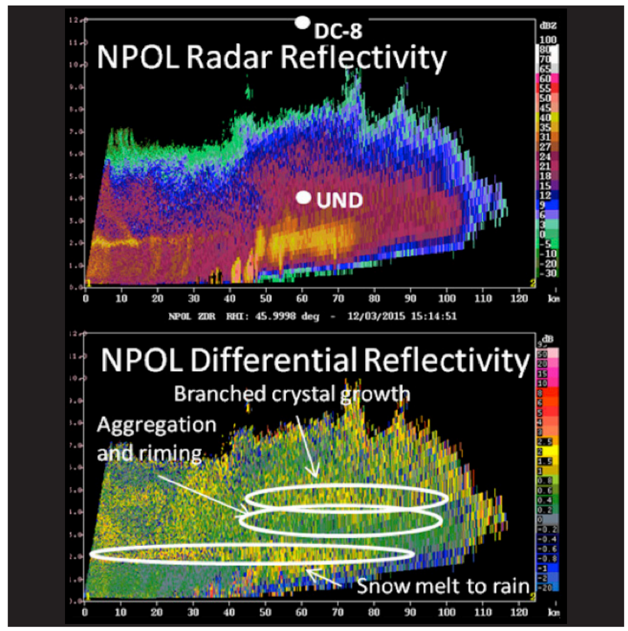
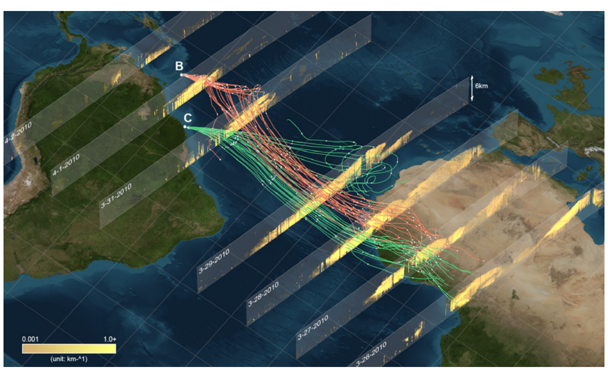
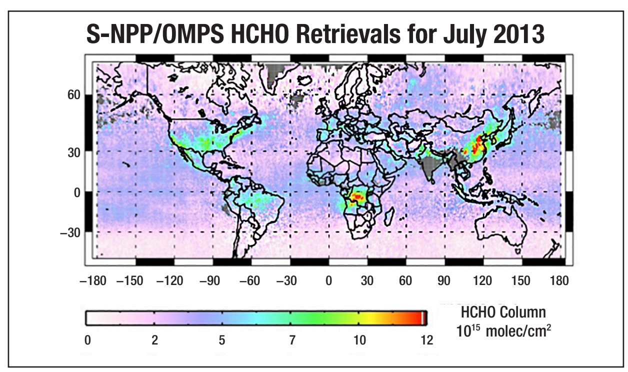
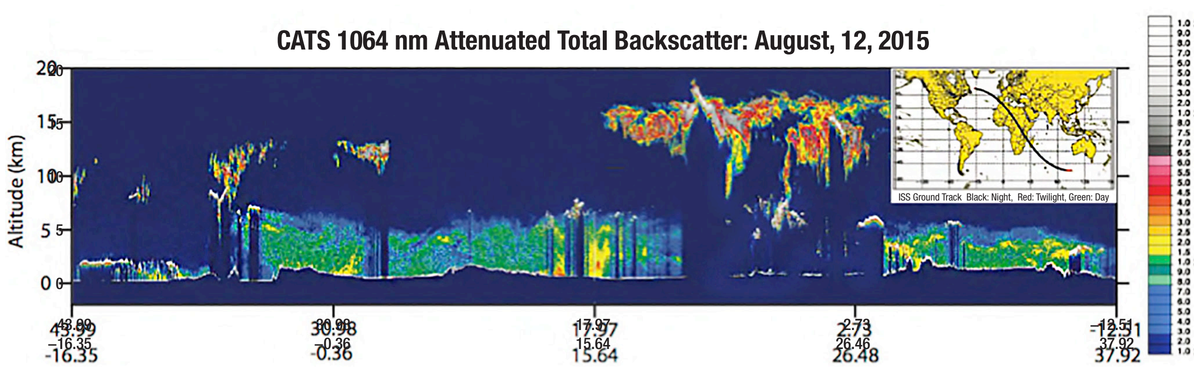
NASA/TM 2016-217550

Goddard Atmospheric Research 2015 Technical Highlights









May 2016

Cover Photo Captions

UPPER LEFT

EPIC. The Deep Space Climate Observatory (DSCOVR) is an Earth observation and space weather satellite launched on February 11, 2015, from Cape Canaveral. The Goddard Earth Polychromatic Imaging Camera (EPIC) is one of the instruments observing our planet from the L1-point. The image was made by combining information from EPIC's red, green, and blue bands.

UPPER RIGHT

OLYMPEX Showing Wallops Data. NPOL Radar vertical cross-sections across the Global Precipitation Measurement (GPM) satellite/aircraft tracks indicate the snow crystal growth and aggregation process that makes rain below.

CENTER LEFT

Saharan Dust Transport. NASA space-borne CALIOP lidar reveals the three-dimensional characteristics of dust transport from North Africa to America (March 26 to April 2, 2010). Curtains show profiles of dust extinction coefficient (1/km) as described in Yu et al. (*Remote Sens. Environ.*, 2015). An ensemble of 8-day back trajectories, starting from Barbados (B, red) and Cayenne (C, green), is overlaid on the curtains.

CENTER RIGHT

Atmospheric Formaldehyde (HCHO) Retrieval. Global monthly mean HCHO vertical column density for July 2013 retrieved with the S-NPP OMPS instrument using a new algorithm based on principal component analysis of measured radiances.

BOTTOM

Saharan Dust Transport. The CATS 1064 nm backscatter at local nighttime hours (23:08 to 23:26 UTC on August 12, 2015, as the International Space Station passed over Africa) shows Saharan dust that extends to 6 km (+35 to +12 degrees latitude), ice clouds as high as 17 km (+18 to -2 degrees latitude), and smoke from biomass burning (-2 to -30 degrees latitude) in southern Africa.

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

NASA/TM–2016-217550

Atmospheric Research 2015 Technical Highlights

May 2016

NASA STI Program ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

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

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

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- 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 Atmospheric Research 2015 Atmospheric Research Highlights report. This report, as before, is intended for a broad audience. Our readers include colleagues within the National Aeronautics and Space Administration (NASA), scientists outside the Agency, science graduate students, and members of the general public. This report describes atmospheric research science highlights and summarizes our education and outreach accomplishments for calendar year 2015.

The report covers research activities from NASA's Goddard Space Flight Center's (GSFC) Mesoscale Atmospheric Processes Laboratory (612), the Climate and Radiation Laboratory (613), and the Atmospheric Chemistry and Dynamics Laboratory (614), as well as the Wallops Field Support Office (610.W) under the Office of Deputy Director for Atmospheres (610AT), Earth Sciences Division in the Sciences and Exploration Directorate of NASA's Goddard Space Flight Center. Noteworthy events that took place during 2015 include:

On January 22, 2015, robotic flight controllers successfully installed NASA's Cloud Aerosol Transport System (CATS) aboard the International Space Station through a robotic handoff—the first time one robotic arm on station has worked in concert with a second robotic arm. Since February 10, 2015, CATS has collected data on clouds, volcanic ash plumes, and tiny airborne particles that can help improve our understanding of aerosol and cloud interactions and improve the accuracy of climate change models. The CATS principal investigator, Matthew McGill (610), and his 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 Deep Space Climate Observatory (DSCOVR) is an Earth observation and space weather satellite launched on February 11, 2015 from Cape Canaveral. The Goddard Earth Polychromatic Imaging Camera (EPIC) is one of the instruments obtaining observations of our planet from the L_1-point. EPIC views the Earth entirely—from sunrise to sunset—in 10 different wavelengths, ranging from ultraviolet to near-infrared. Jay Herman (614), 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.

Code 610AT scientists also played key roles in numerous field campaigns. The Plains Elevated Convection at Night (PECAN) campaign was designed to better understand severe thunderstorms at night over the continental United States and funded by NASA, the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE). It involved 8 research laboratories and 14 universities, both national and international. PECAN was conducted across northern Oklahoma, central Kansas, and into south-central Nebraska from June 1 to July 15, 2015. This field campaign had its first measurement period on June 1. NASA's Goddard Space Flight Center's (GSFC) GLOW (Bruce Gentry, 612), X-BADGER (Amber Emory, 612), and ALVICE (David Whiteman, 612) systems participated.

Joe Munchak (612), Gerry Heymsfield (612), and Dave Wolff (610.W) participated in the Olympic Mountain Experiment (OLYMPEX) field campaign. The experiment began in November 2015 and will continue through February 2016 on the Olympic Peninsula in the Pacific Northwest of the United States. OLYMPEX brought the NASA ER-2 instrumented with the HIWRAP, CRS, EXRAD radars, CPL lidar, and the Wallops NPOL and D3R ground radars supported by Gerry Heymsfield, Dave Wolff, and other AT instrument scientists and support teams. The campaign was designed to validate rain and snow measurements in mid-latitude frontal systems moving from ocean to coast to mountains and determine how remotely sensed measurements of precipitation by GPM can be applied to a range of hydrologic, weather forecasting, and climate data analysis.

Scientists in 610AT also played key roles in numerous other field campaigns including:

1. Tom Hanisco (614) led a team the using the In-Situ Airborne Formaldehyde (ISAF) instrument in the Shale Oil and Natural Gas Nexus (SONGNEX) campaign in Broomfield, Colorado, to determine emissions of methane, non-methane hydrocarbons, and nitrogen dioxides.
2. Walt Petersen (610.W), Dave Wolff (610.W), and Si-Chee Tsay (613) operated NPOL, D3R, and ACHIEVE radars for the first time at Wallops Flight Facility (WFF) to sample clouds and precipitation.
3. GSFC's SMARTLabs mobile facility, COMMIT, was set up by Si-Chee Tsay and team at a remote site in northern Thailand to participate in the international Seven SouthEast Asian Studies/Biomass-burning Aerosols and Stratocumulus Environment (7-SEAS/BASELInE).
4. The SHADOZ team under Anne Thompson (614) made major progress in re-processing ozonesonde data, interactions with the outside community including numerous seminars, and continued operations at an international Network for the Detection of Atmospheric Composition Change (NDACC) site in Brazil.
5. Bruce Gentry (612) and his team participated in a campaign over Greenland funded by NASA-HQ. The Tropospheric Wind Lidar Technology Experiment (TwiLite) on board the NASA DC-8 aircraft flew over Greenland for five days. The experiment included pre-launch calibration-validation activities requested by the European Space Agency in support of the ADM-Aeolus mission.
6. Scott Braun (612) participated in the Hurricane and Severe Storm Sentinel (HS3) Earth Venture suborbital Key Decision Point-F (KDP-F) review on July 29, 2015. HS3 was the first of the EVs-1 investigations to complete a KDP-F review.
7. The Geostationary Trace Gas and Aerosol Optimization (GeoTASO) instrument has been selected for funding to participate in the KORUS-AQ campaign, headed by Principle Investigator Scott Janz (614). GeoTASO will support horizontally resolved measurements of ozone, formaldehyde, and nitrogen dioxide during the campaign scheduled for May–June, 2016, in Korea. The In Situ Airborne Formaldehyde (ISAF) Measurements was also selected for funding (PI: Tom Hanisco, 614).
8. John Yorks (612) and Matt McGill (610) participated in the CALIPSO-CATS Airborne Validation Experiment (CCAVE) that took place in August 2015 out of Palmdale, California, intended to provide validation data for the CALIPSO and CATS space-based lidar instruments. The Cloud Physics Lidar (CPL) and Airborne Cloud-Aerosol Transport System (ACATS), both lidar systems, were payloads aboard the NASA ER-2.
9. P. Newman (610) and S. Braun (612) were mission scientists for the Sensing Hazards with Operational Unmanned Technology (SHOUT) field campaign to study Atlantic hurricanes using the High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) on Global Hawk AV-6.
10. Paul Newman (610), Leslie Lait (614/MSU), and Peter Colarco (614) participated in the Volcano-Plume Investigation Readiness and Gas-phase and Aerosol Sulfur (VIRGAS) experiment. VIRGAS was a 2-week "mini" mission to develop what NASA and NOAA investigators hope will become a new standing capability for measuring SO_2, other gases, and particles in the plumes form volcanic

eruptions. Newman was the emission scientist for VIRGAS, and Lait developed the flight plans for the WB-57F. Colarco's forecasts of SO_2 have been the primary driver for developing the WB-57F flight plans. The mission concluded on October 30.

11. The Radar Definition Experiment (RADEX), sponsored by the NASA HQ's Aerosols-Clouds-Ecosystems (ACE) Decadal Mission study, was conducted in the Olympic Peninsula region of Washington. RADEX used the NASA ER-2 instrumented with GSFC's HIWRAP, CRS, and EXRAD radars, CPL lidar, as well as the Ames Research Center's (ARC) eMAS and the Jet Propulsion Laboratory's (JPL) AirMSPI instruments. RADEX utilized microphysical and other retrieval algorithms for the dual-frequency ACE radar concept, specifically targeting lighter precipitation, shallow convection, and clouds. Gerry Heymsfield (612) and Arlindo Da Silva (610.1) coordinated the operations for NASA.

As in previous years, atmospheric scientists from Code 610AT garnered numerous top professional honors during 2015. Anne Thompson (610) was honored to receive the 2015 Roger Revelle Medal from the American Geophysical Union (AGU). I felt honored to receive the 2015 AMS Verner Suomi Award. Jose Rodriguez (614) was elected a Fellow of the American Association for the Advancement of Science (AAAS). Lorraine Remer, (613/UMBC-JCET), was honored by the American Geophysical Union (AGU) as a 2015 Fellow. NASA's Johnson Space Center gave a Group Achievement Award to the CATS team, to which Piers Sellers (600) commented: "Always nice to get a salute from another Center." Arthur Hou received a Distinguished Service Medal from NASA for GPM posthumously. Many other individuals and teams received special recognition, which can be found in Section 5–Awards and Special Recognition.

I was pleased to welcome John Yorks and Joe Munchak as civil servants on August 24 and September 7, respectively, to the Mesoscale Atmospheric Processes Laboratory (612). John joined GSFC in 2008 as a research scientist, received a doctorate from the University of Maryland in 2014; he will continue work on space-based and airborne lidar systems. Joe received his doctorate from Colorado State University, joined GSFC in 2010, and will be performing research on precipitation retrievals from active radars and passive microwave imagers and sounders.

And finally, I want to state that I felt honored to have been appointed as the Deputy Director for Atmospheres officially beginning in January 2015. I am looking forward to working with the Goddard Atmospheric Science Community in the years ahead. I also plan to continue serving as the EOS Project Scientist, and I feel confident that each function will be enhanced through this complimentary arrangement.

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

Steven Platnick

Deputy Director for Atmospheres

Goddard Space Flight Center

Earth Sciences Division, Code 610

May 2016

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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 21-year record of peer-reviewed publications and proposals among the various Laboratories.

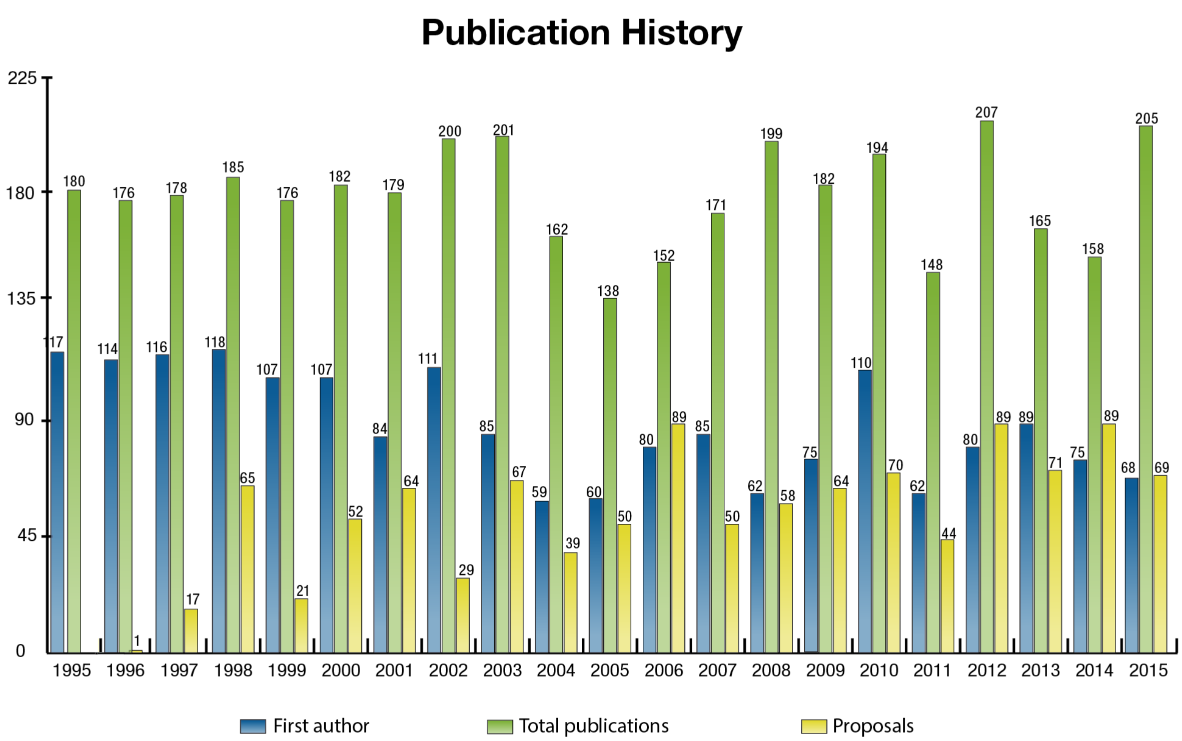


Figure 1.1: Number of proposals and referred publications by Atmospheric Sciences members over the years. The green bars are the total number of publications and the blue bars the number of publications where a Laboratory member is first author. Proposals submitted are shown in yellow.

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 2015. 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/.

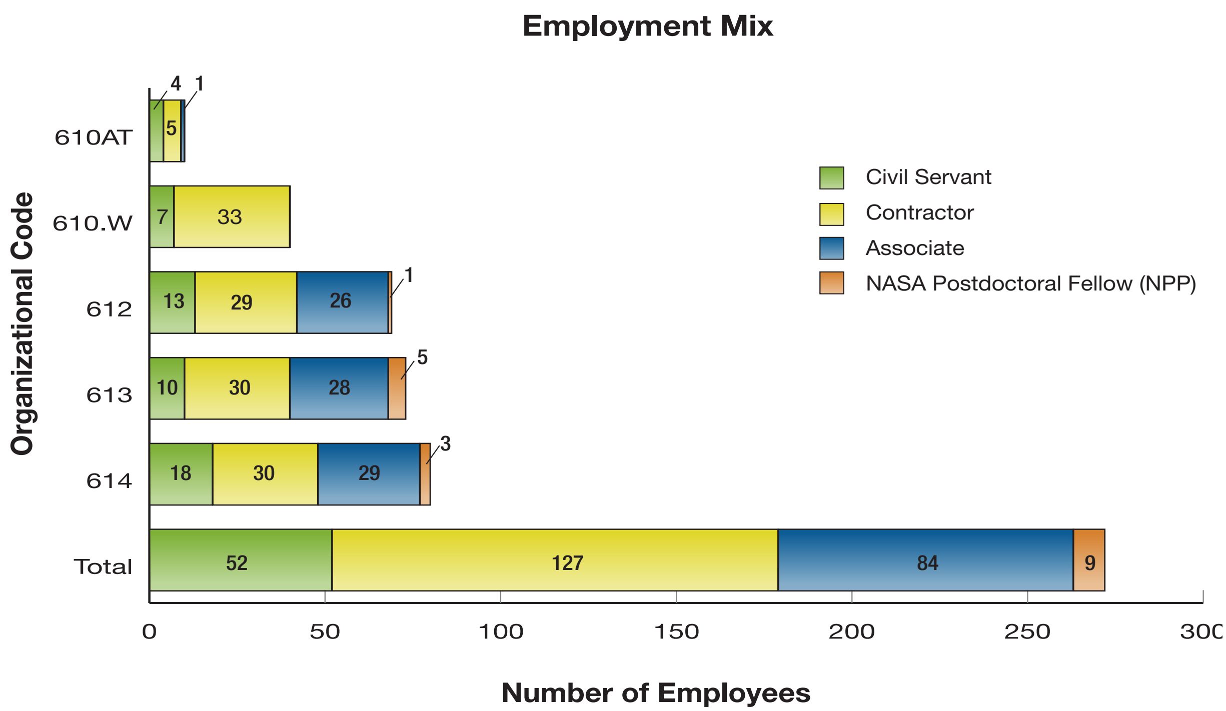


Figure 1.2: Breakdown of the organizational employee mix

2. SCIENCE HIGHLIGHTS

Atmospheric research at Goddard has a long history (more than 40 years) in Earth Science studying both Earth and planetary atmospheres. The early days of the TIROS and Nimbus satellites (1960s–1970s) emphasized ozone monitoring, Earth radiation, and weather forecasting. Planetary atmospheric research was conducted using Explorer, Pioneer Venus Orbiter, and Galileo missions 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 cross-cutting research is being carried out through observations, modeling, and analysis. Satellite missions provide observation data 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 have been implemented based on the decadal mission recommendations made in the *2007 Decadal Survey* by the National Academy of Sciences (http://www.nap.edu/catalog/11820.html). Now that the second *Decadal Survey for Earth Science and Applications from Space 2017–2027* (or "ESAS 2017") is underway atmospheric scientists will be prepared to implement the recommendations.

2.1. Mesoscale Atmospheric Processes Laboratory

The Mesoscale Atmospheric Processes Laboratory seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. The Laboratory conducts research on the physical and dynamic properties, and on the structure and evolution of meteorological phenomena—ranging from synoptic scale down to micro-scales—with a strong focus on the initiation, development, and effects of cloud and precipitation. Significant emphasis is placed on understanding energy exchange and conversion mechanisms; especially cloud microphysical development and latent heat release associated with atmospheric motions. The research is inherently focused on defining the atmospheric component of the global hydrologic cycle, especially precipitation, and its interaction with other components of the Earth system. The Laboratory also plays a key science leadership role in the Tropical Rainfall Measurement Mission (TRMM), launched in 1997 and still operational, and in conceptualizing the Global Precipitation Measurement (GPM) mission. Another central focus is developing remote-sensing technology and methods to measure aerosols, clouds, precipitation, water vapor, and winds, especially using active remote sensing (lidar and radar). Highlights of Laboratory research activities carried out during the year are summarized are below.

2.1.1. Vertical Profiles of Radar Reflectivity

The Plains Elevated Convection At Night (PECAN) field campaign collected vertical profiles, Doppler velocity, and spectrum width with the X-Band Atmospheric Doppler Ground-based Radar (X-BADGER) on June 25, 2015. The data was gathered over a period of nearly three hours where the continued descent of the cloud deck was observed. Rain finally began to fall out of the cloud base and was reported at the surface of the Field Profiling Unit (FP2) site in Greensburg, Kansas.

Figure 2.1 shows that the melting layer is positioned just above the bright band, which is a common feature observed in stratiform precipitation. Approximately fifteen minutes after the rain commenced at the surface, the cloud deck lifted back up and produced small wave-like undulations within the anvil (ice) cloud. Case studies like these allow researchers to study large rain-producing events that impact the Great Plains agricultural region in detail.

A. Emory (612)

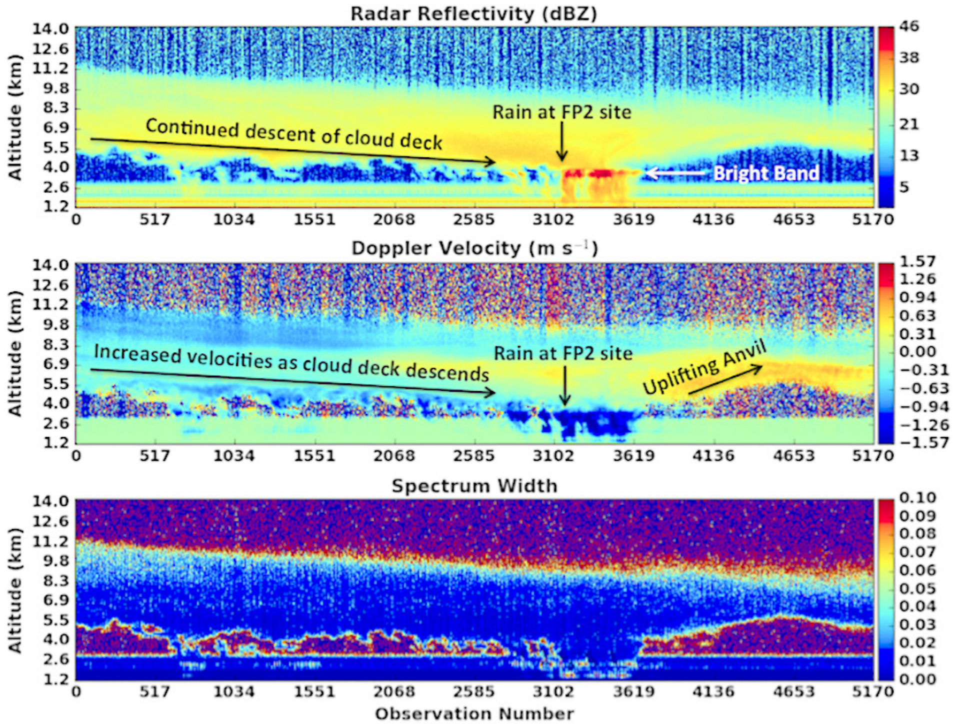


Figure 2.1: Simultaneous altitude observations of radar reflectivity, Doppler velocity, and spectral width during a rainstorm.

