passes over the tip of South America. This is important for understanding the duration that people are exposed to enhanced levels of UV radiation from reduced ozone concentrations. This result is not available from low-earth orbiting satellites such as OMI or OMPS.

J. Herman (614/UMBC/JCET)

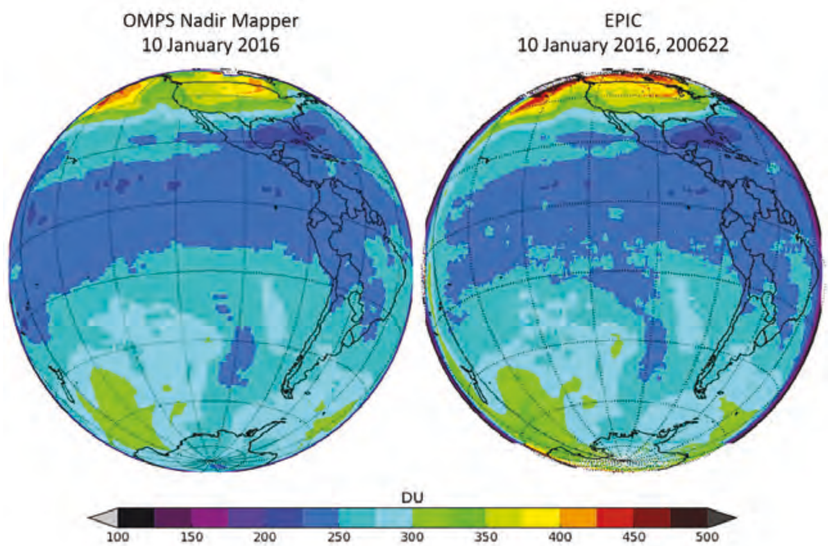


Figure 2.14: The image on the left is a traditional composite of multiple orbits of Suomi NPP data taken over a 24-hour period. The image on the right is a snapshot taken by the EPIC instrument on the DSCOVR satellite at 20:06 GMT observing from the L1 point.

2.3.2. Suomi NPP satellite observes Alaska's Pavlof volcanic cloud

The eruption of Alaska's Pavlof Volcano on Sunday, March 27 sent dense ash and SO_2 clouds up to 30,000 feet (about 9 km) into the atmosphere. The U.S. Geological Survey's Alaska Volcano Observatory declared an aviation Code Red over the surrounding area. Sensors on Suomi NPP satellite tracked the dense volcanic ash close to the volcano, the Visible Infrared Imaging Radiometer Suite (VIIRS) true color imagery (Figure 2.15, upper left) and the OMPS UV Aerosol Index (upper right). OMPS volcanic SO_2 data (lower left) tracked the upper tropospheric part of the cloud moving eastward with jet stream winds over Canada. SO_2 is a health hazard in high concentrations; it is also useful as a proxy for fine ash undetectable by satellite. The ability to detect and track volcanic ash and SO_2 plumes from solar backscattered UV spectrometers, such as OMI on Aura and OMPS on SNPP have proven invaluable in mitigating the effects of volcanic eruptions, including assessing their impact on air quality and delays to air traffic.

The data also provide important input into models used to predict ash and SO_2 trajectories. Following the successful development of the OMI near real-time and real-time systems, OMPS data is now available in both modes. This capability greatly enhances the usefulness of the data, as timely information on the location and trajectory of the ash and SO_2 clouds is critically important for volcanic disaster management.

N. Krotkov (614) and C. Seftor (Ozone SIPS, SSAI)

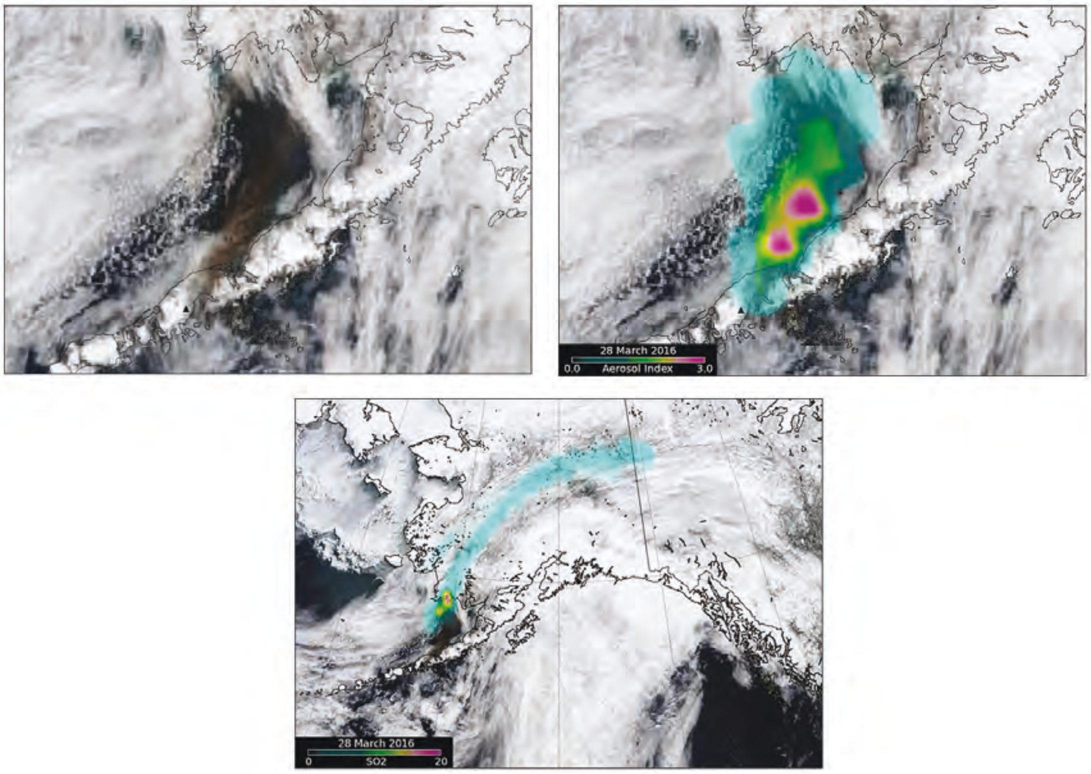


Figure 2.15: Upper left: VIIRS true color image. The brown-colored plume moving to the northeast of the volcano (black triangle) is visible volcanic ash. Upper right: The OMPS Aerosol Index super-imposed on the VIIRS true-color image. Along with color, the transparency of the plume Is directly related to the magnitude of the cloud; the higher the index, the more opaque the cloud. Lower left: The OMPS SO_2 superimposed on the VIIRS true-color image. Again, along with color, the transparency of the plume is directly related to the amount of SO_2; the more SO_2 the more opaque the cloud.

2.3.3. Low ozone over Europe does not mean the sky is falling—it's actually rising

The NASA Aura Microwave Limb Sounder (MLS) (O_3 profiles and columns) observed northern hemisphere stratospheric column ozone on February 1, 2016. Very low columns were seen over the United Kingdom and Europe (<225 DU). To quantitatively understand anthropogenic impacts to the stratospheric ozone layer, we must be able to distinguish between low ozone caused by ozone-depleting substances and that caused by natural dynamic variability in the atmosphere. Observations and realistic simulations of atmospheric composition are both required in order to separate natural and anthropogenic ozone variability. Low column O_3 over Europe on February 1, 2016, was not caused by manmade substances. The GMI model calculated 4 Dobson Units (DU) of O_3 depletion. The high tropopause, shown by MERRA, lifted the O_3 profile to lower pressures, causing the stratospheric column to decrease by more than 100 DU compared to earlier in winter. The ozone was displaced, not depleted.

S. Strahan (614/USRA/GESTAR), P. Newman (614), S. Steenrod (614/USRA/GESTAR)

2.3.4. The first global, satellite based sulfur dioxide emission inventory

A new "top-down" emission-source detection algorithm was applied to the measurements of sulfur dioxide (SO_2) from the Ozone Monitoring Instrument (OMI) onboard the NASA Aura satellite. It was used to compile the first global, satellite-based emissions inventory, and is completely independent of conventional information sources. Nearly 40 of the sources identified by this new method were found to be missing from leading emissions inventories (black symbols and country color code), representing about 12 percent of the global total. Regionally, emissions can be off by factors of two or three. This method has potential applications to detecting emissions for other pollutants (NO_x, particulate matter).

These results represent the first global satellite-derived emissions inventory. It is independent of previous, conventional knowledge sources and hence can be used to both verify emissions and locate new or unaccounted for emissions sources. Further, it provides a consistent method for deriving emissions, independent of source type and geopolitical borders. We find that of the 500 or so large sources in our inventory, nearly 40 are not captured in leading conventional inventories. These missing sources are scattered throughout the developing world (e.g., over a third are clustered around the Persian Gulf) and add up to roughly 6–12 percent of the global anthropogenic total. This method can be used for other short-lived pollutants such as nitrogen oxides, particulate matter, and ammonia.

C. McLinden (EC), V. Fioletov (EC), M. Shephard (EC), N. Krotkov (614), C. Li (614/USRA/ESSIC), R. Martin, (Dalhousie University), J. Joiner, (614)

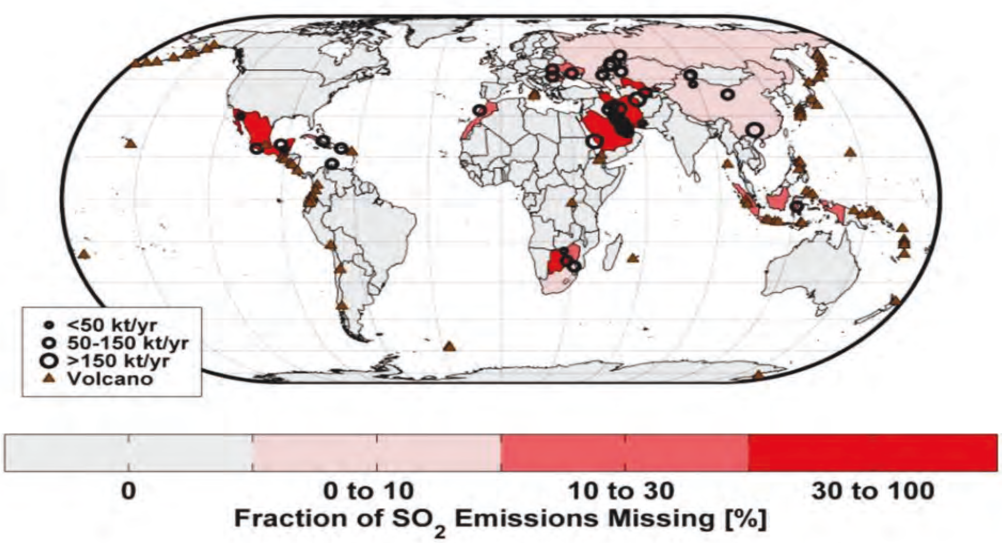


Figure 2.16: The map shows global distribution of location and magnitude of missing anthropogenic (circles) and volcanic (triangles) SO_2 emission sources detected by OMI. The downwind-upwind difference, determined by merging OMI SO_2 measurements with wind information, is an indicator used to determine the presence of a source of SO_2. Many of the missing SO_2 sources were located in the Middle East and related to the oil and gas sector. Also, each nation is color-coded according to the fraction of emissions that were found to be missing from their national totals.

2.3.5. Complex regional trends (2005–2015) in NO_2 and SO_2 pollution from Aura's Ozone Monitoring Instrument (OMI)

Space-based monitoring plays an increasingly important role in the science of tropospheric chemistry and air quality applications to help mitigate anthropogenic and natural impacts on climate, sensitive ecosystems, and human health. U.S. Environmental Protection Agency's (EPA) uses OMI NO_2 data in *Air*

Trends Report (https://gispub.epa.gov/air/trendsreport/2016). It is essential to continue and maintain overlapping long-term satellite data records. The baseline established during the first 12 years of OMI is invaluable for the interpretation of measurements from future satellite atmospheric chemistry missions.

The OMI measurements will be continued by the TROPOspheric Monitoring Instrument (TROPOMI), which is planned for launch on ESA's Sentinel 5 Precursor (S5P) satellite in 2016. TROPOMI is part of the European Sentinel series that will continue the global pollution data record for another 20 years. The space-based capabilities for air quality applications will be further enhanced by the addition of higher-ground resolution hourly observations from the three geostationary satellites over North America (NASA's first EV-I Tropospheric Emissions: Monitoring of POllution (TEMPO), http://tempo.si.edu), over Europe (ESA's and Copernicus Sentinel 4 UVN) and East Asia (Geostationary Environment Monitoring Spectrometer on board the GeoKOMPSAT satellite). This atmospheric composition constellation will provide unprecedented observations of the key pollutants in the atmosphere during next decade.

N. Krotkov (614) and many others

2.3.6. Atom provides a new perspective on tropospheric formaldehyde

The formaldehyde observations from Atom cover an unprecedented range of altitudes and latitudes over the remote oceans. The distribution of formaldehyde, shown in the Figure 2.17, shows how sources of formaldehyde—biogenic volatile organic compounds (VOCs)—are distributed between the poles. The surprisingly high abundance of formaldehyde in even the most remote locations indicates relatively large sources of VOCs in these regions. These sources result in enhancements of formaldehyde, which in turn produces hydroxide, the primary tropospheric sink of methane. Measurements of formaldehyde reveal a distinct pattern that provides new insights to the chemistry of the remote troposphere. Measurements like these also provide an important source for constraining the chemistry-climate models that are used to predict the climate impact of methane and ozone.

T. F. Hanisco (614), J. M. St. Clair (614/UMBC), J. Liao (614/USRA/GESTAR), G. M. Wolfe (614/UMD)

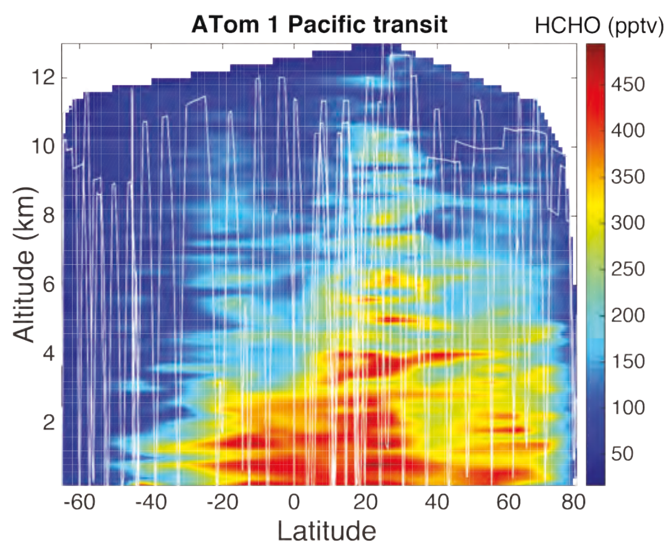


Figure 2.17: The concentration of formaldehyde (HCHO) measured in situ with the ISAF instrument plotted versus latitude and altitude. The thin white lines show the trajectory of the DC-8 and the location of the measurements. The HCHO data are interpolated on a rectangular grid using a linear function. Data obtained over land near the airports used for the deployments are excluded

2.3.7. Toxic benzene levels and source fingerprinting in DISCOVER-AQ (2014)

At the Platteville Atmospheric Observatory (PAO) in Colorado, Goddard and Penn State operated the University of Oslo's PT-RMS to measure benzene in oil and gas fields for three weeks in July and August, 2014, while the DISCOVER-AQ P-3 spiraled overhead three times per day. Data from NOAA's Boulder Tower (BAO), with winds at Platteville pinpointed benzene source between PAO and BAO (Figure xx), where tiny red dots mark fracking waste pits. Each yellow dot is a drill/well site in the "Denver-Julesburg" oil and gas fields. Benzene is a toxic chemical that is a byproduct of oil and gas exploration, chemical manufacture, as well as cars and trucks. The high levels we measured got the attention of the Environmental Protection Agency and Colorado Department of Public Health and Environment, who had to file reports and now—thanks to NASA—will start monitoring unhealthy hydrocarbons (VOCs) at Platteville themselves.

A. M. Thompson (610), H. Halliday (Penn State), A. Wisthaler (U. Oslo)

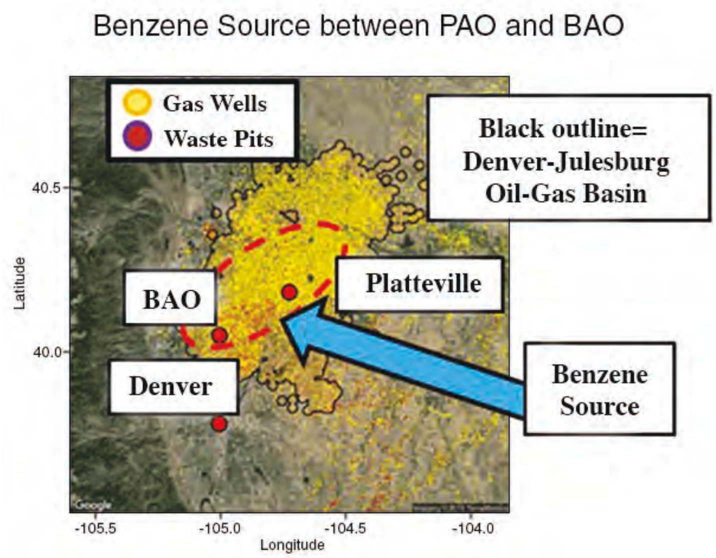


Figure 2.18: Because BAO, located 25 km southwest of Platteville, recorded high benzene to the northwest, scientists determined that the source of this benzene was located about halfway between the two sampling sites.

2.3.8. NASA satellites track air pollution from sulfur fires in Iraq

The SO_2 emissions from sulfur fires created serious air quality issues in Iraq, with several deaths attributed to the fumes. This is an example of air pollution created by a toxic gas cloud. Satellite observations of such events are crucial to assess the geographic extent of the air pollution, estimate ground-level concentrations of SO_2, and forecast transport into other regions. Such sulfur fires also produce a relatively pure SO_2 cloud, which is rarely observed in the atmosphere (other anthropogenic and volcanic SO_2 emissions are mixed with a variety of other gases and particles), which could be used to improve understanding of atmospheric sulfur chemistry. NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) platform ingests the SO_2 data within three hours of acquisition by the OMI on board NASA's Aura satellite. LANCE thus enables multi-product and multi-satellite, near-real-time image generation using public Worldview web application.

S. A. Carn (Michigan Tech. Univ.), N. Krotkov (614), C. Li (614/UMD)

2.3.9. Ozone Monitoring Instrument

The team published a global catalogue of large SO_2 sources and emissions derived from the Ozone Monitoring Instrument (*Atmos. Chem. Phys*., 16, 11497). The paper presented the first global emission inventory of sulfur dioxide, an U.S. EPA criteria pollutant and aerosol precursor, based on satellite remote sensing. Ten years of global SO_2 measurements from the OMI onboard NASA Aura satellite (operated by Goddard) have been combined with a new emission-source detection algorithm to infer annual emissions and trends from approximately 500 medium and large point sources that emit over 30 kt/y. The OMI inventory is completely independent of conventional information sources and has been used to verify traditional "bottom-up" SO_2 emissions inventories and identify missing sources. The catalogue is archived at the Goddard Earth Sciences Data and Information Services Center (GES DISC) and will be updated regularly with future measurements from current and future missions, such as European Sentinel 5 Precursor (TROPOMI) and U.S. JPSS-1 (OMPS) missions planned for launch in 2017.

V. Fioletov, C. A. McLinden, N. Krotkov (614), C. Li (614/UMD), J. Joiner (614), N. Theys, S. Carn, and A. Moran

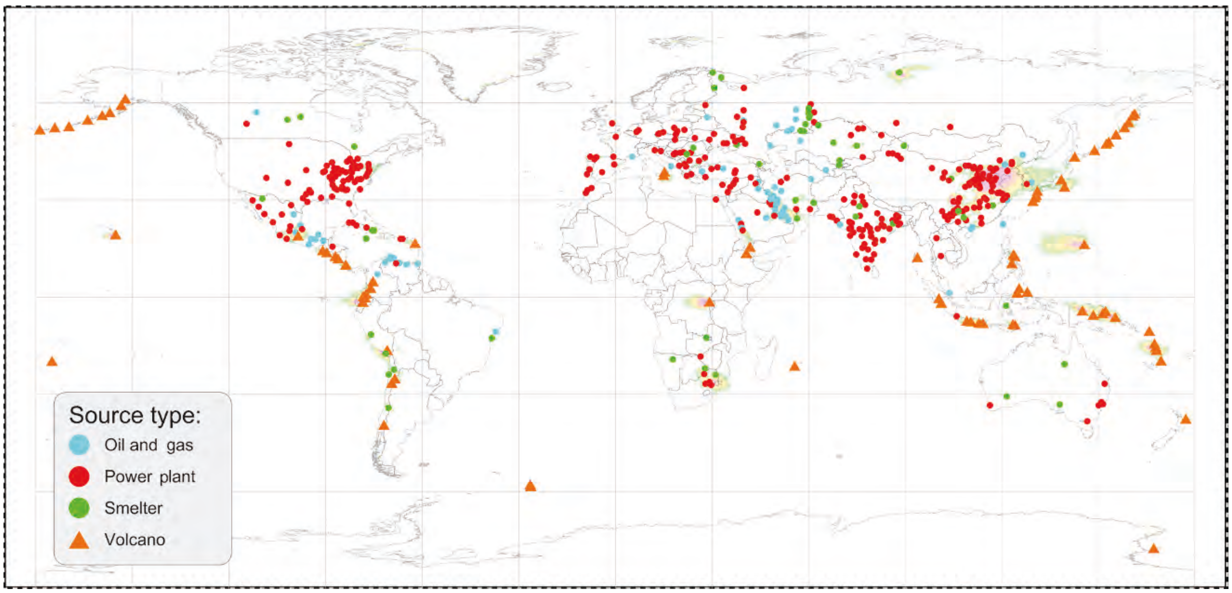


Figure 2.19: This figure shows geographic distribution of the SO_2 sources in the OMI-based inventory.

2.4. 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 at both Wallops and remote sites. Scientists in the Office use radars, aircraft, balloons, *in situ* and laboratory instruments, autonomous surface vehicles, and satellite platforms to participate in the full complement of Earth science research activities. These activities include measurements, retrievals, data analysis, model simulations, and calibration/ validation. Office personnel collaborate with other scientists and engineers across Goddard and other NASA centers as well as universities, and other government agencies, locally, nationally and internationally. The Office has provided instrumentation and scientific research expertise to several NASA missions and field efforts in 2016.

2.4.1. Atmospheric Science

2.4.1.1. Wallops Precipitation Research Facility

Based at Wallops Flight Facility (WFF), the Precipitation Research Facility (PRF) is designed to provide multi-scale, referenced ground-based radar, disdrometer, and rain-gauge-based measurements of hydrometeor properties including size, number concentration, shape, fall speed, and water content 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 of precipitation's 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-Polarimetric Doppler Radar (D3R), 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 WFF, two buoy gauges, weighing bucket gauge to measure the weight of fallen precipitation, vertically pointing micro rain radars (K-band; MRR), snowfall particle imaging, and liquid water content measurement systems. As part of a visiting asset program, Code 610.W at WFF hosted three additional radars in 2016. The Aerosol, Cloud, Humidity, Interactions Exploration and Validating Enterprise (ACHIEVE) W-band radar from Code 613, and the X-BADGER X-band radar from Code 612 were located on the main WFF facility for simultaneous and collocated measurements with the D3R radar. The Transportable Research X-band radar (TReX), on loan from the University of Castilla-La Mancha in Spain, arrived at WFF in August 2016 for a short-term deployment of one year. Due to initial technical difficulties, it is expected that TReX will begin operations in early 2017, and will be collocated with the NPOL radar. When not deployed in remote field campaigns, PRF instruments are stationed regionally in a network around the WFF as a means to support GPM Ground Validation, test instrumentation performance, develop new sampling methodologies, and conduct new PMM science.

D. B. Wolff (610.W)

2.4.1.2. OLYMPEx deployment and execution

The Wallops Field support office played a critical role in the GPM Ground Validation Olympic Mountain Experiment (OLYMPEx) that was conducted from November 10, 2015 through January 15, 2016. This field campaign was centered over the Olympic Mountains with NASA's S-band dual-polarized (NPOL) radar as the lynchpin for the entire experiment. Both NPOL and the Dual-polarization, Dual-frequency, Doppler Radar (D3R) conducted round-the-clock observations throughout the campaign (with short breaks during dry periods and the Christmas holiday). Wallops support staff deployed and maintained dozens of rain gauges, disdrometers, and vertically pointing radars along the Pacific coast and up the Quinault River Valley in Washington. NASA also provided the ER-2 for high-altitude observations and the DC-8 for observations between 30,000 and 38,000 feet. Several "gold cases," where a GPM satellite overpass occurred with all three aircraft aloft, radar scanning and ground instruments observations provided important data for algorithm developers in their quest to improve global precipitation estimates by GPM. NASA aircraft were complemented by University of North Dakota Citation aircraft, which provided lower-level observations. The OLYMPEx campaign was highly successful and the NASA instruments were able to sample numerous large storms that dropped copious amounts of rain at low levels and heavy snow in the Olympic Mountains.

NASA also provided the ER-2 for high-altitude observations and the DC-8 for observations between 30,000 and 38,000 feet. Several "golden cases," where a GPM satellite overpass occurred with all three aircraft aloft, radars scanning, and ground instruments operational. These valuable measurements provide important data for algorithm developers in their quest to improve global precipitation estimates by GPM.

D. B. Wolff (610.W)

Table 2.1: Data sets and number of NASA instruments deployed during OLYMPEx.

Name	Number	Format
NPOL	1	SIGMET
D3R	1	NetCDF
2DVD	4	Joaenneum
Parsivel disdrometer	14	ASCII
Rain Gauges	40	ASCII

Figure 2.20: NPOL (left) and D3R (right) radars shown deployed along the coast Pacific Ocean near Moclips, Washington. Both radars operated nominally and provided high-quality, multi-frequency (S-, Ka-, and Ku-band) observations of rain, mixed-phase, and ice (snow) precipitation.

2.4.1.3. Operations with the SMART/ACHIEVE and X-BADGER platforms

Code 610.W support staff helped engineers from Code 613 operate the Aerosol, Cloud, Humidity, Interactions Exploration and Validating Enterprise (ACHIEVE) radar while it was deployed near the N159 hangar at Wallops Flight Facility. ACHIEVE is a fully deployable mobile laboratory containing active and passive sensors for measuring cloud, aerosols, and precipitation properties and is operated by the Surface-based Mobile Atmospheric Research and Testbed Laboratories (SMARTLabs) team at Goddard.

The primary purpose of ACHIEVE is to obtain quantitative measurements of the time-varying vertical structure of single- and multi-layer clouds, light precipitation, and aerosols over land. Data collected by ACHIEVE's multi-spectral instruments is essential for initializing and constraining model simulations of aerosol-cloud-precipitation interactions, developing, evaluating, and refining cloud retrieval algorithms. It can potentially provide critical ground-based validation for the recently launched GPM and future (ACE) satellite missions.

ACHIEVE's main instrument is a scanning, dual-polarization, W-band (93.93 GHz) pulsed-Doppler radar. Its high-resolution capability (typically 25 to 50 m), 0.25-degree beam width, and great sensitivity of the radar (-55 dBZ at 1 km) allows for detection of small-scale changes in cloud structure owing to changes in droplet size distribution characteristics.

In 2016, ACHIEVE returned to Wallops and performed coordinated scanning of light rain with NASA's D3R radar. This effort provided early validation of both the ACES and Clouds and Precipitation Processes. From August through December 2016, ACHIEVE was at GSFC in Greenbelt, Maryland for upgrades and repairs. ACHIEVE will return to Wallops in early 2017.

Figure 2.21: NASA GSFC's ACHIEVE radar.

Code 610.W support staff also helped engineers and scientists from Code 612 operate the X-BADGER radar. X-BADGER is a 2-beam X-band radar modified from an airborne Doppler system (EDOP). X-BADGER has a single polarization zenith beam and a dual-polarization beam pointing at 20 degrees off-zenith. WFF staff has operated X-BADGER for several GPM overpass events.

D. B. Wolff (610.W), S.-C. Tsay (613), and A. Emory (612)

2.4.1.4. IRAD: Providing multi-frequency observations of clouds and precipitation for ACE and CaPPM ground validation

To support future potential Aerosol-Cloud-Ecosystem (ACE) and Cloud and Precipitation Processes (CaPPM) missions, Principal Investigator David B. Wolff, (610.W) and co-Investigators Si-Chee Tsay (613), Manuel Vega (555), and Greg Martins (543) conducted a science and engineering design study to optimize coordinated cloud and precipitation sampling using existing Ku-/Ka-band (D3R) and W-band (ACHIEVE) radar assets to conduct triple-frequency radar measurements across the cloud and precipitation process spectrum. Additionally, as a means to extend these short-wavelength measurements into heavy precipitation regimes, the team conducted an accompanying engineering design study to add Ku-band capability to NASA's existing dual-polarized S-band radar (NPOL).

D. B. Wolff (610.W)

2.4.1.5. Triple frequency radar measurements using NASA's ACHIEVE and D3R radars

This effort realized the basis for operating the D3R and ACHIEVE radar systems. Particularly, the absolute calibration of the D3R Ku-/Ka-band and ACHIEVE W-band radars was successfully performed on the March 16, 2016, using a 6-inch corner reflector atop a 30-m tower located 450 m from both radars, shown in Figure 1. Comparisons with previous year calibration results showed good agreement with virtually no degradation in W-, Ka-, Ku-band system performance.

Figure 2.22: Collocated D3R and ACHIEVE radar systems (left), and 30-m calibration tower at WFF (right).

Measurements with and without the corner reflector demonstrated minimal surface clutter impacts and provided additional confidence in the calibration results for both systems (calibration uncertainties due to clutter to signal ratio of approximately 0.25 and 0.5 dB for the W-band and Ka-/Ku-band radars, respectively).

Measurements by the nearly collocated (~10 m apart) D3R Ku-/Ka-band and ACHIEVE W-band radars captured a broad range of liquid, frozen, and mixed-phase cloud and precipitation systems (summarized in Table 1), which passed over the area during operations from the March 3 through the May 17, 2016. The D3R system was deployed in Washington state prior to the March 3 for OLYMPEx in western Washington in support of NASA's GPM Ground Validation (GV) program. The D3R system cycled through various scanning modes (RHI, PPI, and profiling) in an attempt to meet the IRAD and GPM GV goals, whereas the W-band operated primarily in vertical-pointing (profiling) mode. Several scanning strategies designed to obtain coincident sampling volumes with the radars were tested and are still under evaluation. Maintaining high sensitivity during scan synchronization between the W-band and D3R radars was often prevented by slower W-band scan speeds and by variable delay times in reconfiguring the W-band radar between scanning modes. Upgrades to the W-band radar operating and radar control systems have begun, along with a revised strategy that relaxes W-band sensitivity requirements, which and may improve scan synchronization during the Fall 2016 to Spring 2017 operations period.