2.1.2. Direct and Indirect Effects of Aerosols Modeled Using the NASA Unified WRF

To study the effects of both direct (in radiation) and indirect (in cloud microphysics) aerosols, an aerosol–microphysics–radiation-coupling model was implemented. Aerosols directly affect the Earth's radiation balance and indirectly affect cloud microphysical processes via the activation of cloud condensation and ice nuclei. These two effects have often been considered separately and independently, hence the need to assess their combined impact given the different nature of their effects on convective clouds. An aerosol–microphysics–radiation coupling model, including Goddard microphysics and radiation schemes, was implemented using the NASA Unified Weather Research and Forecasting model (NU-WRF). Fully coupled NU-WRF simulations were conducted for a mesoscale convective system that passed through an area near Niamey, Niger, on August 6–7, 2006 during an AMMA special-observing period. When the aerosol direct effect was activated, regardless of the indirect effect, the onset of precipitation in the mesoscale convective system was delayed about two hours, in conjunction with the delay in the activation of cloud condensation and ice nuclei. Overall, for this particular environment, model set-up and physics configuration, the effect of aerosol radiative heating due to mineral dust overwhelmed the effect of the aerosols on microphysics.

J. J. Shi (612, MSU), T. Matsui (612, UMD), W.-K. Tao (612), C. Peters-Lidard (617), M. Chin (614), K. Pickering (614), S. Lang (612, SSAI), and E. M. Kemp (SSAI)

2.1.3. Converging to the "Real" Oceanic Precipitation

Knowledge of quantitative precipitation amounts over the ocean has two important uses. First, it is a prime component of the global water and energy cycles, since some 75 percent of the world's precipitation falls over the ocean. The time/space distributions of the latent heat released in precipitating system and of the return of fresh water to the ocean hinge on accurate precipitation estimates. Second, reliable observationally based precipitation estimates are required to accurately validate numerical prediction systems of weather and climate over the vast expanses of ocean that are essentially devoid of surface precipitation observations. Present-day climate models typically forecast rain amounts that are significantly above the satellite estimates in tropical oceanic areas. Establishing confidence in these satellite estimates requires convergence and agreement among their results.

In the tropics, the results of two recent composite climatologies and a modern climate-scale product agree quite well, and generally agree with a second climate product. At higher latitudes, snow becomes important and the satellite estimates are less certain; the Southern Ocean (south of 40°S) has the largest discrepancies.

The GPM Core Observatory, launched in February 2014, is providing advanced observations over the latitudes 65° North and South These observations should substantially improve the data bases used in retrievals by providing routine swaths of channels that are sensitive to all rain rates and to snowfall.

G. J. Huffman (612), A. Behrangi (JPL), J.-J. Wang (UMD/ESSIC)

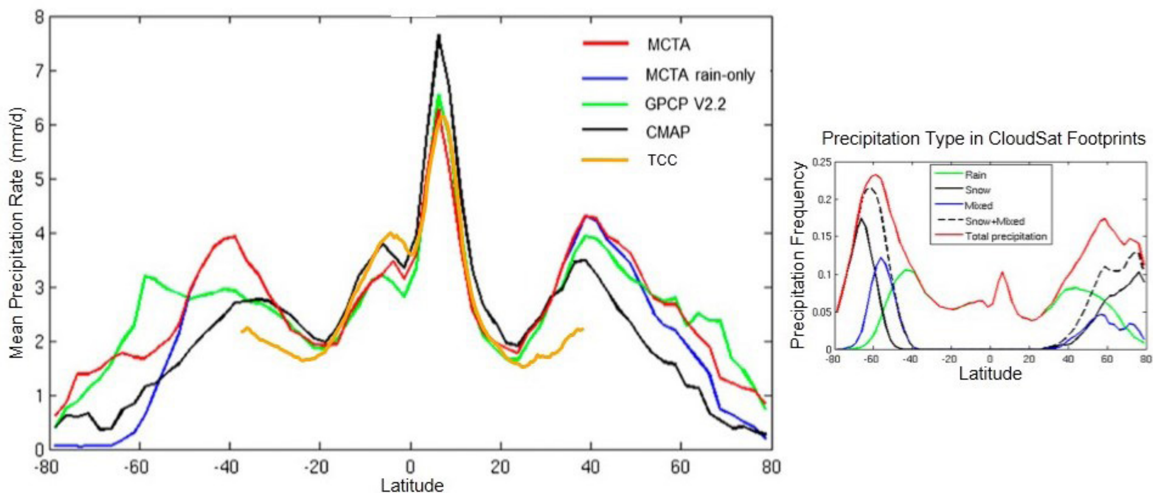


Figure 2.2: (a) Compiled histograms show merged precipitation estimates as a function of latitude over the oceans for the years 2007–2009 for CloudSat, TRMM, and Aqua (MCTA). The TRMM Composite Climatology (TCC) provided an intelligent consensus for 1998–2012 of the three TRMM instrument products; the TRMM Multi-satellite Precipitation Analysis (TMPA) provided quality control. (b) At higher latitudes, snow (both by itself and "mixed" with rain) becomes a significant fraction of the precipitation events as depicted by CloudSat.

2.1.4. Improving Simulated Radar Signatures in the Goddard Cloud Model

Cloud-resolving models (CRMs), such as the Goddard Cumulus Ensemble (GCE) model are critical to both the study and representation of cloud systems and their precipitation processes. Not only have CRMs promoted our understanding of precipitation processes and their interactions with land, ocean, and radiation, but their synthetic cloud data can serve as a crucial proxy for real cloud processes, including those that are difficult to measure (e.g., cloud heating components).

GCE model simulations with the new Goddard 4-class ice (4ICE) scheme produce better peak radar reflectivities and capture the erect, intense convective cores and the trailing, horizontally stratified region as well as producing superior overall echo distributions in the ice-phase regions of convective systems versus NEXRAD data than the earlier 3ICE versions. The vertical cross-section of radar reflectivities simulated using the GCE with the 4ICE scheme show smaller hail for an intense squall line that occurred on May 20, 2011, during the Midlatitude Continental Convective Clouds Experiment (MC3E) in central Oklahoma. The model captures the observed narrow, but intense, erect convective cores (shown in Figure 2.3 by the column of dBZ > 50 in pink and blue) as well as the broad area of weak, horizontally stratified echoes in the trailing stratiform region. The GCE has and continues to be used to provide 4D cloud datasets from numerous environments for the development of TRMM and now GPM precipitation and cloud-heating algorithms. The accuracy of those algorithms depends in part on how well the cloud data from the GCE captures true cloud systems. The new 4ICE scheme significantly improves the quality of cloud data for a variety of environments. Furthermore, with increasing computing power, physics packages developed for CRMs can now be used in meso- and global scale models. Such is the case with the 4ICE scheme, which has now been implemented into the NASA Unified WRF and Goddard MMF models.

S. Lang (612, SSAI), W.-K. Tao (612), J.-D. Chern (612, ESSIC), D. Wu (612, SSAI), and X. Li (612, MSU)

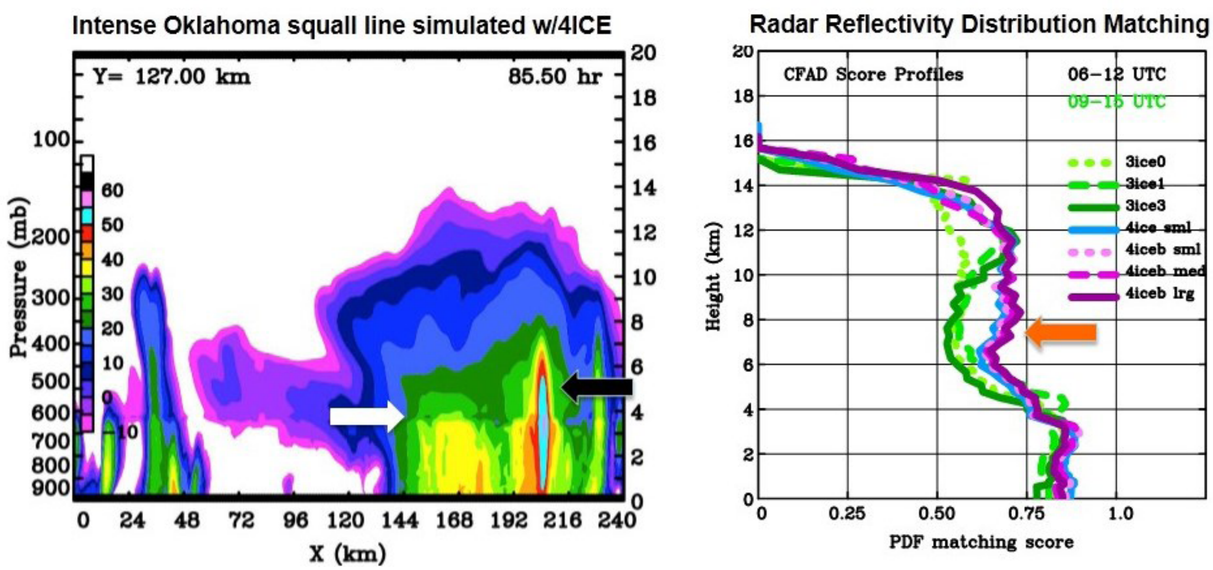


Figure 2.3: Left: Radar image indicates narrow but intense, erect convective cores (shown by the column of dBZ > 50 in pink and blue) as well as the broad area of weak, horizontally stratified echoes in the trailing stratiform region. Right: CFADs (contoured frequency with altitude diagrams) show PDFs of a given field at each vertical level, which are then contoured.

2.1.5. Evaluation of AERONET Precipitable Water Vapor at Atmospheric Radiation Measurement Sites

Water vapor is a key element in the Earth's climate system because of its important role in the hydrological cycle. Its condensation into liquid provides latent heating, and its infrared opacity makes it the most important gaseous element in the atmosphere. Therefore, accurate water vapor measurements are needed in meteorological and climatological studies, including weather forecast and energy budget studies. The evaluation of AERONET precipitable water vapor ($W_{AERONET}$) versus a large set of microwave radiometer and global positioning data reveals a mean low bias in $W_{AERONET}$ of ~9.0 percent and ~6.0 percent, respectively. Comparison with the radiosonde-measured water vapor also reveals that $W_{AERONET}$ has a mean low bias of ~5.0 percent. Here, the capabilities of the AERONET network that rely on Sunphotometry measurements have been validated against more advanced techniques. The great advantage of AERONET is that Sun photometers are located in many remote areas where there are no other water vapor instruments. The results of this study demonstrate that AERONET precipitable water vapor retrievals can be used to help validate satellite measurements and global models. Also, these results are a starting point for the use of the Marine Aerosol Network (a sub-network of AERONET) that makes measurements on cruises, which will provide a unique aerosol database over the oceans.

D. Perez-Ramirez (612, USRA), D. N. Whiteman (612), A. Smirnov (618, SigmaSpace), H. Lyamani (Univ. Granada (Spain)), B.N. Holben (618), R. Pinker (UMD), M. Andrade (Mayor San Andres (Bolivia)), and L. Alados-Arboledas (Univ. Granada (Spain))

2.1.6. Four-Frequency Radar Measurements of Clouds and Precipitation from NASA ER-2

Three radars installed on the NASA ER-2 high-altitude aircraft (HIWRAP, CRS, EXRAD) provide the first 4-frequency reflectivity and Doppler measurements from precipitation and clouds. Radar reflectivity and Doppler velocity corrected for aircraft motions are shown for the four frequencies for two hail storms on May 23, 2014, in northern South Carolina during the Integrated Precipitation and Hydrology Experiment (IPHEx) sponsored by GPM. These storms produced large hail (>2 inches) and created updrafts exceeding 25 ms^{-1} (seen by the deep blue colors in the Doppler plot). Strong-attenuation and Mie scattering occurred in the convective cores at the shorter wavelengths. Cross-sections such as these are being analyzed, along with ER-2 radiometric measurements, to provide a better understanding of convective storms and improve the physics assumptions in satellite retrieval algorithms. The three radars, covering X- through W-bands, provide both a simulation for future missions as well as additional and higher-resolution measurements for current missions such as GPM and CloudSat. This combination of instruments supplies the first dual-frequency Ka- and W-band measurements for development of retrieval algorithms for ACE. It also provides GPM-like measurements at Ku- and Ka-band that along with W-band, can be used to improve the physics of the GPM algorithms and to study significant data issues in current and future missions such as non-uniform beam filling.

G. Heymsfield (612)

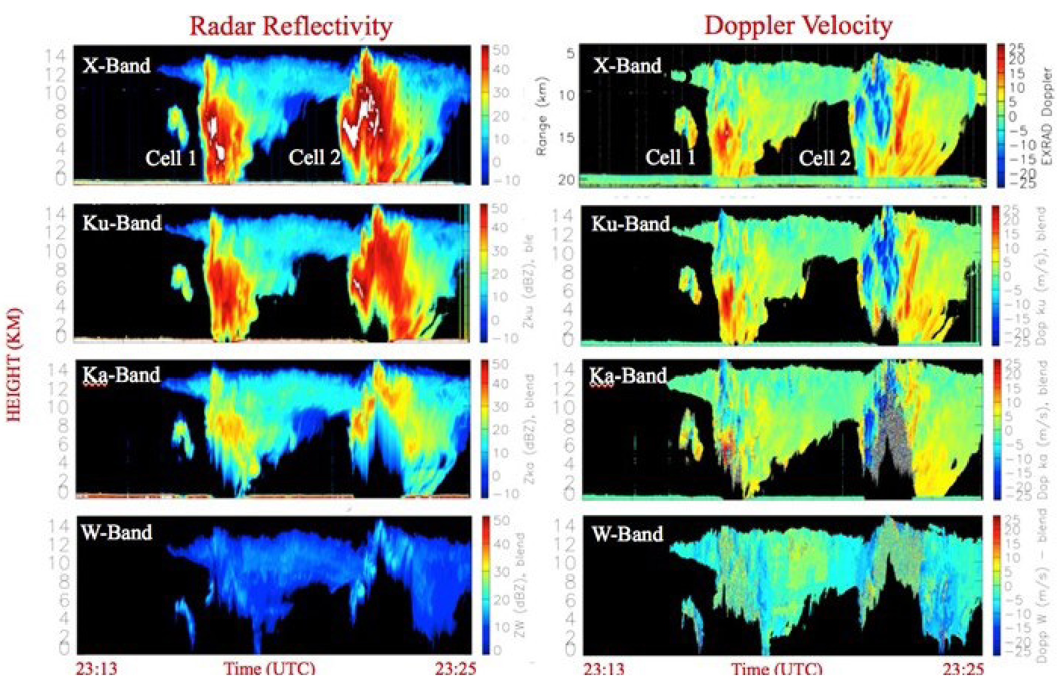


Figure 2.4: Radar reflectivity and Doppler velocity

2.1.7. Improving Storm Forecasts by Data Assimilation of GPM-era Observations

Precipitation plays an important role in both global and regional hydrological cycles. It is also a difficult environmental variable to predict because it is highly nonlinear and has large variability. Satellite radiance data can provide valuable information via data assimilation to improve storm predictions. The Goddard WRF ensemble data assimilation system has been equipped with state-of-art techniques to effectively utilize GPM-era global precipitation measurements. It can also serve as an information integration tool to produce optimal precipitation estimates and associated dynamics for weather prediction and climate studies. The Goddard WRF ensemble data assimilation system has capabilities to utilize GPM-era precipitation observations to improve storm predictions. New techniques have been developed to assimilate satellite radiance at pixel resolution with observation bias correction and microphysics for control variables. The forecast during storm evolution and advection has lower RMSE and higher correlation comparing to forecasts without data assimilation, verified against independent radar data. Microwave radiance observations from GPM constellation satellites including SSMIS, MHS, AMSR-E are assimilated; surface precipitation derived from European ARAMIS radar network is used as verification data; NCEP operational global analysis is used in lateral boundary conditions for regional forecasts.

S. Q. Zhang (612, SAIC), P. Chambon (Météo France), A. Y. Hou (612), M. Zupanski (Colorado State Univ.), and S. Cheung (Univ. of California)

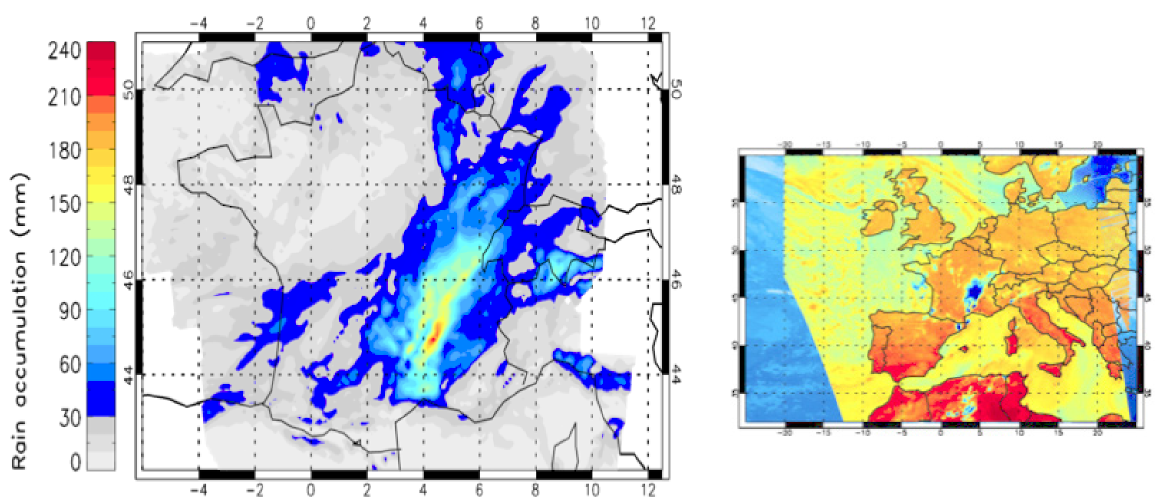


Figure 2.5: Left image shows forecast with GPM-constellation data assimilation. The right shows satellite observations on the storm.

2.1.8. Evaluation of the New Version of the Laser-Optical Disdrometer

One of the key objectives of the NASA's GPM mission is to retrieve the raindrop size distribution (DSD) from its dual-frequency radar measurements. A PARticle Size VELocity (PARSIVEL) disdrometer measures the particle size distribution directly and can be used to test the parameterized form of the DSD retrieval algorithm. This study concluded that the new version of PARSIVEL (P2) is a qualified instrument to parameterize the DSD while the old version of PARSIVEL (P1) is not. PARSIVELs have been widely used during NASA Global Precipitation Measurement (GPM) mission ground validation program field campaigns and direct data observation sites. It is the most affordable commercially available disdrometer. It is robust and requires low maintenance. It is also a present weather sensor. Based on these features, PARSIVELs are the most commonly used disdrometer worldwide. Within GPM, it is used to investigate the various assumptions of spaceborne radar precipitation retrieval algorithms and spatial variability within satellite footprints. In that regard, the PARSIVEL's measurement accuracy in both size and fall velocity of hydrometeors is critical.

O. Parsivel (JCET/UMBC), A. Tokay (612, JCET/UMBC), D. B. Wolff (610.W), and W. A. Petersen (610.W)

2.1.9. Lidar Measurements of Smoke from Western Wildfires

Obtaining an accurate assessment of cloud and aerosol properties and their transport remain a major challenge in understanding and predicting the climate system. The CATS, CPL, and ACATS data products have a large range of applications to significant climate system issues, such as examining cirrus optical properties, assessing dust and smoke transport, and investigating cloud-aerosol interactions. Therefore, validating CATS data products is crucial in quantifying uncertainties and detecting biases in retrievals; it should, in turn, strengthen the results of future studies using CATS data. In additional, ACATS advances component technologies and algorithm development by producing an airborne instrument applicable to prototyping an HSRL for NASA's Aerosols-Clouds-Ecosystems (ACE) mission. Coincident backscatter measurements of smoke from wildfires in the Pacific Northwest from ACATS and CPL on board the NASA ER-2 were used to validate measurements from CATS, located on the International Space Station (ISS). A map of the ISS and ER-2 tracks from August 18, 2015, shows that both platforms flew over smoke from wildfires in the Pacific Northwest region of the United States. The CPL and ACATS instruments on board the ER-2 (track in yellow) were used to validate the CATS instrument located on the ISS (track in blue). The ER-2 flight, planned as part of CCAVE, targeted the ISS track for a segment of coincident data (green) over smoke and cirrus clouds.

J. Yorks (612) and M. McGill (610)

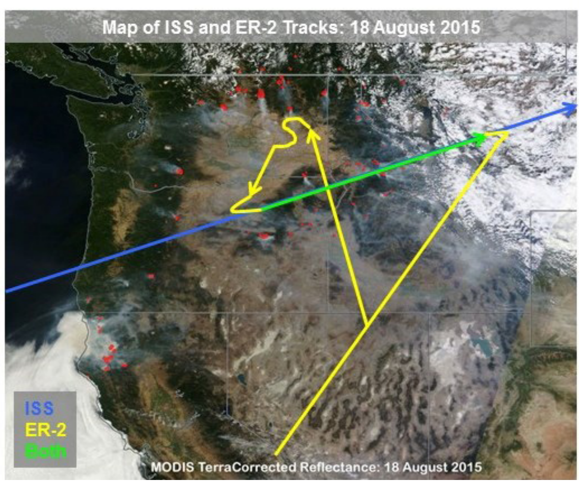


Figure 2.6: A map of the ISS and ER-2 track shows that both platforms flew over smoke from wildfires in the Pacific Northwest region of the United States.

2.1.10. WRF-SBM simulations of bright-band structure observed in LPVEx

"Bright band" is a phenomenon recognized as a layer with relatively high radar reflectivity below the 0 °C temperature level in a radar echo profile. The high reflectivity is caused by several factors related to melting of falling ice particles in the layer. The normalized contoured frequency by temperature diagrams (CFTDs) below highlight the peak radar reflectivity in bright bands in a temperature range of 0 to 3 °C. The Weather Research and Forecasting model, coupled with spectral bin cloud microphysics (WRF-SBM), simulated a mixed-phase precipitation event using two types of ice melting models: a new gradual ice-melting model and an old instantaneous melting model. The new model improved simulation of peak reflectivity profiles in a bright band. Better understanding of bright-bands is a key to reducing errors in an estimate of rainfall rates from satellite measurements such as the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement (GPM); a high backscattering signal in bright bands may be mistakenly interpreted as the existence of a high rainfall rate. Exact representation of bright bands is a significant challenge in high-resolution atmospheric simulation with a detailed cloud microphysics model. Exact representation supports comprehensive investigation of bright bands formation mechanisms related to a gradual change of the melting volume fractions of falling ice particles and their complicated scattering properties at a radar beam wavelength. The WRF-SBM model has been integrated into a synthetic simulator for GPM ground validation programs. The simulation results can be used to provide test-bed databases supporting the development of various rainfall retrieval algorithms. WRF-SBM simulation data for these precipitation scenes in LPVEx will be available to the research community through the Cloud Library data portal.

T. Iguchi (612, ESSIC/UMD), T. Matsui (612, ESSIC/UMD), W.-K. Tao (612), A. P. Khain (Hebrew Univ.), V. T. J. Phillips (Lund Univ.), C. Kidd (612, ESSIC/UMD), T. L'Ecuyer (Univ. of Wisconsin), S. A. Braun (612), and A. Y. Hou (612)

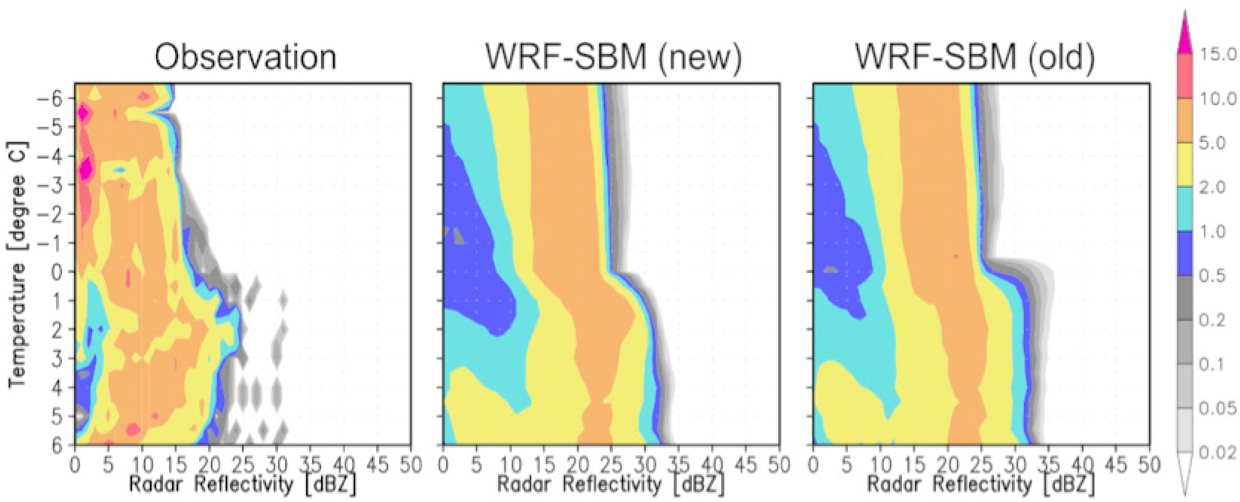


Figure 2.7: K-band dBZ CFTDs (percent) on October 20, 2010.

2.1.11. High-Resolution Vertical Observations of Double Bright-Band Phenomena

Observations of double bright bands are somewhat rare. However, the ability to identify this phenomenon is important for rainfall estimation from spaceborne sensors, such as GPM, because algorithms employing the restriction of a radar bright band to a constant height, especially when sampling across frontal systems, will limit the ability to accurately estimate rainfall. EDOP, a coherent, X-band frequency radar (9.6 GHz/3.123 cm), was used to measure the vertical evolution of the reflectivity, vertical velocity structure, and spectrum width with 0.5 s temporal and 37.5 m spatial resolution on May 11, 2010. This study captured the detailed evolution of a double bright band feature. The Doppler frequency shift of the backscattered energy was retrieved by a Maryland Department of the Environment radar wind profiler, which measure wind speed and direction. A ceilometer with a vertical range of 7 km was also used. The double bright-band event, shown below, was captured by vertically pointing radar, 915 MHz profiler, and ceilometer. The increase in the altitude of the primary bright band is due to the passage of a warm front. An elevated melting layer formed above a preexisting lower melting layer located closer to the surface. By 1744 UTC, the secondary bright band appeared at 2.9 km altitude following the surface warm front passage, which warmed the entire layer below 2.9 km altitude to above 0°C. Continued warming of the lower atmosphere eventually erased the lower melting layer.

A. Emory (612), B. Demoz (JCET/UMBC), K. Vermeesch (JCET/UMBC), and M. Hicks (NWS, Sterling, VA)

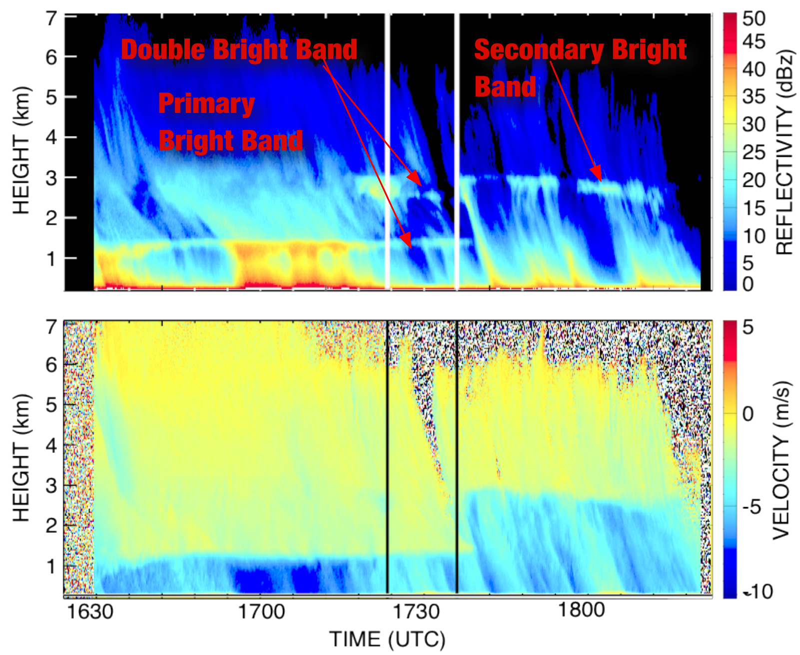


Figure 2.8: Vertical profiles of reflectivity and Doppler velocity from EDOP radar.

2.2. Climate and Radiation Laboratory

Understanding the Earth's climate system and it is affected by how human behavior is one of the most pressing issues facing humankind now and in the future.. This has been the driving force behind many of the activities in the Climate and Radiation Laboratory. Accordingly, the Laboratory has made major scientific contributions in five key areas: hydrologic processes and climate, aerosol-climate interaction, clouds and radiation, model physics improvement, and technology development. Examples of these contributions may be found in the list of refereed articles in Appendix II and in the material updated regularly on the Code 613 Laboratory Web site: http://atmospheres.gsfc.nasa.gov/climate/.

Key satellite observational efforts in the Laboratory include MODIS and MISR algorithm development and data analysis, SORCE solar irradiance (both total and spectral) data analysis and modeling, and TRMM and ISCCP data analysis. Leadership and participation in science and validation field campaigns provide key measurements as well as publications and presentations. Laboratory scientists serve in key leadership positions on international programs, panels, and committees, serve as project scientists on NASA missions and 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 2014 are described below. These cover the areas aerosol-cloud-precipitation interactions, aerosol effects on climate, reflected solar radiation, land - atmosphere feedback, polar region variations, and hydrological cycle changes. The Laboratory also carries out an active program in mission concept developments, instrument concepts and systems development, and Global Climate Models (GCMs). The Projects link on the Climate and Radiation Laboratory Web site contains recent significant findings in these and other areas.

The study of aerosols is important to Laboratory scientists for many reasons: (1) They have direct and indirect effects on climate that are complicated and not well-quantified; (2) Poor air quality due to high aerosol loading 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; (4) Knowledge of aerosol loading is important to determine the potential yield from the green solar energy sources. Highlights of Laboratory research activities carried out during the year are summarized are below.

2.2.1. Cloud Variations Skew the Statistics of Near-Cloud Aerosol Properties

Lidar backscatter from aerosols is known to increase near clouds. The analysis of CALIPSO data indicates that backscatter increase depends on cloud cover *(Figure 2.9a)* and is strongest when cloud fraction is high (*green-diamond line)*. Composite statistics that combine all data from a wide range of cloud fractions can distort the increase. This distortion occurs because near-cloud aerosol backscatter increases with cloud fraction, and areas of high cloud-fraction contribute more to composite statistics than areas far from clouds *(Figure 2.9b)*. A technique has been developed to avoid overestimating near-cloud aerosol contributions in overall statistics *(Figure 2.9c)*. The correction is achieved by resampling the data in such a way that the distribution of cloud fraction is the same for any distance from clouds. In this example, the distribution of cloud fraction was specified by the one observed at the distance of 10 km to avoid overestimating near-cloud enhancements in overall statistics (*Figure 2.9c*).

Understanding the properties of near-cloud aerosol is important for accurate estimation of aerosol radiative forcing. The findings of this research give us new knowledge on how cloud coverage affects near-cloud aerosol properties. The effects of cloud coverage have not been considered in earlier studies of these properties. This finding will also benefit to the study of near-cloud aerosols using future remote-sensing instruments.

W. Yang (613), A. Marshak (613), T. Vérnai (613), and R. Wood (Univ. of Washington)

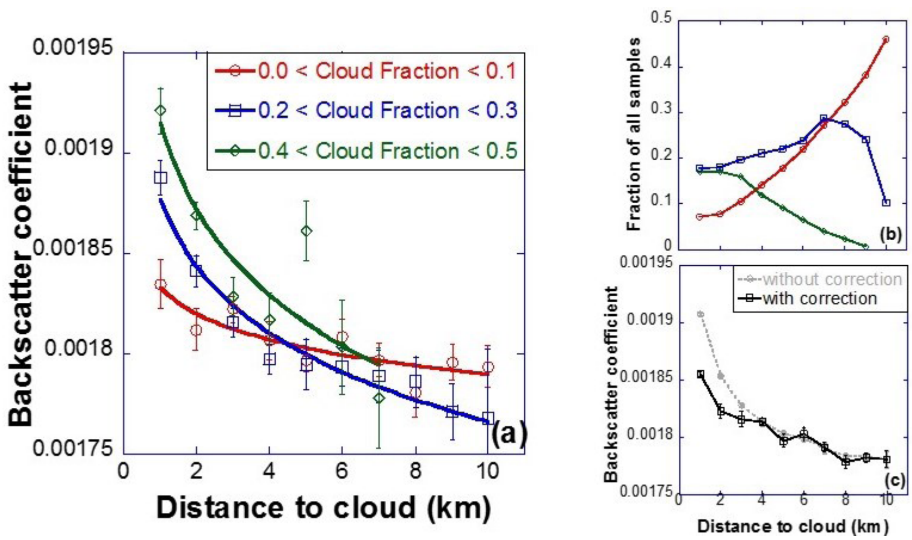


Figure 2.9: CALIPSO lidar data for cloud cover backscatter versus distance. (a) Shows the medians of backscatter coefficient at 532-nm wavelength from CALIPSO are shown as a function of distance to cloud for each cloud fraction. (b) Shows the aerosol sample fraction as a function to distance to cloud for various ranges of cloud fraction. (c) Shows the composite statistics of backscatter coefficient with and without the proposed correction.

2.2.2. Earth's Climate Sensitivity: Apparent Inconsistencies in Recent Analyses

Recent assessments of climate sensitivity exhibit apparent inconsistencies. The causes must be identified and addressed to reduce uncertainties in climate prediction. Possible contributors include: (1) Underestimated aerosol cooling, (2) Overestimated total forcing, (3) Overestimated climate sensitivity, (4) Underestimated ocean heating, and/or (5) Energy balance model limitations. Equilibrium Climate Sensitivity (ECS) is a key diagnostic capability of predictive global climate models that relates, in a simple way, the "forcing" of climate change due to changes in greenhouse gases, aerosols, and other factors to the "response," which is usually taken as the global mean surface temperature change. Our analysis uses a simple energy balance model to assess the consistency between the climate forcing postulated in the *Intergovernmental Panel on Climate Change* (*IPCC*) *Fifth Assessment Report* (AR5) published in 2013 and the corresponding values of climate sensitivity given in the same report, in the previous IPCC report (AR4; 2007), and in a paper by *Otto et al*. (2013).

Energy balance considerations show a consistent relationship among forcing, response, and ECS for AR4. However, this is not the case for AR5 or the Otto et al. study. For AR5, aerosol negative forcing (a net cooling) is estimated as smaller than the value in AR4; and in addition, the positive forcing from greenhouse gases is slightly larger, due to the increasing atmospheric concentration of carbon dioxide. So for AR5, the net forcing increased, and the response (DT) is kept essentially the same as AR4. Yet, the estimated range of the climate sensitivity reported in AR5 also remains almost the same as AR4. So for AR5, the three factors are not consistent with the simple energy balance model.

Our work raised the following questions. (1) Why is the aerosol-forcing estimate reduced in AR5? (2) Given the increased net total forcing estimate, why is ECS not diminished relative to AR4? (3) Why, in AR5, is the forcing-response-*ECS* relationship inconsistent with simple energy balance considerations? We enumerated possible contributing factors: (1) underestimated aerosol cooling, (2) overestimated total forcing, (3) overestimated climate sensitivity, (4) underestimated ocean heating, and/or (5) energy balance model limitations. Improved measurements of aerosol direct and indirect forcing as well as better measurements of ocean heat absorption would help, along with further examination of climate model performance.

S. E. Schwartz (Brookhaven National Lab., NY), R. J. Charlson (Univ. of Washington), R. A. Kahn (613), and H. Rodhe (Stockholm University, Sweden)

2.2.3. The 27-Day Rotational Variations in Total Solar Irradiance

Solar irradiance changes with the 11-year solar cycle (SC) and is associated with variations in solar surface magnetic field. These changes are modulated by a short-term 27-day solar rotation viewed from Earth. The rotational signal is well documented with space-borne total solar irradiance measurements: SORCE/ Total Irradiance Monitor (TIM), ACRIMSAT/ACRIM III, and SOHO/VIRGO. Building an accurate and uninterrupted TSI data record is important for assessing Earth's radiation budget. Space-borne measurements of TSI with unprecedented accuracy and stability enable us to determine the amount of solar irradiance reaching the top of the atmosphere and how solar irradiance varies in different time scales.

J.N. Lee (613, JCET/UMBC), R. F. Cahalan (613, APL/JHU), and D. L. Wu (613)

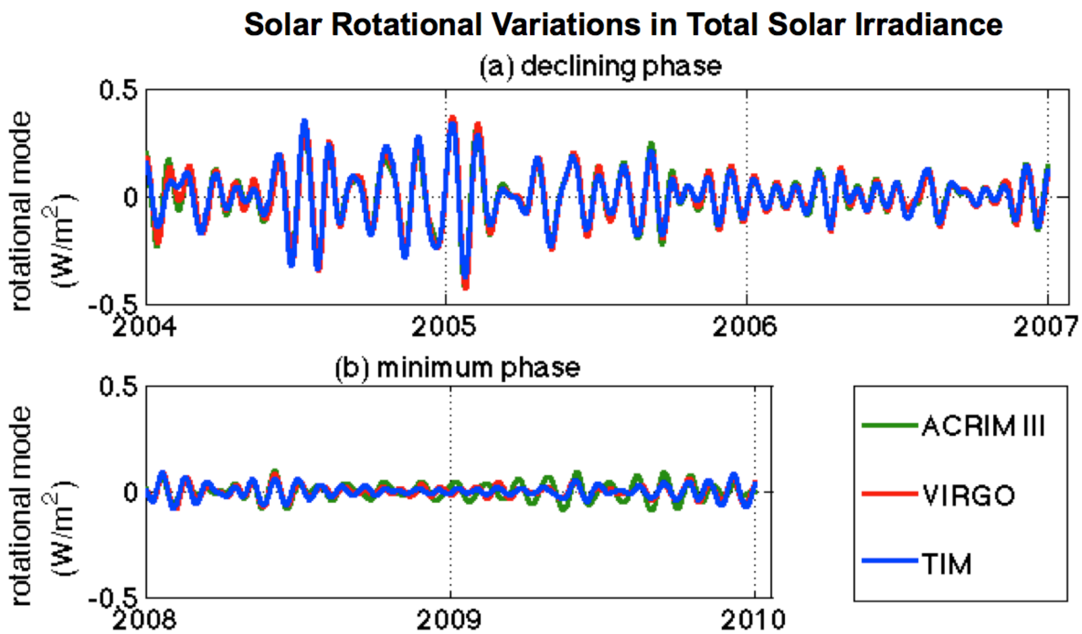


Figure 2.10: (a) Comparison of the TSI rotational variation from TIM (blue), ACRIM III (green), and VIRGO (red), in W/m². By applying Ensemble Empirical Mode Decomposition (EEMD) analysis, the 27-day solar rotational variations are clearly identified and characterized by more than 100 rotational cycles. The three independent measurements show excellent agreement in rotational variations (note that the superimposition of three different colors for the three different records is dominated by blue because of the excellent agreement). During (b) solar minimum phase, the amplitudes of the variations are reduced.

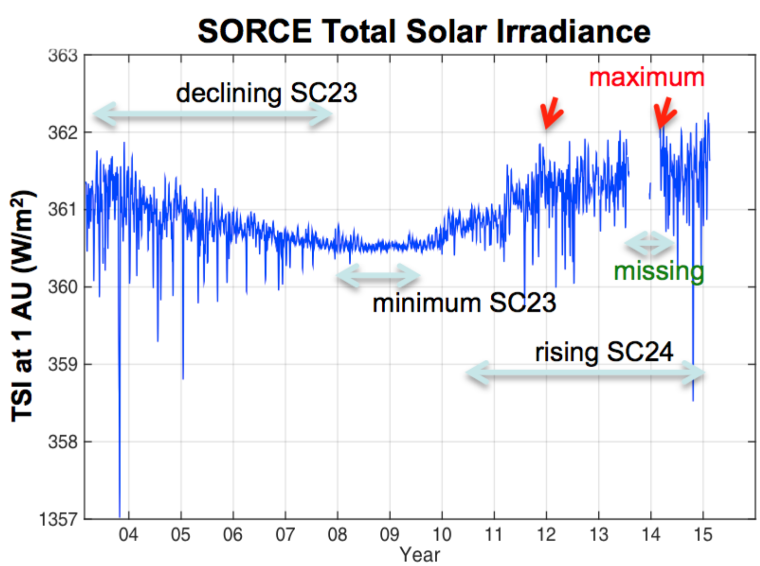


Figure 2.10 (b) Daily averaged TSI measured from TIM. TIM measurement of TSI during the 2008–2009 solar minimum established a new TSI value at 1360.8±0.5 W/m2, which is 4.6W/m2 (0.34%) lower than space-borne estimates of the quiet Sun TSI made in the previous 25 years [Kopp and Lean, 2011]. After an unusually extended minimum, the dual peaks of solar cycle 24 are indicative of the least active cycle in 100 years. At the time of near solar cycle maximum, the degradation of battery performance caused the SORCE data gap from August 2013 to February. 2014

2.2.4. Saharan Dust Prevents Phosphorus Depletion in the Amazon Rainforest

The dust cycle has become an emerging core theme of Earth system science. This study provides the first observation-based, multiyear estimate of dust deposition in the Amazon basin based on the CALIPSO all-sky aerosol measurements. Millions of tons of dust are deposited in the Amazon rainforest annually according to 2007 –2013 CALIPSO record. Saharan dust transports an estimated 22,000 tons of phosphorus the Amazon rainforest with yearly, replenishing the loss of plant-essential nutrients. Our analysis suggests that the phosphorus input associated with this dust can effectively replace phosphorus depletion by rains and flooding from the Amazon basin. Recently launched DSCOVR and CATS missions, with enhanced capabilities, will continue to monitor such dust transports. A future ACE mission could provide more accurate measurements of three-dimensional aerosol distributions and particle properties, which would further improve our ability to assess the implications of dust on the Earth's biosphere through large-scale transport.

H. Yu (613, ESSIC/UMD).

2.2.5. Tropical Upper-Troposphere Ice Clouds Are Systematically Tilted Poleward

This study for the first time presents a global characterization of cloud tilt structures in the upper troposphere within the meridional direction. Upper-tropospheric ice clouds (anvils and cirrus outflows extending from deep convections) have small-scale (~1 km, horizontal) structures that are organized and systematically tilting poleward in the tropics, as revealed by CloudSat ice-water path (IWP) and Aura Microwave Limb Sounder (MLS) Radiance (TB). These tilted cloud structures cover regions over hundred kilometers, contributing up to 20 percent of IWP uncertainty if not accounted for in remote sensing from space. As shown in *Figure 2.11 (b)*, the anvils and cirrus associated with the convective core tend to fan outward for each single convective cloud. Within the active, deep convective center, the effect cancels out when numerous clouds are added together; however, this adding effect becomes cumulative near the peripheries of the deep convective region, resulting in systematic tilt signals. The observed IWP differences in the paired slant-views have important implications for remote sensing and modeling of global cloud systems, including satellite retrieval of cloud properties, atmospheric momentum and energy budget, evaluation of cloud radiative effect, and modulation of the hydrological cycle.

J. Gong (613, Universities Space Research Association), D. L. Wu (613), and V. Limpasuvan (Coastal Carolina Univ.)

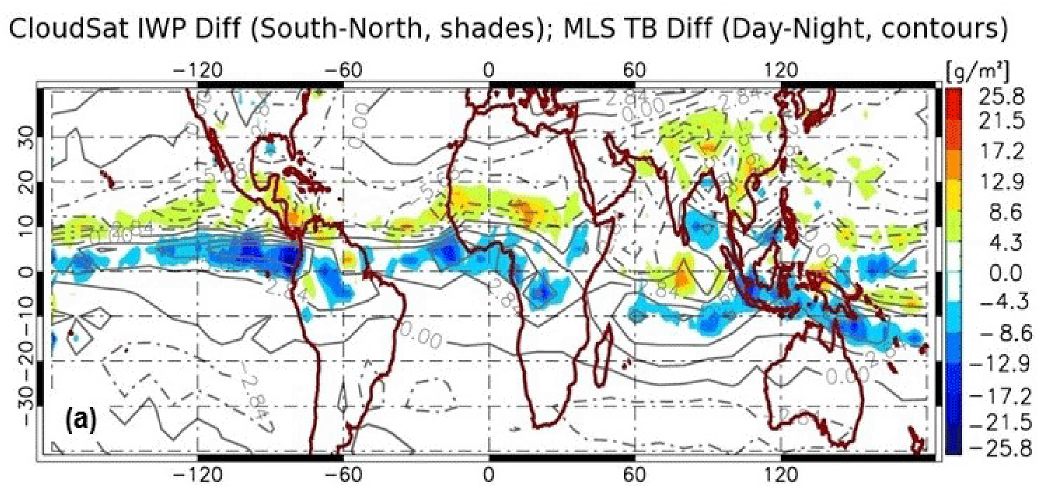


Figure 2.11: (a) CloudSat IWP (colored shades; southward-looking view minus northward-looking view; 11–17-km IWC integration, cloud registration determined by location at 14 km) and Aura MLS 640 GHz ΔTB (descending minus ascending orbits to mimic CloudSat viewing geometry, contours, with dashed indicating negative, and solid positive values) averaged over June, July, and August during 2007–2010.

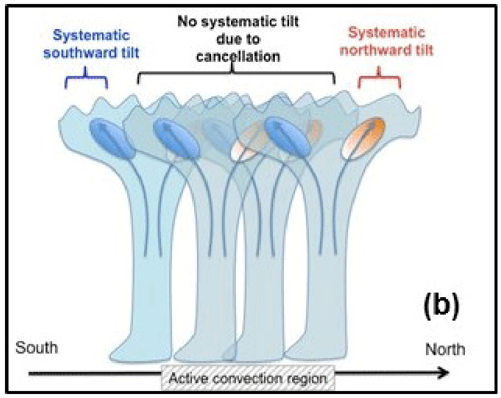


Figure 2.11: (b) A schematic diagram showing the interpretation of systematic poleward tilts of upper-troposphere clouds at the northern and southern peripheries of active tropical convection regions.

2.2.6. TRMM Extreme Precipitation Monitoring System

The TRMM Extreme Precipitation Monitoring System (ExPreS) converts TRMM data into an easily understood average recurrence interval (ARI) warning system for potential rain-triggered hazards. The system computes local extreme statistics and lookup tables, mapping the precipitation amount with using retrospective 3B42RT data based on Generalized Extreme Value (GEV) distribution functions. Real-time 3B42RT data is converted to ARI as soon as it becomes available to provide warnings on potential hazards. The system shows precipitation accumulation and corresponding ARI or Return-Year for the past 1~10 days computed from near-real-time TRMM Multi-satellite Precipitation Analysis (TMPA). Colored dots indicated areas with severe extreme precipitation that could lead to potential hazards, especially over land. The big red dot in the southeastern United States captures the heaviest rain episode, with an ARI greater than 50 years.. The real-time heavy episode is converted to the average recurrence interval during the April–May period in 2011. This episode resulted from a series of heavy rains that led to massive floods in the lower-Mississippi River—one of the largest and most damaging floods recorded along this U.S. waterway in the past century. The ExPreS is intended to raise awareness of potential hazards and support disaster management**.** It facilitates the use of NASA's science and technology for the direct benefit of United States and global disaster-monitoring communities as well as the general public. The system will be improved with better statistics and upcoming high-resolution GPM IMERG data.

Y. Zhou (613, MSU), W. K. Lau (613, MSU), G. Huffman (613, MSU)

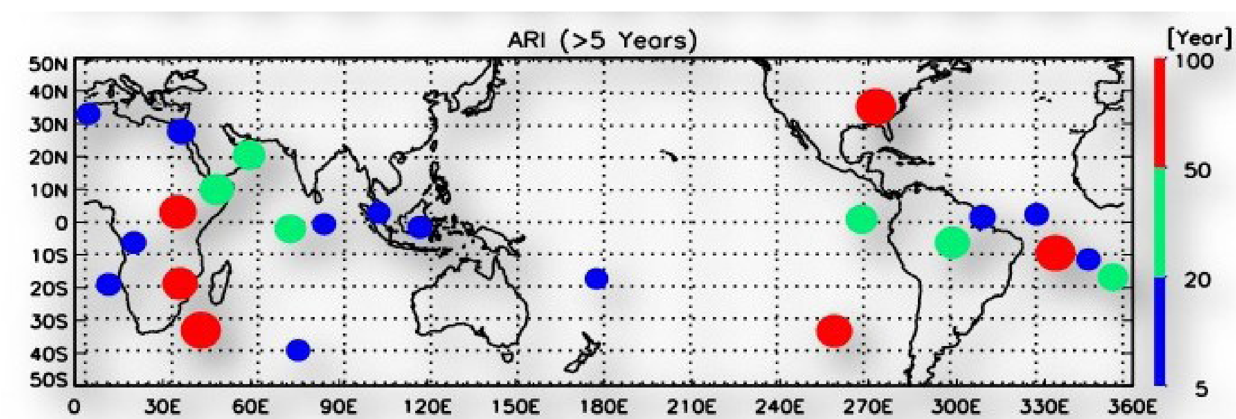


Figure 2.12: Average recurrence interval (ARI) data for hazardous storms generated from TRMM ExPreS.