More than 600 hours of W-, Ka-, and Ku-band spectral and moment data were collected. Ancillary data including aerosol optical depth during cloud-free conditions (AOD), cloud optical depth during cloudy conditions (COD), ceilometer cloud-base heights, and surface precipitation were also continuously recorded during the operational period. Cloud and precipitation events were sampled by all three radars and cataloged. These datasets have undergone further analysis on profiles suitable for multi-wavelength retrievals (e.g., dual wavelength ratio, differential attenuation, spectral characteristics, etc.) to assess combinations of frequencies best suited for differentiating particle phases/sizes and estimating vertical motions and liquid water content in support of future cloud and precipitation missions.

A "golden scenario" case, acquired on March 19, is presented in Figure 2.23. This case featured a mixed phase cloud system with light precipitation falling below cloud base that evaporated prior to reaching the surface. Range-Height Indicator (RHI) scans reveal weaker peak returns at the higher frequencies; however, the much higher sensitivity and range resolution of the W-band reflectivity permits much greater detail near cloud top where the smallest particles would be expected. An examination of reflectivity profiles along radials at 59° elevation for the three frequencies reveals increasing attenuation (due primarily to liquid water) at higher frequencies.

D. B. Wolff (610.W), S.-C. Tsay (613)

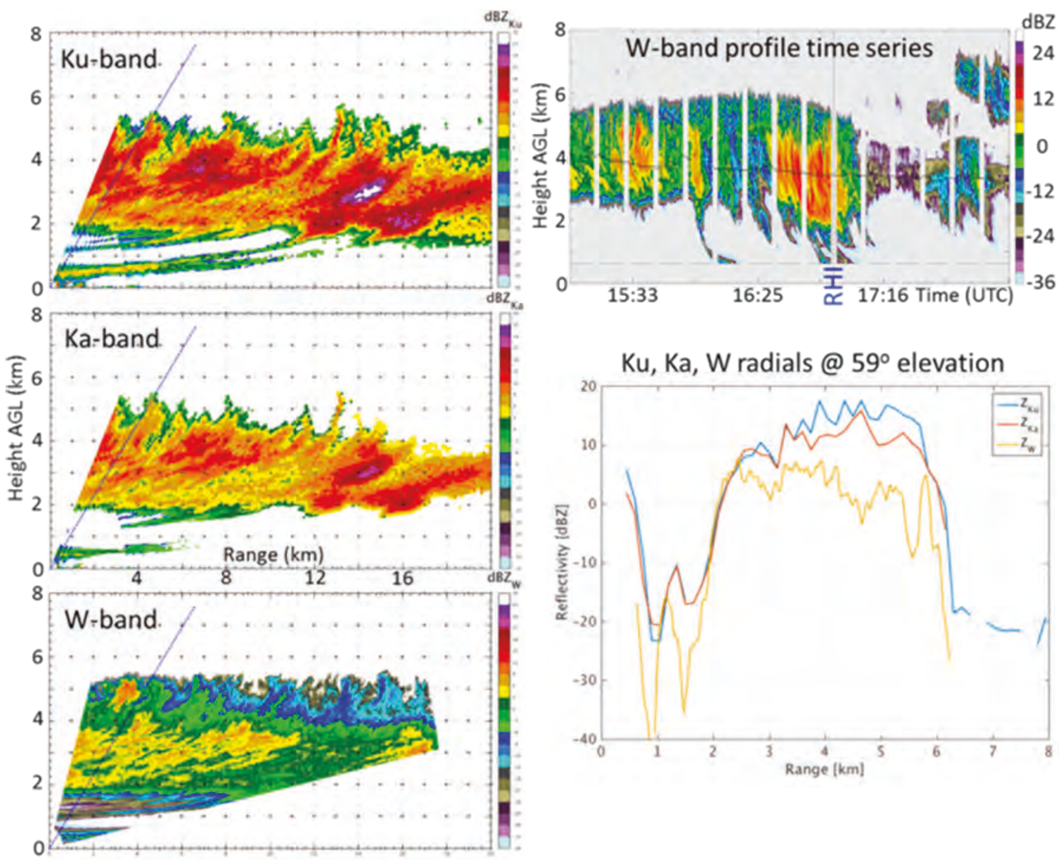


Figure 2.23: Ku-, Ka-, and W-band RHI scans of reflectivity (left column) at 16:54:43 UTC (Ku/Ka) and 16:55:48 UTC (W) on March 19, 2016, through a mixed-phase cloud layer and virga as indicated by the W-band reflectivity profile time series (upper right). Ceilometer-derived cloud base heights are near 4 km as depicted by black dots, and missing reflectivity profiles denote radar is in RHI scanning mode (upper right). Reflectivity color scales are identical for all frequencies. Bottom right panel shows comparison of Ku-, Ka-, and W-band reflectivity.

2.4.1.6. Feasibility study for adding Ku-band capability to NASA's S-band NPOL radar

A study was conducted to determine the feasibility of adding Ku-band capability to NASA's S-band NPOL radar. Two distinct approaches were tested: (1) a two-antenna, matched beam system, and (2) a dual-feed beam using the existing NPOL waveguide. The dual-feed beam was eliminated as the addition of the Ku frequency was shown to degrade the S-band signal, which made the radar unable to achieve signal fidelity requirements. The second approach tested the feasibility of designing a dual-antenna system that would meet science requirements at an affordable price. The first step was to determine the appropriate operational and survival requirements necessary to maintain the integrity of the observed data in various weather conditions. These were obtained from the current NPOL specifications, so some adjustments were possible. With the requirements defined, a second design feasibility study was conducted using a truss system to attach a Ku antenna above the existing NPOL S-band antenna. (See Figure 2.24) The Ku antenna would extend over the existing NPOL antenna mounted on an added truss with electronic boxes and counter weights strategically located to eliminate torque created by the addition of the Ku antenna.

D. B. Wolff (610.W)

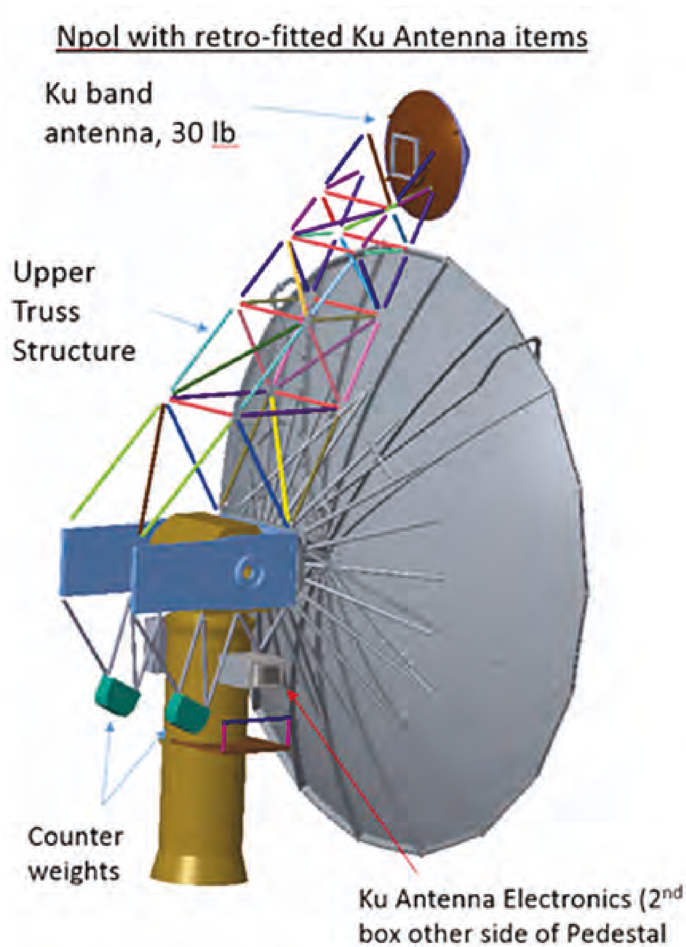


Figure 2.24: Conceptual drawing of a NPOL S-band + Ku dual antenna system. The Ku antenna would be an approximately 1-m antenna co-aligned using a truss attached to the base of the existing 8.5-m NPOL S-band antenna. Electronic boxes and counter weights would be used to eliminate any torque along the elevation axis.

2.4.2. Cryospheric Science

Cryospheric research falls under Goddard Hydrospheric, Biospheric, and Geophysics Sciences (615). Logistical support for IceBridge is provided by 610AT personnel at WFF.

2.4.2.1. Airborne Topographic Mapper deployment in Operation IceBridge

The Airborne Topographic Mapper (ATM) team conducted four NASA IceBridge polar field deployments in 2016 and continued to process and deliver previously collected data to the National Snow and Ice Data Center (NSIDC) for use by climate scientists worldwide.

The ATM team was challenged with a “new” aircraft installation for the 2016 Spring IceBridge campaign, as the “standard” NASA IceBridge aircraft (P3, C130, and DC8) were unavailable. The Operation IceBridge and ATM teams investigated use of a Navy NRL P3 (requiring extensive modifications for remote sensing) and the NOAA “Hurricane Hunter” P3 before deciding on the NOAA P3 “Miss Piggy” aircraft. A substantial amount of planning and engineering was required for this NOAA aircraft installation (special ATM T2 lidar transceiver mods to fit over the only12” square nadir window), which paid off with successful ATM operations for the Spring 2016 deployment.

Figure 2.25: NOAA P3 “Miss Piggy” in Thule, Greenland.

The ATM team installed and tested the ATM instrument suite (ATM T2 lidar data system, IR and visible cameras, and GPS/NAV instruments) on the P3 aircraft in Tampa, Florida, during February and March 2016. The aircraft completed the five-week Spring Arctic deployment starting in April thru May 2016. Sixteen science missions were flown covering 36,282 miles during 141 flight hours, basing from Thule and Kangerlussuaq, Greenland, as well as Fairbanks, Alaska. The ATM team processed and delivered the data to the National Snow and Ice Data Center (NSIDC) on schedule.

After the 2016 Spring Arctic deployment, Goddard’s ATM team coordinated with NASA’s Langley Research Center to engineer, install, test, and fly the ATM T5 transceiver data system, IR-sensor, and GPS/NAV data system on a small NASA Falcon jet, operating at altitudes ranging from 1500 feet to 30,000 feet. Langley’s Falcon aircraft was deployed twice during the summer. The first deployment to Barrow, Alaska, conducted six flights at 1,500 feet to survey summer sea ice conditions in the Arctic Ocean. The second deployment, in August and September, conducted Greenland summer-melt land ice missions at high altitude. The team has been processing the data for on-scheduled delivery to NSIDC.

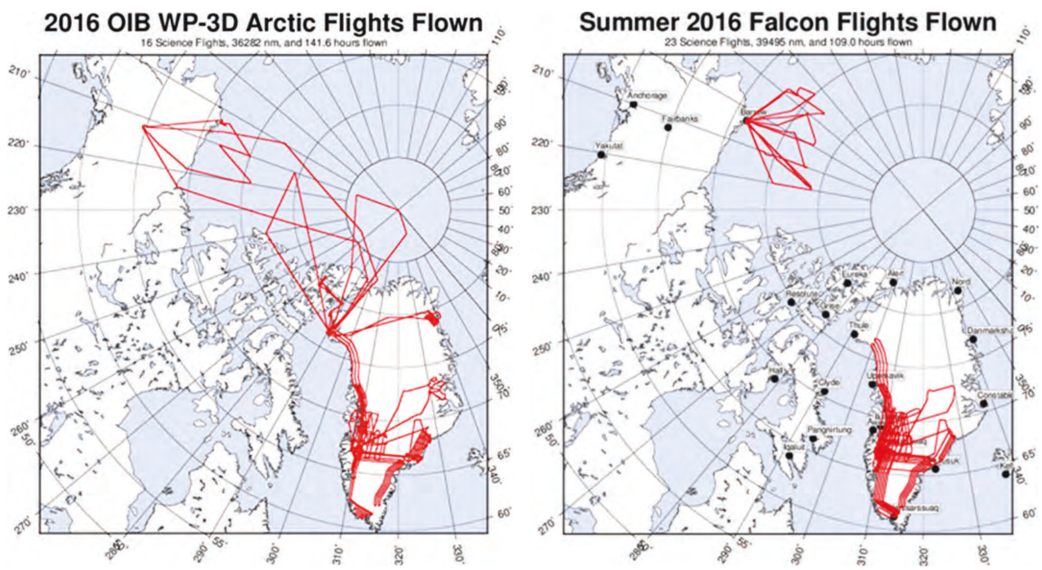


Figure 2.26: Plot of flight tracks for the 2016 spring and summer IceBridge campaigns

The Falcon jet transited from Greenland directly to NASA's Armstrong Flight Research Center in Palmdale, California, to transfer the ATM instrument to the NASA DC_8 aircraft. The ATM instruments were installed and tested on the DC_8 for the Fall 2016 OIB deployment over West Antarctica, based from Punta Arenas, Chile. The Fall IceBridge campaign was successfully completed, covering 113761 miles during 306.9 flight hours and tying the IceBridge record of 24 missions launched from Chile.

J. K. Yungel (610.W)

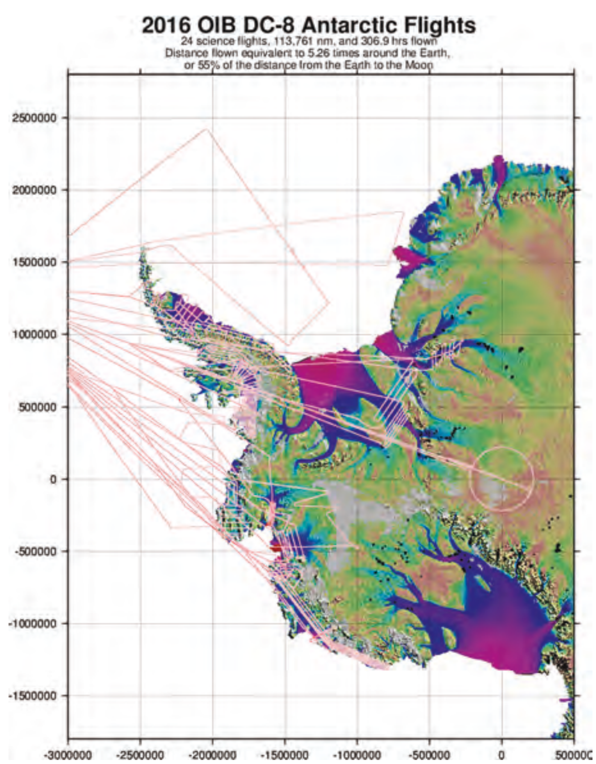


Figure 2.27: DC-8 Antarctic flight tracks from 2016 OIB campaign.

2.4.2.2. ICESat-2 data system

During 2016, the Cryospheric Science group developed, tested and released Versions 3.0 and 3.1 of the software and hardware in support of the ICESat-2 Instrument Support Facility (ISF). The ISF is used by the instrument operations team to monitor, maintain, and operate the Atmospheric Laboratory for Applications and Science (ATLAS) instrument during the ICESat-2 mission.

The ATLAS Science Algorithm Software (ASAS) is a data processing component of the ICESat-2 Science Investigator-led Processing System (SIPS) that will receive ICESat-2 raw data, process into upper-level products, and deliver those products to NSIDC for archiving and distribution. ASAS Version 3 was developed and tested for delivery to SIPS. The software was based on Algorithm Theoretical Basis Documents (ATBDs) provided by the Project Science Office. During the year, both the ISF and SIPS provided ground-readiness testing to validate the system's functionality and ability to support ICESat-2 mission operations. ISF and SIPS also provided support to ATLAS integration and testing with software developed to monitor the performance of ATLAS during this phase.

2.4.3. Ocean Science

2.4.3.1. Ocean ecology

Studies in ocean ecology at WFF focus primarily on understanding the dynamics of phytoplankton populations in the global ocean. Recent efforts have resulted in the development of a novel inverse modeling capability that use either observations of phytoplankton absorption spectra or hyperspectral observations of remote-sensing reflectance to estimate a suite of 18 or so different phytoplankton pigments. In addition, some of these pigments are markers for specific phytoplankton functional types. Efforts in the past year have focused on using satellite-based measurements of chlorophyll along the U.S. northeastern coastal ocean to model the *in situ* absorption spectra to develop estimated maps of phytoplankton pigments, which were then used to identify regions where specific phytoplankton functional types were prevalent.

T. Moisan (610.W) Contact: D. Wolff, (610.W)

2.4.3.2. Airborne sensors for AirSHRIMP

An airborne instrument, designed to be flown on Unmanned Airborne Vehicles (UAVs), was developed for measuring hyperspectral remote-sensing reflectance spectra (200–800 nm) at sub-nanometer scales. The Airborne Sensors for Hyperspectral Reflectance Imaging of Marine Pigments (AirSHRIMP) is a small, low-cost instrument package that can measure remote-sensing reflectance over the ocean. It was developed to obtain remote-sensing data over coastal areas and is specifically intended for use with hyperspectral inverse models. In addition to science field campaigns, the AirSHRIMP can be further developed to support vicarious calibration and validation activities for NASA ocean color missions. The instrument can also be used to support terrestrial remote-sensing studies. It is completely stand-alone, requiring no instrumentation integration with its carrier platform.

The AirSHRIMP was installed in a NASA contract Cessna 310 aircraft in November 2016 and several successful test flights were flown over the Tampa Bay and southwest Florida. Flights were also carried out during December 2016. Analysis of these observations included mapping the hyperspectral data onto the 3D topographic point clouds generated from the instrument's digital cameras. The resulting hyperspectral observations will be used to help develop ocean color products for hyperspectral missions such as PACE.

J. Moisan (610.W)

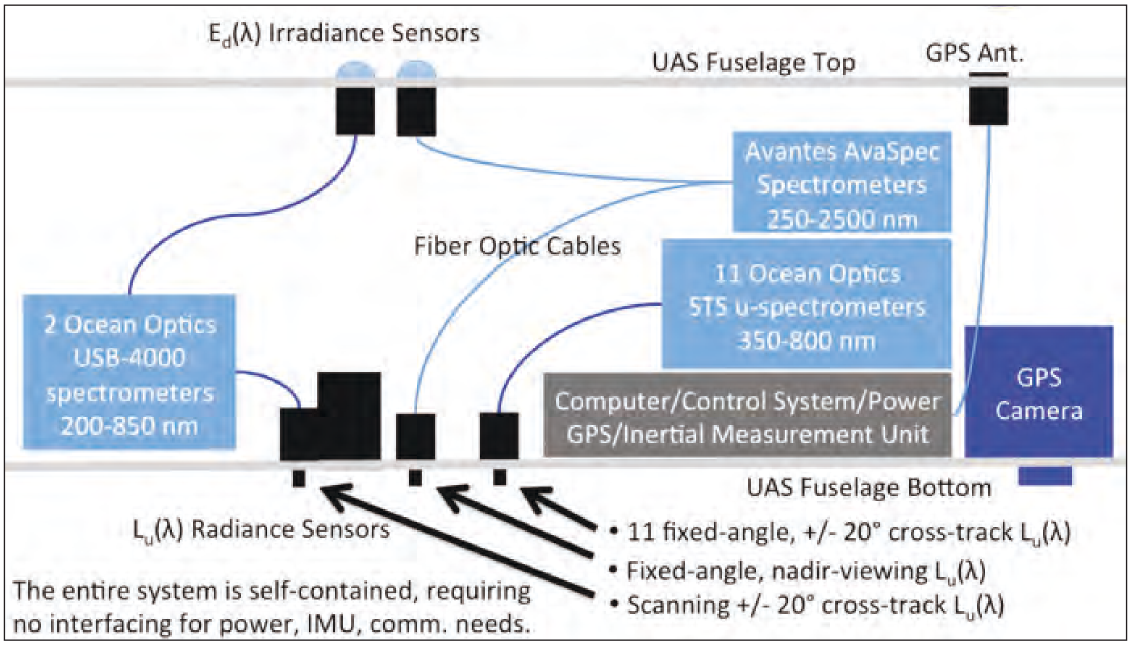


Figure 2.28: Schematic of the AirSHRIMP instrument package noting all of the various sub-elements: 14 radiometers, inertial measurement unit, camera, and power/data system.

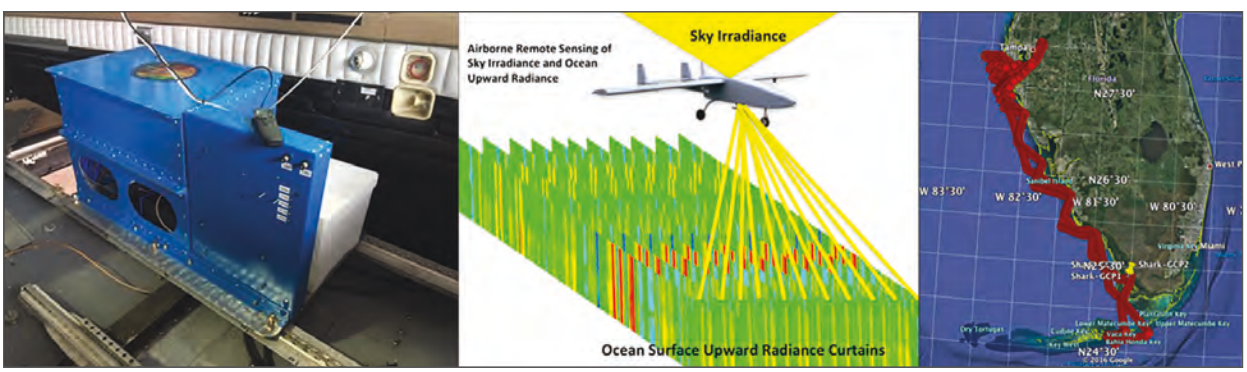


Figure 2.29: A photograph (left) of the AirSHRIMP instrument installed in a Cessna 310 aircraft for test flights, an illustration of the AirSHRIMP measurement configuration (center), and portion of the flight lines carried out in December, 2016 (right).

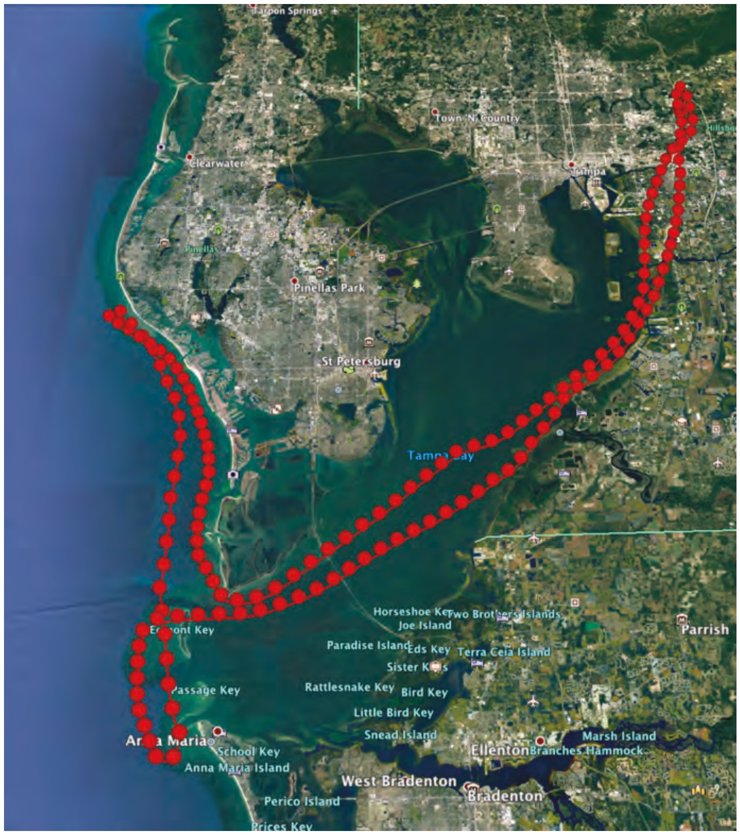


Figure 2.30: A map of check flight on November, 29, 2016; the mission overflew a variety of water types.

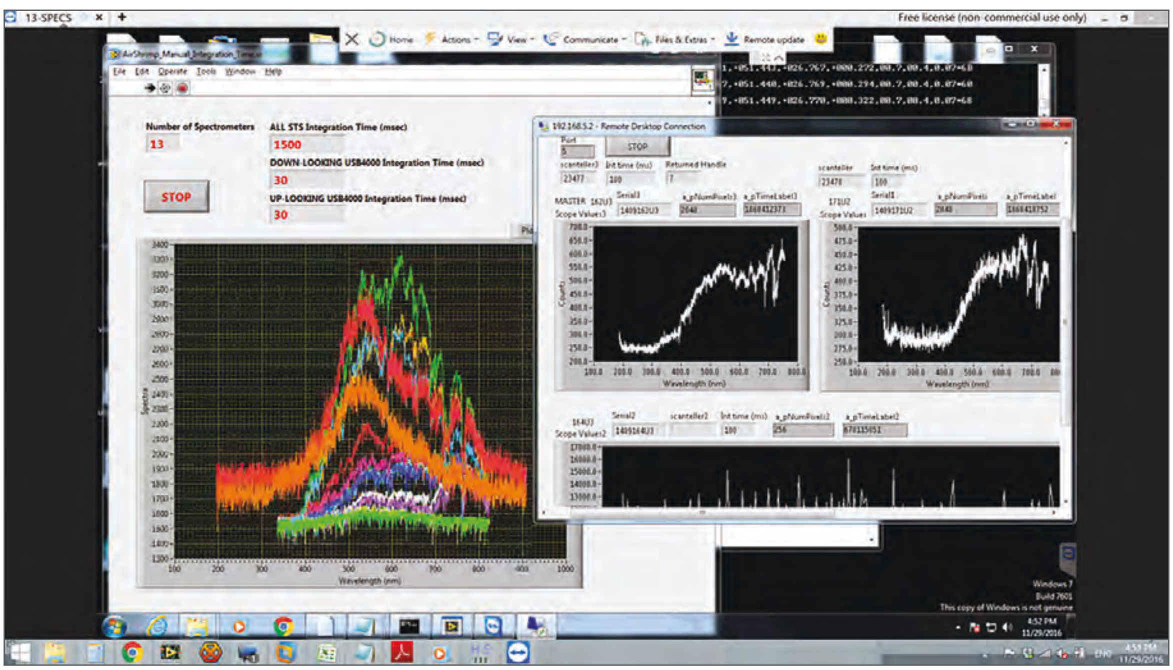


Figure 2.31: An image of the instrument screen during the checkout flight. Each colored spectrum corresponds to data collected from a different spectrometer.

2.4.3.3. Genetic programming for ocean microbial ecology and biodiversity

In 2012, NASA Headquarters and The Gordon and Betty Moore Foundation jointly funded a project to develop a method of using genetic programming to model the microbial diversity of the ocean. This three-year project was intended to create an artificial intelligence capability to evolve systems of coupled differential equations. Code development and testing has been completed. The genetic programming code's capability was verified using "twin experiments" that used output variables from several coupled ecosystem models in order to retrieve the full set of model equations and parameters required to generate the simulated observations

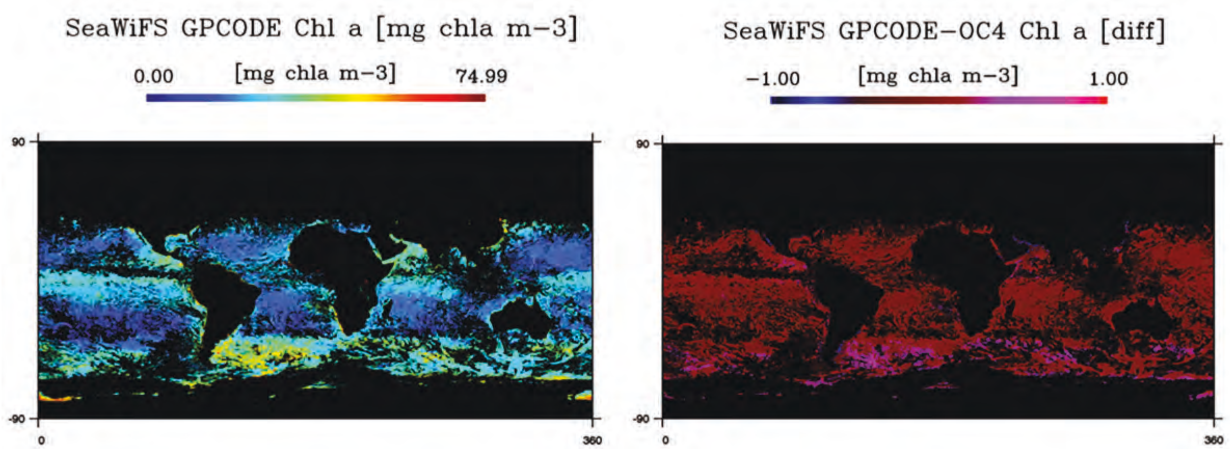


Figure 2.32: .An image of the chlorophyll a field generated by applying the GPCODE algorithm to a 7-day-averaged SeaWiFS dataset.

An additional experiment was performed that generated a new chlorophyll *a* algorithm for the SeaWiFS satellite data set. This genetic programming code can be used to develop satellite algorithms for other NASA Earth Science data sets.

J. Moisan (610.W)

2.4.4. Air-Sea Interaction Science

2.4.4.1. Relocated NASA Air-Sea Interaction Research Facility

NASA's Air-Sea Interaction Research Facility relocated to the University of Washington's Applied Physics Laboratory (UW/APL) in Seattle. The move to the Applied Physics Laboratory has been completed and installation of the NASA systems is underway. Several modifications were necessary due to the configuration of available space.

In prior years, research teams of UW/APL faculty and students have attended two, 6-week campaigns at the former Wallops location to study flux exchange dynamics, looking at the exchange of heat and gases across the air-sea interface. The new Seattle location will be used for both teaching and research purposes. It will provide a unique controlled environment for future studies into the complex interactions occurring between the atmosphere and oceans. The facility conducted its first water-fill and demonstration at UW/APL in April 2016, in conjunction with a site visit by Eric Lindstrom rom NASA Headquarters.