2.2.7. Long-term Global Aerosol Optical Depth Records: A consistent retrieval algorithm for MODIS and VIIRS

Aerosols are fundamental components of Earth's climate and radiation budget. Trends in global and regional aerosol properties may influence future climate. To quantify changes in global and regional aerosol properties, we need an accurate and consistent aerosol data record that is both long-term (multi-decadal), and free from artificial jumps or trends. Currently, we have collected 15 years of derived global aerosol optical depth (AOD) from the Moderate-resolution Imaging Spectrometers (MODIS) aboard NASA's Terra and Aqua satellites. As these instruments age, we hope to extend the data record using the Visible and Infrared Spectrometers (VIIRS) aboard Suomi-NPP and the future Joint Polar Satellite System (JPSS). The MODIS "dark-target" (DT) aerosol retrieval algorithm produces stable, validated, and well-characterized global AOD. However, applying the MODIS DT algorithm, without accounting for the differences between VIIRS and MODIS (e.g., wavelengths, orbits, resolutions, etc.), would lead to the kind of jumps and trends that we do not want. Although our algorithm is consistently retrieving AOD data from VIIRS that are very similar to those from MODIS, there are still offsets that require explanation. Differences in calibration and capabilities for cloud masking are both examples of obstacles we need to overcome. We intend to generate a consistent, long-term aerosol climate data record that can be used in conjunction with models for many climate and air quality applications. We started with spectral reflectance data from the two sensors and applied a "consistent" aerosol retrieval algorithm to both. The two maps look very similar, both in AOD magnitude and spatial distribution. As we continue with the two-year time series of monthly global means, the two datasets track each other very well. While of similar magnitude, global AOD from VIIRS is biased high by 20 percent as compared to MODIS. Over land, offsets average near zero, but the difference between the two datasets seems to be trending over time.

R. C. Levy (613), L.A. Munchak (613, SSAI), S. Mattoo (613, SSAI), F. Patadia (613, GESTAR/MSU), L. A. Remer (UMBC/JCET), and R. E. Holz (SSEC/Univ. of Wisconsin)

2.2.8. Better Deep Blue Products: Aerosol Single-Scattering Albedo and Height from Combined S-NPP VIIRS, OMPS, and CALIOP Observations

Aerosol altitude is one of the key parameters required for better assessment the radiative effects of aerosols, because it is critical for determining the vertical structure of the radiation field. In particular, absorbing aerosols are known to have a significant impact on the atmospheric heating rate, which in turn modulates atmospheric stability and the lifetime of adjacent clouds. Height can also be reveal information on possible long-range transport of aerosols and help to improve air quality monitoring. Currently, CALIOP spaceborne lidar provides aerosol vertical profiles in great detail, but its narrow swath makes it difficult to observe their spatial distribution over broad areas. The use of multiple satellite sensors can provide a more complete picture of the global distribution of aerosol heights, enhancing existing data sets. This synergy can continue with the current S-NPP and CATS missions and planned JPSS and ACE missions. Combined with VIIRS, CALIOP, the Ozone Mapping and Profiler Suite (OMPS), these observations makes possible the retrieval of aerosol single-scattering albedo and height over broader areas than ever before.

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

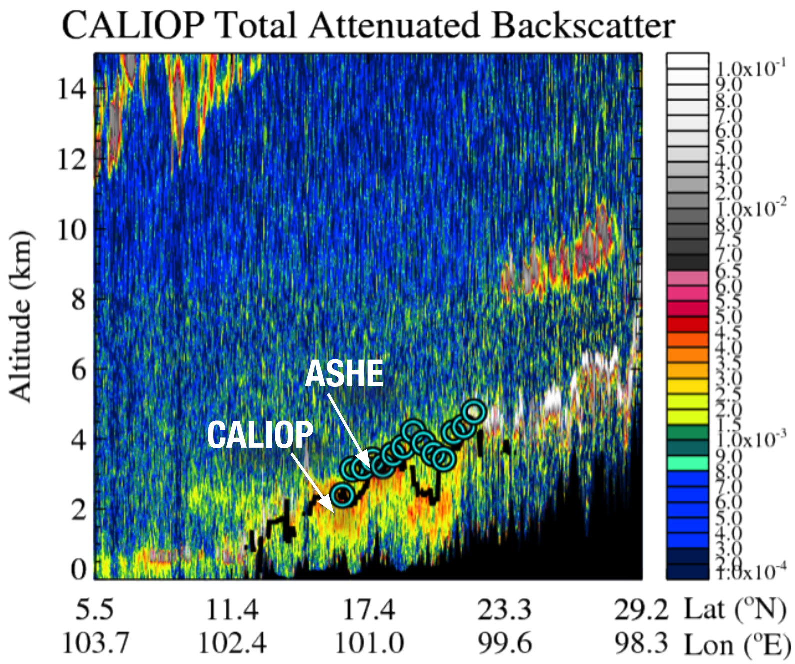


Figure 2.13: CALIOP total attenuated backscatter

2.2.9. The CHIMAERA System for Universal Cloud Retrievals

The Cross-platform HIgh resolution Multi-instrument AtmosphEric Retrieval Algorithms (CHIMAERA) system handles the operational MODIS cloud optical and microphysical properties retrieval algorithm. This MODIS algorithm retrieves information from one instrument to run on any other instrument having a minimum set of useful channels. *Figure 2.14* illustrates CHIMAERA's capabilities. All the data was produced using one unified code. A shared science core executes the retrieval once all necessary parameters have been loaded. CHIMAERA runs on any operating system and on any size machine, from a laptop at a field campaign to a supercomputer as a true parallel code. CHIMAERA can be expanded easily at will to include other sensors, and all output is in standard format compatible with the MOD06 product format. The figure illustrates the individual images that have been generated using a single Python visualization code then applied to all images without any changes whatsoever to the code.

CHIMAERA can also be a valuable tool when data record continuity and traceability is important since there is never a question of which exact retrieval algorithm had been used. It is already being used in such capacity for MODIS-VIIRS data continuity and for validation and calibration work with airborne sensors. CHIMAERA's existence allows the MODIS group also to collaborate with many different organizations that have sensors and would like to obtain MODIS-like cloud property retrievals from them.

G.Wind (SSAI), S. Platnick (610), K. Meyer (GESTAR/USRA), N. Amarasinghe (SSAI), T. Arnold (SSAI), and B. Marchant (GESTAR/USRA)

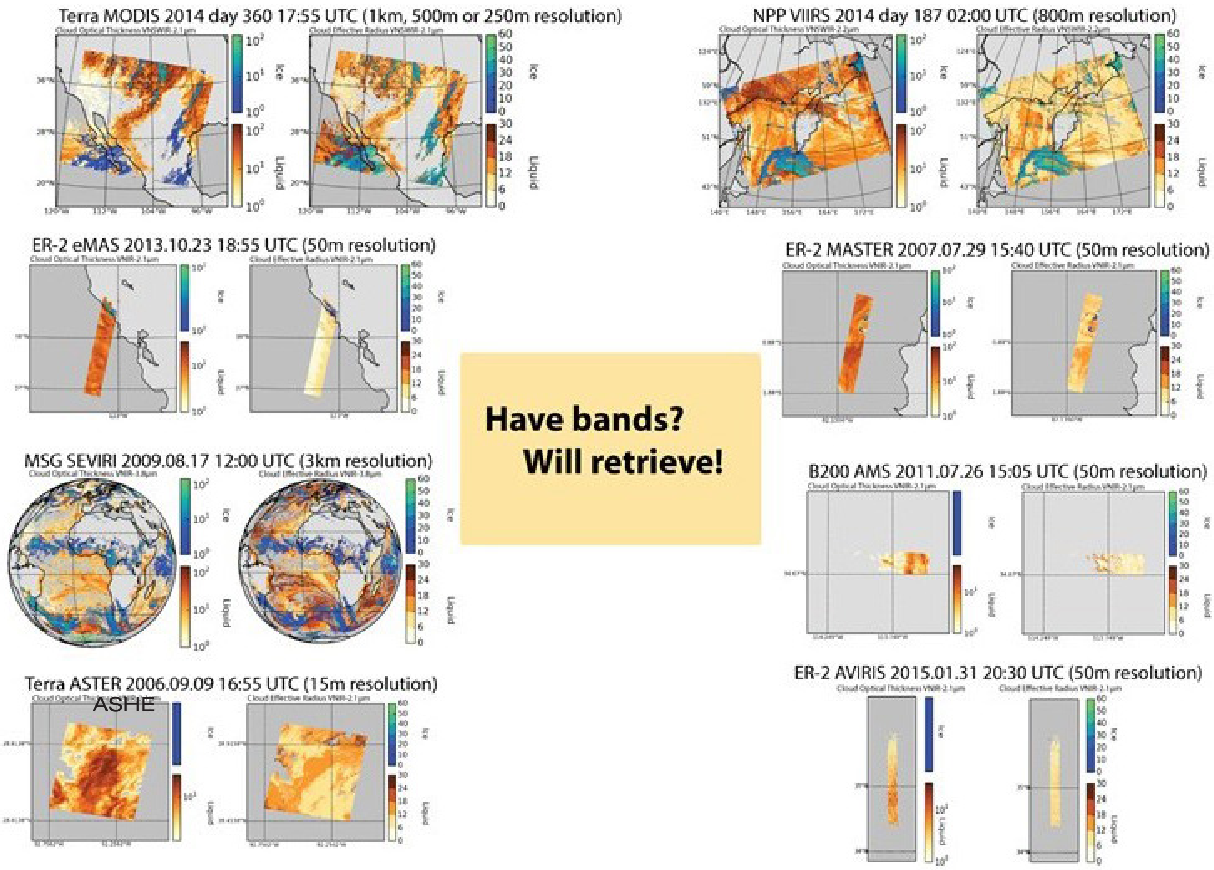


Figure 2.14: Demonstration of CHIMAERA's data capabilities

2.2.10. A New Tool for Earth Observations Using Small Satellites

Our new software system allows investigators to assess the value of small satellites in Earth observations. We show that using a formation of a few small satellites, optimally arranged and maintained, minimizes angular sampling gaps and yields better bidirectional reflectance-distribution functions (BRDF). The figure below shows a maintainable formation or constellation of small satellites proposed to improve near-simultaneous angular sampling. The formation can make multi-spectral and multi-angle contemporaneous measurements of a ground target as it passes overhead by using narrow field of view (NFOV) instruments in controlled formation flight.

S. Nag (613, BAERI), and C. Gatebe (613, USRA)

2.2.11. MODIS Terra-Aqua C6+ Cross-Calibration Improvements

The calibration of MODIS Collection 6 record has been improved through cross-calibration polarization corrections. The C6+ corrects of changing polarization sensitivity of MODIS Terra, removes of residual trends, and cross-calibrates gain adjustment between Terra and Aqua. The cross-calibration of sensors on different orbits is achieved via a novel strategy that uses geometric (BRDF) normalization. The latest assessment of the calibration-related artifacts in MODIS Terra C5 products reveal globally decreasing decadal trends of ~27 percent aerosol optical thickness, ~17 percent cloud optical thickness, and ~0.01 normalized difference vegetation index (NDVI) over land (*Lyapustin et al.*, 2014).

The C6 calibration (*Sun et al*., 2014) removed major calibration trends. In this work, we further improved C6 calibration by adding: (1) polarization correction of MODIS Terra based on polarization sensitivity coefficients provided by the GSFC Ocean Biology Processing Group (*Kwiatkowska et al*., 2008); and (2) de-trending of both Terra and Aqua and their cross-calibration based on analysis of MAIAC (*Lyapustin et al*., 2012) processing over stable desert "calibration" sites. MAIAC science analysis over the southern United States showed that the enhanced C6+ calibration improved agreement between Terra and Aqua decadal NDVI change by a factor of three (*Lyapustin et al*., 2014). Currently, C6+ calibration is being used in the MODIS Land discipline C6 re-processing, while the atmospheric (aerosol) global analysis is underway. This work is directly related to major NASA missions by improving sensor calibration and long-term stability, providing climate-quality data record for the Earth Sciences and applications.

A. Lyapustin (613), X. Xiong (618), Y. Wang (UMBC), G. Meister (616), S. Platnick (610), R. Levy (613), B. Franz (616), A. Wu (SSAI), and A. Angal (SSAI)

2.2.12. New Ways to Evaluate IPCC Model Cloudiness Using ISCCP Cloud Regimes

We have developed a novel framework of detailed cloud evaluation for GCMs employing a satellite simulator of passive measurements. The primary goal of our work was to identify common deficiencies and strengths in Coupled Model Intercomparison Project (CMIP5) cloudiness using an analysis that provides a different perspective on how a model fares compared to its peers. Replication is possible with other observational datasets as long as output from appropriate satellite simulators is available. For example, our group has also derived global cloud regimes from MODIS; since this instrument's simulator is also part of the COSP satellite simulator package, future intercomparison protocols should consider requiring this particular output. A revisit of the analysis with MODIS would allow us to determine the degree to which the major findings of the study reflect inherent model characteristics rather than idiosyncrasies of the particular observational dataset and simulator.

L. Oreopoulos (613), D. Jin (613), and D. Lee (613)

2.3. Atmospheric Chemistry and Dynamics Laboratory

The Atmospheric Chemistry and Dynamics Laboratory conducts research that includes 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 U.S. science team for EOS Aura satellite and the OMI instrument come from this group. The Laboratory also is a leader in the integrating and executing the National Polar-orbiting Operational Environmental Satellite System (NPP) mission and is also providing leadership for the former NPOESS, now the newly reorganized Joint Polar Satellite System (JPSS).

This Laboratory has also developed a state-of-the-are chemistry-climate model, in collaboration with the Goddard Modeling and Analysis Office (GMAO). This model has proved to be one of the best performers in a recent international chemistry-climate model evaluation for the stratosphere. Highlights of research activities carried out during the year have been summarized. Dry deposition of NO_2 and SO_2 contributes excess nitrogen and sulfur to vegetation, soil, and water.

2.3.1. Dry Deposition of NO_2 and SO_2 in Urban Areas Inferred from Aura/OMI

Annual 2005–2007 mean measurements of NO_2 and SO_2 columns from the 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 fluxes. 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 the Ozone Monitoring Instrument (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 TEMPO (Tropospheric Emissions: Monitoring of Pollution) will allow dry deposition to be quantified at very high spatial and temporal resolution.

P. Nowlan (Dalhousie Univ.), L. Lamsal (614, USRA), and N. Krotkov (614)

2.3.2. Improved Nimbus-7 TOMS Shows Smoke Impact of 1991 Gulf War Oil Fires

Near 700 oil wells were set on fire in January and February 1991 by the retreating Iraqi army that had invaded Kuwait on August 2, 1990. The smoke plume formed in the aftermath of the Kuwait oil fields fires during the 1991 Persian Gulf War was observed by existing spaceborne instrumentation. Using the Total Ozone Mapping Spectrometer (TOMS) aerosol index developed in 1995, the smoke plume associated with this historic event was retrospectively analyzed. Post-processed Nimbus-7 TOMS sensor data captured the spatial and temporal variability of the plume in terms of the aerosol index.

The TOMS record showed that the smoke plume extended in both East and West directions from the source. The aerosol index increased by at least 50 percent, in relation to previous years, over a large area from the Eastern Saharan to India during the May–July 1991 period. The increase in the observed aerosol index was equivalent to a similar increase in the atmospheric aerosol load.

Combined analysis of TOMS observations and NCEP winds (700 mb) data indicate that the smoke plume mixed with desert dust layers forming a combined dust-smoke aerosol cloud that, at times, seemed to extend continuously westward from northwestern India to the Western Saharan. According to TOMS observations, the spatial extent of the Kuwait plume was significantly more widespread than previously reported. (*Figure 2.15)*

O. Torres (614), P.K. Bhartia (610), and D. Larko (SSAI)

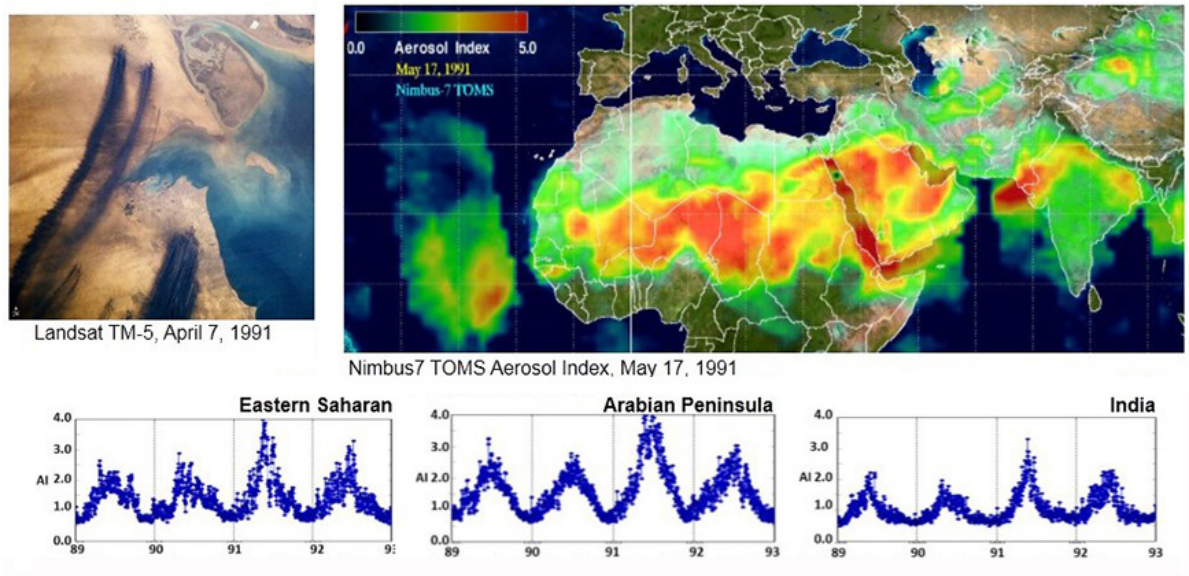


Figure 2.15: (Top left): High-resolution Landsat TM-5 image on April 7, 1991, depicting the spread of individual oil well fires. (Top right): Spatial extent of the aerosol layer over a large region east and west of the source region as shown by the TOMS aerosol index. (Bottom): Monthly means (1989–1992) of regionally averaged TOMS aerosol index data over the Eastern Saharan (left), Arabian Peninsula (middle), and north-west India (right).

2.3.3. Tropical Winds Affect Chlorine Levels Inside the Antarctic Ozone Hole

Tropical winds cause chlorine levels and ozone depletion to vary inside the Antarctic ozone hole. The dynamics of the tropical middle stratosphere have a direct effect on the trace gas composition of the Antarctic ozone hole. The quasi-biennial oscillation (QBO) of the east-west wind in the tropical stratosphere modulates chlorine levels inside the ozone hole and therefore affects ozone depletion. The QBO makes a small contribution to area variations in the size of the ozone hole through its effect on chlorine levels. The direction of the wind in the tropical stratosphere during one year affects how much chlorine will be in the Antarctic ozone hole the following year.

Over the course of one year, variations in nitrous oxide (N_2O) and chlorine, driven by the tropical winds, travel nearly undiminished from their origin in the middle stratosphere (*Figure 2.16;* Box A) to the Antarctic lower stratosphere (*Figure 2.16;* Box C). The year-to-year chlorine variations are large (up to ± 200 ppt) compared to the predicted decline in chlorine per the Montreal Protocol (20 ppt /year).

Increasing greenhouse gases are expected to change stratospheric circulation. Changes in the circulation, including possible changes in the QBO, will impact stratospheric ozone as well. Measurements of a long-lived trace gas such as N_2O are essential (1) for detecting and measuring changes in stratospheric circulation and its variability, and (2) for correctly attributing trends in ozone.

Ozone in the Antarctic has been mapped by Nimbus TOMS, Earth Probe TOMS, and is now being mapped by OMI on Aura, and now OMPS on NPP. Each day, maps are created showing the area where ozone is

S. Strahan (614, USRA), L. Oman (614, USRA), and A. Douglass (614, USRA)

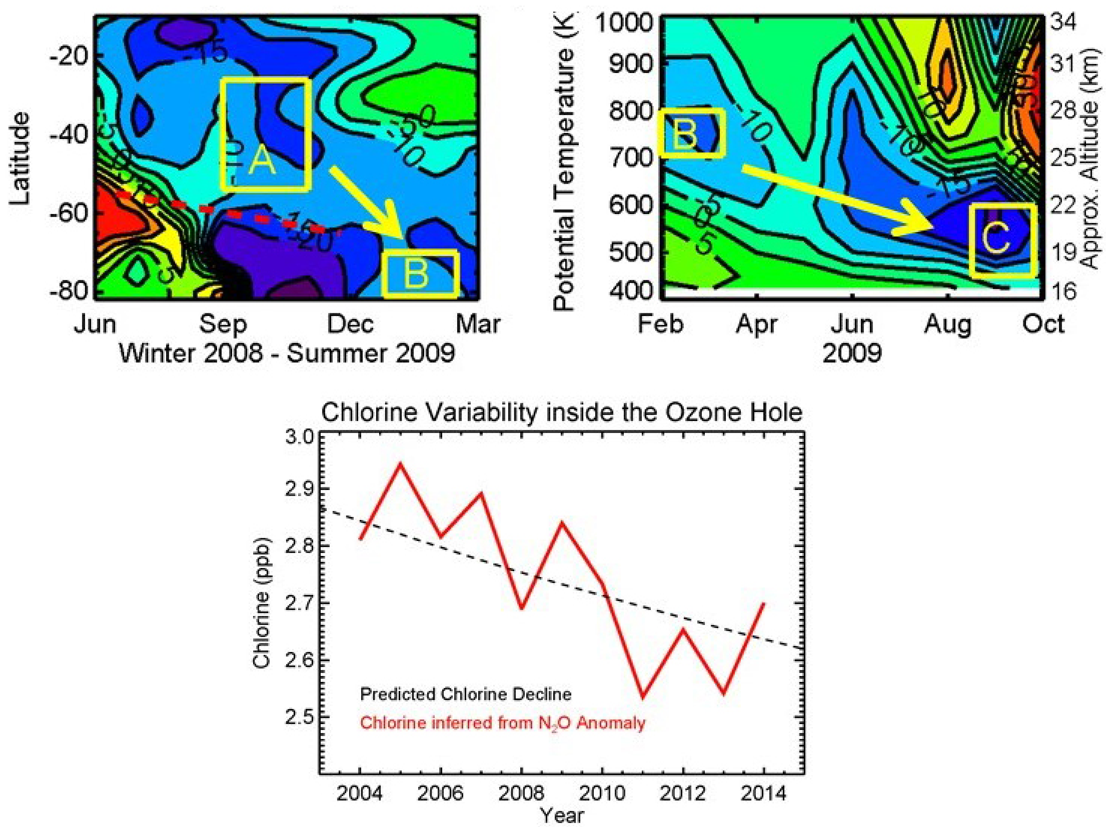


Figure 2.16: The top figures shows horizontal transport of N_2O anomaly (A→B) then vertical descent over Antarctica (B→C). The bottom figure shows chlorine variability inside the ozone hole

2.3.4. Is the Antarctic Ozone Hole Beginning to Recover?

An ozone hole is defined an area where ozone is less than 220 Dobson units (DU). Now that chlorofluorocarbons (CFCs) and other ozone depleting chemicals have been controlled, researchers predict a full recovery of ozone to pre-1979 levels should occur by about 2050. less than the 220-DU threshold. The 30-day average areas are plotted for each year from 1979 to the present. The vertical bars show the range of minimum to maximum daily area over the averaging period. Notice that the ozone hole in 2002 was anomalous when the meteorology of the Antarctic that year led to a very early breakup of the ozone hole *(Figure 2.17).*

Ozone observations are important because ozone is a critical absorber of ultraviolet radiation and because it affects climate. The abundance of ozone directly affects the Earth's biosphere since the total column amount of ozone overhead determines the amount of ultraviolet light that reaches the ground. The release of CFCs by humans has impacted the development of the Antarctic ozone hole, a clear example of mankind's effect on the global environment. An accurate time series of total column ozone is needed to document the changes that have occurred in ozone. A continuing time series is required to verify the expected recovery of ozone as a result of the Montreal Protocol.

R. D. McPeters (614)

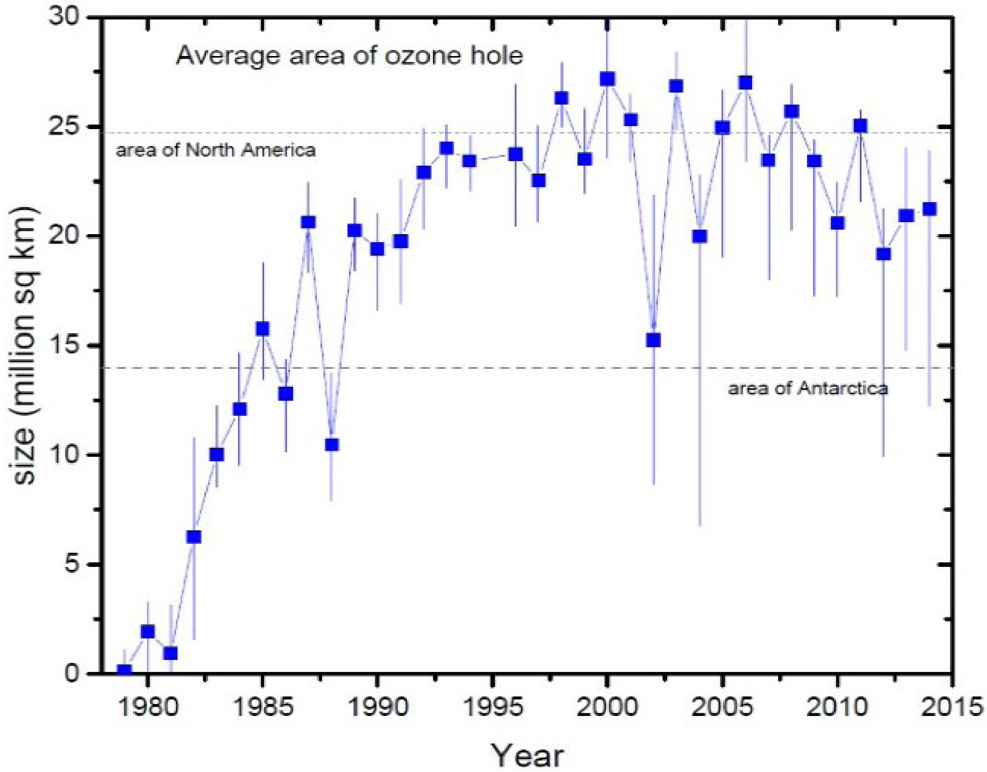


Figure 2.17: Growth in the average area of the Antarctic ozone hole.

2.3.5. First demonstration of formaldehyde retrieval with Suomi NPP OMPS

Satellite retrieval of atmospheric formaldehyde (HCHO) data has been useful in providing constraints on the emissions of non-methane volatile organic compounds (NMVOCs), important precursors of tropospheric ozone and organic aerosols that can adversely affect air quality. But satellite observations suffer from weak signals and strong interferences, creating relatively large uncertainty in the data. There are also significant differences between the various satellite instruments and algorithms. HCHO had not been anticipated as an OMPS product, but a new principal component analysis (PCA) technique produced retrievals with comparable quality to those from other sensors, which allowed for the continuation of a long-term record started by the Aura OMI.

The map in *Figure 2.18* shows global monthly mean HCHO vertical column density for July 2013 retrieved with the S-NPP OMPS instrument using a new algorithm based on PCA of measured radiances. To estimate HCHO loading while minimizing interference, the algorithm extracts spectral features, or principal components, from OMPS radiance data in the spectral range of 328.5 nm to 356.0 nm, fits the leading principal components (those explaining over 99.9999 percent of the spectral variance), and pre-computes HCHO Jacobians.

HCHO retrievals also provide insights into the sources of volatile organic compounds (VOCs) that contribute to smog and haze. The PCA algorithm developed in this study can be potentially applied to different polar orbiting satellite instruments, such as OMI, OMPS, GOME, GOME-2, and TROPOMI, as well as geostationary instruments, such as TEMPO and GEMS. It can help to build long-term, consistent HCHO datasets that can provide insights into the climate effects on atmospheric chemistry and air quality.

C. Li (614, UMD), J. Joiner (614, UMD), N. Krotkov (614, UMD), and L. Dunlap (614, UMD)

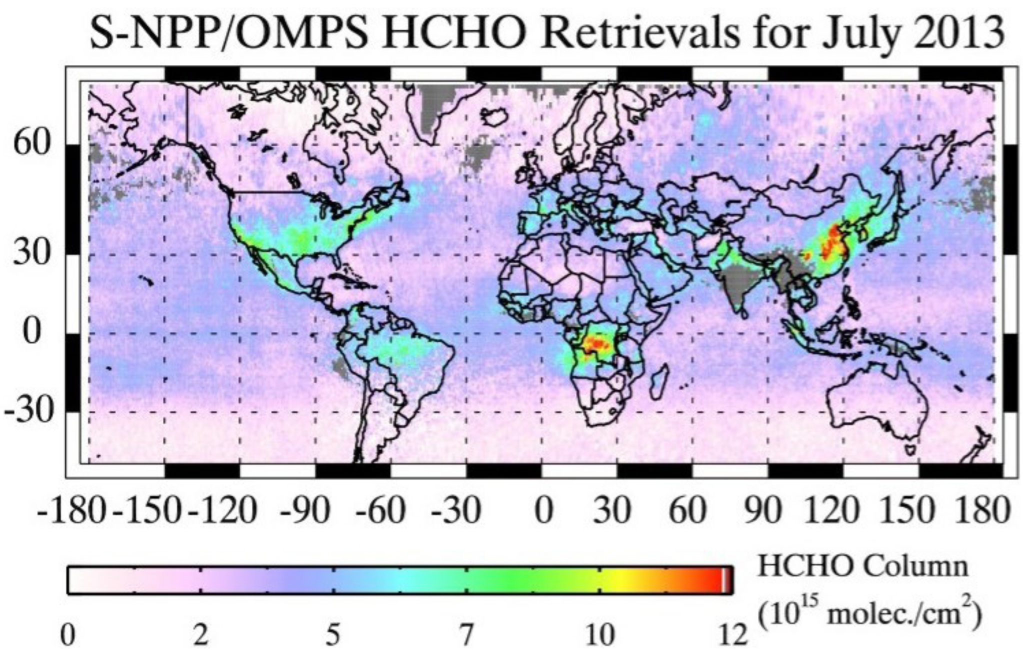


Figure 2.18: Global monthly mean-HCHO vertical column density for July 2013. Retrieved with the S-NPP OMPS instrument, data was generated using a new algorithm based on PCA of measured radiances.

2.3.6. Improvements in the Simulation of Ozone in GEOSCCM

The Goddard Earth Observing System Chemistry-Climate Model (GEOSCCM) was featured prominently in the most recent 2014 World Meteorological Organization's (WMO) quadrennial Scientific Assessment of Ozone Depletion. Due to continued model development, the 2014 ozone simulation compares better with satellite and ground-based observations than prior simulations that were contributed to WMO's 2006 and 2010 reports. *Figure 2.19* shows the evolution of quasi-global (60°S–60°N) total column ozone simulated in different versions of the model as compared to observed satellite and ground-based measurements. Different versions of GEOSCCM (labeled 2006, 2010 and 2014) represent contributions to the WMO Scientific Assessment of Ozone Depletion reports. Continued model development—including an internally generated quasi-biennial oscillation, impacts of volcanic eruptions, very short lived bromine sources, and a better representation of photochemistry at high solar zenith angles—has significantly improved the simulation of ozone compared to satellite and ground-based data.

GEOSCCM has not only impacted the understanding past changes in ozone, but it also has helped researchers understand and project changes over the 21st century. Data from operational SBUV/2 instruments is being used to continue this long climate record of total column ozone from satellites like Suomi-NPP. Future missions, such as JPSS, are the next generation of satellites slated to carry ozone sensors and can continue this critical record into the future.

L. Oman (614) and A. Douglass (614)

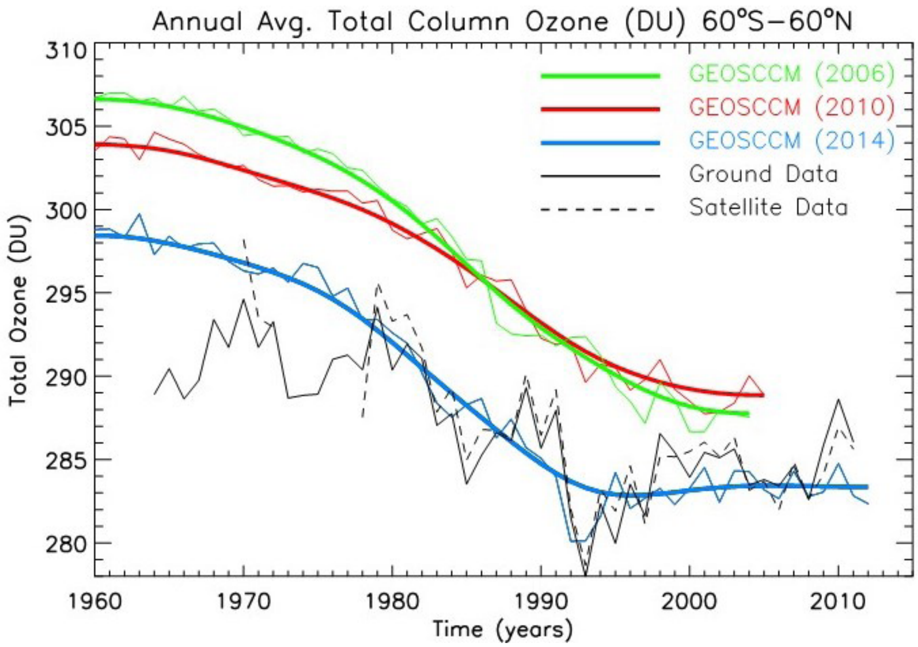


Figure 2.19: The over 40-year analysis of quasi-global (60°S–60°N) total column ozone, simulated in three versions of GEOSCCM, as compared to observed satellite and ground-based measurements.

2.3.7. Aerosol Optical Depth Over South Asia Underestimated in Multiple Models

Atmospheric pollution over South Asia attracts special attention due to its effects on regional climate, water cycle, and human health. These effects are growing potentially owing to rising trends of anthropogenic aerosol emissions. Therefore, it is critical to accurately represent aerosol sources, distributions, and properties in models over this heavily polluted region in order to project the future climate and air quality changes in South Asia with confidence. Previous studies, however, reported that global models generally underestimate aerosol loading over South Asia, especially over the Indo-Gangetic Plain (IGP) in winter. We have identified the major discrepancies in seven state-of-the-art global aerosol models when simulating aerosol loading over South Asia. Results from this study has suggested clear directions to improve model simulations over this important region, including improving meteorological fields (particularly relative humidity), revising biofuel and agriculture fire emission inventories, and adding/improving nitrate aerosol.

Global models have difficulty simulating high AOD. Six out of seven models consistently underestimate AOD by 34 percent, on average, compared to NASA satellite data. There are several possible causes for these discrepancies. (1) The near-surface relative humidity in winter is too low (e.g., about 20 percent below the observed value of > 60 percent in the IGP in six out of seven models) such that the hygroscopic growth of soluble aerosols and formation of secondary inorganic aerosol, such as nitrate (NO_3) and sulfate (SO_4) are suppressed. (2) NO_3 is missing or inadequately accounted for. (3) Anthropogenic emissions, especially from biofuel in winter, are underestimated in the emission datasets. The lack of seasonal variation of such emissions amplifies the discrepancies in winter models.

X. Pan (614, NPP)

2.3.8. What Caused Steps in Stratospheric Global Temperature Anomalies?

Observed global stratospheric temperatures have been decreasing for the past decades. Their decrease, however, has not been linear, but rather has taken place in two steps coincident with the two major volcanic eruptions during the time period. Our study identifies, for the first time, the causes of such features of the global stratospheric temperature anomalies time series. In the upper stratosphere, general stratospheric cooling is attributed mainly to increasing greenhouse gases (GHG) with a smaller contribution by ozone-depleting substances (ODS) increasing into the mid-1990s. The flattening of the temperature anomalies between 1985 and 1991 and after 1995 was caused by the solar cycle's effect on radiation and ozone concentrations and, therefore, due to natural forcing. In the lower stratosphere, changing ODS concentrations have dominated the overall pattern of stratospheric temperatures. The post-1995, the flattening of the temperature anomalies has reflected the decrease of ODS concentrations initiated by the Montreal Protocol and is of anthropogenic origin. Flattening between 1985 and 1991, again, is due to the solar cycle. Monitoring stratospheric temperatures allows us to identify signs showing the effect of the Montreal protocol on the global climate. With the progressive decrease of ozone depleting substances, stratospheric temperatures anomalies will reflect increases in greenhouse gases, showing even more clearly the fingerprint of anthropogenic greenhouse gases on the global climate**.**

V. Aquila (613, GESTAR/USRA), W. Swartz (APL/JHU), P. Colarco (613), S. Pawson (610.1), L. Polvani (Columbia Univ.), R. Stolarski (JHU), and D. Waugh (JHU)

2.3.9. Ozone Depletion due to Hydrofluorocarbons

Hydrofluorocarbons (HFCs) are strong radiative forcers and increasing rapidly in atmospheric concentrations. GSFC's 2D model simulations show that HFCs warm the troposphere and stratosphere, enhance the Brewer–Dobson circulation, and are weak ozone–depleting substances. This study is the first to quantify the impacts of HFCs in a coupled chemistry-climate model. Considering the interactions between chemistry, radiation, and dynamics, HFCs have positive ozone depletion potentials and thus should be considered as ozone-depleting substances. While the impact of HFCs on stratospheric ozone is far weaker than that of the CFCs, halons, and other substances that caused the ozone hole, the implication of this study shows that HFCs can be regulated under existing legislation (internationally by the Montreal Protocol, and domestically by the U.S. Environmental Protection Agency). The Montreal Protocol already has played an important role in protecting global climate. Restricting the future production and use of HFCs could be an important step toward mitigating significant global climate change. Planned GEOSCCM simulations will investigate the global and regional impacts of HFCs.

M. Hurwitz (614, GESTAR/MSU), E. Fleming (614, SSAI), F. Li (614, USRA), and P. Newman(614, GESTAR/MSU)

2.3.10. Aura OMI NO_2 data: Regional Changes in Air Pollution

There were major changes in air pollution around the world as discussed in Duncan et al. [2015]. We used high-resolution nitrogen dioxide (NO_2) data from the OMI to analyze changes in urban NO_2 levels around the globe, from 2005 to 2014, and found complex heterogeneity in the changes. We showed the potential of high-resolution data for quantifying NO_x emissions in regions with a complex mix of sources. NO_2 is produced during combustion processes and, thus, may serve as a proxy for changes in fossil-fuel–based energy usage and co-emitted greenhouse gases (such as CO_2) and other pollutants.

We found that NO_x changes were determined by several factors: First, environmental regulations resulted in large decreases. The only large increases in the United States occurred over three areas of intensive energy activity. Second, rapid economic growth elevated NO_2 levels over many Asian, tropical and subtropical cities. Two of the largest increases occurred over recently expanded petrochemical complexes in Jamnagar (India) and Daesan (Korea). Third, pollution transport from China influenced the Republic of Korea and Japan, diminishing their local emission controls. However, in China, there were large decreases over Beijing, Shanghai, and the Pearl River Delta associated with local emission control efforts. Fourth, civil unrest and its effect on energy usage resulted in lower NO_2 levels in some countries. Economic changes and migration within the Middle East has led to major changes in the distribution of air pollution as shown by Aura OMI NO_2 data in the following Figures. Fifth, spatial heterogeneity within several megacities reflects mixed efforts to cope with air quality degradation. Intensive monitoring of the world's tropical/subtropical megacities will remain a priority as their populations and emissions of pollutants and greenhouse gases are expected to increase significantly (>2 billion by 2050).

B. Duncan (614), L. Lamsal (614, USRA), A. Thompson (610), Y. Yoshida (614, SSAI), M. Hurwitz (614, GESTAR/MSU), and K. Pickering (614)

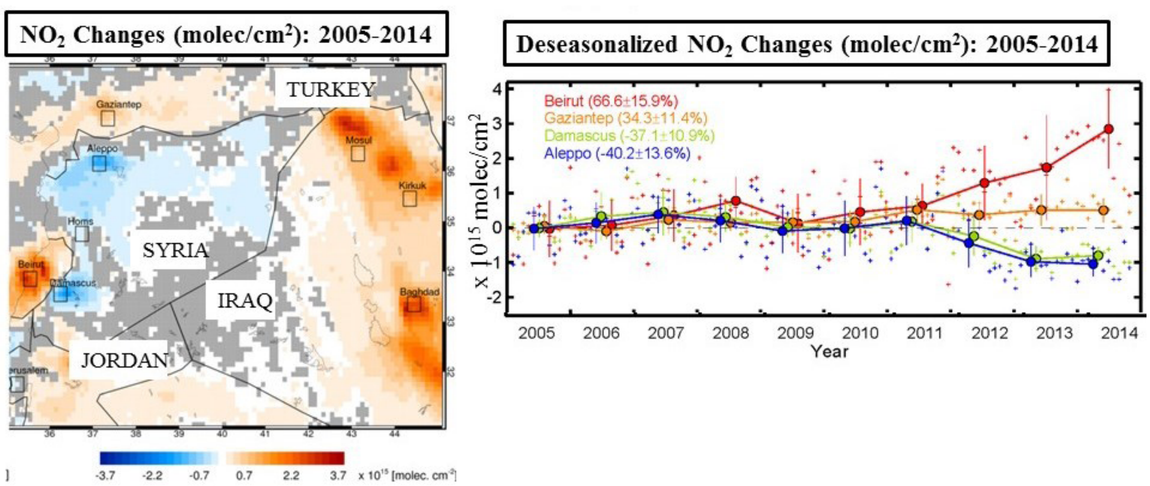


Figure 2.20: (a): Absolute difference of annual average OMI NO_2 data (x10^{15} molecules/cm^2; 0.1° latitude, 0.1° longitude) between 2005 and 2014. Warmer colors indicate increases and cooler colors represent decreases. Gray areas represent where there are no statistically significant changes. (b): De-seasonalized OMI NO_2 data (x10^{15} molecules/cm^2) for several Middle Eastern cities. Monthly and annual average values are shown as pluses (+) and circles, respectively. Vertical bars on the annual average values represent the standard deviation for a given year.

2.3.11. Quantifying Chemical Transformations and Surface-Atmosphere Exchange

Predictive capability requires understanding the fundamental processes that control atmospheric composition. During SEAC4RS, the NASA DC-8 flew over the Ozark Mountains, a hotspot for vegetative emissions of volatile organic compounds that fuel production of ozone and aerosol. Vertical fluxes for a suite of reactive gases, derived from this novel dataset, provide direct observational constraints on the physical and chemical processes that impact air quality and climate. Understanding the chemistry of the lowermost atmosphere requires knowledge of a wide range of chemical species, their interactions with one another, and how those interactions vary in different environments. To date, most observational efforts have focused on measuring the concentrations of the most important gases, but what we ultimately need to know for predictive capability is the rates of underlying processes—chemistry, emissions, deposition, and transport.

This study demonstrated the first-ever calculation of vertical fluxes from the DC-8, and furthermore shows how to use such data to build a picture of the boundary layer that is at once quantitative, comprehensive, and self-consistent. Fluxes offer a direct observational constraint on photochemistry and surface-atmosphere exchange – central drivers of variability in air quality and climate. On future airborne missions, airborne fluxes will allow us to link space-borne observations of atmospheric composition (including reactive compounds, greenhouse gases and aerosols) to the fundamental processes that control their abundance.

In Situ Observations Laboratory, 614, and JCET/UMBC

2.4. Wallops Field Support Office

The Wallops Field Support Office (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 2015.

2.4.1. Atmospheric Science

2.4.2. Wallops Precipitation Research Facility

Home 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, vertically-pointing micro rain radars (K-band; MRR), snowfall particle imaging, and liquid water content measurement systems. 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.

2.4.2.1. OLYMPEx Deployment and Leadership

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. NPOL was located on a mountaintop just east of the Pacific Ocean coast near Moclips, Washington. Wallops engineering staff deployed both the NPOL and the Dual-polarization, Dual-frequency, Doppler Radar (D3R) and conducted round-the-clock observations throughout the campaign (with short breaks during dry periods). Wallops technicians deployed dozens of rain gauges and disdrometers along the Pacific coast and up the Quinault River Valley. 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 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.

Figure 2.21: 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.

2.4.2.2. Operations with the SMART/ACHIEVE Platforms

NASA Wallops 610.W support staff helped engineers from Code 613 operate the Aerosol, Cloud, Humidity, Interactions Exploration and Validating Enterprise (ACHIEVE) radar while deployed near N159. 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. The 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 will return to Wallops to perform coordinating scanning of light rain with NASA's D3R radar. This effort will provide early validation of both the ACES and Clouds and Precipitation Processes

Mission (CaPPM) and is funded by an IRAD grant entitled "Utilizing NASA Resources to Provide Multi-Frequency Observations of Clouds and Precipitation for ACE and CaPPM Ground Validation" (PI: David Wolff).

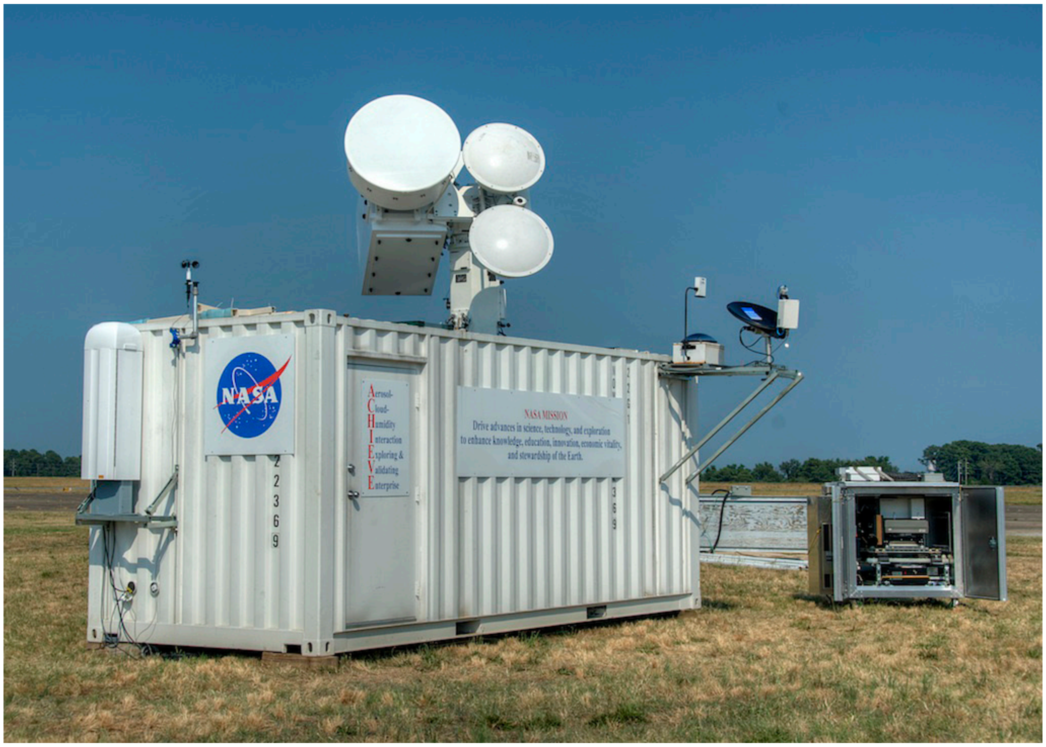


Figure 2.22: Goddard's ACHIEVE radar as deployed north of N159.

2.4.3. Cryospheric Science

2.4.3.1. Airborne Topographic Mapper Deployment in Operation IceBridge

The Airborne Topographic Mapper team conducted two major NASA IceBridge deployments in 2015 and continued to process and deliver previously collected data to the National Snow and Ice Data Center (NSIDC) for use by climate scientists worldwide.

Of particular note is that both 2015 IceBridge deployments involved ATM instrument installations on "new" (for IceBridge ops) aircraft platforms, as the "standard" NASA IceBridge aircraft (P3 and DC8) were unavailable. A substantial amount of planning and engineering was required for each new aircraft installation, and paid off with successful ATM ops for both deployments.

The ATM team installed the ATM instrument suite (2 ATM lidar data systems, IR and visible cameras, spectrometers, and GPS/NAV instruments) on the NASA C130 aircraft in the January thru March 2015 timeframe. During March thru May 11-week 2015 Spring Arctic deployment, 33 science missions were flown covering 73,005 miles during 289 flight hours, basing from Thule and Kangerlussuaq, Greenland, and Fairbanks, Alaska. The ATM team processed the data and delivered it to the National Snow and Ice Data Center (NSIDC) on schedule.

After the 2015 Spring Arctic deployment, the 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 Langley's small NASA Falcon jet, operating at altitudes above 30,000 feet (nominal ATM altitude is 1500 feet AGL). The project conducted 22 flights covering 33,507 miles with over 98 flight hours from bases in Thule and Kangerlussuaq, Greenland. The team is processing the data and is on-scheduled for delivery to NSIDC.