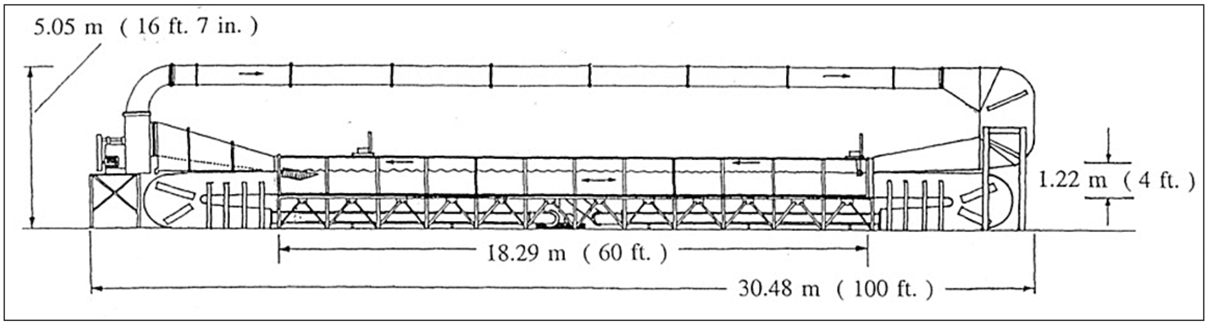


Figure 2.33: The wave tank at the Wallops Air-Sea Interaction Research Facility prior to dismantling.

2.4.4.2. New analysis approach based on the study of air-sea interactions

A new approach to time series analysis was developed to study the nonlinear and non-steady nature of water waves under the action of wind and water currents. The initial results of this work first appeared in 1998 in the *Proceedings of the Royal Society of London, Series A*, which has since received more than 13,850 citations and generated several NASA patents. More recently, the approach was refined and capabilities extended, including the development of applications beyond water waves to the study of heartbeat irregularities, brain waves during seizures, earthquakes, bridge safety, speech analysis, gunshot noise studies, vibration studies in machinery, and spacecraft, just to name a few. As successful as those results were, only the linear additive processes within the nonlinear, non-steady data had been addressed.

Subsequent work has been devoted to nonlinear and non-steady analysis. By focusing on both the linear additive and nonlinear multiplicative processes, such analysis has produced a complete result that accounts for both amplitude and frequency modulations simultaneously, expressed in a multi-dimensional spectrum. These results have now appeared in a 2016 publication, a special issue of *Philosophical Transactions of the Royal Society A*, available at: http://dx.doi.org/10.1098/rsta.2015.0206. This complete approach is expected to produce more results than the initial 1998 introductory methods.

S. Long (610.W)

2.4.5. Unmanned/Remotely Operated Vehicles

2.4.5.1. The AEROKATS and ROVER Education Network

The AEROKATS and ROVER Education Network (AREN) project got underway as part of the Science Mission Directorate Science Education Cooperative Agreement Collective (PI: David Bydlowski/Wayne County Regional Educational Service), with co-investigators and participants from multiple institutions across the United States, including Geoff Bland (610.W). This novel technology and approach has been developed with internal GSFC support, including the Ignition Fund and IRAD projects.

Advanced Earth Research Observation Kites with Atmospheric and Terrestrial Sensors (AEROKATS) system has brought an affordable and easy-to-field aerial perspective for introducing remote-sensing and *in situ* measurement concepts for local-scale Earth observations and data gathering. By using commercial kites and miniature sensor systems, AEROKATS offers a new and engaging method for gathering airborne remote-sensing and *in situ* data for classroom analysis.

Remotely Operated Vehicles for Education and Research (ROVER) has introduced team building for mission operations and research using modern technologies for exploring aquatic environments. ROVER projects combine remote control and electric propulsion hardware with affordable in-water instrumentation to help students explore interests and develop numerous skills needed for "real-world" research missions.

Figure 2.34: Students preparing to launch kites and readying sensors.

2.4.5.2. Unmanned and manned aircraft development activities.

Geoff Bland (610.W) is a co-investigator on an unmanned-aircraft campaign planned for 2017. Dragon Eye (a small unmanned aircraft) will integrate sensor packages developed by 610.W for sulfur dioxide measurements in preparation for a Hawaii deployment for calibration and validation of ASTER and planned HyspIRI support. The unmanned aircraft will be operated by NASA's Ames Research Center with PI David Pieri of JPL.

Figure 2.35: Dragon Eye aircraft

A few accomplishments are particularly noteworthy within the NASA Small Business Innovation Research (SBIR) program. The Blackswift Technologies, LLC, effort to fly a miniature L-band radiometer for high-resolution soil moisture readings was highly successful, demonstrating its capability for research and commercial applications. Blackswift Technologies also supported the Multi AngLe Imaging Bidirectional Reflectance Distribution Function small UAS (MALIBU) (Román, et al.) with flying multiple spectral imagers aboard unmanned aircraft similar to those being developed under the SBIR project. Both of these flight series required extensive coordination with the Wallops Aircraft Office via Code 610.W.

Code 610.W also provided hardware, operations, and data support for three cameras as part of the GSFC CARbon Airborne Flux Experiment (CARAFE) (Kawa, et al.) summer campaign, including high-resolution color, thermal-infrared, and multispectral imagery. Additionally, a Code 610.W multispectral camera was flown on the Vanilla Aircraft (VA001) prototype for a record breaking 56-hour mission. The Wallops Remote Sensing Team (Yungel, et al) provided critical support to enable these missions.

G. Bland (610.W)

Figure 2.36: (Right) NASA C-23 Sherpa aircraft used in the CARAFE campaign. (Left) Vanilla (VA001) aircraft.

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 defining 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 and their role in climate and global change, especially with regards to characterizing and understanding the physical 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 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 submillimeter spectral regions are also included in the mission concept.

A comprehensive report on ACE's progress over the past five years was released in 2016 and it is available from https://acemission.gsfc.nasa.gov/resources.html . This report constitutes a substantial update from an early 2011 report and has been provided as input to 2017 NRC *Decadal Survey for Earth Sciences*. Among the topics covered in this report are updates to mission science objectives and science traceability matrices, technological assessment of instrument concepts, status of algorithm development as well as an overview of the several field campaigns that ACE has sponsored. In 2016 the ACE Science Study Team contributed nine white papers to recent Requests for Information by the 2017 Decadal Survey Panel (see https://acemission.gsfc.nasa.gov/whitepapers.html.) Currently, there are three active ACE working groups (Clouds, Polarimeters, and Lidars) holding monthly teleconferences and with active discussion lists. The Multi-Angle Imager for Aerosols (MAIA) instrument was recently selected by the EVI-3 Program. MAIA leverages MSPI developments funded by ESTO and ACE. Likewise, recently selected EVS investigations (NAAMES and ORACLES) are consistent with a subset of ACE concepts and science objectives.

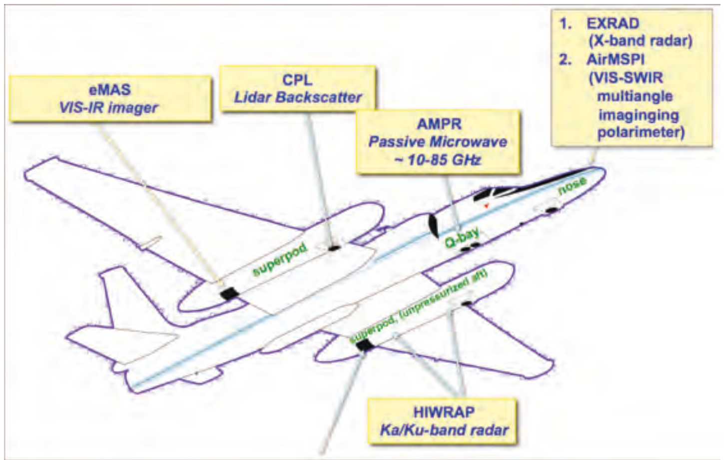


Figure 3.1: ER-2 Payload for RADEX-15

In collaboration with the Global Precipitation Mission (GPM) Ground Validation program, ACE augmented GPM's OLYMPEX field campaign to demonstrate the capability of ACE-like multi-sensor cloud retrievals for precipitating shallow and deep cloud systems. ACE's contribution to OLYMPEX, the Radar Definition Experiment (RADEX-15), took place in Seattle during November–December 2015. Data analysis is currently in progress with the goal of defining ACE's Radar characteristics to meet L1 requirements, and to provide basis for development of integrated multi-sensor algorithms. ACE has also sponsored the deployment of the AMPR microwave radiometer in the ORACLES 2016 deployment as to provide a payload suitable for development of ACE cloud algorithms.

Significant progress was made in advancing the technical readiness of the instrument concepts in 2015 and 2016 with strong activity in algorithm development, including multi-sensor data fusion (e.g., clouds and aerosols.) The (High Spectral Resolution Radar (HSRL) lidar is at Technology Readiness Level (TRL) 5 with interferometric receiver subsystem, pulse-laser transmitter, and seed laser expect to reach TRL 6 in 2016. All the polarimeter concepts (Multi-angle SpectroPolarimeter Imager (MSPI), Hyper-Angular Rainbow Polarimeter (HARP), and Aerosol Polarimetry Sensor (APS)) are expected to achieve TRL 6 in 2017. All three radar concepts (JPL's Multi-Parameter Atmospheric Profiling Radar for ACE (ACERAD) and Cloud Profiling Radiometer (CPR) and GSFC's ACE Radar) are expected to reach TRL 5 in 2017.

For further information, please contact the ACE Science Study Lead, Arlindo da Silva (arlindo.dasilva@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, 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 respiration processes, and provide useful new constraints for global carbon cycle models. NASA currently plans for launch in the FY 2023 timeframe. The ASCENDS mission white paper is available at https://cce.nasa.gov/ascends_2015/.

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 in collaboration with the Laser Remote-sensing Laboratory, which targets instrument and mission development for ASCENDS. The laboratory plays a key role in radiative transfer modeling, retrieval algorithm development, instrument field deployment, and data analysis 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, with the goal of measuring atmospheric pollution (aerosols and trace gases) and coastal water from a geostationary platform. Scientists in Codes 613 and 614 have been involved in GEO-CAPE atmospheric studies for several years, including defining science objectives, measurement requirements, retrieval accuracy, retrieval sensitivity, etc. In FY 2016, Goddard scientists involved in GEO-CAPE's Aerosol Working Group have focused on the following tasks: (1) using the data from UV to IR from the Global Imager (GLI) sensor on the ADEOS satellite as a testbed for TEMPO+GOES-R synergistic retrieval products and information contents, (2) testing the aerosol retrieval algorithm with the GEOS-5 Nature Run (in collaboration with the GEO-CAPE global OSSE team), (3) exploring the value of high spatial resolution measurements from the GEO-CAPE ocean color instrument for aerosol observability for megacity air quality study, and (4) generating spectral BRDF climatology with the MODIS MAIAC products for aerosol and gas retrievals. The outcome was reported to the GEO-CAPE leadership and NASA HQ. The Aerosol Working Group continues in FY 2017.

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 zero 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 test bed 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, demonstrated 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 (HS_3) 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
Mian Chin	GEO-Cape
Randy Kawa	ASCENDS
Bruce Gentry	Global 3D-Winds
Arlindo da Silva (GMAO)	ACE

3.1.2. NASA's Planned Missions

3.1.2.1 JPSS

The Joint Polar Satellite System (JPSS) is the Nation's next generation polar-orbiting operational environmental satellite system. JPSS is a collaborative program between NOAA and its acquisition agent, NASA. JPSS was established in the President's FY 2011 budget request (February 2010) as the civilian successor to the restructured National Polar-orbiting Operational Environmental Satellite System (NPOESS). As the backbone of the global observing system, JPSS polar satellites circle the Earth from pole-to-pole and cross the equator about 14 times daily in the afternoon orbit—providing full global coverage twice a day.

JPSS represents significant technological and scientific advances in environmental monitoring and will help advance weather, climate, environmental, and oceanographic science. JPSS will provide operational continuity of satellite-based observations and products for NOAA Polar-orbiting Operational Environmental Satellites (POES) and the Suomi National Polar-orbiting Partnership (Suomi NPP) mission. NOAA is responsible for managing and operating the JPSS program, while NASA is responsible for developing and building the JPSS spacecraft.

In 2016, the JPSS program continued its mission to support 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 launch on September 23, 2017, and in July of 2021. The J1 mission will be very similar to Suomi NPP, using the same spacecraft and instrument complement. The four of the five instruments had been integrated on J1 observatory by the end of 2016. J1 observatory environmental testing should be complete in the early summer of 2017. The JPSS-2 spacecraft was selected in 2015. The Polar Follow-on Program, JPSS-3 and JPSS-4 was approved in 2015, launching in 2026 and 2031, respectively. The JPSS-2, JPSS-3, and JPSS-4 missions will have the same spacecraft and similar instruments to Suomi NPP, VIIRS, CrIS, ATMS, and OMPS. The Cloud and Earth Radiant Energy System (CERES) instrument, on SNPP and J1, will be replaced with a successor NASA instrument, the Radiation Budget Instrument (RBI).

For further information, please contact James Gleason (james.gleason@nasa.gov).

3.1.2.2 Earth-IceCube

NASA's Science Mission Directorate (SMD) has chosen a team at Goddard Space Flight Center to build its first Earth science-related CubeSat mission (http://www.nasa.gov/cubesat/). The IceCube team is led by Dong Wu who serves as the mission Principal Investigator, with a Greenbelt team responsible for payload development and a Wallops team for CubeSat and ground system development. The 1.3-kg payload in 1.2 U CubeSat units (1 U=10x10x10 cm3) will demonstrate and validate a new 883-gigahertz submillimeter-wave receiver to advance cloud-ice remote sensing and help scientists to better understand the role of ice clouds in the Earth's climate system. Global distribution and microphysical properties of ice clouds remain highly uncertain, which is one of the leading error sources in determining Earth's radiation budget and precipitation processes. IceCube is manifested on ELaNa-17 in rideshare with Cygnus payload (OA-7 mission) to the International Space Station (ISS) and subsequent release from ISS. The planned delivery date to NanoRacks is December 15, 2016. The launch is scheduled for March, 9, 2017, from Cape Canaveral on Atlas-5. Its nominal mission lifetime is 28 days with an estimated orbit lifetime of 2.3 years. IceCube will use the NASA's UHF station at Wallops Island to up-/down-link its mission data.

For further information please contact Dong Wu (dong.l.wu@nasa.gov).

3.1.2.3 TROPICS

The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission was selected as part of the Earth Venture Instruments–3 solicitation. TROPICS is led by William Blackwell of MIT/Lincoln Laboratory. Scott Braun (GSFC/612) is the project scientist. TROPICS will provide rapid-refresh (21-minute median refresh rate) microwave measurements over the Tropics to observe the thermodynamic environment and precipitation structure of tropical cyclones over much of their lifecycle. TROPICS comprises 12 CubeSats in three ~600-km altitude, 30°-inclination orbital planes for up to 1 year. TROPICS funds will cover the project scientist, data assimilation work in the Global Modeling and Assimilation Office, research on moisture impacts on the structure and intensity of storms, ground stations, and a Mission Planning Center at Wallops Flight Facility.

For further information please contact Scott Braun (scott.a.braun@nasa.gov).

3.1.3. NASA's Active Flight Missions

3.1.3.1 Aqua

Aqua is one of NASA's flagship missions for Earth Science operating in the A-Train constellation. It launched on May 4, 2002, and since that time has provided a wealth of information about the Earth system, generated from the 88 Gbytes/day of Earth science data being transmitted by Aqua's Earth observing instruments. Aqua observations span almost all fields of Earth science, from trace gases, aerosols and clouds in the atmosphere, to chlorophyll in the oceans, to fires on land, to the global ice cover, and numerous other geophysical variables.

Thousands of scientists and operational users from around the world are making use of the Aqua data to address NASA's six interdisciplinary Earth science focus areas: atmospheric composition, weather, carbon cycle and ecosystems, water and energy cycle, climate variability and change, and earth surface and interior. Since the 2013 Senior Review, there have been important scientific results obtained through the use of data from Aqua instruments. Among these are the followings: quantification of seasonal draw-down of atmospheric CO_2 into the boreal forests, from AIRS CO_2 and MODIS gross primary productivity data; quantification of the increase in moisture flux to the atmosphere in response to the decrease in Arctic sea ice coverage, from AMSR-E and AIRS data; examination of the structure of the marine boundary layer in the northeast Pacific, from AIRS and MODIS data; and assessment of the impact of aerosol layers on southeast Atlantic stratocumulus cloud microphysics, from a combination of CERES, MODIS, and AMSR-E data, along with data from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). The Aqua spacecraft is still going strong after 13 years, and four of its instruments (AIRS, AMSU, CERES, and MODIS) continue to collect valuable data about the atmosphere, oceans, land, and ice. The panel ranked this mission as the first among those missions reviewed. Based upon Aqua's high quality climate data records, the continuity of this time series is critical for the scientific community, governmental agencies, and the international operational user community. Therefore, the panel found that Aqua mission should be continued as currently baselined.

For further information, please contact Lazaros Oreopoulos (lazaros.oreopoulos@nasa.gov).

3.1.3.2 Aura

On July 15, 2004, The Aura spacecraft was launched with 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 aerosols, clouds, and ozone and constituents related to ozone in the strato-sphere and troposphere. With these measurements the science team has addressed questions concerning the ozone hole and stratosphere's protective ozone layer (OMI, MLS), and tropospheric composition and air pollution (OMI, TES). Twelve years have passed since launch, and two of the instruments continue to make daily measurements. HIRDLS suffered an anomaly in 2008 and is no longer operational. The pres-ent TES observing strategy is designed to make good use of the limited remaining life of the instrument, focusing on air pollution in "megacities," i.e., large densely populated metropolitan areas such as Mexico City, Mexico, and Lagos, Nigeria.

Recent retrieval algorithm development substantially improved several data products. They were used in 2016 to identify significant errors in the inventories of trace gas emissions. Nitrogen oxides (NOx = NO + NO_2), precursors to formation of unhealthy levels of "nose-level" ozone, are regulated by air quality agencies. Researchers combined NASA OMI NO_2 data, NASA SEAC4RS field campaign data, and an atmospheric model to show that industrial and mobile source NOx emissions in the U.S. EPA National Emission Inventory (NEI) are likely 30 to 60 percent too high. This finding has broad implications for identifying the most effective strategies to improve air quality, and also has significant economic implica-tions because additional emissions reductions are more expensive than the early reductions. OMI NO_2 data were used by President Obama to show in a video (https://airquality.gsfc.nasa.gov/video/president-obama-pollution) that the Clean Air Act is working. In addition, OMI has detected 40 SO_2 sources missing from leading emissions inventories (12 percent of the global total). Many of the missing sources are located in the Middle East and related to the oil and natural gas sector.

In 2016, Aura data revealed new and unexpected changes of Earth's atmospheric composition, while continuing to build a multiyear, global dataset. The Quasi-Biennial Oscillation (QBO) is a pattern of alternating easterly and westerly zonal wind regimes that descend through the tropical middle and lower stratosphere with a variable period averaging 28 months and is an important driver of composition variations in the tropics and middle latitudes. A disruption in the normal pattern of descending winds that began late in 2015 has continued through 2016 and is unique in the 63-year QBO record. Aura Microwave Limb Sounder (MLS) measurements (O_3, HCl, N_2O, and H_2O) and the Ozone Mapping and Profiler Suite Limb Profiler (O_3) have revealed the impact of this disruption on lower stratospheric composition. By August 2016, lower stratospheric O_3 and total column O_3 measured by Solar Backscatter Ultraviolet (SBUV) showed that the lingering disruption led to unusually high tropical O_3 and near-record low midlatitude O_3 in both hemispheres along with an increase in the surface UV index during the peak of northern summer. Such variability must be accounted for to identify the expected increase in ozone due to chlorofluorcarbon decrease or the decrease in tropical stratospheric ozone that is expected due to climate change.

More information on Aura science highlights can be found at http://aura.gsfc.nasa.gov/ or contact Aura's Project Scientist, Anne Douglass (anne.r.douglass@nasa.gov).

3.1.3.3 DSCOVR

Deep Space Climate Observatory (DSCOVR) is a NOAA Earth observation and space weather satellite launched by SpaceX on February 11, 2015, from Cape Canaveral. The mission is a partnership between NOAA, NASA and the U.S. Air Force. NOAA operates the DSCOVR mission, giving advanced warning of approaching solar storms with the potential to cripple electrical grids, communications, GPS navigation, air travel, satellite operations and human spaceflight.

DSCOVR is positioned at the Sun-Earth first Lagrangian point (L1), about 1,500,000 km from Earth with the primary goal of monitoring variable solar wind condition and providing early warning of approaching coronal mass ejections. The satellite orbits the L1 point in a six-month Lissajous orbit, with a spacecraft-Earth-Sun angle varying from 4 to 12 degrees. While the primary science objectives of DSCOVR are to make unique space weather measurements, the secondary goal of DSCOVR is to provide Earth measurements.

There are two NASA Earth Science Instruments on board the DSCOVR satellite: the Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR). The description of these instruments is available at http://avdc.gsfc.nasa.gov/pub/DSCOVR/.

EPIC provides spatially resolved radiances from the sunlit face of the Earth on a 2048 x 2048 pixel CCD in 10 narrowband channels between UV (317 nm), and near-IR (780 nm) with a nadir sampling field of view of approximately 8 km. The time cadence of these spectral band images is provided on a best effort basis given existing ground system and network capabilities and is no faster than 10 spectral-band images approximately every hour (from mid-April to mid-October) or every two hours (rest of the year). The DSCOVR project provides raw instrument data, EPIC Level-1 images in CCD counts that are geolocated and both dark-current and stray-light corrected. Calibration conversions into reflectance are given based on the most recent in-flight calibration data. The true-color (RGB) images are generated daily and are available at http://epic.gsfc.nasa.gov. As an example, Fig. 1 provides two images: the famous Apollo 17 "blue marble" image and the EPIC image taken on the same day 44 years apart.

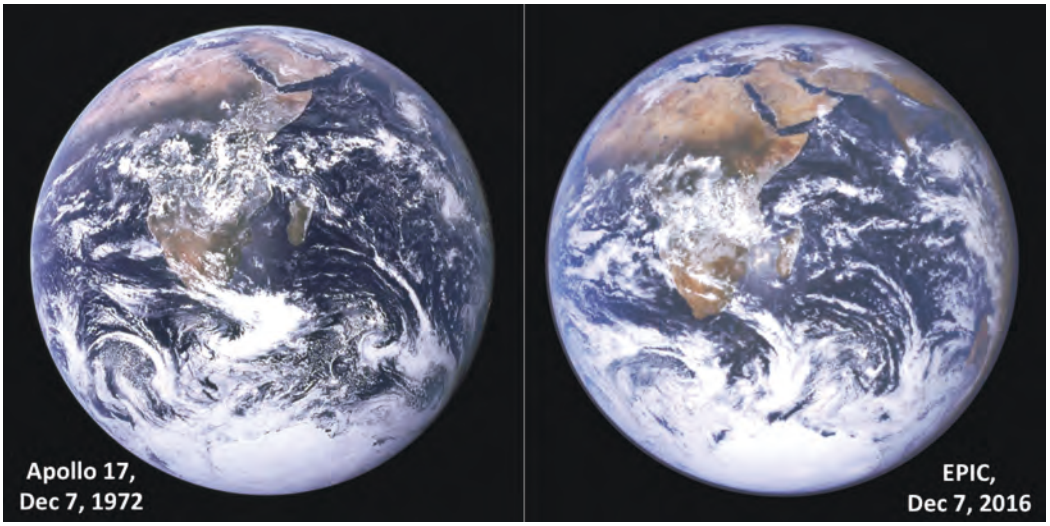


Figure 3.2: Apollo 17 ("blue marble") and DSCOVR EPIC images acquired on December 7, 1972 and 2016, 44 years apart. NISTAR measures the absolute "irradiance" as a single pixel integrated over the entire sunlit face of the Earth in four broadband channels: (i) visible to far IR (0.2 to 100 mm); (ii) solar (0.2 to 4 mm); (iii) near-IR (0.7 to 4 mm); and (iv) photodiode (0.3 to 1 mm) used for calibration. The Level-1 EPIC and NISTAR products are available from the NASA Langley Atmospheric Science Data Center (ASDC).

The Earth Science instruments onboard DSCOVR provide sunrise to sunset observations of global ozone levels, amount and distribution of aerosols, dust and volcanic ash, cloud height over land and ocean, spectral surface reflectance and vegetation cover; the instruments will monitor changes in climate including Earth radiation budget. The first release of Level 2 data product is expected early 2017. DSCOVR activities are now concentrated on deriving an accurate in-flight calibration to use in production algorithms to produce the listed above science products. Preliminary examples of such products (ozone, UV reflectivity, clouds, atmospherically corrected surface reflectance, and aerosols) are shown in Figures 3.4, 3.5, 3.6, and 3.7

For further information, please contact Alexander Marshak, (alexander.marshak-1@nasa.gov).

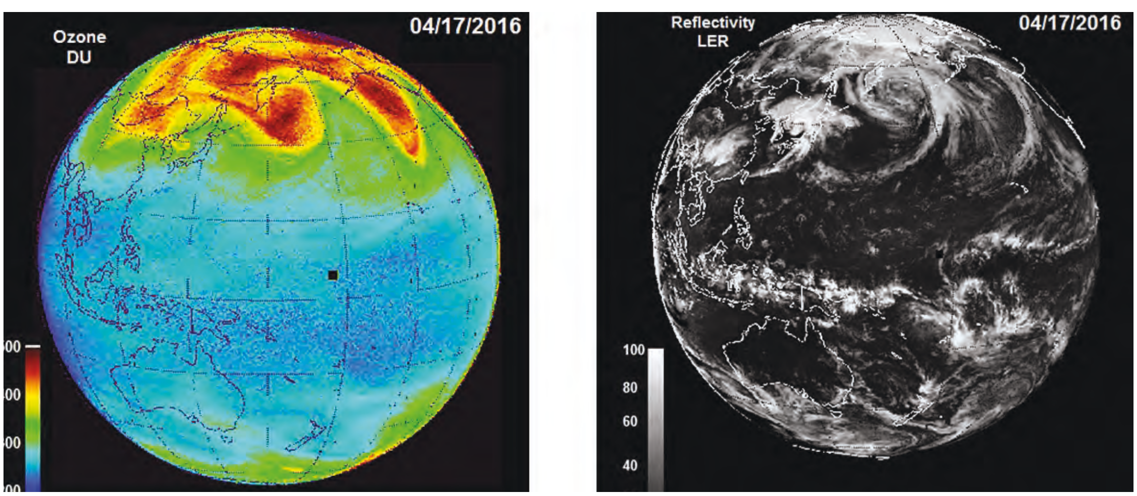


Figure 3.3: The ozone (left) and scene reflectivity (right) products obtained at 00:34 GMT on 17 April 2016. Local time varies across the image with sunrise on the left (west) and sunset on the right (east). The reflectivity gives the cloud transmission of UV radiation permitting a calculation of the amount of UV radiation reaching the ground when combined with ozone absorption. Notice the large ozone plumes flowing from the Arctic to lower latitudes. (Courtesy of Jay Herman.)

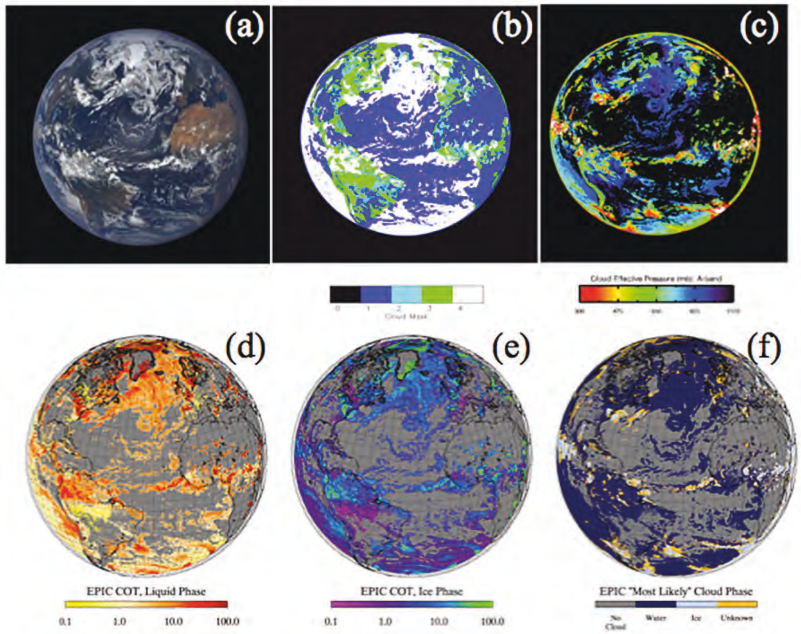


Figure 3.4: Sample EPIC cloud products for the observations at 14:57 GMT on June 23, 2016: (a) EPIC RGB image. (b) EPIC cloud mask 1: High-confidence clear, 2: Low-confidence clear, 3: Low-confidence cloudy, and 4: High-confidence cloudy. (c) O_2 A-band cloud effective pressure. (d) Cloud optical thickness assuming liquid phase. (e) Cloud optical thickness assuming ice phase. (f) Most likely cloud phase. (Courtesy of Yuekui Yang)

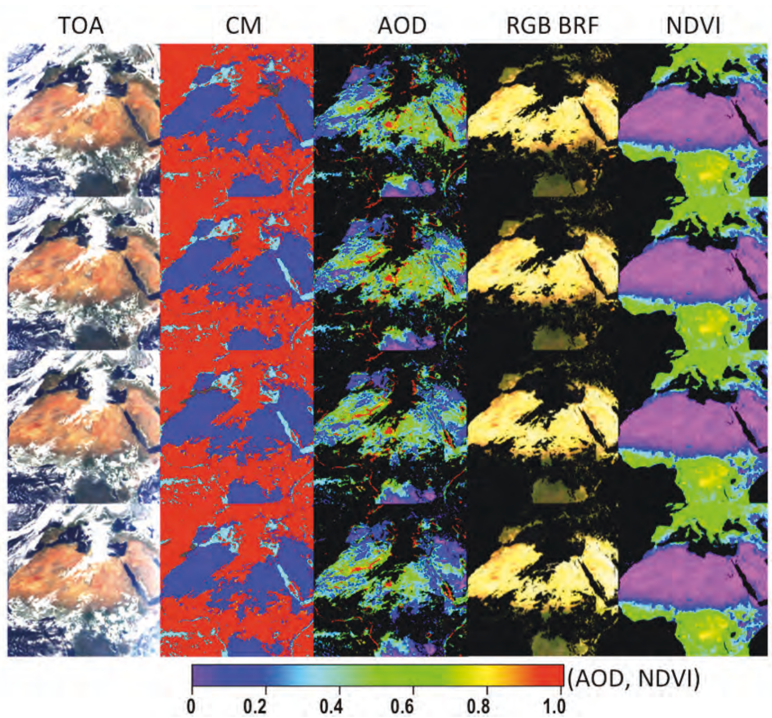


Figure 3.5: Atmospheric correction for four consecutive EPIC observations (in rows) from 9:48 to 13:03 UTC on DOY 141, 2016. Shown are: top-of atmosphere RGB EPIC reflectance, cloud mask (CM), aerosol optical depth (AOD) at 443 nm, atmospherically corrected RGB surface reflectance (BRF), and composite normalized difference vegetation index (NDVI). Color scale for RGB BRF was reduced to emphasize accuracy of atmospheric correction over dark vegetation. (Courtesy of Alexei Lyapustin)

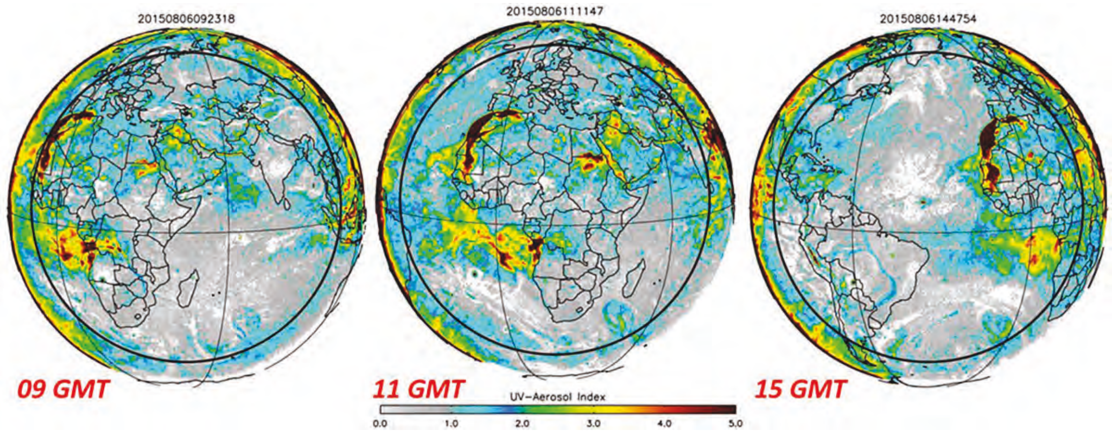


Figure 3.6: Spatial distribution of Saharan dust and biomass burning aerosols in terms of EPIC UV Aerosol Index (UVAI) on August 6, 2015. The UVAI is calculated from EPIC observations at 340 nm and 388 nm. UVAI values beyond the 60° satellite zenith angle (black circle) are less reliable. (Courtesy of Omar Torres)

3.1.3.4 GOES

NOAA's Geostationary Operational Environmental Satellites (GOES) are built, launched, and initialized by Goddard's GOES Flight Project Office under an interagency program hosted at Goddard (http://www.goes-r.gov/)The GOES series of satellites carry sensors that continuously monitor the Earth's atmosphere for developing planetary weather events, the magnetosphere for space weather events, and the Sun for energetic outbursts. The flight project scientist at Goddard assures the scientific integrity of the GOES sensors throughout the mission definition, design, development, testing, and post-launch data analysis phases of each decade-long satellite series. During 2016, five new and improved instruments were integrated and tested on GOES-R, and successfully launched in November 2016. The flight project scientist also operates a GOES ground station that offers real-time, full-resolution, calibrated GOES images to support scientific field experiments and to supply Internet users with high-quality data during severe weather events. 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 August 2016, the site served 2.5 terabytes to 261 thousand guests from around the world at the average rate of three requests-per-second.