Of particular note was the ATM FLIR Infrared (IR) camera data system, first flown during the 2015 Spring C130 campaign, and also on the 2015 Fall Falcon deployment. The IR camera data collected by this system has proven to be extremely valuable to our climate science customers. http://climate.nasa.gov/

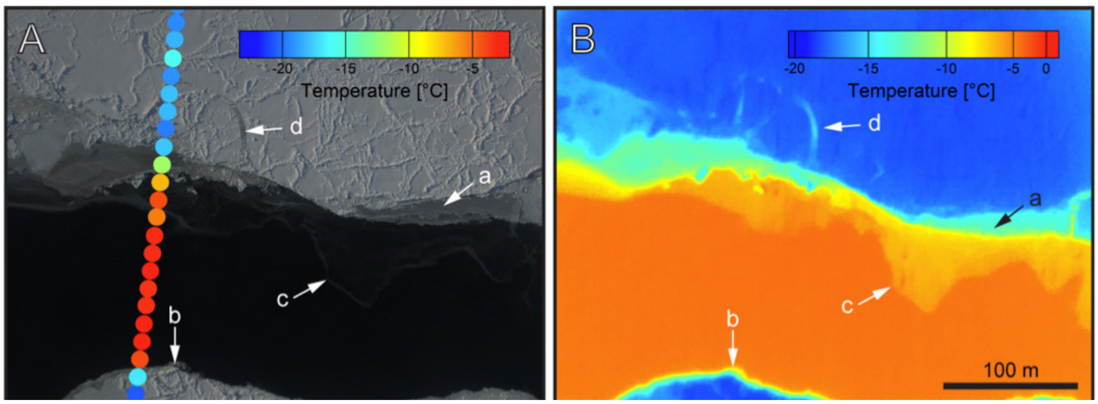


Figure 2.23: (a) DMS and KT-19 pyrometer data over a lead. (b) FLIR A325sc thermal image over the same area. Pixel resolution is 1.2m x 1.2m.

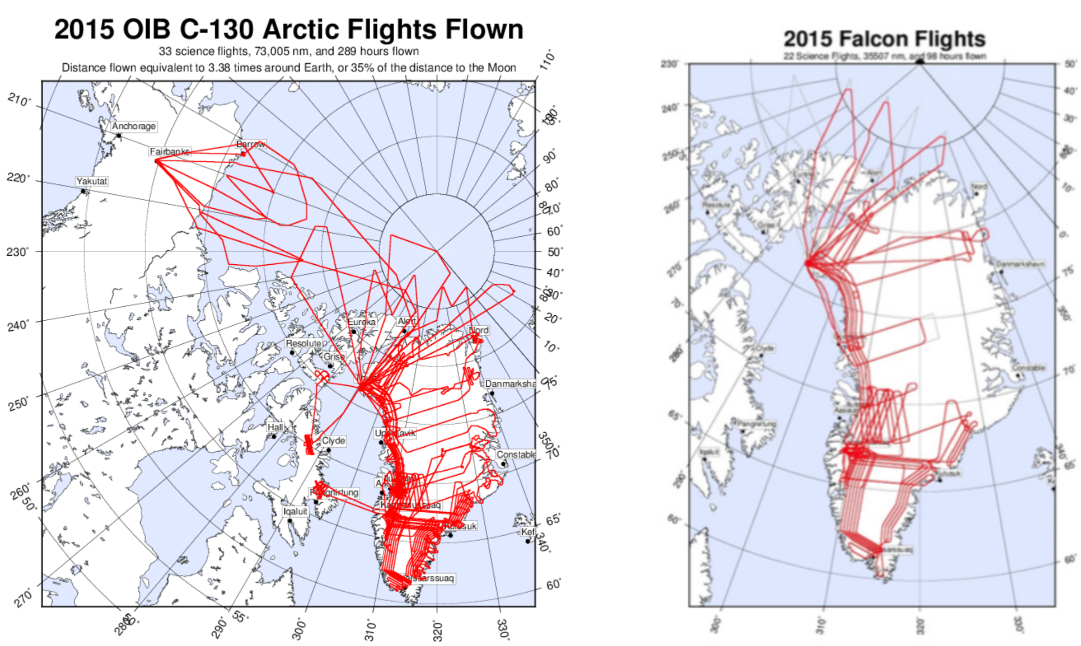


Figure 2.24: Map of completed flight lines for 2015 NASA IceBridge

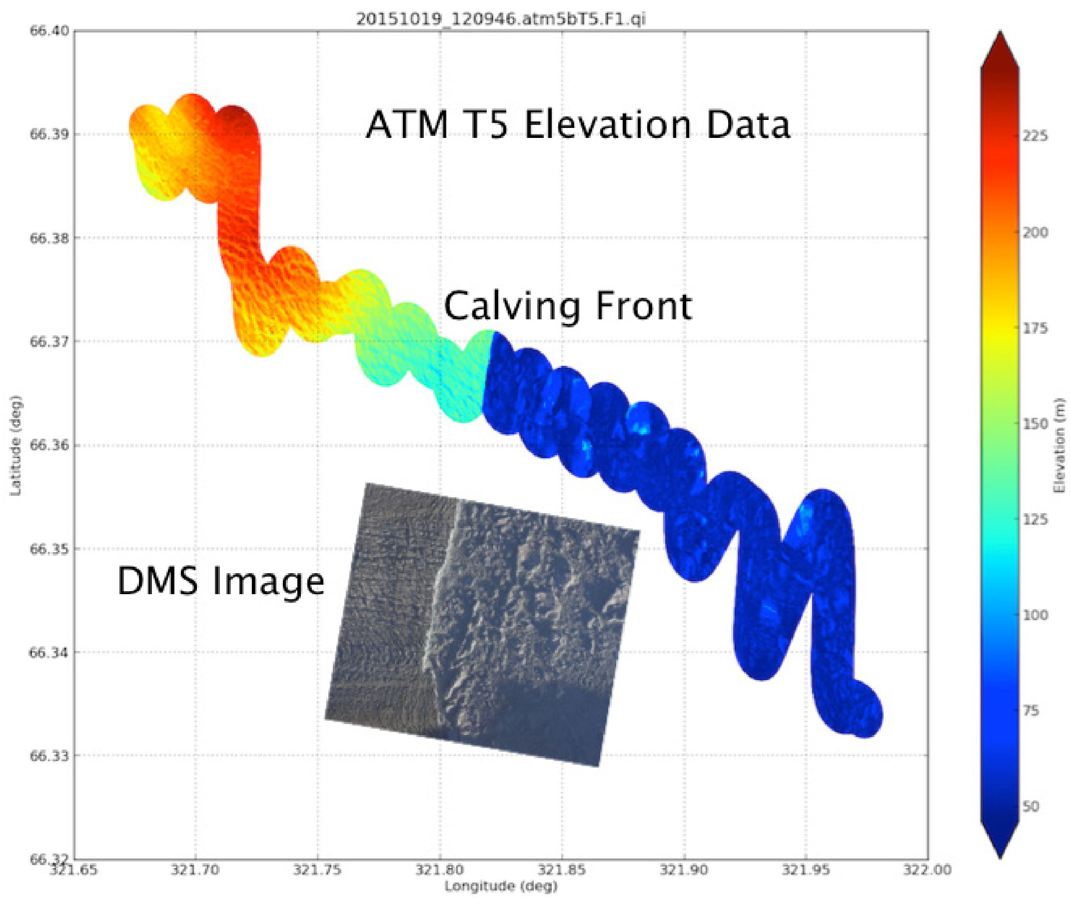


Figure 2.25: Plot of high-altitude ATM T5 elevation data taken over a Greenland glacier calving front.

2.4.3.2. ICESat-2 Data System

During 2015, Cryospheric Science developed, tested and released 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 ATLAS instrument during the ICESat-2 mission.

The ATLAS Science Algorithm Software (ASAS) processes ATLAS raw data into the upper-level science products; Version 1 was developed and tested for the delivery. The software was based on Algorithm Theoretical Basis Documents (ATBDs) provided by the Project Science Office. ASAS is a 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. 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. They also provided support to ATLAS integration and testing with software developed to monitor the performance of ATLAS during this phase.

2.4.4. Ocean Science

2.4.4.1. 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 *in situ* 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. Tiffany Moisan (610W) Contact: David Wolff, david.b.wolff@nasa.gov.

2.4.4.2. ICESat-2 Data System

During 2015, Cryospheric Science developed, tested and released 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 ATLAS instrument during the ICESat-2 mission.

The ATLAS Science Algorithm Software (ASAS) processes ATLAS raw data into the upper-level science products; Version 1 was developed and tested for the delivery. The software was based on Algorithm Theoretical Basis Documents (ATBDs) provided by the Project Science Office. ASAS is a 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. 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. They also provided support to ATLAS integration and testing with software developed to monitor the performance of ATLAS during this phase.

2.4.4.3. Airborne Sensors for Hyperspectral Reflectance Imaging of Marine Pigments (AirSHRIMP)

An airborne instrument, designed for flying on Unmanned Airborne Vehicles (UAVs), was developed for measuring hyperspectral remote-sensing reflectance spectra (200–800 nm) at sub-nannometer 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, this instrumentation can be further developed to support vicarious calibration/validation activities for NASA ocean color missions such as PACE. It can also be used to support terrestrial remote-sensing studies. The instrument is completely stand-alone, requiring no instrumentation integration with its carrier platform.

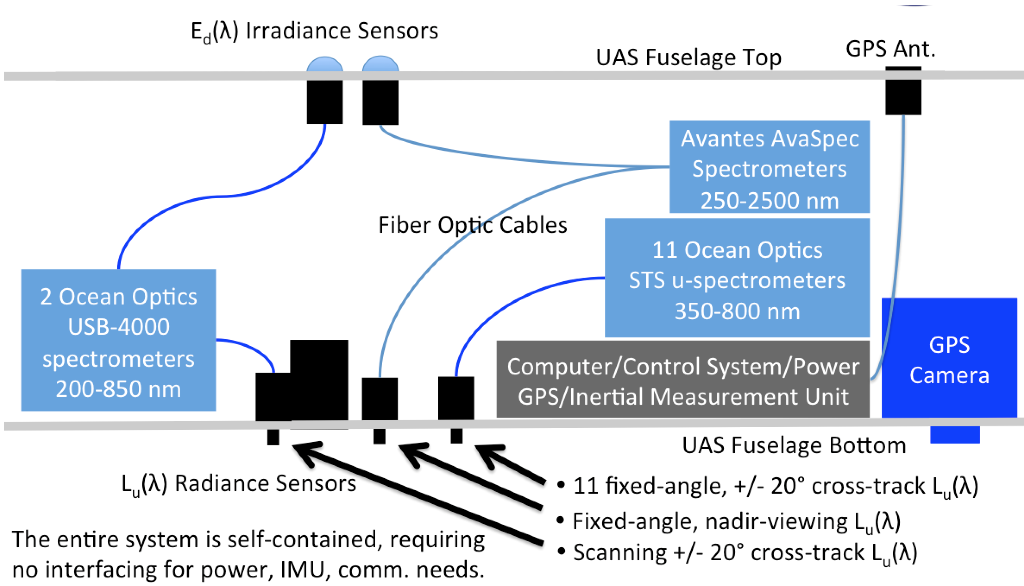


Figure 2.26: A schematic of the AirSHRIMP instrument package noting all of the various sub-elements: 14 radiometers, Inertial Measurement Unit, Camera, and power/data system.

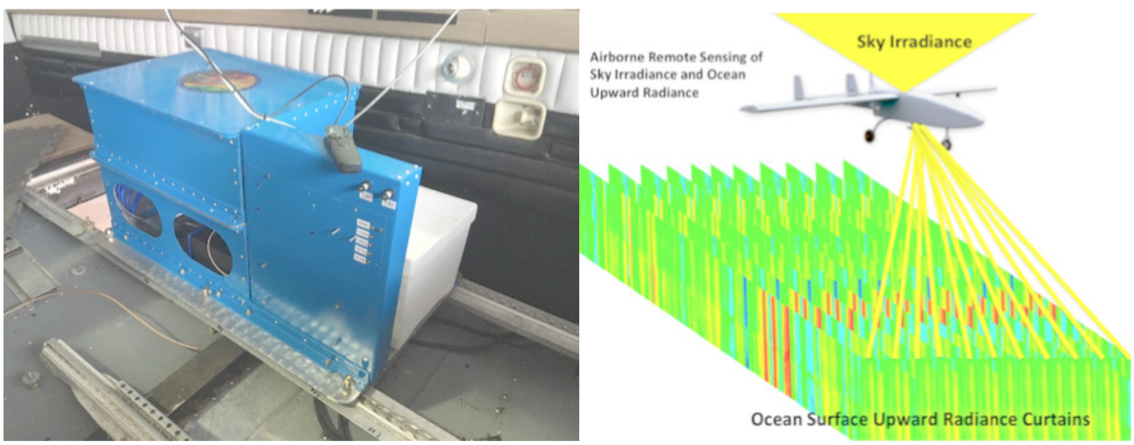


Figure 2.27: Photograph of the AirSHRIMP instrument installed in a Cessna 310 aircraft for test flights, and cartoon of AirSHRIMP measurement configuration.

2.4.4.4. Climate Adaptation Science Investigation Sea-Level Risk Assessment

The launch range facilities of the Wallops Flight Facility are located on Wallops Island, a barrier island that is exposed to the Atlantic Ocean. Facilities on this island support a wide range of launch services, ranging from launching suborbital sounding rockets, to larger International Space Station commercial resupply and scientific satellite launches, to supporting an unmanned-aircraft runway capability. In addition to these NASA-specific activities, the U.S. Navy operates a training and research facility on the island. The island itself provides invaluable environmental services by protecting landward coastal regions from storms and by providing important habitat for large-scale bird migrations and nesting of threatened and endangered species.

Operating a launch facility on any island situated adjacent to the open North Atlantic Ocean has its risks. For instance, during winter Nor'easter storms, the island often suffers damage to its beaches and experiences overwash in low-lying areas. Assessing the risk of inundation for island facilities in a quantifiable way is necessary for informing any proactive facility planning activity that seeks to address these risks. Future climate change scenarios and observed, present sea-level rise (SLR) trends point to an elevated risk of ocean flooding events. How risk changes over time for the various WFF assets depends on the location of the asset; the long-term SLR scenario and storm activity forecasts; observed tidal and storm-related sea level variability; and the risk of hurricanes and other regional storm events for the Eastern Shore.

A cost-based risk analysis on SLR was carried out using a simple Monte Carlo analysis program using observations from: (1) two Digital Elevation Models, GPS locations; (2) valuations of the various NASA assets on Wallops Island; (3) sea-level observations from January 1996 through July 2013 from the NOAA's National Ocean Service sea-level data archives on Kiptopeke, Virginia, and; (4) predicted SLR estimates out to 2100 from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. The resulting analysis (*Figure 2.28*) was reported in a NASA Technical Memorandum. Tiffany Moisan (610W) Contact: David Wolff, david.b.wolff@nasa.gov.

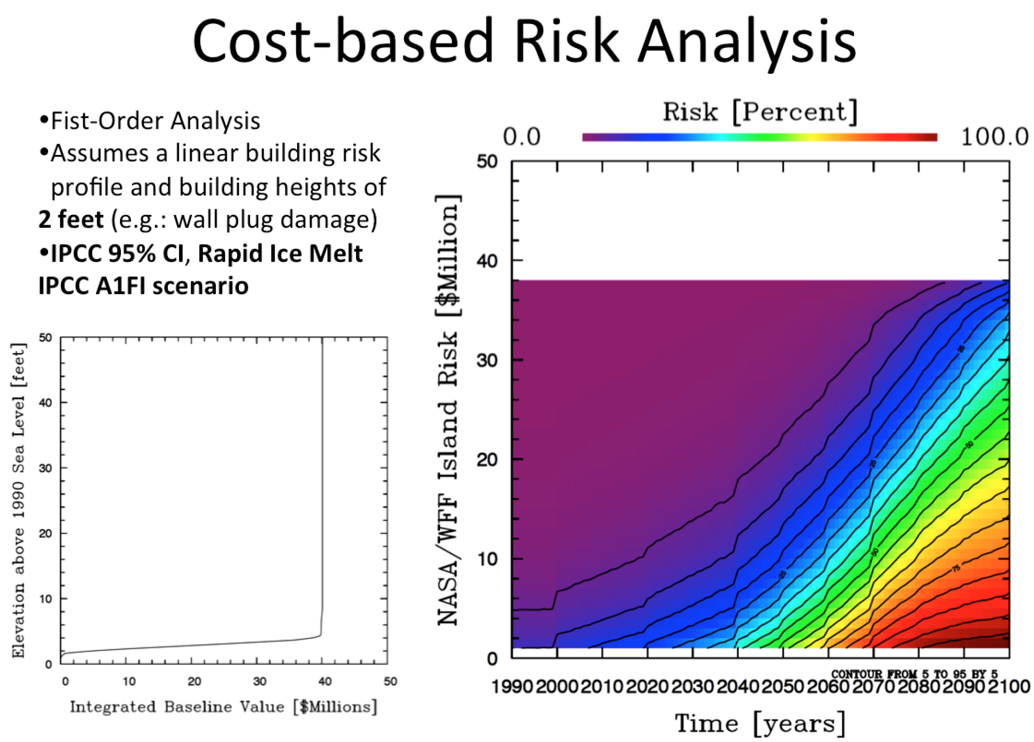


Figure 2.28: Results from the cost-based risk analysis using a simple linear building risk profile that assumes full loss at two-foot inundation levels (left figure) shows a rapid increase in the cost-based risk near 2040, when the rates of sea-level rise are expected to increase.

2.4.4.5. 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 was a three-year project to create an artificial intelligence capability to evolve systems of coupled differential equations. Development and testing of the code has been completed. Verification of the genetic programming code's capability occurred using "twin-experiments" that used the 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. 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. Contact: John.R.Moisan@nasa.gov.

John Moisan, (610.W)

2.4.5. Air-Sea Interaction Science

2.4.5.1. NASA Air-Sea Interaction Research Facility Relocated

The NASA Air-Sea Interaction Research Facility relocated to the Applied Physics Laboratory, University of Washington (UW/APL). The facility has completed the move; assembly and installation is underway in the Harris Hydraulics Laboratory on Seattle campus. Several modifications were necessary due to the configuration of available space. In previous years, research teams of UW/APL faculty and students have gone twice to the former Wallops location to study Flux Exchange Dynamics, looking at the exchange of heat and gases across the air-sea interface. The new 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.

Figure 2.29: The wave tank at the Wallops Air-Sea Interaction Research Facility prior to dismantling

2.4.5.2. 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 received more than 10,000 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 sea-air analysis has produced a complete result that accounts for both amplitude and frequency modulations simultaneously, expressed in a multi-dimensional spectrum. These results will appear in a 2016 publication, *Philosophical Transactions of the Royal Society of London A*.

2.4.6. Unmanned/Remotely Operated Vehicles

2.4.6.1. AEROKATS and ROVER Education Network

The AEROKATS and ROVER Education Network (AREN) project was selected for a Science Mission Directorate Science Education Cooperative Agreement award (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 brings affordable and easy-to-field remote sensing and *in situ* measurements within reach for local-scale Earth observations and data gathering. Using commercial kites, a wide variety of sensors, and a new NASA technology, AEROKATS offers a easy-to-learn method for gathering airborne remote-sensing and *in situ* data for classroom analysis.

Remotely Operated Vehicles for Education and Research (ROVER) introduces 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.

2.4.6.2. Dragon Eye UAS Sulfur Dioxide Sensor Development

Geoff Bland (610.W) is a co-investigator on a two unmanned-aircraft campaigns planned for 2016 and 2017. Dragon Eye (a small unmanned aircraft) will integrate sensor packages for sulfur dioxide measurements developed by 610.W in preparation for Salton Sea and Hawaii deployments. Both deployments will also employ the SIERRA unmanned aircraft. Science objectives for the mission include aerial chemistry sampling in support of calibration and validation of *ASTER* and planned *HyspIRI* support. The University of Costa Rica for the SIERRA flights has provided a miniature mass-spectrometer. The unmanned aircraft will be operated by the Ames Research Center, with PI David Pieri of JPL.

2.4.7. Wallops Upper-Air Instrumentation Research Project

In 1966, the first Brewer-Mast Ozonesonde was flown from Wallops Island. The first Dobson observations were initiated mid-1967. Upper-air observations of the vertical ozone profile using the Electro-Chemical Concentration (ECC) Ozonesonde have continued since 1970. This make the Wallops Flight Facility the longest sustained operational ozone-measuring site. For calendar year 2015, 52 ozonesonde flight events were scheduled for 5 weekly "routine" observations and 47 satellite-overpass-support observations. Five flights had to be rescheduled due to range operations, weather, or facility closure. No backup sonde flights were required due to either primary or secondary flight system failure.

Fifty-two actual balloon releases resulted in 51 successful flights (i.e., balloon termination altitude surpasses 13 hPa) and 1 partially successful flight (i.e., balloon altitude surpasses the tropopause), all producing vertical-profile data sets, and zero failed flights. Of the actual ascensions, 9 flights were routine observations, and 43 flights supported the Suomi-NPP satellite. The Natal, Brazil, ozone-observing site, operating under the joint NASA-INPE Memorandum of Understanding, continued in the first full year since resuming weekly ozonesonde soundings in late 2014. Forty-nine balloon instrument releases from Natal resulted in 47 successful, 1 partially successful flight, all producing profile data, and one 1 failed instrument flight. Data sets for Wallops and Natal flights were delivered to the archives at the Network for the Detection of Atmospheric Composition Change (NDACC) and the World Ozone and Ultraviolet Radiation Data Centre (WOUDC). Data from Natal flights were delivered to SHADOZ data archive.

The Ozone Research Facility continued in operation with the Dobson spectrophotometer and the ground-based GUV-51C UV-radiometer; however in early summer the GUV instrument exhibited high internal temperatures and was removed from operation. Although the instrument required computer and digital encoder replacement, and it experienced issues with the standard and Mercury calibration lamps, the Dobson operated a total of 48 “acceptable sky days” for a total of 168 total-column ozone measurements. Dobson observation and calibration data were supplied to the NOAA Climate Monitoring and Diagnostics Laboratory (CMDL). Data acquisition and management continued for the “VAWI” site (CORS site Station Code) operating the Trimble NetRS GPS instrument for the NOAA/National Geodetic Survey (NGS) Continuously Operating Reference Station (CORS) network. The VAWI instrument sustained high data-rate collection for position and supplemental water vapor data without interruption, with the exception of planned facility power shutdowns or emergency outages.

With over eight years of continuous data collection, the Trimble base station eventually failed in December. Two Thermo Fisher Scientific Environmental Instruments Model 49*i* Ozone UV Analyzer/Monitors were obtained through the Earth Sciences Division. The first instrument was placed in service as a part of the ozonesonde calibration bench in late March. Testing began with the second instrument for deployment in the ORF as an autonomous surface-ozone monitor site; this monitor is expected to be fully operational on site by Spring 2016. Finally, flight hardware resupply planning and logistics support were provided for the ongoing Wallops site and Natal station operations.

Larry Bliven (610.W), Peggy Jeste (610.W, SGT) r, Chris Ashburn (610.W, SSAI), George Brothers (610.W, CHEMAL), and Tom Northam (610.W, SSAI).

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 2023 launch into low Earth-orbit at an altitude of 400–450 km. The nominal ACE payload includes an advanced polarimeter for aerosol and cloud measurements, a nadir-pointing, 7-channel HSRL ($3\beta+2\alpha+2\delta$), and a dual-frequency (W- and Ka-band) Doppler radar with limited scanning capability. Broad-swath radiometers sensing in the infrared, microwave, and sub-millimeter spectral regions are also included in the mission concept.

A comprehensive report, including detailed science traceability matrices, is available for review at: http://acemission.gsfc.nasa.gov/. Significant progress was made in advancing the technical readiness of the instrument concepts in 2013 and 2014. Significant progress was also made in developing and maturing the associated science algorithms, especially polarimeter retrievals of aerosol properties and also including initiation of efforts to develop multi-sensor algorithms for clouds that are mission critical to advance the science. The polarimeter definition experiment (PODEX) was successfully conducted over California in January through February 2013. Analysis of data acquired during PODEX is proceeding. These data and their analysis directly support algorithm development and ultimately trade studies to resolve questions about the polarimeter concepts. PODEX was conducted in close coordination with DISCOVER-AQ. DISCOVER-AQ acquired highly valuable in situ and remote-sensing validation data and also included HSRL-2, a simulator for the full $3\beta +2\alpha +2\delta$ system envisioned for ACE. Analysis indicates excellent data and target quality, and acquisition of a substantial subset of the desired scene types. The first radar definition experiment (RADEX) was conducted in May through June 2014 in the vicinity of North Carolina and over nearby waters. This experiment leveraged the International Precipitation-Hydrology Experiment (IPHEx) that was sponsored largely by the Ground Validation Program for the Global Precipitation Mission (GPM). For the first time, radar data were concurrently collected at four frequencies (at W, Ka, Ku, X bands) from NASA's high-altitude ER-2, along with lidar and microwave radiometer observations. *In situ* microphysical data were also obtained (UND Citation). The goal of RADEX is to demonstrate the potential and limitations of radar retrievals of cloud microphysical profiles, especially multi-sensor approaches. A second deployment is planned, this time to the Seattle region in November and December 2015 (RADEX-15), again in coordination with GPM GV (OLYMPEX). A Science Working Group (SWG) workshop was held in June 2014 to revisit and update the ACE science traceability matrices, the technical readiness of radars, lidars, polarimeters, and its potential international collaborations.

A comprehensive report on ACE's progress over the past five years is presently in final stages of preparation and will constitute a substantial update and input to the upcoming next NRC *Decadal Survey for Earth Sciences*. 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 respirations processes, and provide useful new constraints for global carbon cycle models. NASA currently plans for launch in the FY 2023 time frame. The ASCENDS mission white paper is available at http://cce.nasa.gov/ascends_2015/ASCENDS_FinalDraft_4_27_15.pdf.