For further information, please contact Dennis Chesters (dennis.f.chesters@nasa.gov).

3.1.3.5 GPM

The Global Precipitation Measurement (GPM) is an international satellite mission that provides next-generation observations of rain and snow, worldwide. NASA and the Japan Aerospace Exploration Agency (JAXA) launched the GPM Core Observatory satellite on February 27, 2014, carrying advanced instruments that set a new standard for precipitation measurements from space. Its data is used to unify precipitation measurements made by an international network of satellites provided by partners from the European Community, France, India, Japan, and the United States and 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- and at-launch precipitation retrieval algorithm development, GPM has been conducting a series of field campaigns with international and domestic partners in the past five years. From November 2015 to January 2016, GPM and the University of Washington in Seattle conducted the Olympic Mountain

Experiment (OLYMPEX) field campaign. During the campaign, NASA and its partners gathered precipitation data through both ground and airborne instruments around the Olympic Peninsula in Washington State. They measured the abundance and variety of precipitation including light rain, heavy thunderstorms, and snowfall in the coastal forest. More than 115 inches of rain fell during the field campaign. The data collected provides crucial information to improve the GPM mission's measurements of light rain and snow, as well as help researchers understand how precipitation changes across land and ocean.

Significant milestones and activities were met in 2016 including:

- GPM's Version 04 products were reprocessed by the Precipitation Processing System (PPS) in Spring 2016
- GPM's precipitation retrieval algorithms were updated for Version 05 which is expected to be released Spring 2017.
- The GPM team is recalibrating TRMM merged products back to the start of TRMM with expected reprocessing to start in the second half of 2017.
- GPM/PPS has released GIS, ASCII, and other "easy-to-read" product datasets.
- The GMI radiometer was deemed the best conically-scanning precipitation-sensing radiometer in space (Wentz and Draper, "On-Orbit Absolute Calibration of the Global Precipitation Mission Microwave Imager," *J. Atmos. Oceanic Tech.*, 2016).
- GPM held an extremely successful field campaign called OLYMPEX during the winter of 2016–2017 (https://pmm.nasa.gov/OLYMPEX).
- GPM direct ground validation is being used to evaluation the performance of the GPM retrieval products. As part of these validation activities, GPM's Level 1 Mission Science Requirements (for the End of Prime review) are completed and met, with documentation drafted for the 2017 Senior Review and End of Prime Review.
- GPM released two new data visualization tools: (1) the Global Viewer for viewing near real-time IMERG data that allows views of the latest near–real-time GPM IMERG global precipitation datasets (30 minute, 1 day, 7 day) on an interactive 3D globe in a web browser, and (2) the Precipitation and Applications Viewer [that allows users to view and download precipitation and applications datasets from the past 60 days (30-minute, 1-day, 3-day, and 7-day precipitation, flood nowcasts, landslide nowcasts). These datasets can be downloaded in various popular formats (TIF, SHP, arcJSON, geoJSON, topoJSON) and users can learn how to directly access the data via the PMM publisher. (https://pmm.nasa.gov/data-access/visualization).
- In October 2016, the science team met in Houston, Texas, to review algorithm development and plan future activities, including a retrieval algorithm product reprocessing to occur in 2017.
- A vigorous outreach and education effort included numerous video and online features, website updates for all big weather events, presentations to educators and students, and more.

For further information, please contact Gail Skofronick Jackson (gail.s.jackson@nasa.gov) or visit the GPM home page at http://gpm.nasa.gov.

3.1.3.6 GPM/ICE-POP

In August 2106, Walt Petersen (MSFC) and Gail Skofronick-Jackson (612) hosted a meeting at Goddard with Dr. Sangwon Joo (Korean Meteorological Administration (KMA)) and collaborating NASA Weather Program investigators from Goddard and Marshall Space Flight Center (MFSC). This meeting was held to coordinate NASA's GPM and Weather Program contributions to the KMA-led International Collaborative

Experiment–PyeongChang Olympics Paralympics (ICE-POP) field campaign and forecast demonstration project occurring in conjunction with the 2018 Winter Olympic Games to be held in South Korea. In November 2016, an ICE-POP Letter of Agreement (LOA) was concluded between NASA and KMA. The LOA identifies the roles and responsibilities of each agency in preparation for and execution of the campaign. Principles for data collection and data sharing between the agencies are also included in the agreement. Also in November, a workshop was held in Seoul to lay out the scientific objectives and methodologies for the campaign, including plans for the observation network, numerical weather prediction, and nowcasting.

For further information, please contact Gail Skofronick Jackson (gail.s.jackson@nasa.gov).

3.1.3.7 ISS/JEM-EF (CATS)

The Cloud-Aerosol Transport System (CATS) is a laser remote-sensing instrument designed to provide vertical profiles of clouds and aerosols (tiny airborne particles) while also demonstrating new space-based technologies for future Earth Science missions. On January 22, 2015, flight controllers successfully installed CATS aboard the on the Japanese Experiment Module–Exposed Facility (JEM-EF) of the International Space Station (ISS) through a robotic handoff—the first time one robotic arm on-station has worked in concert with a second robotic arm. CATS began operations on the ISS two weeks later (early February 2015) and has been operating near-continuously ever since, well beyond its 6-month designed lifetime. The ISS orbit provides comprehensive coverage of the tropics and mid-latitudes, where primary aerosol transport tracks and clouds from mid-latitude storm tracks and tropical convection are located.

During the nearly two years of operation, CATS has provided several benefits to society and the science community. CATS both extends and improves the global climate record of cloud and aerosol vertical profiles that are critical to understanding the Earth's changing climate. CATS has also demonstrated several new technologies in space for future Earth Science missions, such as high-repetition rate lasers and highly sensitive detectors. Finally, CATS provides information about the vertical structure of hazardous volcanic, dust, and smoke plumes that can cause poor air quality and respiratory illnesses. The CATS data is used by aerosol and air quality modeling groups around the world to improve forecasts of hazardous plume transport. The CATS data and analysis team includes Laboratory members Dennis Hlavka, Andrew Kupchock, Edward Nowottnick, Scott Ozog, Steve Palm, Rebecca Pauly, and Patrick Selmer.

For further information please contact Matt McGill (matthew.j.mcgill@nasa.gov) or John Yorks (john.e.yorks@nasa.gov).

3.1.3.8 SORCE

SORCE has been making daily measurements of Total Solar Irradiance (TSI) and Solar Spectral Irradiance (SSI) since March 2003. On July 30, 2013, SORCE went into its safe hold mode, which temporarily ceases science operations including the collection of TSI measurements. SORCE satellite's battery power declined to a level too low to maintain instrument power for solar observations. Following a five-month gap (August 2013–February 2014) in SORCE daily solar measurements, new flight software was developed by Orbital Sciences Corporation (OSC) and CU-LASP. The software was installed via uplink radio commands in time for a special campaign in the last week of December 2013 to ensure overlapping measurements between SORCE and TSI Calibration Transfer Experiment (TCTE)/ Total Irradiance Monitor (TIMs) launched in November 2013 on the Air Force's Operationally Responsive Space (ORS) Space Test Program Satellite-3. Additional SORCE flight software, deployed in February 2014, enabled a "Day-Only Operations" (DO-Op) mode to stabilize the battery substantially. There have not been any additional battery cell failures since July 2013, and the battery has been stable for more than two years. The DO-Op mode allows SORCE to make the solar observations during the daylight part of the orbit and then put itself into safe-hold every eclipse. Further improved flight software has been developed with the goal for SORCE to survive through the eclipse without battery power. It is expected that SORCE could operate in its DO-Op mode for several more years, to overlap with the Total and Spectral Solar Irradiance Sensor-1 (TSIS-1), which is currently scheduled to launch in 2017 for operation on the International Space Station (ISS).

For further information, please contact the SORCE project scientist Dong Wu (dong.l.wu@nasa.gov).

3.1.3.9 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. Suomi 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 products are publically available from the NOAA CLASS archive: http://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, which 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 continue 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.

The current Suomi NPP Science Team members have the mandate to create NASA data products from Suomi NPP mission that continue the data record from the EOS missions. Science Team members from Earth Science/Atmospheres include: N. Christina Hsu, VIIRS aerosol products using the Deep Blue algorithm; Robert Levy, VIIRS aerosol products using the Dark Target algorithm; Steven Platnick, cloud properties using only the channels available on both MODIS and VIIRS; Richard McPeters, total ozone continuing OMI with OMPS; P.K. Bhartia, OMPS Limb Team Leader; Alexei Lyapustin, VIIRS aerosol and surface reflectance products using MAIAC; and Joel Susskind, continuing temperature and water vapor profiles using CrIS and ATMS.

For further information, please contact James Gleason (james.f.gleason@nasa.gov).

3.1.3.10 Terra

(1) Launched on December 18, 1999, as NASA's Earth Observing System flagship observatory, Terra carries a suite of five complementary instruments:

(2) ASTER (contributed by the Japanese Ministry of Economy, Trade, and Industry with an 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.

(3) 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.

(4) 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).

(5) 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.

(6) 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 17 years, the Terra mission has been providing the worldwide scientific community with an unprecedented 81 core data products (some new products will be added after the 2017 Senior Review), making a significant contribution to all of NASA's Earth Science focus areas. These core data products are currently used for: air quality mapping by the EPA (MODIS, MISR); volcanic ash monitoring for the FAA (ASTER, MISR, MODIS); weather forecasting through NESDIS (MODIS, MISR, CERES); forest fire monitoring for resource allocation by U.S. Forest Service (ASTER, MODIS, MISR); and carbon management and global crop assessment by USDA and USDA-FAS (MODIS, CERES). After 17 years of continuous operation, the project office has 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).

3.2. 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 at 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 3.3: 610AT Project and Deputy Project Scientist

Project Scientists		Deputy Project Scientists	
Name	**Project**	**Name**	**Project**
Anne Douglass	Aura	Bryan Duncan	Aura
Steve Platnick	EOS	Joanna Joiner	Aura
Dennis Chesters	GOES	Lazaros Oreopoulos	Aqua
Gail Skofronick Jackson	GPM	Alexander Marshak	DSCOVR
James Gleason	JPSS	Scott Braun	GOES-R

Project Scientists		Deputy Project Scientists	
Name	Project	Name	Project
Joanna Joiner	OMI	George Huffman	GPM
Pawan K. Bhartia	OMI	Si-Chee Tsay	Terra
James Gleason	SNPP	Christina Hsu	SNPP
Dong Wu	SORCE		
Dong Wu	TSIS		
Scott Braun	TROPICS		
Dong Wu	Earth-ICECube		

Table 3.4: 610AT Validation, Instrument, and Mission Scientists

Validation Scientists	
Name	Mission
Ralph Kahn	EOS/MISR
Matthew McGill	ISS/JEM-EF/CATS

Instrument Scientists/Managers		
Name	Instrument System	2016 Campaigns
Judd Welton	MPLNET	SEALS-sA, ORACLES
Amber Emory/David Wolff	XBADGER	Wallops Facility Operations
Si-Chee Tsay/David Wolff	ACHIEVE	Wallops Facility Operations
David Wolff	NPOL, D3R	Wallops Facility Operations
Gerry Heymsfield	HIWRAP	SHOUT
Tom Mcgee	TROPOZ	KORUS-AQ
Anne Thompson	SO3 Sondes/SHADOZ	KORUS-AQ
James Gleason	Pandora	KORUS-AQ
Anne Thompson	SO3 Sondes/SHADOZ	Ascension Island Sondes
Paul Newman/Tom Hanisco	ISAF	ATom
Steve Platnick	eMAS	ORACLES

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 2016, atmospheric research personnel supported activities in the planning and coordination phases as scientific investigators or as mission participants.

4.1. MPLNET

Judd Welton (612) and **Sebastian Stewart (612/SSAI)** were in Namibia from June 1 through June 14 to finalize the installation of a new MPLNET site located near Etosha National Park. The new site is located immediately downwind from the Etosha salt pan, a large dust source in Northern Namibia. The lidar data collected along with data from AERONET will provide information on dust emissions and transport from Etosha. The MPLNET observations are in partnership with the Namibia University of Science and Technology (NUST) in Windhoek. MPLNET observations are part of a new research initiative in the region called the Sea Earth Atmosphere Linkages Study in Southern Africa (SEALS-sA). SEALS-sA is a long-term international science initiative to understand the interactions of the biosphere, atmosphere, land and ocean in the southern African subcontinent. Dr. Welton attended a meeting at NUST to discuss ongoing support, SEALS-sA partnerships, and provide lidar training for the staff. Sebastian Stewart will return to Namibia in August to finalize site details and provide instrument training for NUST staff. He will also install a short term MPLNET site in Henties Bay for the French AEROCLO-SA campaign during August–September 2017. The MPLNET sites will also provide support for the NASA ORACLES campaign.

4.2. GPM

4.2.1. Wallops GPM Cloud and Precipitation Radar – Xbadger

Amber Emory (612) and Michael Coon (555) delivered the X-Band Atmospheric Doppler Ground-based Radar (X-BADGER) to the Wallops Flight Facility on Friday, April 8. The X-band zenith and dual-polarimetric, forward-pointing (20° off-zenith), beam-profiling radar is located approximately 50 feet from a densely-populated rain gauge and disdrometer site as part of GPM ground validation efforts at WFF. The X-BADGER location allows for comprehensive study of radar data from profiling and scanning radars with measurements of precipitation at the ground.

4.2.2. ICE-POP

Walt Petersen (MSFC) and **Gail Skofronick-Jackson (612)** hosted a meeting with Dr. Sangwon Joo (KMA) and collaborating NASA Weather Program investigators from GSFC and MSFC to coordinate NASA GPM and Weather Program contributions to the KMA-led ICE-POP field campaign and forecast demonstration project occurring in conjunction with the 2018 Winter Olympic Games to be held in South Korea. (See 3.1.3.6)

4.3. SHOUT

Scott Braun (612) participated as a mission scientist during the NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) experiment at Wallops. SHOUT used the NASA Global Hawk to conduct operational flights over Atlantic hurricanes to evaluate the impact of the airborne and sensor technologies in operational hurricane forecasts. SHOUT utilized three of the NASA Hurricane and Severe Storm Sentinel (HS_3) payloads, including the Goddard High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) Doppler radar, the JPL HAMSR microwave sounder, and NOAA dropsonde system. The goals of SHOUT are to demonstrate a prototype UAS concept of operations that could be used to improve high impact weather forecasts. The emphasis is on real-time data from the instruments and their insertion into the forecast models. In addition to studying hurricane intensification from an operational perspective, SHOUT also demonstrated that the Global Hawks can be operated with a much leaner staff in the field than in previous campaigns.

SHOUT-El Niño Southern Oscillation (ENSO) campaign was conceived subsequently because of the unusually strong El Niño year and the large amount of rain on the west coast. The El Niño was among top three on record and had a more central Pacific focus. The long-duration Global Hawk, stationed at Edwards Air Force Base, was advantageously situated to reach events in the central Pacific.

Flights in August and September 2016 focused on hurricanes in the Atlantic and Caribbean. Two 24-hour flights were performed over Tropical Storm Gaston in the Atlantic on August 24 and August 27. Flights in September included two over Hurricane Gaston in the Atlantic, one over Tropical Depression 9 in the Gulf of Mexico, and three more flights over Hurricane Matthew that traversed the eastern U.S. coast. HIWRAP worked well during these flights, providing near-real-time radar reflectivity images for the mission scientists. HIWRAP was supported by Heymsfield (612), Venkatesh (612/SSAI), (Li (555), McLinden (555), and Coon (555).

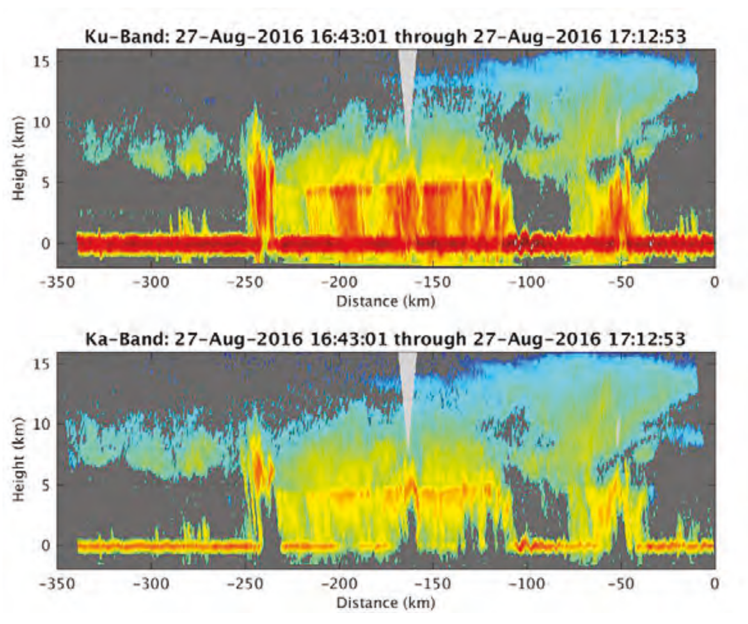


Figure 4.1: Real-time radar reflectivity cross section from HIWRAP radar on Global Hawk AV-6 flight across Hurricane Gaston on August 27, 2016. The nadir section is reconstructed from the HIWRAP scanning Ku- and Ka-band channels. The center of Gaston is at about 100 km wide in the image.

The three Global Hawk AV-6 flights over Hurricane Matthew were the highlight of the campaign. HIWRAP collected very beneficial data during Matthew and Tropical Storm Hermine, and it had almost 100 percent data collection during the campaign. The HIWRAP team for these flights included **G. Heymsfield (612)**, **Vijay Venkatesh (612/SSAI)**, Matt McLinden (555), Lihua Li (555), Jack Zebley (As and D). These recent flights notably included: nine science flights with a total of 214.3 hours covering ~72,500 nautical miles, four "back-back" flight series over four named storms (Matthew was a "back-back-back" series), and 647 drop sondes deployed.

4.4. KORUS-AQ

4.4.1. Tom McGee and team

PI Tom McGee (614) and CO-I's **John Sullivan (614/USRA)**, **Laurence Twigg (614/SSAI)**, and **Grant Sumnicht (614/SSAI)** oversaw ozone lidar measurements from KORUS-AQ at the Taehwa Research Forest (TRF) in South Korea. Vertical profiles of O_3 were measured at the Taehwas Forest site using the NASA Goddard Space Flight Center TROPospheric OZone Differential Absorption Lidar (GSFC TROPOZ DIAL or TROPOZ) in support of the joint NASA–NIER KORUS-AQ study (Figure 4.2). The campaign included three heavily instrumented aircraft and numerous ground-based measurements. The TROPOZ system, a charter NASA instrument in the Tropospheric Ozone Lidar Network (TOLNet) derives O_3 concentrations to within 10–15 percent mostly, as compared to nearby O3-sonde profiles, and previously has been used to characterize O_3 episodes, such as stratospheric-tropospheric exchange and terrain-driven recirculation events (http://www-air.larc.nasa.gov/missions/TOLNet/).During the field study at TRF, the TROPOZ operated nearly continuously in order to understand sub-hourly (15-min) variability of O_3 during the early morning, afternoon, and evening. In addition to lidar measurements, the TROPOZ trailer hosted *in situ* instruments from the EPA (a surface ozone monitor and an NO_2 monitor), ground-level meteorological data, and a ceilometer for aerosol measurements. Ozone sondes were also launched from the TROPOZ trailer on a near daily basis.

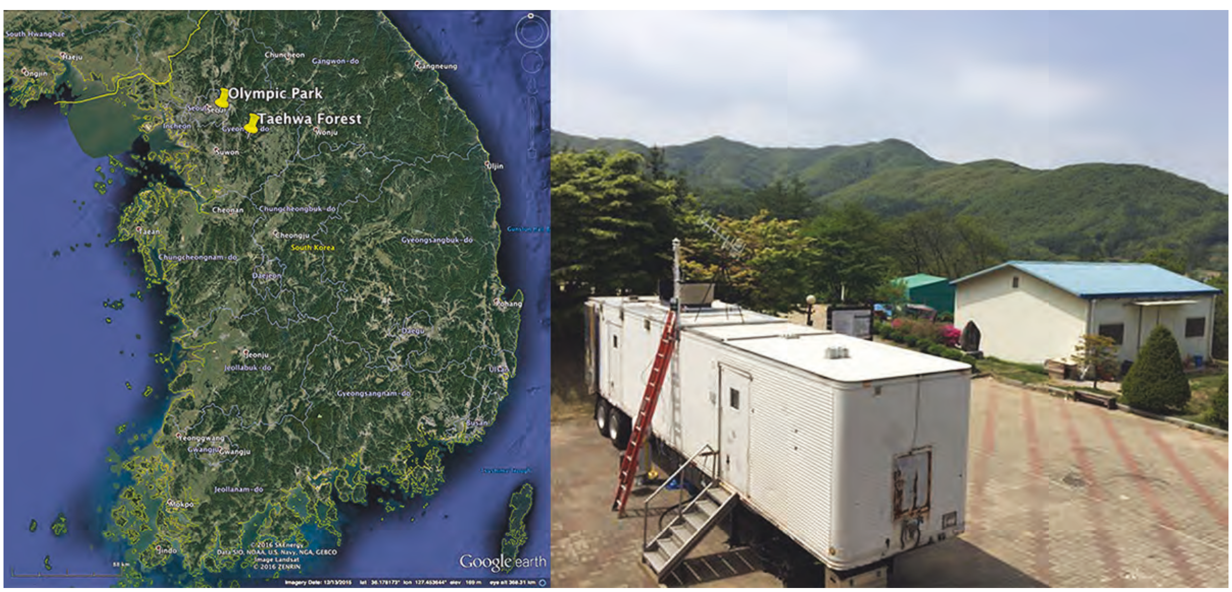


Figure 4.2: (Left) Map of South Korea with the Taehwa Forest site, and (right) GSFC's tropospheric ozone lidar equipment at the rural Taehwa Forest site.

The team planned to evaluate early morning residual layers of pollution observed at the Taehwa Forest site during the KORUS-AQ campaign using the GSFC ozone lidar, sondes, and surface records. They intended to compare how well the surface ozone observations match the mean PBL ozone concentrations derived from the lidar. Their ozone lidar observations would also show any substantial increase in ozone during the well-mixed late afternoon/early evening hours, as solar radiation/photochemical processes weaken.

The Taehwa site is located about 30 km southeast of Seoul—a city with roughly half the entire population of South Korea. Therefore, a majority of the late-day ozone would likely transported to the site from local, upwind sources. By using the time and height of the late-day peak ozone at Taehwa from the GSFC ozone lidar in conjunction with high-resolution back trajectories, The team planned to assess the time history of the pollution as it reaches the rural, forested area. A typical lidar curtain from the campaign is shown in Figure 4.3.

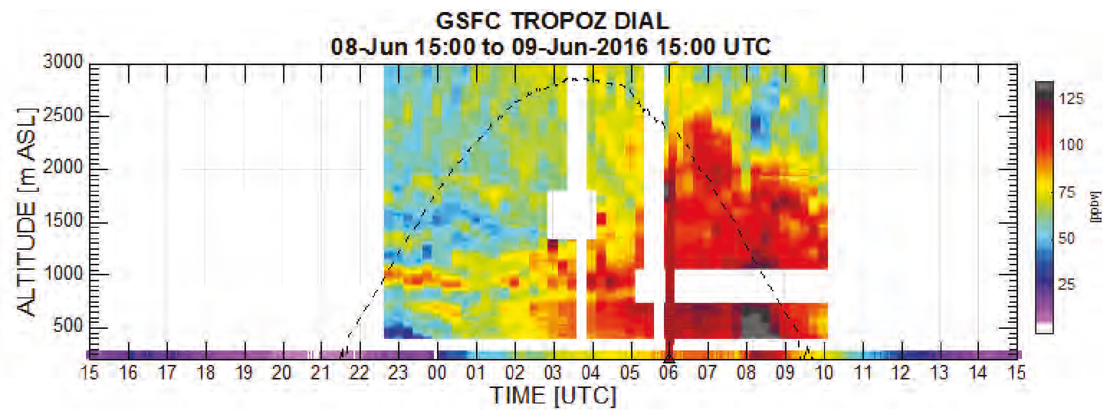


Figure 4.3: (Top) Ozone profiles acquired during the GSFC TROPOZ DIAL during the KORUS-AQ campaign. This curtain shows a high-ozone event and peak concentrations reaching near 125 pbbv, which were confirmed with the surface ozone measurements (bottom bin of the figure). The dashed line shows the solar radiation. Ozone continued to increase as the solar input decreased, indicating that transport is an important factor in the high ozone readings observed.

The team acquired over 250 hours of observations and archived over 1000 15-min profiles at the rural forest site in order to characterize downwind urban plume pollution as it reaches the site. They were co-located with many other instruments, with approximately 50 ozonesonde launches at the site. Analyses of this data have begun and will continue into FY 2017.

4.4.2. The Thompson group

Anne Thompson (610) and **Ryan Stauffer (614/USRA)** supported the Lidar group (**T. McGee (614) and team**) by launching daily ozonesondes at the Taehwa Research Forest ground site, about 60 km southeast of Seoul. The sonde profiles calibrated the TROPOZ and provided comparisons for DC-8 spirals over Taehwa. Pollution layers, many associated with plumes from Seoul, were an important feature of ozone measured over the site. The figure below compares a curtain of several weeks' ozone concentrations. Data taken in South Korea, figure (a), shows that ozone below 5 km over Taehwa is frequently greater than 100 ppbv, a level designated as a "Code Red" pollution alert in the United States. Figure (b) shows ozonesonde data taken during over Edgewood, Maryland (located 25 km northeast of Baltimore) during the July 2011 DISCOVER-AQ, when we had up to 40°C temperatures. The Maryland ozone averaged about half of the Taehwa levels, and Maryland did not record Code Red during DISCOVER-AQ. The tendency to form ozone is less than in Korea due to heightened efforts to decrease NOx emissions over the United States since 2003.

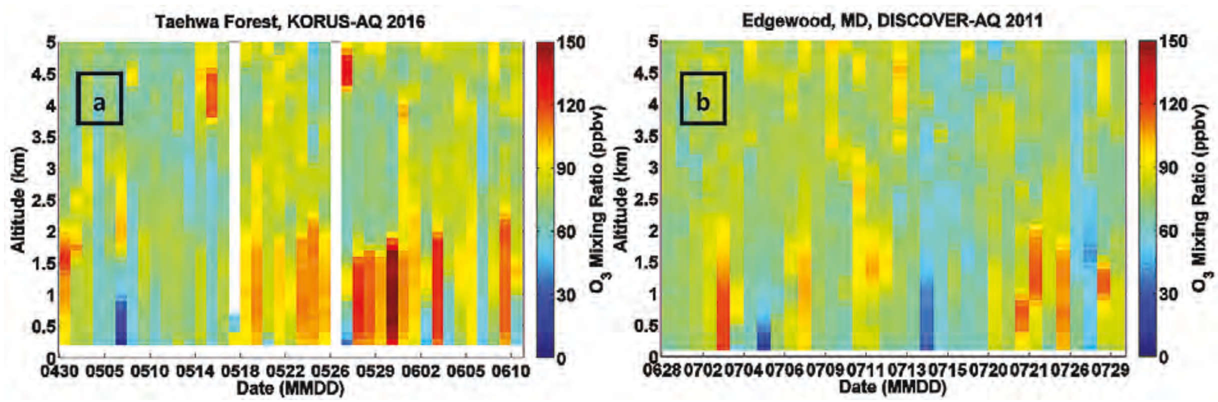


Figure 4.4: Pollution profiles over South Korea (left) as compared wth Maryland (right).