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

3.1.1.3 GEO-CAPE

Geostationary Coastal and Air Pollution Events (GEO-CAPE) is one of the missions recommended by the National Research Council's Decadal Survey, with the goal of measuring atmospheric pollution (aerosols and trace gases) and coastal water from a geostationary platform. Scientists in Code 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 2015, Goddard scientists involved in GEO-CAPE's Aerosol Working Group have focused on the following tasks: (1) working together with a NOAA group, we have evaluated the aerosol from MODIS that are retrieved with the MAIAC algorithm over North America and compared the quality and spatial coverage with MODIS Dark Target and VIIRS and evaluated with AERONET measurements; (2) testing the retrieval of aerosol single scattering albedo (SSA) with UV technique and inferring the aerosol composition in the boundary layer from the distinguishable spectral-dependence of SSA for different aerosol species; (3) investigating the effects of aerosol daytime variability on estimating the aerosol direct radiative forcing over North and South America; and (4) processing the bidirectional reflectance distribution function (BRDF) from aircraft measurements for comparing with the BRDF data used by satellite retrievals and assessing the impacts on satellite AOD retrieval accuracy. The outcome was reported at the GEO-CAPE workshop last September. The Aerosol Working Group continues in FY 2016. 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: Decadal Survey 610AT Mission Study Scientists

Name	Mission
Mian Chin, Omar Torres	GEO-Cape
Randy Kawa	ASCENDS
Bruce Gentry	Global 3D-Winds

3.1.2. NASA's Planned Missions

3.1.2.1 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 2015, 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 in the first quarter 2017 and the last quarter 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 2015. J1 observatory environmental testing should be complete in the summer of 2016. The JPSS-2 spacecraft was selected in 2015. The Polar Follow-on Program, JPSS-3 and JPSS-4 was approved in 2015, launching in 2027 and 2032, 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).

3.1.3. NASA's Active Flight Missions

3.1.3.1 Aqua

The Aqua spacecraft, launched on May 4, 2002, carries six Earth-observing instruments: AIRS, AMSU, AMSR-E (no longer operational), CERES (two copies), HSB (no longer operational), and MODIS. The report of the 2015 Senior Review Panel for satellite missions in extended operations awarded Aqua a utility score of "Very High" while recognizing that technical and cost risks remain low (http://science.nasa.gov/media/medialibrary/2015/07/15/2015_ESDSeniorReviewReport_FINAL.pdf). In addition to collecting data pertaining to Earth's water in all its phases, as highlighted by the name "Aqua," mission instruments also provide measurements for (among others) radiative energy flux, atmospheric temperature and composition, aerosols, cloud properties, land vegetation, phytoplankton and dissolved organic matter in the oceans, and surface albedo, temperature and emissivity. These measurements help scientists to quantify the state of the Earth system, validate climate models, address key science questions about the planet's environment, and serve the applications community. Aqua Deputy Project Scientist Lazaros Oreopoulos assists Project Scientist Claire Parkinson in a variety of activities that support the mission and has the lead on budgetary matters and fund disbursement. For further information, please contact Lazaros Oreopoulos (Lazaros.Oreopoulos@nasa.gov).

3.1.3.2 Aura

The Aura spacecraft, which was launched July 15, 2004, carries four instruments to study the composition of the Earth atmosphere. The Ozone Monitoring Instrument (OMI), the Microwave Limb Sounder (MLS), the High Resolution Dynamics Limb Sounder (HIRDLS), and the Tropospheric Emission Spectrometer (TES) make measurements of ozone and constituents related to ozone in the stratosphere and troposphere, aerosols, and clouds. With these measurements the science team has addressed questions concerning the stratospheric ozone layer, air quality, and climate. Eleven 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 present TES observing strategy is designed to make good use of the limited remaining life of the instrument, focusing on "megacities," i.e., large densely populated metropolitan areas such as Mexico City Mexico and Lagos, Nigeria.

In 2015, Aura data revealed new aspects of the Earth atmospheric composition while continuing to build a multiyear, global dataset. OMI measurements of pollutants nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) show significant declines in much of the United States and Canada; these declines are due to pollution control measures implemented by both nations. However, NO_2 increases by 5–10 percent/year and SO_2 levels are steady over the Canadian oil sands and hydraulic fracturing areas in North Dakota, showing that OMI data identify and quantify emerging pollution "hot-spots." TES measurements are being used to quantify seasonal biomass burning impacts on the already poor megacity air quality where biomass burning emissions, geography and urban pollutants all worsen air quality. The MLS measurements give new insights into stratospheric composition and variability, such as the modulation of the composition of the winter Antarctic polar vortex by the tropical quasi-biennial oscillation in the zonal wind through its influence on meridional transport. Although HIRDLS is no longer operational, recent analysis of HIRDLS high vertical resolution profiles quantify global and seasonal variations in three-dimensional gravity wave momentum flux. More information on Aura science highlights can be found at http://aura.gsfc.nasa.gov/ or contact Anne Douglass (anne.r.douglass@nasa.gov).

3.1.3.3 DSCOVR

Deep Space Climate Observatory (DSCOVR) (formerly known as Triana), is a NOAA Earth observation and space weather satellite launched by SpaceX on a Falcon 9 launch vehicle on February 11, 2015 from Cape Canaveral. The mission is a partnership between NOAA, NASA and the U.S. Air Force. NOAA will operate 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. Experts estimate damages from these types of severe solar storms could range between $1–$2 trillion. DSCOVR was originally proposed in 1998 by then Vice President Al Gore and developed as a NASA satellite for the purpose of Earth observation. It is intended to be positioned at the Sun-Earth L_1 Lagrangian point, 1,500,000 km (930,000 mi) from Earth, to monitor variable solar wind condition, provide early warning of approaching coronal mass ejections and observe phenomena on Earth including changes in ozone, aerosols, dust and volcanic ash, cloud height, vegetation cover and climate. At this location it will have a continuous view of the Sun and the sunlit side of the Earth. The satellite is planned to orbit the Sun-Earth L_1 point in a six-month period, with a spacecraft-Earth-Sun angle varying from 4 to 15 degrees. It will take full-Earth pictures about every 65 minutes in the summer and every 95 minutes in the winter. DSCOVR arrived at L_1 near the beginning of June and transmitted the first image on June 13, 2015. Close examination shows that we are obtaining a resolution of about 10 km from a distanced of 1.5 million km (Figure 3.1) based on details of the Suez Canal.

Two NASA Earth Science Instruments—the Earth Polychromatic Imaging Camera (EPIC) and the National institute of Standards and Technology Advanced Radiometer (NISTAR)—are obtaining observations of our planet from the L_1-point.

President Barak Obama released the first image of the United States from DSCOVR/EPIC. The image shows North and South America in a color image representing the Earth as the human eye would perceive its color in full sunlight. The image includes the "blue haze" from Rayleigh scattering. At the top of the image, Greenland is clearly visible as is the partially cloud-covered Artic ice cap. Just to the west of Central America, there is a clear indication of Sun glint that is expected from an Image obtained from a Sun-Earth L_1-orbit, 1.5 million kilometers from Earth.

Figure 3.1: DSCOVR's first image of the United States.

This image differs from all previous "blue marble" images obtained from spacecraft in that the whole sunlit earth is imaged simultaneously from sunrise in the west to sunset in the east in realistic "eye-natural" colors. We have constructed animations of successive images showing the development of cloud structures as a function of time of day, and of the movement of storms across the oceans. DSCOVR activities are now concentrated on deriving an accurate in-flight calibration to use in production algorithms to produce useful science products, such as the example of ozone shown in *Figure 3.2*.

These images are available from http://epic.gsfc.nasa.gov/. For further information, please contact Jay Herman, jay.r.herman@nasa.gov or Alexander Marshak, alexander.marshak-1@nasa.gov.

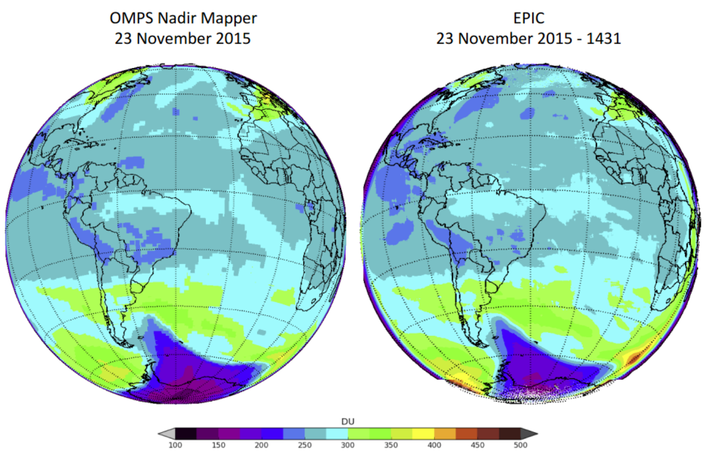


Figure 3.2: A preliminary comparison of ozone derived from EPIC (sunrise on left and sunset on right) and from the low Earth-orbiting satellite OMPS (always at 13:15 to 13:30 hours).

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 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 2015, the first flight models of five new and improved instruments were integrated and tested on GOES-R, scheduled for launch in October 2016. NOAA is scheduled to operate the all-new GOES-R/S/T/U generation from 2017 to 2035.

The 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 2015, the site served 4.0 terabytes to 365 thousand guests from around the world at the average rate of four 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, every three hours. NASA and the Japan Aerospace Exploration Agency (JAXA) launched the 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 will provide 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 during 2015. GPM direct ground validation is being used to evaluation the performance of the GPM retrieval products. In July, the science team met in Baltimore, Maryland, to review algorithm development, plan for future activities, including a general reprocessing during early 2016. 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 ISS/JEM-EF (CATS)

On January 22, 2015, flight controllers successfully installed NASA's Cloud Aerosol Transport System (CATS) aboard the International Space Station through a robotic handoff—the first time one robotic arm on station has worked in concert with a second robotic arm. CATS will collect data about clouds, volcanic ash plumes, and tiny airborne particles, which can help improve our understanding of aerosol and cloud interactions and improve the accuracy of climate change models.

CATS had been mounted inside the SpaceX Dragon cargo craft's unpressurized trunk since it docked at the station on January 12. Ground controllers at NASA's Johnson Space Center in Houston used one of the space station's robotic arms, called the Special Purpose Dexterous Manipulator, to extract the instrument from the capsule. The NASA-controlled arm passed the instrument to a second robotic arm—like passing a baton in a relay race. This second arm, called the Japanese Experiment Module Remote Manipulator System, is controlled by JAXA. The Japanese-controlled arm installed the instrument to the Space Station's Japanese Experiment Module, making CATS the first NASA-developed payload to fly on the Japanese module and the first time one robotic arm on station has worked in concert with a second robotic arm.

CATS is a lidar remote-sensing instrument designed to last from six months to three years. It is specifically intended to demonstrate a low-cost, streamlined approach to developing science payloads on the space station. The instrument reached a milestone on Thursday, February 5, 2016, as the laser was fired for the first time. The CATS team collected three segments of data, using the first two segments to verify laser temperatures and functionality. The laser operated nominally, and a third segment of data was collected for approximately 67 minutes that consisted of clouds at various altitudes. On Friday, February 6, the CATS laser was operated over 4 hours and the first Level-0 data files were produced. Since then, Matthew McGill and his science lead, John Yorks, have been actively collaborating with the scientific community to utilize the measurement results. The CATS data and analysis team includes Laboratory members Patrick Selmer, Andrew Kupchock, Dennis Hlavka, Steve Palm, and Edward Nowottnick. For Further information please contact Matt McGill, matthew.j.mcgill@nasa.gov or John Yorks, John.E.Yorks@nasa.gov.

3.1.3.7 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).

3.1.3.8 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 publicly available from the NOAA CLASS archive: www.class.noaa.gov. Suomi NPP is on track to extend and improve upon the Earth system data records established by NASA's Earth Observing System (EOS) fleet of satellites, 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).

3.1.3.9 Terra

Launched on December 18, 1999 as NASA's Earth Observing System flagship observatory, Terra carries a suite of five complementary instruments: (1) ASTER (contributed by the Japanese Ministry of Economy, Trade and Industry with a American science team leader at JPL) provides a unique benefit to Terra's mission as a stereoscopic and high-resolution instrument used to measure and verify processes at fine spatial scales; (2) CERES (LaRC) investigates the critical role that clouds, aerosols, water vapor, and surface properties play in modulating the radiative energy flow within the Earth-atmosphere system; (3) MISR (JPL) characterizes physical structure from microscopic scales (aerosol particle sizes and shapes) to the landscape (ice and vegetation roughness and texture) to the mesoscale (cloud and plume heights and 3D morphologies); (4) MODIS (GSFC) acquires daily, global, and comprehensive measurements of a broad spectrum of atmospheric, ocean, and land properties that improves and supplements heritage measurements needed for processes and climate change studies; and, (5) MOPITT (sponsored by the Canadian Space Agency with an NCAR science team) retrieves carbon monoxide total-column amounts as well as mixing ratios for 10 pressure levels; its gas correlation approach still produces the best data for studies of horizontal and vertical transport of this important trace gas. For more than 16 years, the Terra mission has been providing the worldwide scientific community with an unprecedented 81 core data products, 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 16 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).

3.1.3.10 TRMM

The Tropical Rainfall Measuring Mission (TRMM) mission successfully completed a mission decommissioning review on March 17, 2015, at Goddard and a Phase-F review at headquarters on March 24. TRMM is a joint project between NASA and JAXA. TRMM was built at Goddard and both mission operations and science leadership were at Goddard. It was launched on November 27, 1997 and has provided the research and operational communities with unique precipitation information from space for more than 17 years. The mission ended on April 8, 2015, when all instruments were turned off in preparation for re-entry, which occurred on June 16, 2015. The overarching TRMM science goal was to advance our knowledge of the global energy and water cycles by observing time and space distributions of tropical rainfall, convective systems and storms, and their associated hydrometeor structure and latent heating distributions. TRMM data provided the most accurate estimate ever of tropical rainfall and lightning and its variations (from sub-daily to monthly, seasonal, annual, and interannual time scales). It led to new insights into the structure and evolution of convective systems, including extreme events like tropical cyclones and flood producing storms. TRMM provided a benchmark climatology used to validate and improve global climate and weather forecast models and shed light on ways in which humans impact precipitation.

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 3.2: Atmospheres 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-R	Lazaros Oreopoulos, Scott Braun	Aqua
Gail Skofronick Jackson	GPM	George Huffman	GPM
James Gleason	JPSS	Alexander Marshak	DSCOVR
Joanna Joiner	OMI	Si-Chee Tsay	Terra
James Gleason	SNPP	Christina Hsu	SNPP
Dong Wu	SORCE		
Scott Braun	TRMM		
Dong Wu	TSIS		

Table 3.3: Atmospheres Validation, Instrument, and Mission Scientists

Validation Scientists		Instrument Scientist	
Name	**Mission**	**Name**	**Campaign**
Ralph Kahn	EOS/MISR	Kenneth Pickering	DISCOVER-AQ
Matthew McGill	ISS/JEM-EF/CATS	Scott Braun	HS3
Dong Wu	TCTE/PFF	David Wolff	OLYMPEX
		Judd Welton	MPLNET
		James Yungel	Operation IceBridge
		Judd Welton, Si-Chee Tsay	7 SEAS
		Geoff Bland	Dragon Eye/VOLCANO

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 2014, atmospheric research personnel supported activities in the planning and coordination phases as scientific investigators or as mission participants.

4.1. SONGNEX

The *In Situ* Airborne Formaldehyde (ISAF) instrument participated in the Shale Oil and Natural Gas Nexus (SONGNEX) campaign in Broomfield, Colorado, in March and April 2015 (http://esrl.noaa.gov/csd/projects/songnex/). The SONGNEX campaign sampled each of the major tight-oil and shale basins (Bakken, Marcellus, Niobrara, Permian, Haynesville) to determine emissions of methane, non-methane hydrocarbons, and nitrogen dioxides and study the chemical evolution of these emissions. Formaldehyde measurements were an important objective needed to determine the emissions of non-methane hydrocarbons that lead to tropospheric ozone and fine-particle pollution. Enhanced concentrations of formaldehyde in several fields were used to quantify ozone and fine particle production, which impacts local air quality. Participants on the ISAF team included Thomas Hanisco (614), Glenn Wolfe (614/JCET), and Jason St. Clair (614/JCET).

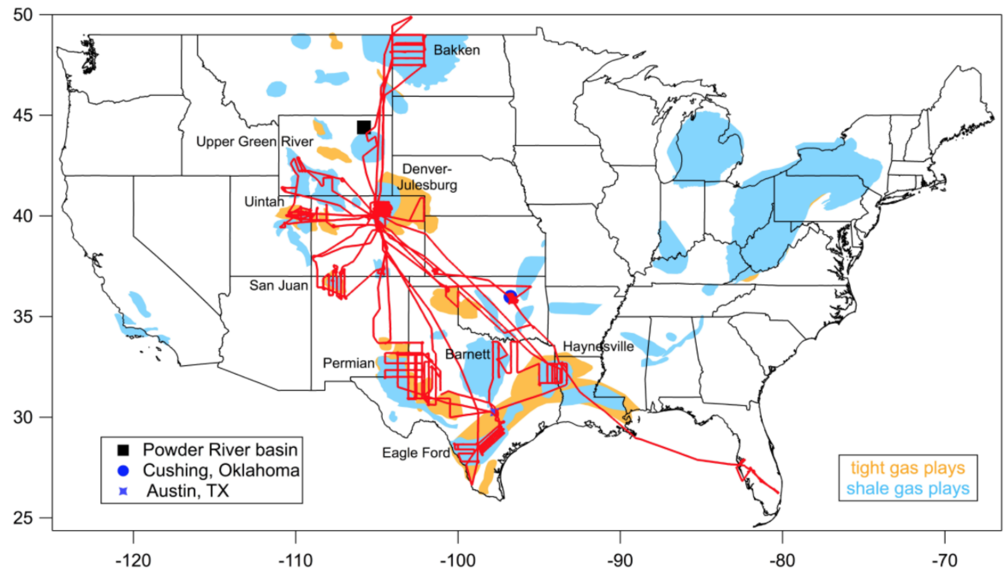


Figure 4.1: The SONGNEX project flights over the tight-oil and shale plays, shale formations containing significant accumulations of natural gas that share similar geologic and geographic properties. SONGNEX sampled the emissions of these gas fields in April 2015.

4.2. Wallops Clouds and Precipitation Radars

Walt Petersen (610.W) and Si-Chee Tsay (613) operated NPOL, D3R and ACHIEVE radars for the first time at WFF to sample clouds and precipitation on March 20, 2015. The radars operated at five different frequencies: W-, Ka-, K-, Ku-, and S-band. Following the joint calibration exercise, a coordinated effort by the SMARTLabs and GPM teams began to make simultaneous measurements— the first of their kind—of cloud-system, precipitation, and GPM overpass sampling of a complex mixed-phase event using multi-frequency ground-based radars (W-, Ka-, Ku- and NPOL/S-band) along with a 910 nm ceilometer and various rain gauges (Figure 4.5). These coordinated operations provided an excellent opportunity to support basic cloud and precipitation science in addition to cal-val and traceability studies, useful for future NASA aerosol-cloud-precipitation missions.

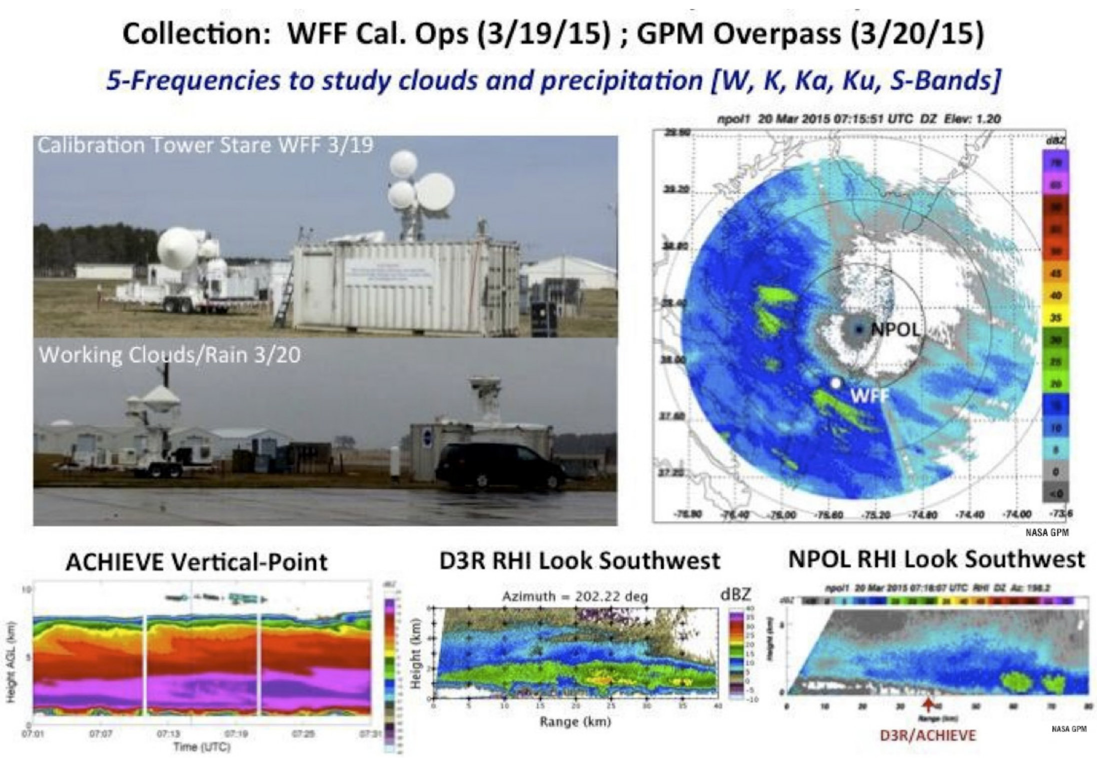


Figure 4.2: First NPOL, D3R, and ACHIEVE coordinated (610.W, 613) radar data collections.

4.3. 7-SEAS/BASELInE

Si-Chee Tsay (613) participated in the spring campaign (March–April 2015) of the international Seven SouthEast Asian Studies/Biomass-burning Aerosols & Stratocumulus Environment: Lifecycles & Interaction Experiment (7-SEAS/BASELInE) using COMMIT, the GSFC SMARTLabs mobile facility. The facility was situated near the aerosol source region in a remote site in northern Thailand, Doi Angkhang (19.93°N, 99.05°E, 1536 m a.s.l.) that is located ~200m east of the Myanmar border (http://smartlabs.gsfc.nasa.gov/). The project used collocated COMMIT and AERONET/MPLNET measurements as well as chemical composition samplings from regional contributing instruments to support cal-val and science goals for Suomi-NPP products (e.g., plume height, aerosol absorption, etc.) in addition to future ACE studies (e.g., aerosol-cloud interaction).

Figure 4.3: COMMIT and AERONET/MPLNET set up at in Doi Angkhang, a remote site northern Thailand.

4.4. SHADOZ

The SHADOZ team—Anne Thompson, PI (610); Jacquie Witte (614/SSAI); Ryan Stauffer, (614/UMD), Frank Schmidlin (610.W/Emeritus), Larry Bliven (610.W), Tom Northam (610.W/SSAI), Chris Ashburn (610.W/SSAI)—made major progress in three areas.

1. In March 2015, Witte and Ashburn were trained on the Skysonde software for re-processing ozonesonde data during a March visit to the Ozone and Water Vapor Group in Boulder at NOAA's ESRL/Global Monitoring Division. SHADOZ data from five stations were re-processed by Witte, including Ascension and Natal, and a paper on this data was presented at the San Francisco Fall AGU Meeting, December 2015.

2. Interactions of SHADOZ with the outside community included two university seminars by Anne Thompson (NOAA's Geophysical Fluid Dynamics Laboratory in Princeton University in January and the University Alabama in Huntsville in March). An invited SHADOZ paper was presented by Thompson at the General Assembly of the International Union of Geodesy and Geophysics Symposium in Prague in July. Thompson presented a SHADOZ status report, along with a summary of Wallops ozone operations, to the NDACC Scientific Steering Committee annual meeting in LaJolla, California, in October. Thompson and Witte committed to working with GCOS Reference Upper Air Network (GRUAN) to develop a protocol for the inclusion of ozonesonde operations into GRUAN. Thompson served on the Steering Committee of the IGAC Tropospheric Ozone Assessment Report (TOAR).

3. Operations at Brazil, a NDACC site as well as a SHADOZ station, continued with nominally weekly ozonesonde launches. (NDACC reporting and data archiving also continued for Wallops ozonesondes and the Dobson). Visits were made GSFC's Greenbelt and Wallops locations to streamline operations and facilitate data exchange. This included a September training element in Beltsville using the Greenbelt DMT-Imet sonde setup. Regular SHADOZ operations resumed after some gaps at Fiji and San Cristobal (Galapagos, Ecuador). Water vapor and SO_2 sondes have been launched monthly, along with ozonesondes, at the Costa Rica station in conjunction with H. Selkirk (614/USRA). A memorandum of agreement

between GSFC and the USAF (Patrick Air Force Base, 45th Space Wing) was completed in September to facilitate the resumption of SHADOZ operations at Ascension Island, after a five-year gap. Launches will resume in March 2016. For further information please contact Anne Thompson, anne.m.thompson@nasa.gov.