4.4.3. Pandora

A network of nine Pandora instruments was installed in Korea as part of the KORUS-AQ campaign (May–June 2016) at eight locations (Figure 1 and Table 1). Five of these sites were selected to be "downwind" from Seoul, an extremely NO_2 polluted area. Part of the network was installed in April 2015. There are three Pandora instruments currently operating, one in Busan and one Seoul since 2012, and one in Gwangju operating since April 2015. Two locations, Busan and Seoul, have collected NO_2 data since 2012. Studies show the very high levels of NO_2 pollution present in the northern industrial region in and near Seoul compared to the southern cities and a relatively clean coastal site. The Pandora spectrometer instrument (PSI) is described in detail by Herman et al., 2009 and 2015; and on NASA's Pandora website http://acdb-ext.gsfc.nasa.gov/Projects/Pandora/index.html

KORUS-AQ Locations (South to North)	Latitude	Longitude
Gwangju	35.2260	126.8430
Busan	35.2353	129.0825
Anmyeondo	36.5380	126.3300
Taewha Mtn	37.3123	127.3106
Yeoju-1	37.3385	127.4895
Songchon	37.4100	127.5600
OlympicPark	37.5232	127.1260
Seoul	37.5644	126.9340
Yeoju-2	37.5665	126.9780

Figure 4.5: KORUS-AQ sites for 9 Pandora instruments at eight sites.

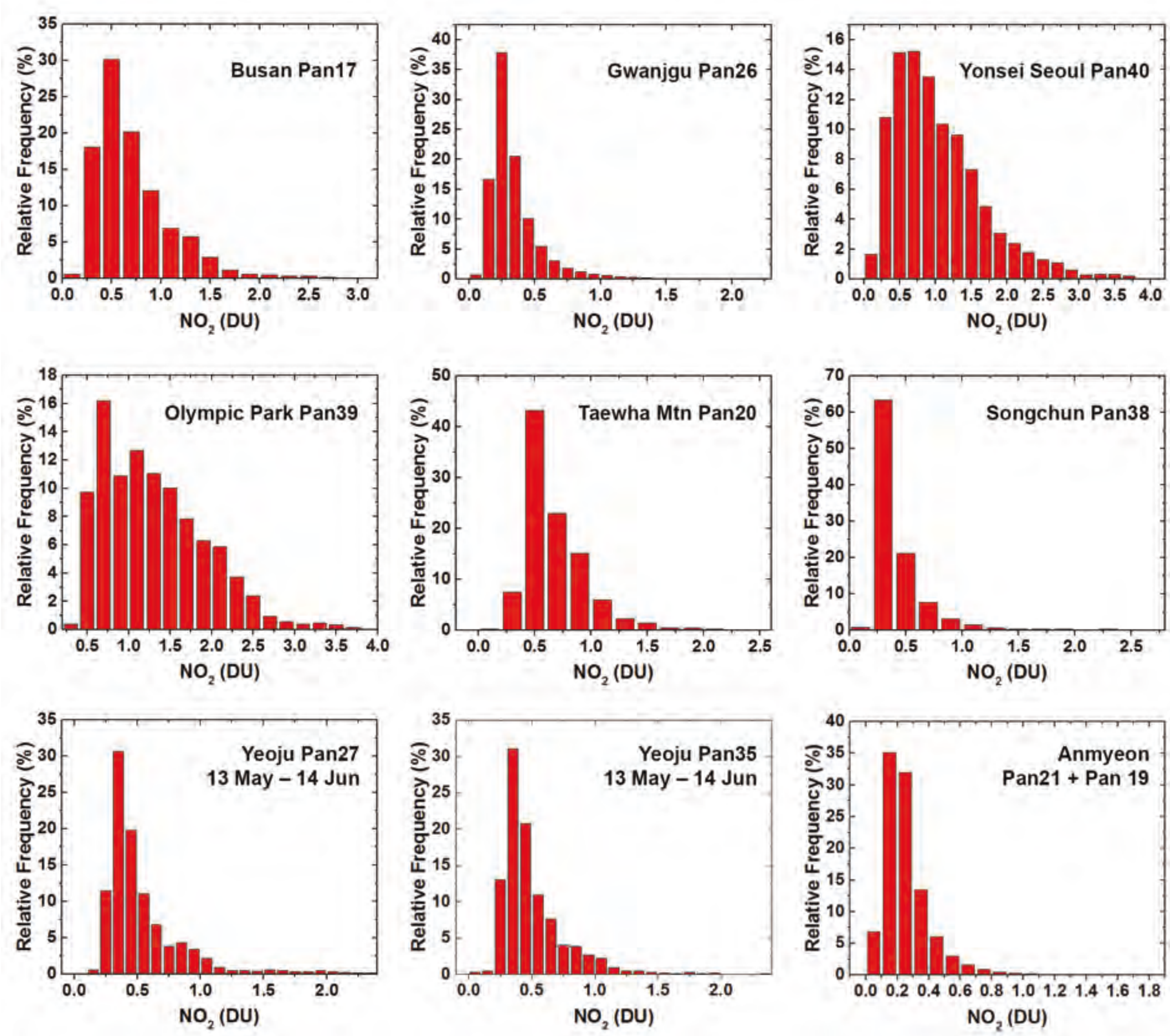


Figure 4.6: Percent frequency of occurrence of NO_2 amounts at nine locations in Korea: April 20 to Jun 6, 2016, except as labelled.

4.4.3.1 Diurnal Variation

An example of diurnal variation can be seen for Seoul (Pan40). For Seoul, the amounts of NO_2 during the morning (1 DU at 10:00) are much less than later in the afternoon (over 2–3 DU at 16:00) on almost every day, and occasionally reaching 6 DU. Even the relatively low morning values of NO_2 represent a significant amount of pollution. Seoul is unusual, since the NO_2 levels occasionally reach 6 DU and the peak values occur in the late afternoon.

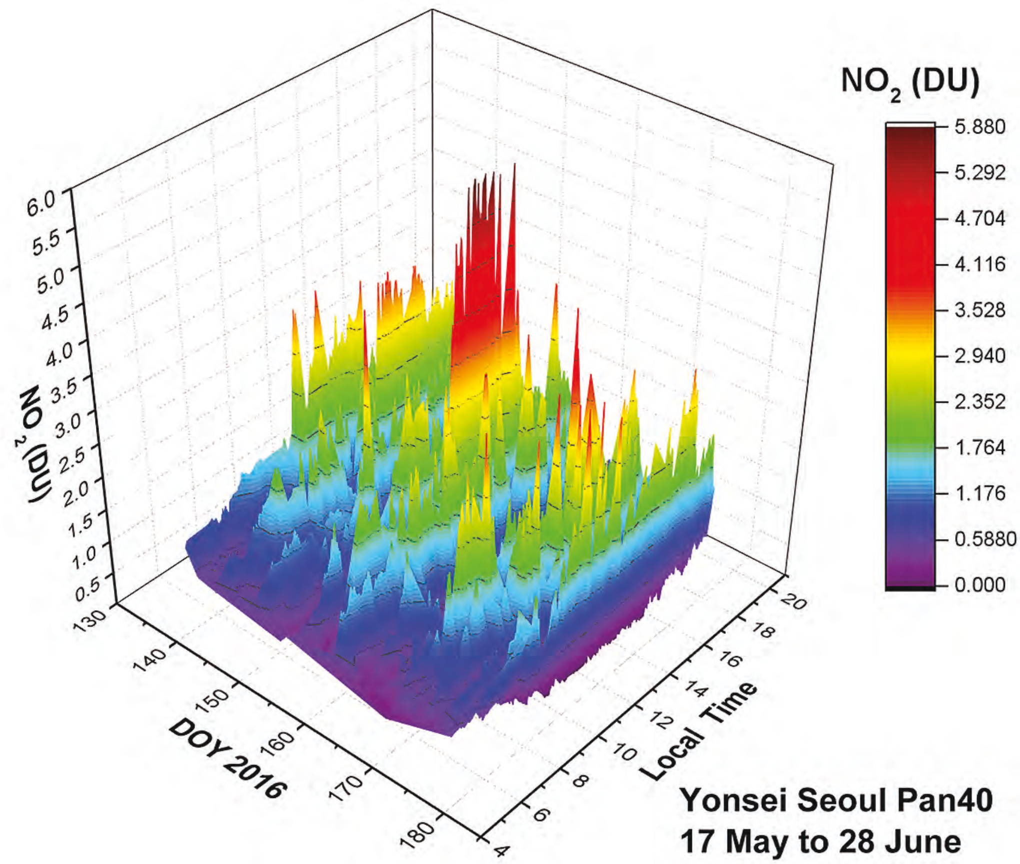


Figure 4.7: NO_2 amounts vs day of the year (DOY) and local time for Yonsei University, Seoul, Korea.

4.5. SHADOZ

On March 25, **Anne Thompson (610)** and **Ryan Stauffer (614/USRA)** launched the first ozonesonde at the Ascension Auxiliary Airfield (8.0S, 14.4W) since NASA and NOAA/NWS Ascension sonde operations ended in mid-2010. Thompson and Stauffer spent two weeks at the airfield training U.S. Airforce (USAF) contractors to conduct weekly ozonesonde launches for the SHADOZ (Southern Hemisphere Additional Ozonesondes) network, as part of a new agreement between GSFC and USAF. The figure below displays the ozone (sonde) profile along with relative humidity (RH) and potential temperature on March 29, 2016. Near the surface of clean marine air, the ozone concentration is ~20 ppbv. In the mid- and upper troposphere, there are relatively dry layers (RH <15%) with elevated ozone (97 ppbv maximum at 450 hPa). The profiles shown are atypical for this time of year, but they do resemble approximately five percent of prior Ascension soundings in March–April–May (Jensen et al., 2012). Biomass burning in western Africa is likely responsible for the mid-tropospheric layers of high ozone recorded.

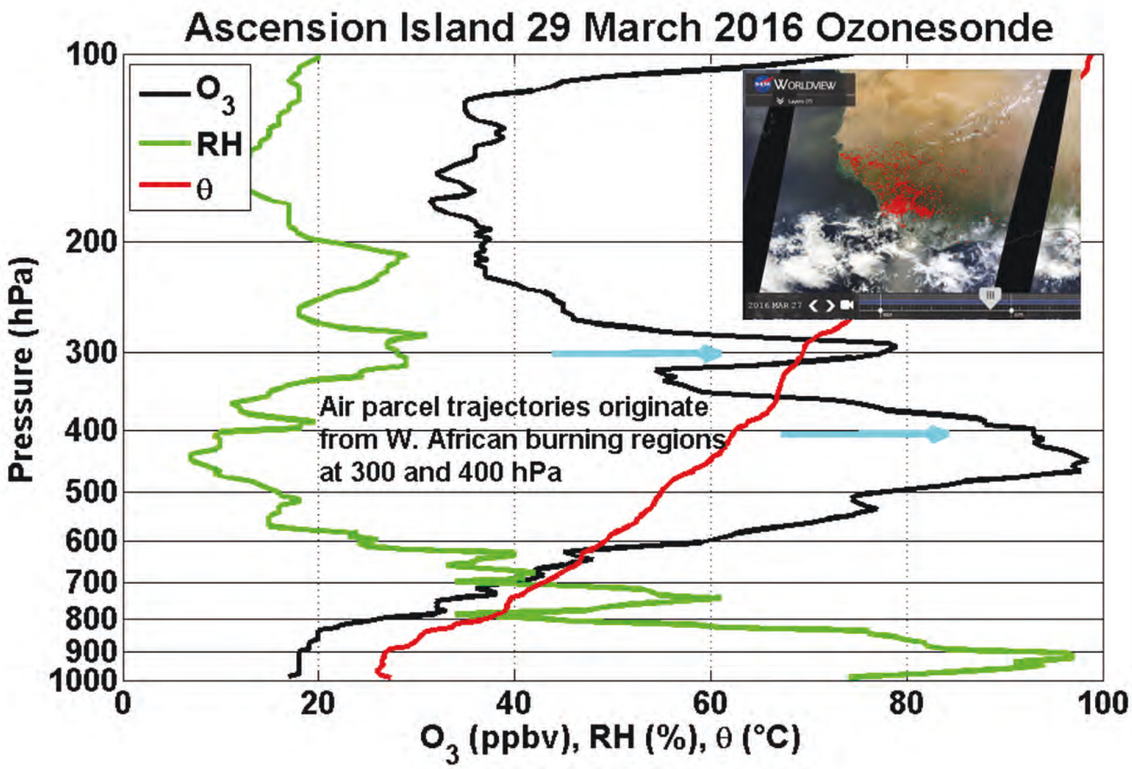


Figure 4.8: Profiles from a radiosonde showing data gathered from the surface to the upper troposphere (100 hPa). The inset figure displays a cluster of Terra and Aqua MODIS fire hotspots (red dots) in the days prior to the ozone profile. Air parcel back trajectories indicate that air over Ascension at 300 and 400 hPa (cyan arrows) originated from these burning regions.

4.6. ATom

The Atmospheric Tomography Mission (ATom) will study the impact of human-produced air pollution on greenhouse gases and on chemically reactive gases in the atmosphere. Reductions of atmospheric concentrations of methane (CH_4), tropospheric ozone (O_3) and black carbon (BC) aerosols are effective measures to slow global warming and to improve air quality. Airborne instruments will look at how atmospheric chemistry is transformed by various air pollutants and at the impact on CH_4 and O3. Mitigation of these short-lived climate forcers is a major component of current international policy discussions.

ATom has a global scale deployment in each of four seasons over a 4-yr period in order to identify seasonal patterns in chemical reactivity and the integrated impact of anthropogenic emissions from the major continents. Each deployment will be comprised of 10 flights in a circuit transecting the Pacific and Atlantic basins from nearly pole-to-pole.

The campaign is led by Steven Wofsy (Harvard, Principal Investigator (PI)) and Michael Prather (University of California, Deputy PI). The science team, comprised of 15 instrument teams and several theory teams, is led by Tom Ryerson (National Oceanic and Atmospheric Administration (NOAA)) aided by **Paul Newman(610)**, **Tom Hanisco (614),** and David Fahey (NOAA). During the next five years, the science team will use research aircraft flights around the world to better understand chemical processes in the atmosphere that control the short-lived greenhouse gases—methane and ozone, the latter of which is also a health-damaging air pollutant.

ATom will deploy an extensive gas and aerosol payload on the NASA DC-8 aircraft for systematic, global-scale sampling of the atmosphere, profiling continuously from 0.2 to 12 km altitude from 85°N to 65°S in both the Pacific and the Atlantic (our definition of "tomographic") in the four separate seasons. *In situ* airborne measurements in low-risk airspace over the oceans to will provide information on CH_4 and O_3 processing relevant to more than 60 percent of the total reactivity of the global atmosphere. ATom is tightly linked to satellites measuring atmospheric chemical composition and to global chemistry-climate models. The data will be applied to model testing and development as well as satellite validation.

For further information please contact Tom Hanisco (thomas.hanisco@nasa.gov) or Paul Newman (paul.a.newman@nasa.gov).

4.7. eMAS and ORACLES

Several 610 scientists were in Namibia participating in the ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) campaign. ORACLES is an Earth Venture Suborbital Project focusing on the interaction of African biomass burning aerosol with the extensive marine boundary layer clouds off the coasts of Namibia and Angola. To date those that have been in the field include: **Steve Platnick (610)**, **Kerry Meyer (613/USRA)**, and **Tom Arnold (613/SSAI)** with the Enhanced MODIS Airborne Simulator (eMAS) imager on the ER-2; Brian Cairns (611), Jacek Chowdhary (611/CU), Kirk Knobelspiesse (616) and Ken Sinclair (graduate student with 611/CU) operating the RSP polarimeter on the ER-2 and the P-3; Brent Holben (618) installing and supporting AERONET sunphotometers throughout the country; Arlindo da Silva and Karla Longo (610.1) providing GEOS-5 model support; and Andrew Ackerman (611) and Ann Fridlind (611) attending as part of the theory team.

Steve Platnick was the Principal Investigator for the eMAS imager flown on the NASA ER-2 high-altitude research aircraft during the campaign. Flight missions with the ER-2 and/or NASA WFF P-3B were conducted from September 3 to September 27 out of Walvis Bay, Namibia. ORACLES is a five-year investigation with three intensive observation periods (IOP) designed to study key processes that determine the climate impacts of biomass burning aerosols in Southern Africa. Southern Africa produces almost a third of the Earth's biomass-burning (BB) aerosol particles, yet the fate of these particles and their influence on regional and global climate is poorly understood. The overall scientific goal of ORACLES is to understand the processes that control the radiation balance and cloud properties over the Southeast Atlantic, which impact the regional and global distribution of surface temperatures and precipitation. The eMAS 38-channel scanning spectrometer acquires high spatial resolution imagery of cloud, aerosol, and surface features from its ER-2 vantage point of about 20 km. In addition to providing essential data for ORACLES science, eMAS observations will also help to develop, test, and refine algorithms for the MODIS and VIIRS, key NASA sensors used for cloud process and climate studies.

Figure 4.9: This mission utilizes the NASA P-3 aircraft as a low-flying platform for in situ *and remote-sensing measurements of aerosols and clouds. Using the NASA ER-2 with a combination of polarimeter, radar, and lidar measurements, ORACLES will provide a high-altitude view of the science data set. In addition to field observations, it includes satellite remote-sensing and modeling at regional and large eddy simulations scales.*

5. AWARDS AND SPECIAL RECOGNITION

5.1. Introduction

This year many deserving employees were recognized for outstanding accomplishments, leadership, or service. Notable achievements were recognized by Goddard, NASA, and by national, international, or professional organizations. Such accomplishments were achieved through individual dedication and perseverance as well as through close cooperation with co-workers and associations and collaborations with the outside community.

Welcome to new lab member Meghan Fitzgerald (613/SSAI). Meghan is working on a new project to develop a catalog of communication products from across the agency's Earth Sciences Division. Her background is in library and information science, and she comes from archive work at HBO and Turner Broadcasting

5.2. Agency Honor Awards

In 2016, NASA identified the following people for special recognition.

Honor Award	Recipient	Citation
Exceptional Scientific Achievement Medal	Alexander Marshak 613	*For great advancements in our understanding of the three-dimensional nature of clouds and its implications on satellite observations.*
Exceptional Scientific Achievement Medal	Matthew DeLand 614/SSAI	*For exceptional and sustained scientific insight in understanding long-term solar spectral irradiance variability and Polar Mesospheric Cloud morphology.*
International Space Applications Challenge Team	Kevin Ward 613/SSAI	*For outstanding achievement convening a collaborative international initiative to solve mission-related data and technology challenges, spurring innovation and diplomacy.*

5.3. Robert H. Goddard Awards

Atmospheric Research team member received an individual awards.

Robert H. Goddard Award	Recipient	Citation
Science	Ralph Kahn 613	*For unveiling the mysteries of aerosols in innovative research efforts that made us understand better their importance in climate and everyday life.*

Atmospheric Research scientists also received a team award.

Robert H. Goddard Award	Recipient	Citation
Science: High Altitude Radar	Gerald Heymsfield 612; Lihua Li 555; Matthew McLinden 555; Michael Coon 555; Martin Perrine 566; Gerry McIntire SGT; Vijay Venkatesh SSAI; Steven Guimond ESSIC; Anthony Didlake PSU; John Zebley AS&D, Inc; Lin Tian GESTAR; Amber Emory 612; Di Wu SSAI	*For success deploying multiple radars on multiple high-altitude NASA aircraft for multiple field campaigns, analyzing the data, and developing proposals for spaceborne radars.*

5.4. External Awards and Recognition

TRMM was selected for the 2016 Group Pecora Award (http://remotesensing.usgs.gov/descriptionaward.php). The William T. Pecora Award is presented annually to individuals or groups that make outstanding contributions toward understanding the Earth by means of remote sensing. The award is sponsored jointly by the Department of the Interior (DOI) and the National Aeronautics and Space Administration (NASA).

Paul A. Newman (610) was elected as the Vice President of the International Ozone Commission. The scientific goals of the Commission include advances in understanding dynamical and chemical processes involved in the variability of the atmospheric ozone and interactions of stratospheric and tropospheric processes including interactions with aerosols, air pollutants and climate. In addition, global impacts of UV changes on health have formed a growing new area of research falling within the interests of the Commission.

Pawan Gupta (614/USRA) won the 2016 GESTAR Annual Excellence Award for "his contributions in both the NASA Applied Remote Sensing Training (ARSET) program and the MODIS science team."

Galina (Gala) Wind (613/SSAI) was awarded a PhD in Atmospheric and Oceanic Science from the University of Maryland, College Park, August 19, 2016.

5.5. William Nordberg Award

The William Nordberg award for Earth Sciences is given annually to an employee of the Goddard Space Flight Center who best exhibits those qualities of broad scientific perspective, enthusiastic and technical leadership on the national and international levels, wide recognition by peers, and substantial research accomplishments in understanding Earth system processes which exemplified Dr. Nordberg's own career. The first award was presented to Dr. Joanne Simpson on November 4, 1994. All current and past atmospheric science recipients of this award are listed below.

Recipient	Year
Joanne Simpson	1994
Mark Schoeberl	1998
William K. M. Lau	1999
Yoram J. Kaufman	2000
Michael D. King	2001
P. K. Bhartia	2003
Robert Adler	2007
Wei-Kuo Tao	2008
Paul Newman	2011
Anne Douglass	2013

5.6. American Meteorological Society

Founded in 1919, the American Meteorological Society (AMS) is the nation's premier scientific and professional organization promoting and disseminating information about the atmospheric, oceanic, hydrologic sciences.

5.6.1. Honorary Members

Honorary AMS Members are persons of acknowledged preeminence in the atmospheric or related oceanic or hydrologic sciences, either through their own contributions to the sciences or their application or through furtherance of the advance of those sciences in some other way. The following current and former Goddard atmospheric scientists have achieved this award.

David Atlas   Joanne Simpson   Eugenia Kalnay

Figure 5.1: Honorary AMS members David Atlas, Joanne Simpson, and Eugenia Kalnay

5.6.2. Fellows

Fellows shall have made outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period of years.” The following current and former Goddard atmospheric scientists have achieved this award.

Recipient	Recipient	Recipient
Robert F. Adler	Eugenia Kalnay	Mark R. Schoeberl
Dave Atlas	Jack A. Kaye	Siegried D. Schubert
Robert M. Atlas	Michael D. King	J. Marshall Shepherd
Wayman E. Baker	Steven E. Koch	Jagadish Shukla
John R. Bates	Christian Kummerow	Johanne Simpson
Antonio J. Busalacchi	William K. Lau	Eric A. Smith
Robert F. Calahan	Paul A. Newman	Wei-kuo Tao
Anne R. Douglass	Gerald R. North	Anne M. Thompson
Franco Einaudi	Steve Platnick	Louis W. Uccellni
Donald F. Heath	David A. Randall	Thomas T. Wilheit
Arthur Hou	Richard R. Rood	Warren Wismombe

5.7. American Geophysical Union

Established in 1919 by the National Research Council, the American Geophysical Union (AGU) is an international non-profit scientific association with more than 62,000 members.Roger Revelle Medal: Anne Thompson, 2015 Award Recipient

5.7.1. Union Fellows

A Union Fellow is a tribute to those AGU members who have made exceptional contributions to Earth and space sciences as valued by their peers and vetted by section and focus group committees. Eligible Fellows nominees must have attained acknowledged eminence in the Earth and space sciences. Primary criteria for evaluation in scientific eminence are: (1) major breakthrough, (2) major discovery, (3) paradigm shift, or (4) sustained impact. The following current and former Goddard atmospheric scientists have received this distinguished honor.

Recipient	Year
David Atlas	1972
Joanne Simpson	1994
Mark R. Schoeberl	1995
Richard S. Stolarski	1996
David A. Randall	2002
Anne M. Thompson	2003
Marvin A. Geller	2004
Gerald R. North	2004
Eugenia Kalnay	2005
Michael D. King	2006
William K.-M. Lau	2007
Anne R. Douglass	2007
Paul Newman	2010
Warren Wiscombe	2013
Lorraine Remer	2015

5.7.2. Yoram J. Kaufman Unselfish Cooperation in Research Award

The Atmospheric Sciences Section of the American Geophysical Union established the Yoram J. Kaufman Unselfish Cooperation in Research Award in 2009. This award is named in honor of Yoram J. Kaufman, an outstanding atmospheric scientist, mentor, and creator of international collaborations who worked on atmospheric aerosols and their influence on the Earth's climate for his entire 30-year career. The following Goddard atmospheric scientists have been honored with this award.

Recipient	Year
Ralph Kahn	2009
Pawan Bhartia	2012

6. COMMUNICATION

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 they to increase the public's understanding of why and how such advances affect their lives through formal and informal education as well as 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 following sections summarize many such activities.

6.2. University and K-12 Interactions

On January 28, Dorian Janney (612/ADNET) delivered a presentation on the GPM mission and shared the GLOBE/GPM satellite collaboration with 63 high school students and 14 adults at the Princess Chulabhorn College in Nakhon Si Thammarat, Thailand. She also spent a few hours assisting 16 groups of students with their science projects which were all related to environmental and biological science concepts.

On February 10, Dorian Janney (612/ADNET) and Kristen Weaver (612/USRA) conducted activities for 65 second graders and 10 teachers/chaperones from Farmland Elementary School in Rockville, Maryland during a field trip to the Goddard Visitor Center.

On February 19, Kristen Weaver (612/USRA) presented at the Teachers for Global Classrooms Resource Fair in Washington, D.C., providing information to teachers about the GLOBE program and available protocols.

Dorian Janney (612/ADNET) and Kristen Weaver (612/USRA) held the monthly GPM Earth SySTEM webinar on February 20 for the 27 teachers and scientists from around the world who participate intros program. Two scientists from Thailand shared their research on mosquitos and how to engage GLOBE Program teachers and students in the new mosquito protocol.

Dorian Janney (612/ADNET) and Kristen Weaver (612/USRA) presented on NASA science at the Montgomery County Public Schools' "Astronomy Night" program on February 26. Approximately 25 children and 20 adults participated in this event.

Charles Ichoku (613) was one of the judges at the STEM science fair at the Wilde Lake High School, Columbia, Maryland, on February 26. He also gave a presentation at the STEM night at the Centennial Lane Elementary School, Elliott City, Maryland, on February 29. The presentation was entitled: "Observing the Earth from Space through STEM."

The GLOBE El Niño Field Campaign, commenced on March 1. This field campaign focused on six GLOBE student measurement protocols that all showed how the El Niño phenomena affected local environments and impacted the globe. Students were able to develop their results into research projects and science fair projects. This campaign was led by Brian Campbell (610.W/GST) with an amazing team made up of Dorian Janney (612/ADNET), Kristen Weaver (612/USRA), Peter Falcon (1865/JPL), Ann Martin (LaRC-E303/SSAI), Matt Pearce (GISS/160), and several university researchers and GLOBE Program personnel.

On March 2, Dorian Janney (612/ADNET) gave two remote presentations to the upper and lower schools of Kent Place School in Summit, New Jersey, about how GPM and other NASA satellites study the water cycle. A total of 109 students and 15 adults attended.

On March 3, Dorian Janney (612/ADNET) and Dalia Kirschbaum (617) presented a web seminar through the National Science Teachers Association entitled, "Global Precipitation Measurement Mission: Water Cycle." There was a live audience of 44 attendees, and the archived session was made available to educators on the NSTA Learning Center.

David Wolff (610.W) presented demonstrations of *in situ* ground observations for GPM to approximately 50 students from Somerset Middle School (grades 4 and 5) at the NASA Wallops Flight Facility Visitor's Center on March 3. These students were parts of the Green Engineers and SAIL afterschool programs.

On March 10, Gail Skofronick Jackson (612) was a science fair judge at the Madeira School, an all-girl school in McLean, Virginia.

Dorian Janney (612/ADNET) visited Banneker Middle School in Burtonsville, Maryland, on March 10. She worked with a group of 15 middle school girls as a part of a "Women in STEM" program for underserved students. She discussed the engineering behind GPM and shared some of the science behind the mission as well. There were 16 students and 4 adults during the event.

Dorian Janney (612/ADNET) served as a judge for student science projects at the Parkland Magnet Middle School for Aerospace Technology STEM Night on March 10. After she finished her duties as a judge, she ran a NASA table to share information on the science and engineering behind the GPM mission to the approximately 350 students and their families who attended this event.

On March 21, Ginger Butcher (610/SSAI) gave a Skype presentation to 23 third through sixth grade girls at the Kopernik Observatory as part of their GIRL POWER program, designed to interest girls in STEM subjects and careers. The presentation covered a variety of science topics including the Electromagnetic Spectrum and Earth Observation, summarized the types of work a Public Outreach and Communications professional does at NASA, and held a question and answer session.

Dorian Janney (612/ADNET), Mike Taylor (618/SSAI), and Dalia Kirschbaum (617) assisted with the 53 students and 12 chaperones who came to the GSFC Visitor's Center for their second-grade field trip. They learned about the Landsat mission from Mike Taylor, the GPM mission from Dorian Janney, and about how NASA studies precipitation and landslides from Dalia Kirschbaum.

Dorian Janney (612/ADNET) ran a table at the Fort Belvoir STEM Night event on March 16. The 650 adults and children learned about the GPM satellite as they made edible models of the satellite.

On March 24, Matthew McGill (612) traveled to Gettysburg College in Pennsylvania where he spoke to students about lidar remote sensing, its applications, and how lidar measurements can impact climate models. His presentation was well received, and he was even heard to express, "this was actually enjoyable."

Dorian Janney (612/ADNET) shared NASA Earth science and GPM educational materials at the National Science Teachers Association convention in Nashville, Tennessee, from March 31 to April 2. She gave a formal presentation, titled "NASA is Looking for a Few Good Teachers and their Students," to over 75 participants. She hosted a table at the National Earth Science Teachers Association roundtable and at a middle school share-a-thon, with audiences of more than 1000 teachers between the two. She also assisted with the NASA booth in the exhibit hall (including GPM handouts), which reached over 8,000 people over the three days.

On April 15–17, the GPM outreach team hosted a table as part of the larger NASA presence at the U.S.A. Science and Engineering Festival at the Walter E. Washington Convention Center in downtown Washington, D.C. Kristen Weaver (612/USRA) and Dorian Janney (612/ADNET) led the outreach effort to share the science and technology of precipitation measurement with the general public. Other volunteers included Eric Nelkin (612/SSAI), Ellen Gray (130/ADNET), Jacob Reed (617/Telophase), Jasper Lewis (612/UMBC), Amber Emory (612), Trena Farrell (130), Charles Hicks (443/Embedded Flight Systems), Deepak Patel (545), and Elaine Gunter (372/Ares Corp), as well as GPM Earth SySTEM Ambassador Michael Wilkinson. Several hundred thousand visitors attended the event overall, and an estimated 2500 to 3000 stopped by the GPM table.

On April 13, Dorian Janney (612/ADNET) facilitated a webinar via the National Science Teachers Association's online learning center about watersheds and how GPM and NASA satellites are helping to monitor these vital natural resources. Also presenting were Christa Peters-Lidard (610) and Eric Brown de Colstoun (618).

Dorian Janney (612/ADNET) worked with 207 sixth-grade students and their 5 teachers from the Parkland Magnet Middle School for Aerospace Technology in Wheaton, Maryland, on April 27. She ran three sessions to teach the participants about the GPM mission and career possibilities with NASA.

Brian Campbell (610.W/GST) gave webinar presentations to the Rhode Island Road Scholars Teacher Workshop for Woonsocket, Rhode Island, teachers on April 25, 27, 28, and 29. These presentations covered the SMAP mission and the GLOBE Program's field campaigns. Teachers were given online resources, as well as opportunities to join the existing GLOBE Program El Niño Field Campaign.

Dorian Janney (612/ADNET) assisted with the Cedar Grove ES Career Day program on May 2, in Clarksburg, Maryland. She ran three sessions with the fifth-grade students to share potential career options that are available with NASA, as well as share the science and technology behind the GPM mission. She worked with 4 teachers and 59 students during this event.

On April 27, Brian Campbell (610.W/GST) gave a webinar presentation to the Toledo Ohio School for the Arts. The presentation was given to 40 sixth-grade students who have been taking GLOBE protocol measurements that can be used as part of the El Niño field campaign. Discussion of the SMAP and ICESat-2 satellites were also a part of the webinar.

David Wolff (610.W), Jason Bashor (610.W/ASRC), Katherine Wolff (610.W/SSAI), Shaena Hicks (610.W/OSC), Stephanie Wingo (610.W/SSAI) and Brandon Jameson (610.W/ASRC) participated in a Career Day for students in grades pre-kindergarten to third at Pocomoke Elementary School in Pocomoke City, Maryland, in May. They provided discussions of the GPM satellite and ground validation programs. They also demonstrated prototypes of some GPM spacecraft parts and a tipping-bucket rain gauge used for measuring surface rain rates.

While in South Korea in May, Glenn Wolfe (614/UMD-JCET) shared the excitement of the KORUS-AQ mission with over 500 K–12 students at Osan American Elementary, Middle, and High Schools. He was part of a team that gave ten in-person presentations at the schools, welcomed students and teachers to see their aircraft on base, and conducted live chats with students and teachers from onboard the NASA DC-8 while flying over the Korean peninsula.

Dorian Janney (612/ADNET), Kristen Weaver (612/USRA), Mike Taylor (618/SSAI), and Brian Campbell (610.W/GST) attended and presented at the 2016 Odyssey of the Mind World Finals in Ames, Iowa on May 26–28. During the event, there were approximately 18,000 student participants, teachers, chaperones, and parents attending the event. Several thousand of these individuals participated in the NASA Classroom activities, attended the Creativity Festival, and heard live speakers as part of the NASA E-Theater. Throughout the three days, Mike Taylor presented on the Landsat Mission, Dorian Janney presented in the GPM Mission and how NASA studies Earth's water cycle, and Brian Campbell presented on the SMAP and ICESat-2 missions. The NASA Classroom had two separate activities: The GLOBE Program's Cloud App and an Ocean Color activity, designed by Stephanie Uz (614/GST). Kristen Weaver led the Ocean Color classroom activity, which included hands-on, optical comparisons of ocean color samples. Dorian Janney led the GLOBE Cloud App activity, which was an introduction to clouds, followed by cloud observations using the interactive GLOBE Cloud App. Brian Campbell presented both the Ocean Color activity and the GLOBE Cloud App. Mike Taylor led the NASA Earth Science efforts at the Odyssey of the Mind Creativity Festival, including the Landsat cubes and Earth Science Missions.

Co-Is Geoff Bland (610.W) and Sallie Smith (606.3/SE) with Brian Campbell (610.W/GST) participated in the kick-off team meeting for the AEROKATS and ROVER Educational Network (AREN), held at the University of Maryland Eastern Shore on June 7–8. The sponsoring NASA HQ's Earth Science program manager, Dr. Ming-Ying Wei, attended the first day, and the team really enjoyed her engagement with the group. Plans for this multi-institution effort include the development of new protocols for the NASA GLOBE Program and introduction of novel concepts and practices to K–12, undergraduate, and informal educational environments. AREN emphasizes increasing scientific literacy through hands-on remote sensing and *in situ* observation activities.

Charles Ichoku (613) participated on a panel of judges for presentations on Mission to Mars design projects by 6th grade science technology and geography students at Burleigh Manor Middle School, Ellicott City, Maryland, on June 9–10.

On July 7, Kristen Weaver (612/USRA) gave a presentation about how NASA studies the water cycle (including precipitation and GPM) to educators at a workshop hosted by the Goddard Office of Education. On July 11, she gave a virtual presentation to educators attending a workshop at WFF.

On August 24, Brian Campbell (610.W/GST) gave a talk on the ICESat-2 mission and conducted the "ICESat-2 Bouncy Ball Photon-Counting Challenge" with 70 participants, as part of the Summer Family Engineering Challenge held on Wednesdays at the NASA Wallops Flight Facility's Visitor Center. Families competed in several levels of "photon-collecting" activities by trying to catch the green bouncy balls. The person (acting as the ICESat-2 satellite) dropping the photons (balls) tried to collect as many photons as they could on the first bounce off the ground, replicating how laser photons are emitted and collected by the ICESat-2 satellite. In the activity designed by Brian, there were several surfaces that came into play during the challenge, including linoleum (representing ice), carpet (representing vegetation), and boxes (representing buildings). For each level of the challenge, the participants had to modify/engineer the "satellite" based on the results of the previous level. The challenge was a single elimination format.

Brian Campbell (610.W/GST) gave an online presentation on the ICESat-2 satellite mission as part of pre-visit session to Goddard. At the September 26 webinar, there were 20 teachers present from the Hopatcong Middle School in New Jersey. Discussions presented the science and engineering of the satellite and shared classroom activities. On September 29, the outreach team interacted with the New Jersey middle and high school students visiting Goddard at the ICESat-2 altimeter exhibit.

Brian Campbell (610.W/GST) gave an online lecture about the SMAP satellite mission to pre-service teachers in the agricultural sciences at Sam Houston State University in Huntsville, Texas. The lecture, presented on September 29, highlighted the science, instrumentation, and engineering of the satellite, as well as the GLOBE SMAP Block Pattern Soil Moisture Protocol. Students were shown how to collect data via the protocol, enter the data, and then compare their data to NASA Worldview SMAP satellite data. The student teachers are graduating in the Spring and will then have their own classrooms next Fall.

On October 4, Brian Campbell (610.W/GST) gave four webinar talks about NASA Earth Science, the SMAP Mission, and the GLOBE ENSO Student Research Campaign to students at the Shumate Middle School in Gibraltar, Michigan. Each talk was 30 minutes in length given to three separate classrooms, totaling approximately 380 students and 3 teachers participating. The students have already begun taking measurements in five of the six ENSO-related GLOBE protocols.

Dorian Janney (612/ADNET) met with 32 high school students and 2 teachers at Damascus High School in Maryland on October 14. They discussed plans for working together with the GLOBE ENSO Student Research Campaign and to collaborate with several GLOBE schools around the world using the mosquito protocol. They plan to meet regularly, both electronically and face-to-face, to continue these efforts during the school year.

Dorian Janney (612/ADNET) held a webinar for the GLOBE Mission Earth 2016 High School Professional Development and Training group in California. She shared information on the GPM mission science and technology, and showed them how to access GPM data. She also provided several good NASA-unique resources that they can use to access NASA Earth Science data and shared many of the best online NASA resources for high school students. There were 24 teachers and 2 team leaders in attendance.

Gala Wind (613/SSAI) gave a presentation to five third-grade classes of the HCPSS Bollman Bridge Elementary School about weather forecasting. The students discovered what it is like to interpret the surface wind/temperature/humidity maps to make their own weather forecast, which included issuing a tornado watch and later a tornado warning. Everyone likes a good twister.

On October 17, Dorian Janney (612/ADNET) and Pedro Falcon (JPL) ran the second webinar for the GLOBE ENSO Student Research Campaign. The focus was on learning more about the second phase of this campaign and reviewing the six protocols that are being used to collect data. Several GLOBE schools from around the world sent in slides to share how the El Niño conditions of late 2015 and early 2016 had impacted their locations. Over 20 GLOBE teachers were in attendance during the webinar.

Brian Campbell (610.W/GST) gave an online presentation on the SMAP Mission and an interactive, virtual demonstration of some of the tools needed to do the GLOBE SMAP Block Pattern Soil Moisture Protocol, on October 17, to teachers at the North Point Educational Service Center in Sandusky, Ohio. The teachers were part of the two-day "GLOBE Soil and Land Cover Workshop." The workshop was led by faculty at Bowling Green State University in Ohio. Sixteen, grades 4–12 teachers received the demonstration followed by a discussion of the current GLOBE ENSO Student Research Campaign.

On October 31, Kristen Weaver (612/SSAI) spoke about the GPM mission and NASA STEM careers to 6–8 graders at Parkland Magnet Middle School for Aerospace Technology in Rockville, Maryland. About 35 students came during their lunch hour to hear the presentation.

Kristen Weaver (612/SSAI) and Brian Campbell (610.W/GST) represented NASA Earth Science on November 2–3 at the 2016 STEM Festival at the Furnace Town Historical Site in Worcester County, Maryland. Kristen's activities highlighted the GPM mission with a focus on precipitation measurement using technology, progressing from rain gauges to satellites, as well as the GLOBE Observer app and clouds protocols. Brian's activities highlighted the SMAP mission, soil profiles, and GLOBE protocols including SMAP soil moisture, soil moisture sensors, and soil characterization. During this two-day, Maryland STEM event, 500 elementary school students and 26 teachers attended from six different elementary schools in Worcester County, Maryland. The schools attending were: Ocean City Elementary School, Buckingham Elementary School, Berlin Intermediate School, Pocomoke Elementary School, Snow Hill Elementary School, and Showell Elementary School.

On November 8, 40 high school students from Kangwon-do, Korea, supported by the Kangwon Land Welfare Foundation visited Goddard. Daeho Jin (613/USRA) and Wonsik Yoon (662/USRA) gave presentations introducing them to science and the life of a NASA scientist.

On November 10, Kristen Weaver (612/SSAI) talked about GLOBE Observer to a group of District of Columbia Public Schools students at the National Academy of Sciences as part of an event celebrating the first International Science Center and Science Museum Day. The event was sponsored by the Association of Science-Technology Centers and the United Nations Information Center. Approximately 100 high school students were in attendance, and the event was also streamed live (https://youtu.be/mHgy0aIp728?t=16m11s), with 50 views as of November 14.

On November 12, Holli Kohl (610/SSAI) and Kristen Weaver (612/SSAI) presented at the 4H Science Adventures program held at the University of Maryland, College Park. The group of 14 middle and high school students and six college helpers were introduced to the GLOBE Observer program, made cloud and surface temperature observations, and learned about the connection between ground and satellite measurements.

Dorian Janney (612/ADNET), Kristen Weaver (612/SSAI), and Brian Campbell (610.W/GST) designed and implemented the GLOBE ENSO Student Research Campaign on November 15. This webinar, led by Dorian and Kristen focused on the importance of collaboration in scientific research. Brian discussed several models for using collaboration as a learning tool. Several GLOBE teachers shared some best practices and challenges that they have faced when working collaboratively with other GLOBE schools around the world. The participants were shown how to use the GLOBE collaboration tool to find other GLOBE teachers to work with, and few ideas were highlighted for collaboration in the student research project cycle. Stephanie Schollaert Uz (616/GST) shared how she has used collaboration to conduct her research. The webinar finished with some quotes from students who have been collaborating during this school year who shared the positive benefits that have resulted from this interaction.

Brian Campbell (610.W/GST) gave an online presentation to Arima North, a secondary school in Trinidad on November 16. The purpose of the presentation was to highlight how the school can participate in the GLOBE ENSO Student Research Campaign. Protocols such as the SMAP Block Pattern Protocol and the Precipitation Protocol were highlighted, as well as the SMAP and GPM satellite missions. Brian has been collaborating with several GLOBE partners that live, work, and teach in Trinidad.

December 6, Dorian Janney (612/ADNET), Kristen Weaver (612/SSAI), Brian Campbell (610.W/GST) and Peter Falcon ran the fourth webinar for the GLOBE ENSO Student Research Campaign. Stephanie Schollaert Uz (616&610/GST) was a guest subject matter expert. She discussed how scientists share the results of their research with others in the scientific community and told about her upcoming research venture onboard a research ship. Over 20 GLOBE teachers were in attendance during the webinar.

On December 7, Dorian Janney (612/ADNET) met with 24 high school students and 1 teacher at Damascus High School in Maryland. They discussed plans for working together with the GLOBE ENSO Student Research Campaign and to collaborate with several GLOBE schools around the world using the mosquito protocol. They plan to meet regularly both electronically and in face-to-face meetings to continue these efforts during the school year.

Brian Campbell (610.W/GST) gave two classroom presentations on December 7 at the James M. Bennett High School in Salisbury, Maryland. The presentations discussed NASA Earth Science at Wallops and the GLOBE Program's Earth Observer Cloud App. Highlights included the ICESat-2, SMAP, and the GPM satellite missions, as well as the Operation IceBridge Airborne Campaign. Students were taken outside to take cloud observations and submit data via the GLOBE Observer Cloud App.

On December 7, Brian Campbell (610.W/GST) held a virtual discussion with eighth grade students from Chicago Public Schools. The students were creating science fair projects on SMAP soil moisture collection for the GLOBE Program. Brian has been serving as the NASA SMAP advisor for this student venture.

6.3. Public Outreach

Dorian Janney (612/ADNET) delivered a presentation outlining the science and technology behind the GPM mission on January 15 for the participants of the GLOBE Asia-Pacific Regional Meeting of Country Coordinators in Chiang Rai, Thailand. The 37 attendees included heads of secondary education for their countries, members of the STEM coordination council for Thailand, and representatives of the GLOBE office, as well as two GPM Earth SySTEM Ambassadors who are university professors in Thailand.

On January 18, Dorian Janney (612/ADNET) delivered a 45-minute presentation to 58 scientists, teachers, and GLOBE administrators on the science and technology behind many of NASA's Earth-observing missions, and explained how several of these missions were aligned with GLOBE protocols and thus had ongoing satellite collaboration campaigns. This was during the opening of the GLOBE Train-the-Trainer at Mae Fah Luang University in Chiang Rai, Thailand.

On January 22, Dorian Janney (612/ADNET) delivered the keynote presentation during the Thailand GLOBE Train-the-Trainer Celebration dinner, which was held at Mae Fah Luang University in Chiang Rai, Thailand. The presentation focused on sharing the science and technology behind the GPM mission. There were approximately 114 adults at this event.

On January 28, Dorian Janney (612/ADNET) taped both a television and a radio show at the Walailak University in Nakhon Si Thammarat, Thailand, describing the purpose of the GPM mission and the societal and research applications for GPM data. She also described how students are able to use the GLOBE Program protocols to gather precipitation data from the ground and can compare their data to that of GPM. The television and radio shows were scheduled for broadcast throughout Thailand during the week of January 29 through February 5.

Geoff Bland (610.W) was interviewed for the *Chemical & Engineering News* article "Drones Swarm to Science" (Davenport, Everts: Volume 94 Issue 9 | pp. 32–33: February 29; http://cen.acs.org/articles/94/i9/Drones-swarm-science.html). Of particular interest was NASA supported research using small drones for volcanic plume sampling (Pieri, et al, http://cen.acs.org/articles/94/i9/Drones-detect-threats-chemical-weapons.html).

On February 13–14, Kristen Weaver (612/USRA) staffed a table at the AAAS Family Days including hands-on demonstrations of GLOBE protocols for precipitation, surface temperature, and air temperature. Approximately 300 people visited the table over the course of the two days.

George Huffman (612) provided one in person and eight remote studio interviews and one telephone radio interview in the NASA El Niño Live Shots campaign on February 26.

On March 1, the GLOBE-El Niño Field Campaign team, including Brian Campbell (610.W/GST), Dorian Janney (612/ADNET) and Kristen Weaver (612/USRA), held the first webinar to kick off the field campaign, which featured guest scientist Dr. Veronica Nieves from JPL discussing the science of El Niño. In attendance were 55 individuals representing 15 U.S. states and Puerto Rico, plus 14 other. countries.

Dorian Janney (612/ADNET), Kristen Weaver (612/USRA), and Brian Campbell (610.W/GST) held the second webinar, in a series, for the GLOBE El Niño Field Campaign on March 8. This webinar featured the "nuts and bolts" of the campaign, as well as a GLOBE web site tour and a presentation on the campaign blog series. The campaign began on March 1 and has a total of 108 GLOBE protocol measurements since commencement. Dorian and Brian also held virtual office hours in response to this webinar on March 10.

On March 20, Holli Riebeek (610/SSAI) and Dorian Janney (612/ADNET) hosted and led hands-on activities a public event, the Sunday Experiment, at the NASA Goddard Visitor Center. Erica McGrath-Spangler (610.1/USRA) and Manisha Ganeshan (613/USRA) gave science talks. Stephanie Schollaert Uz (614/GST) prepared a Science on a Sphere playlist. An estimated 185 people attended, with 98 adults and 87 children.

Dorian Janney (612/ADNET) and George J. Huffman (612) presented the webinar, "Weather," as part of the National Science Teachers Association (NSTA) Webinar Series on May 5. A premier forum, this webinar series provided science content to teachers across the country and were archived for future use by NSTA members.

Xiaohua Pan (614/UMD/ESSIC) gave a talk to about 100 students at Gorman Crossing Elementary School in Maryland on April 21. Sharing with these young and eager learners, she talked about how atmospheric scientists contribute to the community, such as by monitoring air pollutions and performing weather forecast. Children were encouraged to protect environment through 3 R's (reuse, reduce, and recycle). The lenticular cards of Air Pollution around the World (NASA OMI NO_2) provided by Bryan Duncan (614) were shared as tools to encourage the children learn more about air pollutions.

NASA had a large presence at the U.S.A. Science & Engineering Festival that took place April 15–17 at the Walter E. Washington Convention Center in Washington, DC. Several hundred thousand visitors attended the event overall.

- The GPM outreach team hosted a table led by Kristen Weaver (USRA/612) and Dorian Janney (612/ADNET). Other volunteers at the table helping to share the science and technology of precipitation measurement with the general public were Eric Nelkin (612/SSAI), Ellen Gray (130/ADNET), Jacob Reed (617/Telophase), Jasper Lewis (612/UMBC), Amber Emory (612), Trena Farrell (130), Charles Hicks (443/Embedded Flight Systems), Deepak Patel (545), and Elaine Gunter (372/Ares Corp), as well as GPM Earth SySTEM Ambassador Michael Wilkinson. An estimated 2500 to 3000 attendees stopped by the GPM table.
- On April 16, Brian Campbell (610.W/GST) gave an impromptu interview at the festival with videographers from "*The Cloud and the Crowd*" and Periscope TV about citizen science and the SMAP mission. This interview was inside the NASA exhibit.
- On April 16, Brian Campbell (610.W/GST) participated in the NASA Meet and Greet at the festival. This hour-long activity was part of the NASA "Ask the Scientist and Engineers" event in the career pavilion and had people of all ages ask questions about NASA careers, NASA science, and NASA exploration.

On April 28, Dorian Janney (612/ADNET) worked with Deborah Klepp, Director of Environmental Quality and Transboundary Issues, to assist the U.S. State Department with their “Take Your Child to Work Day.” In this cross-agency effort, they ran two sessions for a total of 40 children and their parents. In her presentation, “Acid Rain,” Dorian discussed the work that GPM is doing to help us measure precipitation around the globe.

The East Pacific Origins and Characteristics of Hurricanes (EPOCH) Project successfully passed its system requirements review on June 29, the first major milestone for the project. EPOCH is part of the Hands On Project Experience (HOPE) Program, designed to train a junior-level workforce in the skills necessary for the future of NASA Flight Projects. The representatives from the team included PI Amber Emory (612), Project Manager Alfred Fordan (Code 840, WFF), Co-I and EXRAD radar PI Matt McLinden (555), Systems Engineer Giovanni De Amici (555), and Global Hawk team members Kirsten Fogg (AFRC), Robert Rivera (AFRC), and Mark Buschbacher (AFRC).

The 2016 GLOBE Annual Meeting was held in Estes Park, Colorado, July 16–21. Goddard participation included:

- Dorian Janney (612/ADNET) who presented about GPM’s collaboration with GLOBE during the Collaborating Satellite Missions and Campaigns panel discussion. She also demonstrated the precipitation measurement protocol for ground observations in a later conference session. About 150 people attended the panel discussion, and about 50 the protocol demonstration. In addition, Dorian had a poster on display in the exhibit hall entitled, “GLOBE-GPM Satellite Partnership: Freshwater! Our Most Precious Natural Resource.”
- Kristen Weaver (612/USRA) had a poster in the exhibit hall, entitled “The El Niño Field Campaign: Setting a Precedent for Multi-Mission/Multi-Protocol Field Campaigns,” which included information about involvement from the outreach teams for GPM, SMAP, and others in the student field campaign.
- Brian Campbell (610.W/GST) presented a talk discussing the two GLOBE field campaigns he led, including the SMAP Soil Moisture Measurement Field Campaign and the El Niño Field Campaign. Brian also presented three posters during the NASA session. The posters focused on the results from the SMAP Field Campaign, the upcoming GLOBE collaboration with the ICESat-2 mission, and the NASA-funded CAN project named the AEROKATS and ROVER Education Network (AREN). Brian also served as a trainer during the GLOBE Soil Characterization, Profile, and Identification training.
- Holli Riebeek Kohl (610/SSAI) presented two sessions on GLOBE Observer, the new non-student citizen science arm of the GLOBE Program. She also provided a poster exhibit on the program and attended planning meetings to map future implementation of citizen science within GLOBE.

Japanese science comic artist Hayanon presented a Climate and Radiation Laboratory special seminar on July 15, featuring her newest comic designed for middle school students entitled *Learning Earth Science with MIRUBO—Sun, Moon and Climate*, co-authored with Robert (Bob) Cahalan (610/Emeritus). In the book, Mirubo, the robotic dog, and Mol, an elementary school girl who is enthusiastic about science, discuss climate change with Bob Cahalan. Hayanon presented this book and briefly described her progress on two other science comic books, one about melting ice, featuring Claire Parkinson (615), and the other about monsoon–climate interactions, with William Lau (610/Emeritus). In addition, she created live portrait drawings of NASA scientists whom she met with during the visit. http://www.nasa.gov/topics/people/features/hayanon.html

On August 26, the Earth Observatory published a feature profile on Charles Ichoku (613) and his research on fires and precipitation in sub-Saharan Africa, “A Tale of Fire and Water: A NASA Scientist’s Quest to Understand the Rain in Africa.” http://earthobservatory.nasa.gov/Features/IchokuRain/

Joshua Stevens (613/SSAI) from the Earth Observatory Group produced a customized visualization of the Earth’s arctic region, which was presented to the attendees (foreign ministers and heads of delegations) of the White House Arctic Science Ministerial in late September.

On October 7, the GPM communication team hosted “Live Shots about Hurricane Matthew” and the science of hurricane research. Scott Braun (612), Owen Kelley (610.2/GMU), and Dalia Kirschbaum (617) gave 50 interviews, which included: 15 stations in top 20 markets, the Wall Street Journal, FOX NewsEdge, LiveScience.com, Discovery News, five radio interviews, and three MSNBC interviews. Visualizations are available at: https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=12387&button=recent.

Scott Braun (612), Dalia Kirschbaum (612), and Owen Kelley (610.2/GMU) held 48 interviews on October 8, showing NASA views of Hurricane Matthew and talked about the science of hurricanes. Answers to questions emphasized GPM observations of Matthew, NASA Global Hawk flights over Matthew as part of a NOAA campaign, and upcoming launches of GOES-R and CYGNSS. Live Shots interviews began at 5:50 a.m. and ended at about 11:40 a.m. Additional interviews were provided in the afternoon with FOX News, MSNBC, and another in the evening by Kirschbaum with MSNBC at their studio. Kirschbaum and Kelley did a Facebook Live event in the afternoon. Braun and Kirschbaum intereviewed with MSNBC on October 7. Highlights in this Live Shots campaign included: 15 stations in top 20 markets including two New York stations, Los Angeles, and Chicago; the Wall Street Journal; FOX NewsEdge; LiveScience.com; and Discovery News. They also held five radio interviews.

On October 18, Dorian Janney (612/ADNET) led the second of three webinars focused on the NASA-Rio partnership. This webinar focused on air quality, the impact of forest fires on the environment in Brazil, and the Urban Heat Island effect. It also showed how the city of Rio is responding to the challenge of monitoring air quality. Pawan Gupta (614/USRA) and Doug Morton (618) were presenters, and several scientists and end-users of NASA data in Rio also presented. There were 20 participants at the Rio Planetarium as well as many online participants. The recorded session was shown via Rio Educational television to secondary students.

Brian Campbell (610.W/GST) gave an impromptu talk on NASA Earth Science on the Science on a Sphere (SOS) at the NASA Wallops Visitors Center on November 9. Ten datasets were pulled from the SOS catalogue to show everything to the atmosphere, plus black carbon, precipitation, sea ice, and hurricanes. There were approximately 20 people at the 30-minute talk.

On November 20, Kristen Weaver (612/SSAI) organized the Sunday Experiment held at the Goddard Visitor Center focused on the theme of weather. Dennis Chesters (612) presented on the recently launched GOES-R satellite and Todd Toth (160/ADNET), Erica McGrath-Spangler (610.1/USRA), and Jasper Lewis (612/UMBC) assisted with activity tables. Attendance included 61 adults and 59 children.

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 come from outside NASA, and this series gives them a chance to visit with our scientists and discuss their latest ideas with experts. The following lectures were presented 2016 among the various laboratories.

Table 6.1: Atmospheric Sciences Distinguished Lecture Series

Seminar Series Coordinators: Luke Oman, Dong Wu, and Gail Skofronick Jackson

Date	Speaker	Title
January 21	Ralf Bennartz Vanderbilt University	*Satellite and ground-based observations of mixed-phase cloud physical and radiative processes*
February 11	Matthew Kumjian Pennsylvania State University	*Internal precipitation and vertical velocity structures within high-impact storms revealed by dual-polarization radar observations*
April 21	Russ Dickerson University of Maryland	*Air Pollution: How NASA science can be policy relevant*
May 5	Michael Prather University of California	*The NASA* EVS_2 *Atmospheric Tomography Mission (ATOM): A unique design to test the tropospheric reactivity of chemistry-climate models*
May 19	Tristan L'Ecuyer University of Wisconsin-Madison	*New satellite perspectives on the Arctic energy and water cycles*
May 24	Triuvalam Krishnamurti Florida State University	*Scale interactions during passage of MJO and other events*
July 21	Walter Petersen Marshall Space Flight Center	*GPM Level 1 Science Requirements: A View of science and performance from the ground*
August 18	Judith Lean Naval Research Laboratory	*Modern Climate Change: The past (and future?) twenty years*
September 15	Peter Pilewskie University of Colorado	*Climate Monitoring from the International Space Station: TSIS and CLARREO Pathfinder*
October 20	Ronald Cohen University of California	*Ubiquitous in situ sensing of* CO_2 *and other trace gases*
December 8	Wolfgang Steinbrecht Met. Obs. Hohenpeissenberg, Germany	*Stratospheric ozone trends—observations and models*

Table 6.2: Mesoscale Atmospheric Processes

Date	Speaker	Title
March 23	Ethan Nelson University of Wisconsin-Madison	*Warm rain latent heating retrievals for CloudSat and radar characteristics of microphysical processes*
April 7	Ralph Milliff Cooperative Institute for Research in environ-mental Sciences – University of Colorado	*Toward a Bayesian hierarchical model for the Madden-Julian Oscillation; Multi-platform, multi-scale data stage inputs and process model considerations*

Table 6.3: Climate and Radiation

Seminar Series Coordinators: Robert Levy, Yaping Zhou, Hongbin Yu, and Lauren Zamora

Date	Speaker	Title
January 6	Bastiaan van Diedenhoven Center for Climate System Research, Columbia University, NASA Goddard Institute for Space Studies	*Cloud variability observed using multi-angular, multi-wavelength measurements of total and polarized reflectances at high spatial and angular resolution*
January 20	Ross J Salawitch University of Maryland-ESSIC, Department of Atmospheric and Oceanic Science	*A critical evaluation of global warming*
February 3	Zhaohua Wu Department of Earth, Ocean and Atmospheric Science, Center for Ocean-Atmospheric Prediction Studies	*The Florida State University, "On the spatiotemporal evolution of global surface warming*
February 17	Patrick C. Taylor, Climate Science Branch, Science Directorate NASA's Langley Research Center	*Sea ice says jump, Arctic low clouds say why bother?*
March 2	Thomas F. Eck GSFC Biospheric Sciences Laboratory, Code 618/ GESTAR-USRA,	*Aerosol modification by clouds and aerosol interac-tion/transport with clouds as observed from AERONET measurements and retrievals*
March 16	Pawan Gupta GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614/GESTAR-USRA	*MODIS dark target aerosol retrieval over urban area and aerosol trends over global cities*
April 6	Thomas Fauchez, USRA-NPP Fellow, Climate & Radiation Laboratory, Code 613	*Impact of heterogeneities and 3D effects in cirrus clouds from TIR to VIS wavelengths*
April 13	Robert (Bob) Swap Radiation Science Program, Earth Science Division, NASA HQ on rotation from the Department of Environmental Science at the University of Virginia	*Interdisciplinary science in Southern Africa: From nanometers to megameters*
May 18	Amin Koorehpazan Dezfuli USRA-NPP Fellow, Climate & Radiation Laboratory, Code 613	*Driving factors of rainfall variability in equatorial Africa*
June 15	Randal D. Koster Global Modeling and Assimilation Office, Code 610.1	*Soil moisture, rainfall, and the general circulation: An overview of two studies*
September 16	Pavlos Kollias Stony Brook University, Brookhaven National Laboratory-DOE and University of Cologne, Germany	*The EarthCARE cloud profiling radar: capabilities, products and applications*
September 19	Maria Sand Center for International Climate and Environmental Research – Oslo, Guest Researcher: NASA Goddard Institute for Space Studies	*Arctic temperature change to emissions of black carbon aerosols*

Date	Speaker	Title
October 5	Feng Li GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614/GESTAR-USRA,	*Impacts of stratospheric ozone depletion on Southern Hemisphere climate change: A coupled atmosphere-ocean-chemistry GEOS-5 model study*
November 2	Kirk Knobelspiesse GSFC Ocean Ecology Laboratory, Code 616	*Preliminary cloud observations from the Research Scanning Polarimeter (RSP) during the first ORACLES field campaign*
November 16	Ivy Tan USRA-NPP Fellow, Climate and Radiation Laboratory, Code 613	*The climatic impact of thermodynamic phase partitioning in mixed-phase clouds*
December 7	Teppei J. Yasunari Assistant Professor, Faculty of Engineering, Hokkaido University, Japan	*Characteristics of transboundary transports of Asian dust and biomass-burning smoke to Northern Japan*

6.4.1. Maniac Talks

Maniac Talks are about what inspired people to do what they are doing now in their career. They are about the driving forces and motivators. What keeps them going? How have they overcome obstacles? Seminar Series Coordinator: Charles Gatebe, GESTAR-USRA, Climate and Radiation Laboratory

Date	Speaker	Title
February 1	Ralph Kahn GSFC Climate and Radiation Laboratory, Code 613	*The stories data tell*
February 24	Joel Susskind NASA/GSFC, Earth Sciences Division, Code 610	*Journey from chemistry to (who would have thought it) meteorology*
April 13	Florence (Wee Ming) Tan GSFC ExoMars Rover Project, Solar System Exploration Division, Code 565	*From Malaysia to Mars*
May 2	Jagadish Shukla Distinguished Professor, George Mason University	*From Ballia to Boston: A village boy goes to MIT and Goddard*
May 25	Richard R. Fisher GSF, Heliophysics Sciences Division (Emeritus), NASA Headquarters	*The Seventh Cycle – What I needed to know and learned from the secrets of the Japanese garden*
June 22	Cynthia Rosenzweig NASA GISS	*What if and so what? Climate change and corn/wheat/rice/soybeans (and a few words on cities)*
July 25	Charles Ichoku GSFC Climate and Radiation Laboratory, Code 613	*Reminiscences of a scientist's journey from Nawfia to NASA*
August 24	Stephen G. Ungar NASA/GSFC, EO-1 Scientist Emeritus, USRA	*My intellectual journey from "Idiot" to "Savant"*
September 30	Alexander Kashlinsky NASA/GSFC, Astrophysics Science Division, SSAI	*How I planned to travel to space and got to study it instead: a personal journey through 6 different countries in a changing world*

Date	Speaker	Title
November 3	V. Ramaswamy NOAA	*From physics to the science of weather and climate: The fun and excitement of scaling the boundaries across disciplines*
November 16	Michael Kurylo GSFC Atmospheric Chemistry and Dynamics Laboratory, USRA	*An uncharted journey: How I became an atmospheric scientist rather than a cowboy or a farmer*

Table 6.4: Atmospheric Chemistry and Dynamics

Date	Speaker	Title
January 7	Gordon Labow and Jay Herman	*AGU pet peeves/AGU DSCOVR talk*
January 14	Anne Thompson and Bryan Duncan GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614	*AQAST Team meeting talks*
January 21	Nick Krotkov GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614	*SO_2 measurements at NASA: from TOMS to OMPS*
February 4	PK Bhartia GSFC Earth Sciences Division-Atmospheres, Code 610	*Overview of limb scattering technique and OMPS limb data products*
February 11	Elizabeth Schundler OPTRA	*A novel instrument system for greenhouse gas measurements*
February 18	Qing Liang	*Can we use ground-based measurements of HCFCs and HFCs to derive their emissions, lifetimes, and global OH abundance?*
February 25	Glenn Wolfe Jason St. Clair	*Formaldehyde, forests, and fighter jets*
March 3	James Gleason GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614	*ROSES 2016 discussion*
March 24	Dalia Kirschbaum Code 617	*Goddard Applied Sciences discussion*
March 31	Kennedy Chioma Charles Herbert Flowers High School	*Senior Thesis practice talk*
April 7	Valentina Aquila	*Improvements in GEOS-5 simulations of stratospheric aerosol*
April 21	Dan Anderson	*A tropical tropospheric source of high ozone/low water structures*
April 28	Paul Newman NASA GSFC, Earth Sciences Division-Atmospheres, Code 610	*SPARC report on the mystery of carbon tetrachloride*
May 26	Joanna Joiner GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614	*The faces behind the OMI core team, lessons learned from an EV-I proposal, and developments in satellite observations of chlorophyll fluorescence*
June 2	Julie Nicely USRA	*An observationally constrained evaluation of the oxidative capacity in the tropical Western Pacific*

Date	Speaker	Title
June 9	Junhua Liu GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614/USRA	*Source attribution of interannual variability of tropospheric ozone over the southern ocean*
June 16	Pete Colarco GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614	*A GEOS-5 Based observation simulation experiment: Assessment of OMI aerosol retrieval algorithms using synthetic radiances provided by the MERRAero aerosol analysis*
June 23	Paul Newman GSFC Earth Sciences Division-Atmospheres, Code 610	*The oddball quasi-biennial oscillation of 2015–2016*
July 7	Hans Mayr	*Modeling the solar cycle variations of the quasi-biennial oscillation (QBO)*
July 14	Jerry Ziemke	*Recent analyses of tropospheric ozone, convection, and aerosols over four decades from satellite measurements and model simulations*
July 21	Luke Oman GSFC Atmospheric Chemistry and Dynamics Laboratory, Code 614	*Bromine, bugs, and budgets*
July 28	Ed Nowottnick GESTAR	*Exploring dust impacts on the first weakening phase of Hurricane Nadine during HS3*
August 4	Leonid Yurganov JCET	*TIR satellite Arctic methane data: evaluation and preliminary estimates of emission*
August 11	Ryan Stauffer NPP	*Linkages among U.S. ozonesonde profile variability, meteorology, and surface ozone measurements based on self-organizing map clustering*
August 25	Chaim Garfinkel Hebrew University	*Two manifestations of coupling between stratospheric and tropospheric trends over the satellite era*
September 1	Gordon Labow, Susan Strahan, and Ryan Stauffer	*QOS practice talks*
September 8	Ana Prados	*ARSET update*
September 15	Nick Krotkov GSFC Atmospheric Chemistry and Dynamics Lab, Code 614	*Satellite retrievals of air quality and climate relevant trace gases*
October 13	Yasin Elshorbany ESSIC	*The tropospheric oxidizing capacity: Current challenges and future prospects*
October 20	Jae Lee JCET	*The warming in 2016 and its relation with stratospheric cooling*
November 3	Debra Kollonige UMD	*Total-column observations and their use for estimating surface* NO_2
November 10	John Sullivan USRA	*Observations of downwind pollution at the Taehwa Forest site during KORUS-AQ*
December 1	Carrie Anderson Code 691	*Solid-state photochemistry as a formation mechanism for stratospheric clouds on Titan and Earth*
December 8	Elena Spinei	*Pandora measurements during CINDI-2*

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 Goddard and other organizations in the Washington, D.C., metropolitan area (including NOAA, NIST, 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 community, bi-weekly AeroCenter seminars, annual poster session, and annual AeroCenter update.

In 2016, the AeroCenter held 18 seminars with typically 30 to 40 physical attendees. Seminars were also broadcasted via Vydio, and between 5 and 10 attendees joined remotely. In June AeroCenter member Richard Kleidman organized the Yoram Kaufman Memorial Symposium, in honor of Yoram Kaufman who, with Lorrain Remer, initiated AeroCenter in 2001. Since then AeroCenter has played a prime role in the local aerosol community, facilitating the exchange of ideas sand results across NASA laboratories and other institutions.

For further information, please contact Valentina Aquila (valentina.aquila@nasa.gov).

6.6. NASA Cloud-Precipitation Center Annual Report

Cloud and precipitation processes and feedback remain among the largest uncertainties for predicting Earth's energy and water cycle and budget, as well as their socio-economic impacts such as agricultural harvest, water resource management, and even power generation. In order to increase knowledge and understanding of these processes, the NASA GSFC Cloud-Precipitation Center (CPC), was established in 2016 as a cross-laboratory union for cloud-precipitation researchers primarily at GSFC. CPC offers discussions and collaborations across NASA laboratories through an interactive seminar series.

In the 2016–2017 season, CPC hosted 13 seminars, and the current CPC membership stands at 75. Main seminar topics include (1) cloud-precipitation processes and interactions with surface process, aerosols, mesoscale dynamics, and large-scale circulations, (2) remote sensing, radiative transfer, and scattering theory of cloud and precipitation particles, (3) cloud microphysics and convection measurements and parameterizations, and (4) satellite missions and field campaigns associated with cloud and precipitation processes.

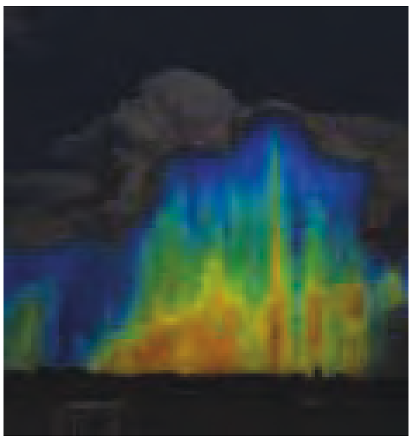
7. ATMOSPHERIC SCIENCE IN THE NEWS

The following pages contain news articles and press releases that describe some of the Laboratory's activities during 2016.

Size matters: NASA measures raindrop sizes from space to understand storms

Published: Friday, April 1, 2016,13:52

in Astronomy & Space



Credits: NASA/Goddard

Not all raindrops are created equal. The size of falling raindrops depends on several factors, including where the cloud producing the drops is located on the globe and where the drops originate in the cloud. For the first time, scientists have three-dimensional snapshots of raindrops and snowflakes around the world from space, thanks to the joint NASA and Japan Aerospace Exploration Agency Global Precipitation Measurement (GPM) mission. With the new global data on raindrop and snowflake sizes this mission provides, scientists can improve rainfall estimates from satellite data and in numerical weather forecast models, helping us better understand and prepare for extreme weather events. "The drop size distribution is one of many factors that determines how big a storm will grow, how long it will last and how much rain it will ultimately produce," said Joe Munchak, research meteorologist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "We've never been able to see how water droplet sizes vary globally until now."

Storm clouds contain a wide variety of drop sizes that ultimately fall as rain or snow. In general, in the cores of clouds the drops tend to be bigger because they collide with each other and aggregate as they fall towards the Earth's surface, while smaller droplets occur at the edges and higher altitudes. Drops tend to be small when they miss colliding into others or break apart. Scientists refer to the number of drops and snowflakes of different sizes at various locations within a cloud as the "particle size distribution."

In order to accurately know how much precipitation is falling in a storm, scientists need to understand the ratio of large drops to smaller or medium sized drops. Previously, researchers had to make assumptions of the ratio because earlier studies were conducted in isolated locations and global data were limited, said Munchak.

"Without knowing the relationship or the ratio of those large drops to the smaller or medium sized drops, we can have a big error in how much rain we know fell and that can have some big implications for knowing long term accumulations which can help with flash flood predictions," said Munchak.

With GPM's three-dimensional snapshots of drop size distribution, scientists can also gain insight into the structure of a storm and how it will behave. Drop size distribution influences storm growth by changing the rate of evaporation of rain as it falls through dry air, said Munchak. Smaller drops, for instance, will tend to evaporate faster and subsequently cool the air more. This leads to stronger flow of downward moving air that can cause damaging winds when they reach the ground. However, these same downdrafts can interfere with the upward flowing air that fuels the storm and cause the storm to weaken or dissipate.

"GPM measurements will really help predict these complex interactions that depend in part of the drop size distribution," said Munchak.

GPM was launched in 2014 and carries the first Dual-frequency Precipitation Radar (DPR) to fly in space, as well as a multi-channel GPM Microwave Imager (GMI). The DPR makes detailed 3D measurements of rainfall, while the GMI uses a set of 13 optimized frequencies to retrieve heavy, moderate, and light precipitation measurements at the Earth's surface. As GPM improves our understanding of precipitation from space, that information will be vital in improving weather models and forecasts.

Source: NASA's Goddard Space Flight Center

Joshua Stevens—Visualizing NASA's World

April 6, 2016

Photo Credit: NASA/W. Hrybyk

Name: Joshua Stevens

Title: QA Lead for Data Visualization for NASA Earth Observatory

Organization: Code 613, Climate and Radiation Laboratory, Earth Sciences Directorate

What do you do and what is most interesting about your role here at Goddard? How do you help support Goddard's mission?

I have two primary roles at Goddard: as a data visualizer, I translate data from NASA missions and instruments into intuitive maps, charts and graphics. Humans are visual beings, and graphics have incredible power to tell stories. The Earth Observatory relies on the communicative power of imagery to share NASA science with a large and diverse audience.

My other role is to ensure that our visualizations meet a high standard of quality and are consistent with established conventions and current research within the fields of cartography, visual perception and data visualization. I create style guides that document our use of color, typography and overall design. This enables our visualizations to be consistent and accurate, while performing well across different media and usage scenarios.

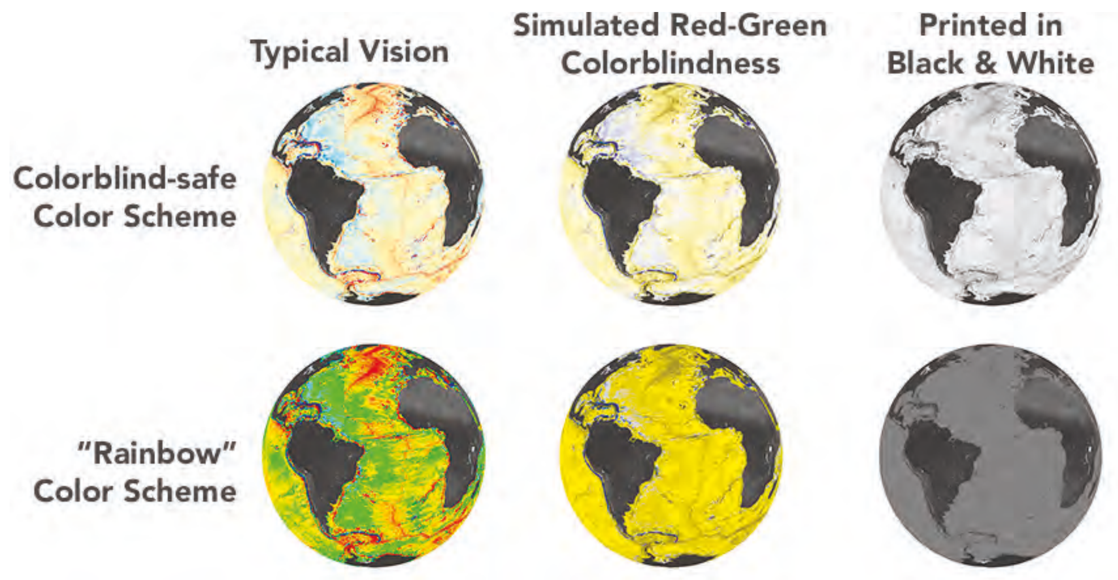
As an example of why we rely on the science of perception in our visualizations: a sizeable portion of the population is red-green colorblind, meaning they have difficulty distinguishing between those colors. All of our data visualizations are colorblind-friendly and are interpretable by our audience. This is among the many reasons you will not find the "rainbow" color palette used in our work.

What is a typical day on the job like for you?

This is what makes my job really exciting: there are not many typical days.

Part of my job as a visual communicator is knowing how to distill complex findings into something the public can understand. But the stories and research that need communicating constantly change, and the Earth Observatory tells a new story every single day. A lot of science happens at Goddard and other NASA facilities, and numerous projects at universities and research labs use NASA instruments all the time. That means there is always something super interesting to share.

The Earth Observatory also publishes imagery of natural hazards and other events. Sometimes this can be predictable (e.g., hurricane season), but often a new event will happen that forces me to put down a current project and rapidly switch gears to visualize a breaking story.



All of our data visualizations are colorblind-friendly and are interpretable by our audience. This is among the many reasons you will not find the "rainbow" color palette used in our work.

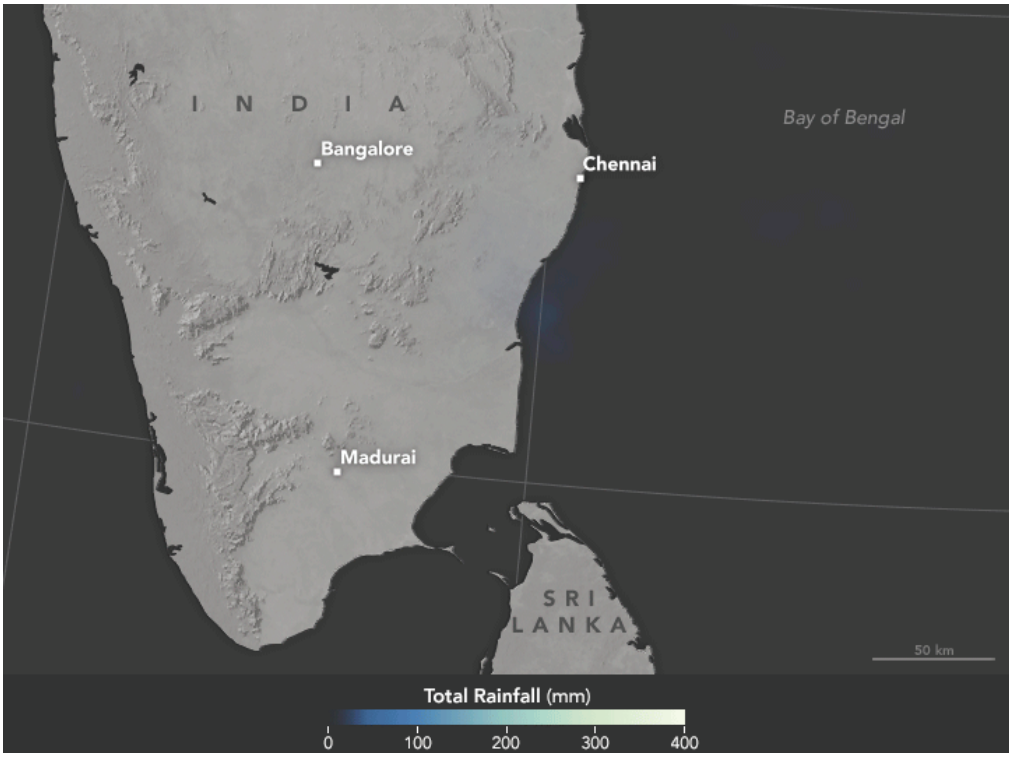
Image Credit: J. Stevens/NASA

What is typical from day to day is that I am always on the lookout for new insights that can be gleaned from NASA's continuous stream of data and the research it enables. I enjoy being able to see the world through a variety of satellites each day, either looking for a particular event or just a beautiful image of a remote corner of Earth.

How important is teamwork or collaboration with others to your being able to do your job?

Collaboration makes my job possible. The Earth Observatory involves work in writing, data visualization, web development and overall project management. Our team is small and we publish daily, so we lean on each other to make things happen.

Each and every one of our visualizations accompanies an article written by one of our science writers. These articles are the result of a ton of effort in reporting, fact checking and review. The imagery and text rely on one another to tell the whole story, and both are made possible by the web development that makes our site function.



Animated GIF showing a visualization of a breaking news story concerning rainfall and flooding in India.
Image Credit: J. Stevens/NASA

The visualizations themselves are also the result of teamwork, in three major ways. First, the Earth Observatory uses a strict editorial process: nothing ships from us without internal review and critique. Second, many visualizations are the result of both of our visualizers, either in gathering data or passing a visualization back and forth as improvements are made. And third, external collaboration is a big factor in my job. Although much of the data I use is available directly from a particular project, I often work with scientists in close collaboration to acquire their data and process it in a way consistent with their methodology. Many—if not most—research projects involve several data sources, and it is important that we bring the data together in a way that is congruent with the science being reported.

Why do you like your job and come to work every day?

As the saying goes, "Do something you love and you'll never work a day in your life." That is absolutely true of my job. I love what I do and Goddard is a fantastic place to do it.

Why did you choose your profession?

As a young student, I never knew exactly what I wanted to do. So I studied a bunch of topics that interested me. Throughout my undergrad years, I had changed my major three different times. I started out in photography, switched to graphic design, then switched for the second time to computer science. During my junior year I wanted to find a way to bring all three of these interests together and that is when I discovered Geographic Information Science and cartography. I switched my major that year.

I went on to graduate school to focus more on the scientific study of design and perception within cartography and visualization. Although my path was indirect, I couldn't have planned a better career trajectory if I tried: design, perception and computer science are the bread and butter of effective data visualization.

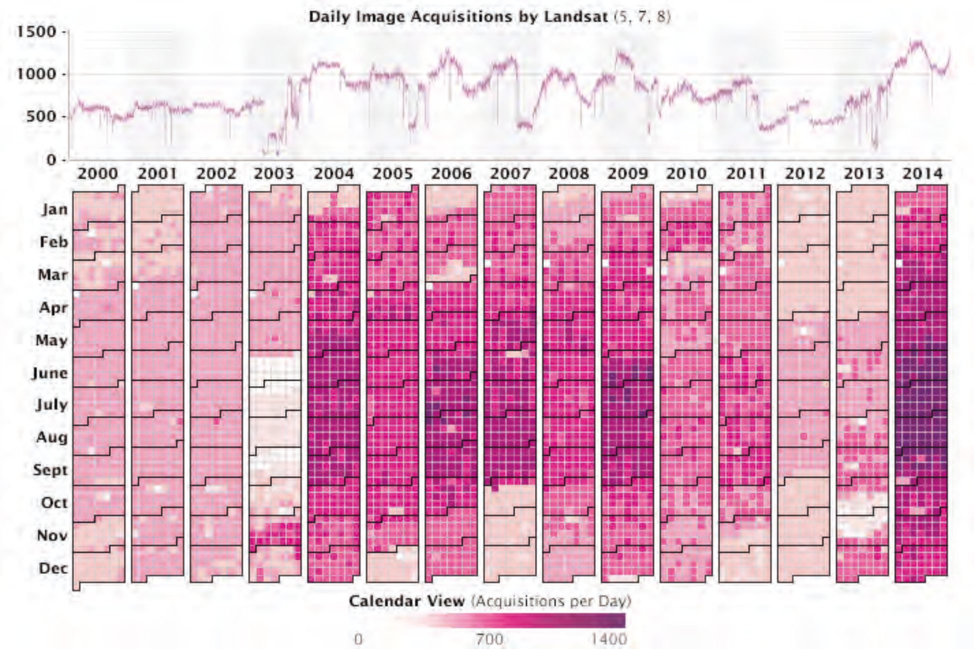


Chart which shows the number of Landsat images acquired by NASA.

Image Credit: J. Stevens/NASA

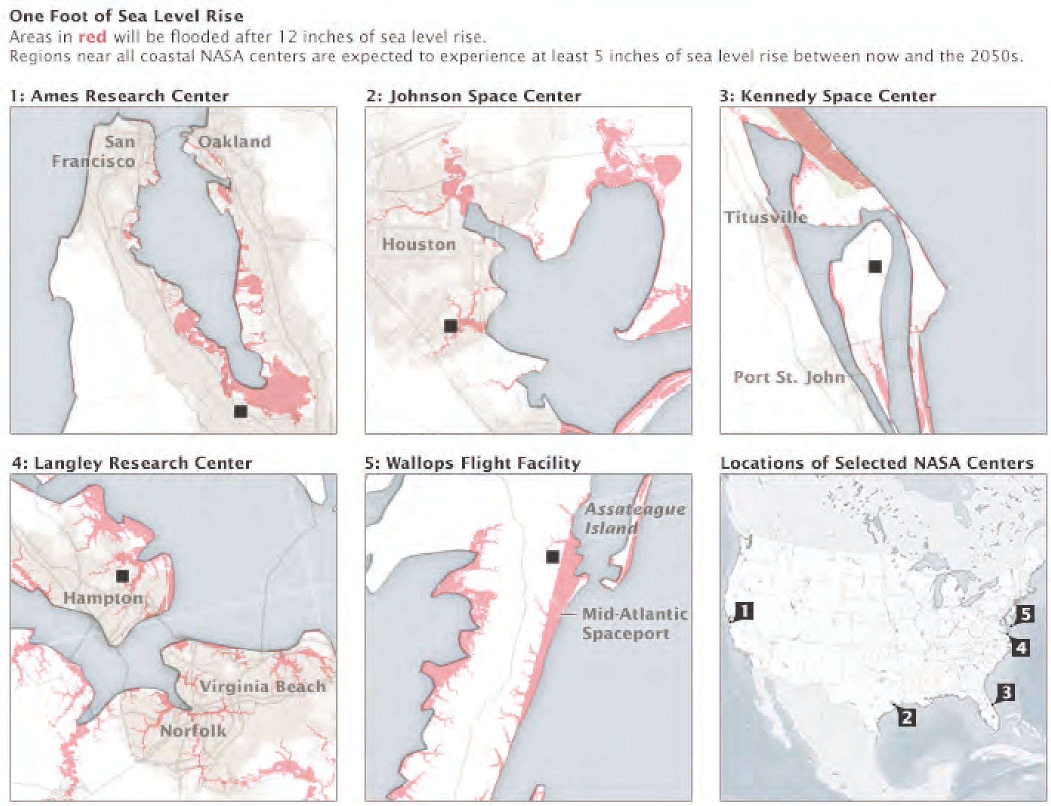
Earth Observatory image of Denali that Stevens added to for story purposes.

Image Credit: J. Stevens/NASA

What is the coolest thing you've ever done as part of your job at Goddard?

We design our imagery for a broad audience, and it is always cool to wake up and see our visualizations in the news. It feels good to know our efforts to make things interpretable and easy to share routinely pay off.

From time to time I get called to review graphics and images that are not yet public. Being one of the first people to see something new is always exciting, too.



Map showing locations of five NASA centers with highlighting to illustrate potential flooding if sea levels were to increase by 12 inches.

Image Credit: J. Stevens/NASA

If you weren't in your current profession, what would you be doing?

Before coming to work at Goddard, I was an instructor teaching map design and geography to university students, while conducting research in visualization. I enjoyed that a lot.

A bit unrealistic, but I would also like to work on maps and visualizations for video games. Games these days collect a wealth of data about the scenarios that unfold during gameplay, and visualization could play a major role in that. We have already seen this happen in sports analytics. Visualization in the game industry is off to a slow start and I feel like it will really grow in the coming years as statistics and visual breakdowns become more integral to competitive strategy.

Do you have a mentor or are you a mentor? If so, please tell us the most important advice you gave or learned?

I am fortunate in having been surrounded by a number of incredible teachers and mentors as I pursued my career. Kirk Goldsberry, who advised my master's thesis, introduced me to cartography and the importance of thinking spatially as an undergrad. He has given me a lot of advice over the years, but one bit stands out: strike when the iron is hot. That's good advice that applies to almost every situation one is in.

Do you have a favorite way or place to kick back, relax or have fun?

My son is about to turn 2, and I spend as much of my free time playing with him as I can. He really likes Hot Wheels, so I am about to begin a project that incorporates a small Raspberry Pi computer and some small screens to create a miniature "Jumbotron" for slow-mo replays of his cars.

Do you have a favorite book, magazine, movie or TV show? What are you reading and what is next on your reading list?

I'm a big fan of "A Song of Ice and Fire" book series and "Game of Thrones" on TV. If George R. R. Martin ever wants some great maps of Westeros, I think I know someone who is interested.

What is your favorite non-work related website/blog/app/magazine?

I'm a moderator of /r/DataIsBeautiful on Reddit, so I spend some time here and there helping to grow our community of data visualization enthusiasts (we have more than 5 million subscribers currently).

Is there some place in the world that you want to visit, or some place you have been and want to go back and visit again?

During my doctoral work I had a fellowship that allowed me to study at the University of Zurich in Switzerland for a short time. The academic opportunity was incredible, and it didn't take long for me to fall in love with the country. I look forward to returning someday.

Joshua Stevens
NASA's Goddard Space Flight Center

Last Updated: April 7, 2016

Editor: Lynn Jenner

Source: NASA's Goddard Space Flight Center

Expanding tropics pushing high altitude clouds towards poles, NASA study finds

Published: Friday, May 6, 2016 - 13:36

Earth & Climate

Image Credit: NASA

A new NASA analysis of 30-years of satellite data suggests that a previously observed trend of high altitude clouds in the mid-latitudes shifting toward the poles is caused primarily by the expansion of the tropics. Clouds are among the most important mediators of heat reaching Earth's surface. Where clouds are absent, darker surfaces like the ocean or vegetated land absorb heat, but where clouds occur their white tops reflect incoming sunlight away, which can cause a cooling effect on Earth's surface. Where and how the distribution of cloud patterns change strongly affects Earth's climate. Understanding the underlying causes of cloud migration will allow researchers to better predict how they may affect Earth's climate in the future.

George Tselioudis, a climate scientist at NASA's Goddard Institute for Space Studies and Columbia University in New York City, was interested in which air currents were shifting clouds at high altitude - between about three and a half and six miles high - toward the poles.

The previous suggested reason was that climate change was shifting storms and the powerful air currents known as the jet streams - including the one that traverses the United States - toward the poles, which in turn were driving the movement of the clouds.

To see if that was the case, Tselioudis and his colleagues analyzed the International Satellite Cloud Climatology Project data set, which combines cloud data from operational weather satellites, including those run by the National Oceanic and Atmospheric Administration, to provide a 30-year record of detailed cloud observations. They combined the cloud data with a computer re-creation of Earth's air currents for the same period driven by multiple surface observations and satellite data sets.

What they discovered was that the poleward shift of the clouds, which occurs in both the Northern and Southern Hemispheres, connected more strongly with the expansion of the tropics, defined by the general circulation Hadley cell, than with the movement of the jets.

The Hadley cell is one of the major ways air is moved around the planet. Existing in both hemispheres, it starts when air in the tropics, which is heated at the surface by intense sunlight, warms and rises. At high altitudes it is pushed away from the equator towards the mid-latitudes to the north and south, then it begins to sink back to Earth's surface, closing the loop.

"What we find, and other people have found it as well, is that the sinking branch of the Hadley cell, as the climate warms, tends to be moving poleward," said Tselioudis. "It's like you're making the tropical region bigger." And that expansion causes the tropical air currents to blow into the high altitude clouds, pushing them toward the poles, he said. The results were published in *Geophysical Research Letters,* a journal of the American Geophysical Union.

Scientists are working to understand exactly why the tropics are expanding, which they believe is related to a warming climate.

The poleward shift of high altitude clouds affects how much sunlight reaches Earth's surface because when they move, they reveal what's below.

"It's like pulling a curtain," said Tselioudis. And what tends to be revealed depends on location - which in turn affects whether the surface below warms or not.

"Sometimes when that curtain is pulled, as in the case over the North Atlantic ocean in the winter months, this reduces the overall cloud cover" in the lower mid-latitudes, the temperate regions outside of the tropics, Tselioudis said. The high altitude clouds clear to reveal dark ocean below - which absorbs incoming sunlight and causes a warming effect.

However, in the Southern Ocean around Antarctica, the high altitude clouds usually clear out of the way to reveal lower altitude clouds below - which continue to reflect sunlight from their white tops, causing little effect on the solar radiation reaching the surface.

When the results are taken together, the bottom line is that the cloud interactions with atmospheric circulation and solar radiation are complicated, and the tropical circulation appears to play a dominant role, said Tselioudis.

That information is a new insight that will likely be used by the climate modeling community, including the scientists who contribute modeling expertise to the Intergovernmental Panel on Climate Change, said Lazaros Oreopoulos, a cloud and radiation budget researcher at NASA's Goddard Space Flight Center in Greenbelt, Maryland, who was not involved in the study. Climate modelers aim for their computer simulations to correspond as closely to reality as possible in order to reliably predict Earth's future climate.

"If current behavior is not well simulated, then confidence in predicted future behavior will be lower," Oreopoulos said. "I anticipate this study to be looked at carefully and affect thinking on these matters."

Source: **NASA's Goddard Space Flight Center**

NASA satellite data could help reduce flights sidelined by volcanic eruptions

Published: Saturday, May 14, 2016 - 19:23

Earth & Climate

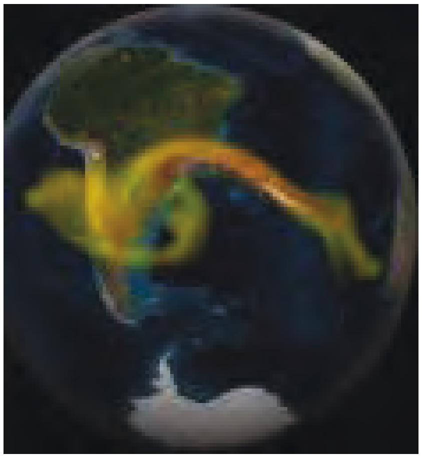


Image Credit: NASA

A volcano erupting and spewing ash into the sky can cover nearby areas under a thick coating of ash and can also have consequences for aviation safety. Airline traffic changes due to a recent volcanic eruption can rack up unanticipated expenses to flight cancellations, lengthy diversions and additional fuel costs from rerouting. Airlines are prudently cautious, because volcanic ash is especially dangerous to airplanes, as ash can melt within an operating aircraft engine, resulting in possible engine failure. In the aftermath of a volcanic eruption, airlines typically consult with local weather agencies to determine flight safety, and those decisions today are largely based on manual estimates with information obtained from a worldwide network of Volcanic Ash Advisory Centers. These centers are finding timely and more accurate satellite data beneficial.

Researchers at NASA's Goddard Space Flight Center in Greenbelt, Maryland, are using already available satellite measurements of sulfur dioxide (SO2), a main components of volcanic emissions, along with the more recent ability to map the location and vertical profiles of volcanic aerosols. Researchers are doing this in a number of ways.

A volcanic cloud contains two kinds of aerosols: sulfuric acid droplets converted from SO2 and silicate volcanic ash. Satellites can detect volcanic ash by observing the scattering of ultraviolet light from the sun. For aviation, volcanic ash is potentially the most deadly because of the danger to aircraft engines. While measurements of aerosol absorption in ultraviolet do not differentiate between the smoke, dust and ash aerosols, only volcanic clouds contain significant abundances of SO2, so satellite measurements of SO2 are especially valuable for unambiguous identification of volcanic clouds.

Knowing both the physical location and the altitude distribution of aerosols in the volcanic cloud allow more accurate forecasts in the days, weeks and months after an eruption. "The capability of mapping the full extent of a three-dimensional structure of a moving volcanic cloud has never been done before," said Nickolay A. Krotkov, physical research scientist with the Atmospheric Chemistry and Dynamics Laboratory at NASA Goddard.

Researchers are currently making these measurements using the Limb Profiler instrument, part of Ozone Mapping Profiler Suite (OMPS) instrument, currently flying on the joint NASA/National Oceanic and Atmospheric Administration (NOAA))/Department of Defense Suomi National Polar-orbiting Partnership (Suomi NPP) satellite, launched in October 2011.

OMPS is a three-part instrument: a nadir mapper that maps ozone, SO2 and aerosols; a nadir profiler that measures the vertical distribution of ozone in the stratosphere; and a limb profiler that measures aerosols in the upper troposphere, stratosphere and mesosphere with high vertical resolution.

“With the OMPS instrument, the volcanic cloud is mapped as Suomi NPP flies directly overhead and then as it looks back, it observes three vertical slices of the cloud,” said Eric Hughes, a research assistant at the University of Maryland, who is working with Krotkov at NASA Goddard.

Knowing the timing and duration of an eruption, the altitude and amount of the volcanic emissions are critical for an accurate volcanic forecast model being developed at the Goddard Modeling and Assimilation Office. The height of the plume is particularly critical for forecasting the direction of the plume. Even several kilometers of height can make a significant difference in predicting plume movement. More accurate volcanic cloud forecasts could reduce airline cancellations and rerouting costs.

While aviation is a short-term immediate application for volcanic cloud modeling, there are also long-term climate applications. “Sulfate aerosols formed after large volcanic eruptions affect the radiation balance and can linger in the stratosphere for a couple of years,” said Krotkov.

There have been large volcanic eruptions that have contributed to short-term cooling of Earth from the SO2 that reaches the stratosphere, which is what happened following the Philippines Mount Pinatubo eruption in June 1991. During volcanic eruptions, SO2 converts to sulfuric acid aerosols. Now researchers are studying the impacts of deliberately injecting SO2 into the stratosphere to contract the effects of global warming, known as climate intervention.

“Nature gives us these volcanic perturbations and then we can see the impact on climate,” Krotkov said. “These are the short- and long-term consequences of volcanic eruptions that have both aviation and climate applications.”

Source: NASA’s Goddard Space Flight Center

NASA satellite finds unreported sources of toxic air pollution

Published: Wednesday, June 1, 2016 - 21:03 in

Earth & Climate

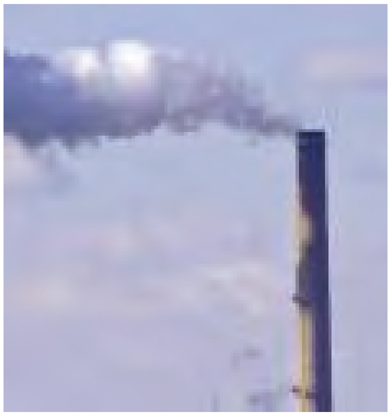


Image Credit: EPA

Using a new satellite-based method, scientists at NASA, Environment and Climate Change Canada, and two universities have located 39 unreported and major human-made sources of toxic sulfur dioxide emissions. A known health hazard and contributor to acid rain, sulfur dioxide (SO2) is one of six air pollutants regulated by the U.S. Environmental Protection Agency. Current, sulfur dioxide monitoring activities include the use of emission inventories that are derived from ground-based measurements and factors, such as fuel usage. The inventories are used to evaluate regulatory policies for air quality improvements and to anticipate future emission scenarios that may occur with economic and population growth.

But, to develop comprehensive and accurate inventories, industries, government agencies and scientists first must know the location of pollution sources.

"We now have an independent measurement of these emission sources that does not rely on what was known or thought known," said Chris McLinden, an atmospheric scientist with Environment and Climate Change Canada in Toronto and lead author of the study published this week in Nature Geosciences. "When you look at a satellite picture of sulfur dioxide, you end up with it appearing as hotspots - bull's-eyes, in effect -- which makes the estimates of emissions easier."

The 39 unreported emission sources, found in the analysis of satellite data from 2005 to 2014, are clusters of coal-burning power plants, smelters, oil and gas operations found notably in the Middle East, but also in Mexico and parts of Russia. In addition, reported emissions from known sources in these regions were -- in some cases -- two to three times lower than satellite-based estimates.

Altogether, the unreported and underreported sources account for about 12% of all human-made emissions of sulfur dioxide - a discrepancy that can have a large impact on regional air quality, said McLinden.

The research team also located 75 natural sources of sulfur dioxide -- non-erupting volcanoes slowly leaking the toxic gas throughout the year. While not necessarily unknown, many volcanoes are in remote locations and not monitored, so this satellite-based data set is the first to provide regular annual information on these passive volcanic emissions.

"Quantifying the sulfur dioxide bull's-eyes is a two-step process that would not have been possible without two innovations in working with the satellite data," said co-author Nickolay Krotkov, an atmospheric scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

First was an improvement in the computer processing that transforms raw satellite observations from the Dutch-Finnish Ozone Monitoring Instrument aboard NASA's Aura spacecraft into precise estimates of sulfur dioxide concentrations. Krotkov and his team now are able to more accurately detect smaller sulfur dioxide concentrations, including those emitted by human-made sources such as oil-related activities and medium-size power plants.

Being able to detect smaller concentrations led to the second innovation. McLinden and his colleagues used a new computer program to more precisely detect sulfur dioxide that had been dispersed and diluted by winds. They then used accurate estimates of wind strength and direction derived from a satellite data-driven model to trace the pollutant back to the location of the source, and also to estimate how much sulfur dioxide was emitted from the smoke stack.

"The unique advantage of satellite data is spatial coverage," said Bryan Duncan, an atmospheric scientist at Goddard. "This paper is the perfect demonstration of how new and improved satellite datasets, coupled with new and improved data analysis techniques, allow us to identify even smaller pollutant sources and to quantify these emissions over the globe."

The University of Maryland, College Park, and Dalhousie University in Halifax, Nova Scotia, contributed to this study.

For more information about, and access to, NASA's air quality data, visit: http://so2.gsfc.nasa.gov/

NASA uses the vantage point of space to increase our understanding of our home planet, improve lives, and safeguard our future. NASA develops new ways to observe and study Earth's interconnected natural systems with long-term data records. The agency freely shares this unique knowledge and works with institutions around the world to gain new insights into how our planet is changing.

Source: NASA's Goddard Space Flight Center

A strange thing happened in the stratosphere

Published: Friday, September 2, 2016 - 14:45

Earth & Climate

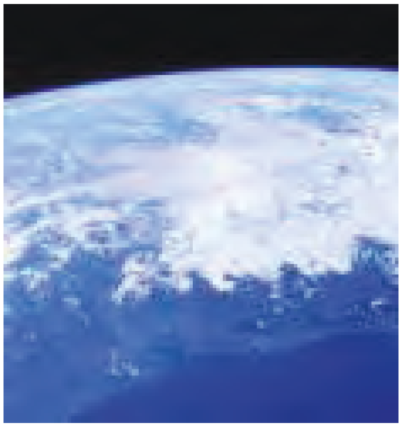


Image Credit: NASA

This disruption to the wind pattern - called the “quasi-biennial oscillation” - did not have any immediate impact on weather or climate as we experience it on Earth’s surface. But it does raise interesting questions for the NASA scientists who observed it: If a pattern holds for six decades and then suddenly changes, what caused that to happen? Will it happen again? What effects might it have? “The quasi-biennial oscillation is the stratosphere’s Old Faithful,” said Paul Newman, Chief Scientist for Earth Sciences at NASA’s Goddard Space Flight Center, Greenbelt, Maryland, and lead author on a new paper about the event published online in Geophysical Research Letters. “If Old Faithful stopped for a day, you’d begin to wonder about what was happening under the ground.”

Winds in the tropical stratosphere, an atmospheric layer that extends from about 10 to 30 miles above Earth’s surface, circulate the planet in alternating easterly and westerly directions over roughly a two-year period. Westerly winds develop at the top of the stratosphere, and gradually descend to the bottom, about 10 miles above the surface while at the same time being replaced by a layer of easterly winds above them. In turn, the easterlies descend and are replaced by westerlies.

This pattern repeats every 28 months. In the 1960s scientists coined it the “quasi-biennial oscillation.” The record of these measurements, made by weather balloons released in the tropics at various points around the globe, dates to 1953.

The pattern never changed - until late 2015. As the year came to a close, winds from the west neared the end of their typical descent. The regular pattern held that weaker easterly winds would soon replace them. But then the westerlies appeared to move upwards and block the downward movement of the easterlies. This new pattern held for nearly half a year, and by July 2016 the old regime seemed to resume.

“It’s really interesting when nature throws us a curveball,” Newman said.

The quasi-biennial oscillation has a wide influence on stratospheric conditions. The amount of ozone at the equator changes by 10 percent between the peaks of the easterly and westerly phases, while the oscillation also has an impact on levels of polar ozone depletion.

With this disruption now documented, Newman and colleagues are currently focused on studying both its causes and potential implications. They have two hypotheses for what could have triggered it - the particularly strong El Niño in 2015-16 or the long-term trend of rising global temperatures. Newman said the scientists are conducting further research now to figure out if the event was a “black swan,” a once-in-a-generation event, or a “canary in the coal mine,” a shift with unforeseen circumstances, caused by climate change.

Source: NASA’s Goddard Space Flight Center

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
AAAS	American Association for the Advancement of Science
ACATS	Airborne Cloud-Aerosol Transport System
ACE	Aerosols, Clouds, and Ecology
ACE	Aerosols-Clouds-Ecosystems
ACHIEVE	Aerosol, Cloud, Humidity, Interactions Exploring and Validating Enterprise
ACRIM	Active Cavity Radiometer Irradiance Monitor
ACRIMSAT	Active Cavity Radiometer Irradiance Monitor Satellite
ADM	Atmospheric Dynamics Mission
AEROKATS	Advancing Earth Research Observation Kites And Tether Systems
AERONET	Aerosol Robotic Network
AETD	Applied Engineering and Technology Directorate
AFI	American Film Institute
AGU	American Geophysical Union
AI	Aerosol Index
AirMSPI	Airborne Multi-angle Spectro-Polarimetric Imager
AIRS	Atmospheric InfraRed Sounder
ALVICE	Atmospheric Lindar for Validation, Interagency Collaboration and Education
AMA	Academy of Model Aeronautics
AMMA	African Monsoon Multidisciplinary Activities
AMS	American Meteorological Society
AMSR-E	Advanced Microwave Scanning Radiometer–Earth Observing System
AMSU	Advanced Microwave Sounding Unit
AOD	Aerosol Optical Depth
AOT	Aerosol Optical Thickness
ARAMIS	Application Radar á la Météorologie Infra-Synoptique
ARC	Ames Research Center
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
ARI	Average Recurrence Interval
ARM	Atmospheric Radiation Measurement
ASCENDS	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
ASIF	Air Sea Interaction Facility

Acronyms

ASR	Atmospheric System Research
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AT	Atmospheres
ATM	Airborne Topographic Mapper
ATMS	Advanced Technology Microwave Sounder
AVHRR	Advanced Very High Resolution Radiometer
BC	Black Carbon
BESS	Beaufort and East Siberian Sea
BEST	Beginning Engineering Science and Technology
BMKG	Meteorological Climatological and Geophysical Agency
BRDF	Bidirectional Reflectance-Distribution Functions
CALIOP	Cloud-Aerosol LIdar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAR	Cloud Absorption Radiometer
CASI	Climate Adaptation Science Investigation
CATS	Cloud Aerosol Transport System
CCAVE	CALIPSO-CATS Airborne Validation Experiment
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
CFC	Chlorofluorocarbons
CFTD	Contoured frequency by temperature diagrams
CHIMAERA	Cross-platform High-resolution Multi-instrument AtmosphEric Retrieval Algorithms
CINDY	Cooperative Indian Ocean experiment on intraseasonal variability
CIRC	Continual Intercomparison of Radiation Codes
CLEO	Conference on Lasers and Electro-Optics
CO	Carbon Monoxide
COMMIT	Chemical, Optical, and Microphysical Measurements of In-situ Troposphere
CoSMIR	Conical Scanning Millimeter-wave Imaging Radiometer
COSP	CFMIP Observation Simulator Package
CPL	Cloud Physics Lidar
CPL	Cloud Physics Lidar
CR	Cloud regimes
CrIS	Cross-track Infrared Sounder

CRM	Cloud-resolving Models
CRM	Cloud-resolving models
CRS	Cloud Radar System
DB-SAR	Digital Beam-forming Synthetic Aperture Radar
DISC	Data and Information Services Center
DISCOVER-AQ	Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DLN	Digital Learning Network
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DOD	Department of Defense
DOE	Department of Energy
DOW	Doppler on Wheels
DPR	Dual-frequency Precipitation Radar
DSCOVR	Deep Space Climate Observatory
DT	Dark-target
DYNAMO	Dynamics of the Madden-Julian Oscillation
EC	Environment Canada
ECO-3D	Exploring the Third Dimension of Forest Carbon
ECS	Equilibrium Climate Sensitivity
EDOP	ER-2 Doppler Radar
EEMD	Ensemble Empirical Mode Decomposition
ENSO	El Niño Southern Oscillation
EO	Earth Observation
EOF	Empirical Orthogonal Function
EOS	Earth Observing System
EPIC	Earth Polychromatic Imaging Camera
ESA	European Space Agency
ESS	Earth and Space Sciences
ESSIC	Earth System Science Interdisciplinary Center
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FMI	Finnish Meteorological Institute
FV	Finite Volume
G-IV	Gulfstream IV
GCE	Goddard Cumulus Ensemble
GCM	Global Climate Model
GCPEX	GPM Cold Season Precipitation Experiment
GEMS	Geostationary Environmental Monitoring Sensor

Acronyms

GEO-CAPE	Geostationary Coastal and Air Pollution Events
GEOS	Goddard Earth Observing System
GEOSCCM	Goddard Earth Observing System Chemistry-Climate Model
GES	Goddard Earth Sciences
GEST	Goddard Earth Sciences and Technology Center
GESTAR	Goddard Earth Sciences Technology Center and Research
GEV	Generalized Extreme Value
GHG	Greenhouse gases
GLOBE	Global Learning and Observations to Benefit the Environment
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
GRUAN	GCOS Reference Upper Air Network
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
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
HSRL	High Spectral Resolution Lidar
HWLT	Hybrid Wind Lidar Transceiver
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
IGAC	International Global Atmospheric Chemistry
IGP	Indo–Gangetic Plain
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
ISAF	*In Situ* Airborne Formaldehyde
ISCCP	International Satellite Cloud Climatology Project
ISS	International Space Station
ITCZ	Intertropical Convergence Zone
IUGG	International Union of Geodesy and Geophysics
IWP	Ice Water Path
JAXA	Japanese Aerospace Exploration Agency
JAXA	Japan Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	NASA's Johnson Space Center
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
MCS	Mesoscale Convective System
MDE	Maryland Department of the Environment
MISR	Multi-angle Imaging Spectroradiometer

Acronyms

MJO	Madden-Julian Oscillation
MLS	Microwave Limb Sounder
MMF	Multi-scale Modeling Framework
MMF-LIS	Multi-scale Modeling Framework Land Information System
MOA	Memorandum of Agreement
MODIS	MODerate-resolution Imaging Spectrometer
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
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NCTAF	National Commission on Teaching and America's Future
NDVI	Normalized Difference Vegetation Index
NEO	NASA Earth Observations
NEXRAD	Next Generation Radar
NFOV	Narrow Field-of-View
NIH	National Institutes of Health
NIST	National Institute of Standards
NISTAR	National institute of Standards and Technology Advanced Radiometer
NLDAS-2	North American Land Data Assimilation System
NMVOC	Non-methane volatile organic compounds
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational 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
ODP	Ozone Depletion Potentials
ODS	Ozone Depleting Substances

OEI	Ozone ENSO Index
OLI	Operational Land Imager
OLYMPEX	Olympic Mountain Experiment
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
ORS	Operationally Responsive Space
OSC	Orbital Sciences Corporation
PACE	Pre-Aerosols, Clouds, and Ecology
PAO	Public Affairs Office
PARSIVEL	PARticle Size VELocity
PCA	Principal Component Analysis
PECAN	Plains Elevated Convection at Night
PI	Principal Investigator
PMM	Precipitation Measurement Missions
POC	Point of Contact
PODEX	Polarimeter Definition Experiment
POES	Polar-orbiting Operational Environmental Satellites
PR	Precipitation Radar
PSCs	Polar Stratospheric Clouds
PUMAS	Practical Uses of Math and Science
PVI	Perpendicular Vegetation Index
RADEX	Radar Definition Experiment
RESA	Regional Education Service Agency
RMSE	Root Mean Square Error
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
S-HIS	Scanning High-Resolution Interferometer Sounder
SAF	Satellite Application Facility
SAIC	Science Applications International Corporation
SC	Solar Cycle
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

Acronyms

SHOUT	Sensing Hazards with Operational Unmanned Technology
SIM	Spectral Irradiance Monitor
SIMPL	Swath Imaging Multi-polarization Photon-counting Lidar
SMAP	Soil Moisture Active Passive
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMD	Science Mission Directorate
SNPP	Suomi National Polar-orbiting Partnership
SONGNEX	Shale Oil and Natural Gas Nexus
SORCE	Solar Radiation and Climate Experiment
SpaceX	Space Exploration Technologies Corp.
SPARRO	Self-Piloted Aircraft Rescuing Remotely Over Wilderness
SPE	Solar Proton Event
SSA	Single Scattering Albedo
SSA	Single scattering albedo
SSAI	Science Systems Applications, Inc.
SSI	Solar Spectral Irradiance
SST	Sea Surface Temperature
STEM	Science, Technology, Engineering, and Mathematics
SWG	Science Working Group
SWOT	Surface Water Ocean Topography
TCC	TRMM Composite Climatology
TEMPO	Tropospheric Emissions: Monitoring of Pollution
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
TMPA	TRMM Multi-satellite Precipitation Analysis
TOAR	Tropospheric Ozone Assessment Report
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPP	Tropospheric ozone pollution project
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
UAS	Unmanned Aircraft Systems
UAVs	Unmanned Aerial Vehicles
UMBC	University of Maryland, Baltimore County
UMSA	Universidad Mayor San Andres
UND	University of North Dakota
USAF	U.S. Air Force
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey
USRA	Universities Space Research Associates
UTLS	Upper Troposphere and Lower Stratosphere
UV	Ultraviolet
VIIRS	Visible Infrared Imaging Radiometer Suite
VIRGAS	Volcano-Plume Investigation Readiness and Gas-phase and Aerosol Sulfur
VIRGO	Variability of solar IRradiance and Gravity Oscillations
VIRS	Visible and Infrared Scanner
VOC	Volatile Organic Compounds
WAVES	Water Vapor Validation Experiments Satellite and sondes
WFF	Wallops Flight Facility
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting

Acronyms

APPENDIX 1. REFEREED ARTICLES

In 2016, Atmospheric Research published 213 peer-reviewed publications listed below.

Abarca, S. F., M. T. Montgomery, S. A. Braun, and J. Dunion. 2016. "On the secondary eyewall formation of Hurricane Edouard (2014)." Monthly Weather Review, MWR-D-15-04211 (10.1175/mwr-d-15-0421.1).

Adams, C., E. N. Normand, C. A. McLinden, A. E. Bourassa, N. D. Lloyd, D. A. Degenstein, N. A. Krotkov, M. Belmonte Rivas, K. F. Boersma, and H. Eskes. 2016. "Limb–nadir matching using non-coincident NO_2 observations: proof of concept and the OMI-minus-OSIRIS prototype product." Atmospheric Measurement Techniques, 9 (8): 4103-4122 (10.5194/amt-9-4103-2016).

Adirosi, E., L. Baldini, N. Roberto, P. Gatlin, and A. Tokay. 2016. "Improvement of vertical profiles of raindrop size distribution from micro rain radar using 2D video disdrometer measurements." Atmospheric Research, 169: 404-415 (10.1016/j.atmosres.2015.07.002).

Alden, C. B., J. B. Miller, L. V. Gatti, M. M. Gloor, K. Guan, A. M. Michalak, I. T. van der Laan-Luijkx, D. Touma, A. Andrews, L. S. Basso, C. S. Correia, L. G. Domingues, J. Joiner, M. C. Krol, A. I. Lyapustin, W. Peters, Y. P. Shiga, K. Thoning, I. R. van der Velde, T. T. van Leeuwen, V. Yadav, and N. S. Diffenbaugh. 2016. "Regional atmospheric CO_2 inversion reveals seasonal and geographic differences in Amazon net biome exchange." Global Change Biology, (10.1111/gcb.13305).

Alexandrov, M. D., B. Cairns, B. van Diedenhoven, A. S. Ackerman, A. P. Wasilewski, M. J. McGill, J. E. Yorks, D. L. Hlavka, S. E. Platnick, and G. T. Arnold. 2016. "Polarized view of supercooled liquid water clouds." Remote Sensing of Environment, 181: 96-110 (10.1016/j.rse.2016.04.002).

Alexandrov, M. D., I. V. Geogdzhayev, K. Tsigaridis, A. Marshak, R. Levy, and B. Cairns. 2016. "New statistical model for variability of aerosol optical thickness: Theory and application to MODIS data over ocean." Journal of the Atmospheric Sciences, 73 (2): 821-837 (10.1175/jas-d-15-0130.1).

Ancellet, G., N. Daskalakis, J. C. Raut, D. Tarasick, J. Hair, B. Quennehen, F. Ravetta, H. Schlager, A. J. Weinheimer, A. M. Thompson, B. Johnson, J. L. Thomas, and K. S. Law. 2016. "Analysis of the latitudinal variability of tropospheric ozone in the Arctic using the large number of aircraft and ozonesonde observations in early summer 2008." Atmospheric Chemistry and Physics, 16 (20): 13341-13358 (10.5194/acp-16-13341-2016)

Anderson, D. C., J. M. Nicely, R. J. Salawitch, T. P. Canty, R. R. Dickerson, T. F. Hanisco, G. M. Wolfe, E. C. Apel, E. Atlas, T. Bannan, S. Bauguitte, N. J. Blake, J. F. Bresch, T. L. Campos, L. J. Carpenter, M. D. Cohen, M. Evans, R. P. Fernandez, B. H. Kahn, D. E. Kinnison, S. R. Hall, N. R. Harris, R. S. Hornbrook, J.-F. Lamarque, M. Le Breton, J. D. Lee, C. Percival, L. Pfister, R. B. Pierce, D. D. Riemer, A. Saiz-Lopez, B. J. Stunder, A. M. Thompson, K. Ullmann, A. Vaughan, and A. J. Weinheimer. 2016. "A pervasive role for biomass burning in tropical high ozone/low water structures." Nat Comms, 7: 10267 (10.1038/ncomms10267).

Aquila, V., W. H. Swartz, D. W. Waugh, P. R. Colarco, S. Pawson, L. M. Polvani, and R. S. Stolarski. 2016. "Isolating the roles of different forcing agents in global stratospheric temperature changes using model integrations with incrementally added single forcings." J. Geophys. Res. Atmos., (10.1002/2015jd023841).

Arvani, B., R. B. Pierce, A. I. Lyapustin, Y. Wang, G. Ghermandi, and S. Teggi. 2016. "Seasonal monitoring and estimation of regional aerosol distribution over Po valley, northern Italy, using a high-resolution MAIAC product." Atmospheric Environment, 141: 106-121 (10.1016/j.atmosenv.2016.06.037).

Bardeen, C. G., D. R. Marsh, C. H. Jackman, M. E. Hervig, and C. E. Randall. 2016. "Impact of the January 2012 solar proton event on polar mesospheric clouds." J. Geophys. Res. Atmos., 121 (15): 9165-9173 (10.1002/2016jd024820).

Behrangi, A., M. Christensen, M. Richardson, M. Lebsock, G. Stephens, G. J. Huffman, D. Bolvin, R. F. Adler, A. Gardner, B. Lambrigtsen, and E. Fetzer. 2016. "Status of high-latitude precipitation estimates from observations and reanalyses." J. Geophys. Res. Atmos., 121 (9): 4468-4486 (10.1002/2015jd024546).

Appendix 1: Refereed Articles

Bi, J., R. Myneni, A. Lyapustin, Y. Wang, T. Park, C. Chi, K. Yan, and Y. Knyazikhin. 2016. "Amazon Forests' Response to Droughts: A Perspective from the MAIAC Product." Remote Sensing, 8 (5): 356 (10.3390/rs8040356).

Braun, S. A., P. Newman, and G. M. Heymsfield. 2016. "NASA's Hurricane and Severe Storm Sentinel (HS_3) Investigation." Bulletin of the American Meteorological Society, (10.1175/BAMS-D-15-00186.1).

Brunt, K. M., T. A. Neumann, J. M. Amundson, J. L. Kavanaugh, M. S. Moussavi, K. M. Walsh, W. B. Cook, and T. Markus. 2016. "MABEL photon-counting laser altimetry data in Alaska for ICESat-2 simulations and development." The Cryosphere, 10 (4): 1707-1719 (10.5194/tc-10-1707-2016).

Buchard, V., A. da Silva, C. Randles, P. Colarco, R. Ferrare, J. Hair, C. Hostetler, J. Tackett, and D. Winker. 2016. "Evaluation of the surface PM2.5 in Version 1 of the NASA MERRA Aerosol Reanalysis over the United States." Atmospheric Environment, 125 (Part A): 100-111 (10.1016/j.atmosenv.2015.11.004)

Bullard, J. E., M. Baddock, T. Bradwell, J. Crusius, E. Darlington, D. Gaiero, S. Gassó, G. Gisladottir, R. Hodgkins, R. McCulloch, C. M. Neuman, T. Mockford, H. Stewart, and T. Thorsteinsson. 2016. "High Latitude Dust in the Earth System." Review of Geophysics, 54: (10.1002/2016RG000518).

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Appendix 1: Refereed Articles

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Appendix 1: Refereed Articles

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Zhu, X., J.-H. Yee, M. Cai, W. H. Swartz, L. Coy, V. Aquila, R. Garcia, and E. R. Talaat. 2016. "Diagnosis of Middle-Atmosphere Climate Sensitivity by the Climate Feedback–Response Analysis Method." Journal of the Atmospheric Sciences, 73 (1): 3–23 (10.1175/jas-d-15-0013.1).

Zoogman, P., X. Liu, R. Suleiman, W. Pennington, D. Flittner, J. Al-Saadi, B. Hilton, D. Nicks, M. Newchurch, J. Carr, S. Janz, M. Andraschko, A. Arola, B. Baker, B. Canova, C. Chan Miller, R. Cohen, J. Davis, M. Dussault, D. Edwards, J. Fishman, A. Ghulam, G. González Abad, M. Grutter, J. Herman, J. Houck, D. Jacob, J. Joiner, B. Kerridge, J. Kim, N. Krotkov, L. Lamsal, C. Li, A. Lindfors, R. Martin, C. McElroy, C. McLinden, V. Natraj, D. Neil, C. Nowlan, E. O'Sullivan, P. Palmer, R. Pierce, M. Pippin, A. Saiz-Lopez, R. Spurr, J. Szykman, O. Torres, J. Veefkind, B. Veihelmann, H. Wang, J. Wang, and K. Chance. 2016. "Tropospheric emissions: Monitoring of pollution (TEMPO)." Journal of Quantitative Spectroscopy and Radiative Transfer, (10.1016/j.jqsrt.2016.05.008).