4.5. TWILite/European ADM-Aeolus

Bruce Gentry (612) and his team participated in a flight campaign over Greenland, funded by NASA Headquarters. The Code 612 Tropospheric Wind Lidar Technology Experiment (TwiLite) was installed on board the NASA DC-8 aircraft and flown for five days over Greenland with flight times ranging up to eight hours. The TWILite airborne mission was primarily focused on gathering wind data in the Arctic Polar Regions near Iceland and Greenland. This area is of particular interest to both NASA and ESA due to the continued rise in arctic temperatures and decrease in polar ice formation.

The Greenland experiment also included pre-launch cal-val activities requested by the European Space Agency (ESA) in support of their Atmospheric Dynamics Mission (ADM) Aeolus mission. Approximately 20 hours of flight time were set aside specifically for this ADM activity, which was coordinated with the German DLR Falcon aircraft that also employed a wind lidar system. The mission goals were to provide current wind data to preexisting weather models and to collect pre-launch calibration and validation data in support of ADM-Aeolus. ESA's ADM-Aeolus satellite, ready for launch in 2016, will be the first of its kind to measure key elements in Earth's wind fields. Using Doppler wind lidar, the satellite will observe profiles of wind, aerosols, and clouds along its orbital path. These measurements will allow scientists to build more complex models of Earth's weather and climate patterns. For further information please contact Bruce Gentry, bruce.m.gentry@nasa.gov.

4.6. PECAN

The Plains Elevated Convection at Night (PECAN) campaign was designed to increase the understanding of severe thunderstorms at night over the continental United States. It involves 8 research laboratories and 14 universities (both national and international) and is funded by NSF, NOAA, NASA and DOE.

PECAN was conducted across northern Oklahoma, central Kansas, and into south-central Nebraska from June 1 to July 15, 2015. It focused on nighttime convection in conditions with strong low-level winds and a stable layer near the surface with the largest instability located aloft. The findings should be applicable to other continental regions with strong nighttime thunderstorms. PECAN is the largest meteorological field campaign hosted in the United States in more than 10 years and involves experimental groups from universities, NOAA, NASA, NCAR, and others.

PECAN had four research objectives:

1. To better explain the environmental characteristics and processes that lead to nocturnal convection initiation and the early phases of large-scale storm clusters
2. To better understand the internal structure and microphysics of the large-scale nocturnal storm clusters
3. To advance the knowledge of wave-like disturbances caused by convective storms
4. To improve prediction of nocturnal convection that will be useful to improving both the operational forecasting and in climate models.

The field campaign had its first measurement period on June 1, 2015. The NASA/GSFC GLOW (Bruce Gentry, 612), Xbadger (Amber Emory, 612) and ALVICE (David Whiteman, 612) systems participated as part of a fixed station in Greensburg, Kansas. The mission focused on events that trigger severe nighttime convection in the Midwestern United States. More information can be found at http://catalog.eol.ucar.edu/pecan. On June 8, a classic undular bore case occurred and was measured by the GSFC X-badger (Amber Emory, 612) and ALVICE (David Whiteman, 612) instruments at a field site in Greensburg, KS known as FP2. Bores can trigger nighttime convection, the central research focus of PECAN, and are thus one of the targets of the campaign. On the evening of July 13 an atmospheric bore wave passed the Greensburg, KS site where the GSFC instruments were stationed. Water vapor mixingratios measured during the bore event are shown below.

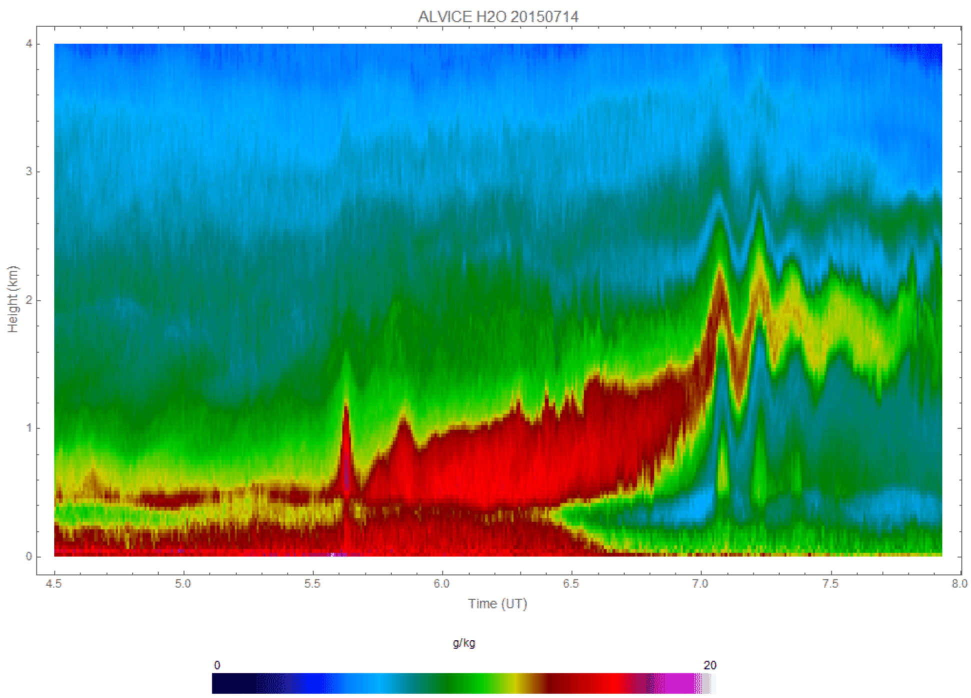


Figure 4.4: Water-vapor mixing ratio (g/kg) measured by the ALVICE Raman lidar system on July 14, 2015, UT. Two wave events were captured—a precursor wave at 0540 UT and the main bore oscillation at 0700 UT.

Operations took place from June 1 to July 15, 2015, over the Central United States. The bases of operations included Hays, Kansas, for the ground crews and operations center; Great Bend, Kansas, for the University of Wyoming King Air; and Salina, Kansas, for the NOAA P-3 and the NASA DC-8. For a summary of the operations that occurred during PECAN visit the mission's summary page http://catalog.eol.ucar.edu/pecan/tools/missions. The Long-Term Data Archive for PECAN is located at http://data.eol.ucar.edu/master_list/?project=PECAN.

4.7. HS3

The Hurricane and Severe Storm Sentinel (HS3) Earth Venture suborbital investigation completed its Key Decision Point-F review on July 29. HS_3 was the first of the EVs-1 investigations to complete a KDP-F review. HS3 was granted a one-year, no-cost extension in order to complete science data processing, analysis, and publication of science results. Four papers were submitted for publication in 2015:

Munsell, E. B., F. Zhang, J. A. Sippel, and S. A. Braun, 2016: Dynamics and predictability of the rapid intensification of Hurricane Edouard (2014). *Mon. Wea. Rev.,* (submitted).

Abarca, S. F., M. T. Montgomery, S. A. Braun, and J. Dunion, 2015: On the secondary eyewall formation of Hurricane Edouard (2014). *Mon. Wea. Rev.,* (submitted).

Braun, S. A., P. A. Newman, and G. M. Heymsfield, 2015: NASA's Hurricane and Severe Storm Sentinel (HS3) Investigation. *Bull. Amer. Meteor. Soc.,* (submitted).

Munsell, E.B., J. A. Sippel, S. A. Braun, Y. Weng, and F. Zhang, 2014: Dynamics and predictability of Hurricane Nadine (2012) evaluated through convection-permitting ensemble analysis and forecasts with NASA HS3 field campaign observations. *Mon. Wea. Rev.* (submitted).

4.8. KORUS

The *in situ* Airborne Formaldehyde (ISAF) Measurements for KORUS was selected for funding (PI: Tom Hanisco, 614). The formaldehyde instrument in support of KORUS: An International Cooperative Air Quality Field Study will take place in Korea during May–June 2016.

4.9. CCAVE

The CALIPSO-CATS Airborne Validation Experiment (CCAVE) took place in August 2015 out of Palmdale, CA with the intention of providing validation data for the CALIPSO and CATS space-based lidar instruments. The Cloud Physics Lidar (CPL) and Airborne Cloud-Aerosol Transport System (ACATS), both lidar systems, were payloads aboard the NASA ER-2. Flights consisted of 30-minute coincident segments over the satellite tracks when cirrus clouds and smoke from wildfires in the western United States were present.

4.10. SHOUT

The NOAA Unmanned Aircraft Systems (UAS) Program has designed a project focused on Sensing Hazards with Operational Unmanned Technology (SHOUT) to quantify the influence of UAS environmental data on high-impact weather prediction and to assess the operational effectiveness of UAS to help mitigate gaps in satellite observations. The NOAA UAS Program will partner with NASA to conduct missions using advanced UAS for operational prototype data collection. The SHOUT project began with a targeted effort using NASA Global Hawk platforms and payloads for observing and predicting high-impact oceanic weather. As the project matures, other viable unmanned observing technologies may be incorporated into the observational strategies tested as operational prototypes.

The High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) was installed on Global Hawk AV-6 at NASA Armstrong for the SHOUT field campaign. SHOUT conducted flights over hurricanes for a five-week period. The AV-6 was based at Wallops to study Atlantic hurricanes. Key participants with HIWRAP include G. Heymsfield (555), M. McLinden (555), V. Venkatesh (SSAI), and other Code 555 engineers. P. Newman (610) and S. Braun (612) were mission scientists during SHOUT.

SHOUT completed two 24-hour flights over Tropical Storm Erika. On August 25–26, the Global Hawk was flown over Tropical Storm Erika in the tropical Atlantic as it neared the Leeward Islands. This was followed on August 29–30 by a second flight that sampled the environment to the northeast of Erika as the storm moved towards the Straits of Florida. The HIWRAP instrument (Gerry Heymsfield, 612) also made substantial observations over Erika on these two flights. For further information please contact Paul Newman, paul.a.newman@nasa.gov.

4.11. RADEX/OLYMPEX

Sponsored by NASA Headquarters' ACE Decadal Mission study, the Radar Definition Experiment (RADEX) was conducted in the OLYMPIC Peninsula region of Washington. RADEX utilized the NASA ER-2 instrumented with the Goddard's HIWRAP, CRS, and EXRAD radars, CPL lidar, as well as the Ames' eMAS and JPL's AirMSPI instruments. RADEX was implemented for microphysical and other retrieval algorithms for the dual-frequency ACE radar concept, specifically lighter precipitation, shallow convection, and clouds. RADEX was a coordinated activity with the larger GPM GV-sponsored OLYMPEX field campaign. The ER-2 conducted nine science flights, several of which were coordinated with the OLYMPEX-sponsored NASA DC-8 and the jointly sponsored University of North Dakota Citation in situ aircraft. For further information please contact Gerald Heymsfield, gerald.m.heymsfield@nasa.gov.

4.12. VIRGAS

Paul Newman, Leslie Lait, and Peter Colarco participated in the Volcano-Plume Investigation Readiness and Gas-phase and Aerosol Sulfur (VIRGAS) Experiment. VIRGAS was a two week, mini-mission for developing what NASA and NOAA investigators hope will become a new standing capability for measuring SO_2, other gases, and particles in the plumes from volcanic eruptions. The premise is based on creating a partnership between NASA and NOAA that would deploy NASA's JSC WB-57F aircraft to acquire atmospheric data soon after volcanic eruptions, giving scientists an unprecedented opportunity to observe volcanic plumes and understand their climatic and the atmospheric implications.

Various satellites have been monitoring SO_2 for many years. During the week of October 18–24, 2015, the WB-57F aircraft was flown over Hurricane Patricia in conjunction the Office of Naval Research's Tropical Cyclone Intensification (TCI) experiment. Newman, mission scientist for VIRGAS, and Lait developed flight plans for the WB-57F. Colarco's forecasts of SO_2 were the primary product for developing these flight plans. The VIRGAS mission had another four flights during the week of October 25–30. The mission concluded on October 30. For further information, please contact Paul Newman, paul.a.newman@nasa.gov.

4.13. OLYMPEX

The NASA GPM Ground Validation Program coordinates ground validation field campaigns at key locations. One of the most comprehensive ground validation field campaigns for GPM will be held from November 2015 through February 2016 on the Olympic Peninsula in the Pacific Northwest of the United States. The primary goal of this campaign, called Olympic Mountain Experiment (OLYMPEX), is to validate rain and snow measurements in midlatitude frontal systems moving from ocean to coast to mountains and to determine how remotely sensed measurements of precipitation by GPM can be applied to a range of hydrologic, weather forecasting, and climate data.

The requirements will be met with an integrated approach, including:

1. Surface precipitation gauge networks and snowpack monitoring instrumentation.
2. Accurate surface measurements of falling liquid and solid precipitation using a combination of radar and gauge instruments.
3. Disdrometer networks to measure microphysical properties of falling hydrometeors.
4. A suite of scanning, dual-polarization and vertically pointing surface-based radars.

5. Satellite-simulator and microphysical measurements from aircraft.
6. Streamflow monitoring.

The campaign was fortunate in the first week of operations to have numerous storm cases to observe. In fact, on November 17 the Doppler On Wheels unit nearly became submerged when heavy rains raised the level of the lake near its site to unexpected depths. Nonetheless, it contributed to the best observational data set to date for a narrow, cold frontal rainband. After a dry period lasting nearly a week in late November, a rainy weather pattern returned providing numerous opportunities to sample precipitation in a variety of meteorological situations, including warm and occluded fronts, atmospheric river events (which again nearly submerged the Doppler On Wheels), and post-frontal convection. Orographic enhancement was present in many of these regimes, which were captured by the full complement of ground and airborne instruments. Aircraft operations ceased mid mid-December but ground radars and instrument networks continued operation (with a short break in late December) until mid-January.

Code 610.W NASA Wallops scientists and engineers have deployed NASA's NPOL and D3R radars on a mountaintop near Moclips, Washington. The engineers were able to overcome issues with the antenna controller to provide high-resolution observations of two significant precipitation events. The first event, which consisted mostly of rain, provided daily rainfall totals of greater than 15 inches in some areas. The second event provided nearly as much rain, but was accompanied by much stronger winds, and provided for near-blizzard conditions in the upper Midwest, United States, over the weekend.

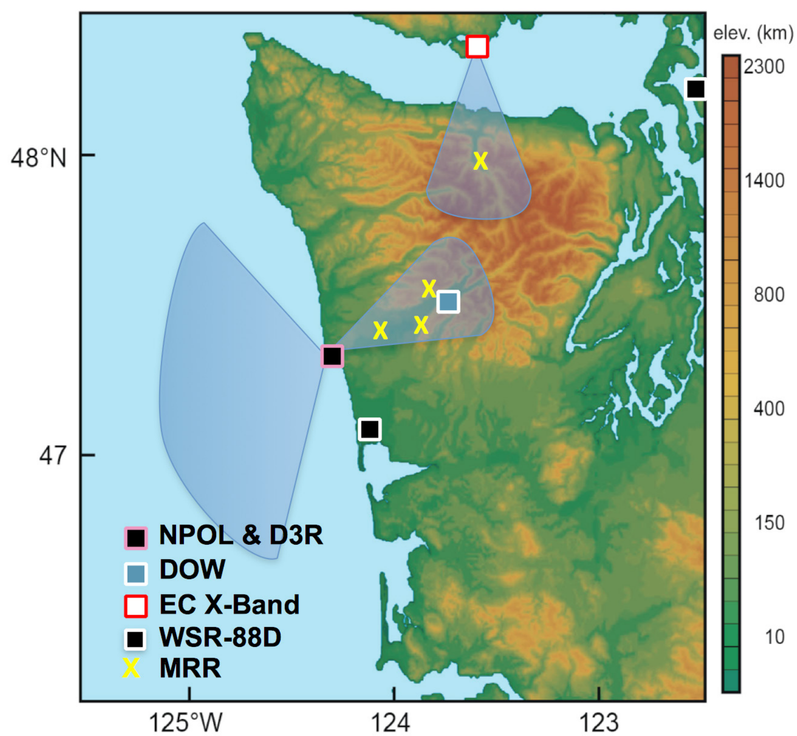


Figure 4.5: The OLYMPEX radar network showing the NPOL scanning region and the DOW location in the Quinault Valley.

The Radar Definition Experiment (RADEX) sponsored by the NASA Headquarters' ACE Decadal Mission study began science flights November 17 in the OLYMPIC Peninsula region of Washington. RADEX brings the NASA ER-2 instrumented with the GSFC HIWRAP, CRS, and EXRAD radars, CPL lidar, as well as the eMAS and AirMSPI instruments. RADEX targets algorithms for the ACE mission for lighter precipitation and clouds and is part of the larger GPM Ground Validation (GV) -sponsored OLYMPEX field campaign. GPM GV is sponsoring the NASA DC-8, NPOL and D3R radars, and shares the University of North Dakota Citation aircraft for in situ microphysics measurements with RADEX. The ER-2 has conducted three science flights, fewer than expected since there was a dry period for the past week over the region. Joe Munchak (612) participated in the OLYMPEX field campaign as a flight scientist from December 3–12, 2015. For further information please contact Joe Munchak, s.j.munchak@nasa.gov or Matt Schwaller, mathew.r.schwaller@nasa.gov.

4.14. Atmospheric Instrument Scientists and Managers

Listed below are the scientists and managers responsible for key instrument systems in 2015.

Table 4.4: Instrument Scientists/ Managers

Name	Instrument Systems	2015 Campaigns
Gerry Heymsfield	EXRAD	ER-2 Test Flights
Jay Herman	Pandora UVNIS	DISCOVER-AQ
Scott Janz	ACAM	DISCOVER-AQ
Matt McGill	UAV-CPL	HS3, SEAC4RS
Walt Petersen	NPOL	GPM OLYMPEX
Walt Petersen	D3R Radar	GPM OLYMPEX
Walt Petersen	*In situ* SO_2	Dragon Eye/Volcano
Si-Chee Tsay	SMARTLabs	7-SEAS
Judd Welton	MPLNET	7-SEAS
Tom Hanisco	ISAF	AToM, DISCOVER-AQ
Anne Thompson	O_3 Sondes	SHADOZ
William Krabill	ATM	Operation IceBridge
Tom Hanisco	ISAF	SONEX
Bruce Gentry	TWILite	TWILite/European ADM-Aeolus
Amber Emory, Dave Whitemen	Xbadger/ALVICE	PECAN
Tom Hanisco	ISAF	KORUS
Matt McGill	ACATS	CCAVE
Paul Newman, Scot Braun		SHOUT
Gerry Heymsfield	HIWRAP	RADEX/OLYMPEX
Paul Newman, Pete Colarco		VIRGAS
Joe Munchak		OLYMPEX

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. The year Steve Platnick and Anne Thompson were honored with highly distinguished awards from the American Meteorological Society (AMS) and American Geophysical Union's (AGU) respectively.

5.2. Special Recognition

5.2.1. 2015 AGU Roger Revelle Medal

Figure 5.1: Anne Thompson, 2015 AU Roger Revelle Medal recipient

Of particular significance this year was the selection of Anne Thompson, PhD, to receive the 2015 Roger Revelle Medal. This medal honors scientists *"for outstanding contributions in atmospheric sciences, atmosphere-ocean coupling, atmosphere-land coupling, biogeochemical cycles, climate, or related aspects of the Earth system,"* and is awarded once annually. The medal is named in honor of Roger Revelle, who made substantial contributions to the awareness of global change. Established in 1991, this is a distinct honor for both Thompson and Goddard since Goddard's people are the foundation that supports the Center's science, engineering, and projects. The following is a summary of her accomplishments that led to this recognition.

Thompson is being recognized for her pioneering work in understanding ozone and other trace gases in the troposphere and stratosphere and as one of the world's leaders in helping to make atmospheric chemistry a truly global discipline, with scientists around the world working together to obtain high quality data. Her research interests include investigations of tropospheric chemical and dynamical processes, from air-sea gas exchange to interactions with the lower stratosphere. Thompson's discoveries about the chemistry of the atmosphere have ranged from computer model studies to experiments on ship and research aircraft. Trends of atmospheric ozone and the interaction of natural variability and human influence (biomass fires, urban pollution) are on-going themes of her research that employ satellite data from a variety of atmospheric air and land-surface sensors. She is a veteran of dozens of NASA aircraft missions, ground-based campaigns and oceanographic cruises

In 1986, she joined GSFC in the Atmospheric Chemistry and Dynamics Branch where she provided the scientific leadership and technical direction of the SHADOZ program that led to important scientific discoveries on tropospheric ozone. Her work in the 1980s and early 1990s was among the first to link chemical changes, climate forcing's and the earth's oxidizing capacity. In 2004 she accepted a position at Penn State University as a Professor of Meteorology. Anne returned to GSFC 8 years later to continue research in atmospheric chemistry and climate change, pollution studies, and applications of satellite data to Earth systems studies.

She is a Fellow of the AAAS (American Association for the Advancement of Science, 2002), the American Geophysical Union (AGU, 2003) and American Meteorological Society (1995). She also received the NASA ESM Medal in 1995. In 1998 Dr. Thompson received the William Nordberg Medal of COSPAR (Committee for Space Research) for "achievements in developing tools that use and improve space remote-sensing data to better understand chemical and physical phenomena on Earth." In 2004, Dr. Thompson received the Women in Aerospace International Achievement Award, largely for SHADOZ. Anne has served on the International Commissions, Executive Committees of the American Meteorological Society, and President of the International Commission on Atmospheric Chemistry and Global Pollution.

A native of Pennsylvania, she received a Bachelor of Arts with Honors in chemistry from Swarthmore College, a master's degree from Princeton University and a doctorate in physical chemistry from Bryn Mawr College. This was followed by postdoctoral research at Woods Hole Oceanographic Institution, Scripps Institution of Oceanography and by a visiting scientist appointment at the National Center for Atmospheric Research in Boulder, CO, prior to joining GSFC in 1986.

5.2.2. 2015 AMS Verner E. Suomi Award

Figure 5.2: Steve Platnick
2015 AMS Verner E. Suomi Award recipient

The Verner E. Suomi Award is granted to individuals in recognition of highly significant technological achievement in the atmospheric or related oceanic and hydrologic sciences. The term "technological" is here used in the broadest sense; it encompasses the entire spectrum of observational, measurement, data transmission, and data analysis and synthesis methodologies. The award is in the form of a medallion.

Steve Platnick, PhD, was honored *"For cutting-edge research and leadership in spaceborne observations of the atmosphere, particularly remote sensing of cloud properties."* He has been recognized for the high quality of his scientific investigations, for his scientific integrity, and his papers and presentations, which are always of the highest quality. The following is a summary of his career that led to this recognition.

Platnick was one of the first scientists to use the NOAA's Advanced Very High Resolution Radiometer (AVHRR) instrument's 3.7-μm band for cloud particle-size retrievals. This early effort was part of a larger study to assure the extent to which cloud optical thickness and particle size influences the susceptibility of cloud albedo to modification by aerosols (i.e., the indirect effect). He was also the first to validate AVHRR cloud droplet size retrievals with *in situ* aircraft (i.e., ASTEX).

His 1994 paper on susceptibility of cloud albedo to changes in droplet concentration has been widely cited in the scientific community. He designed radiative transfer code and an inverse algorithm to retrieve cloud microphysical parameters (Platnick and Twomey, *J. Appl. Meteor*. 1994), carefully analyzed radiometric calibration (Platnick et al., *SPIE* 1996), developed considerations for vertical and horizontal inhomogeneity in the cloud field destitution (Platnick, J. *Geophys. Res.* 2000: Platnick, *JQSRT* 2001), and detailed analysis of microphysical properties of ship trail clouds (Platnick et al. *J. Geophys. Res.* 2000). His research expanded to include theoretical and experimental studies of satellite, aircraft, and ground-based remote sensing for clouds. He has been involved extensively with remote-sensing field studies, including use of the MODIS Airborne Simulator instrument flown on the NASA ER-2, and he has served in the flight scientist role on a number of field campaigns. Platnick is a member of the MODIS and S-NPP Atmosphere Science Team working on operational cloud optical and microphysical products, and he is the MODIS Atmosphere Team Lead.

Steve became a civil servant in the Climate and Radiation Branch in the Laboratory for Atmospheres in 2002 and then moved to the Earth Science Division in 2009. He has served as the head EOS Project Science Office since 2008, and as Deputy Director for Atmospheres in the Earth Science Division since January 2015. Prior to becoming a civil servant, Platnick was a research associate professor in the Joint Center for Earth Systems Technology, University of Maryland Baltimore County - an affiliation begun in 1996. During this time he led the development of a comprehensive set of graduate-level atmospheric physics courses within the Department of Physics of which he taught several. He previously held a National Research Council Research Associate position at the NASA Ames Research Center as well as a research and development position at the Hewlett-Packard for six years. His work with Hewlett-Packard included two years as a visiting faculty in the Department of Electrical Engineering at North Carolina A&T State University. His background in electrical engineering and atmospheric science is a very complementary and was particularly relevant when considering a career in NASA.

Throughout his career Steve has demonstrated imagination, understanding, ability, and he has always worked to exercise his gifts and share them with others.

5.3. Agency Honor Awards

In 2015, NASA identified the following people for special recognition.

Honor Award	Recipient	Citation
Distinguished Service Medal	Arthur Hou (Posthumous) 610	*For distinguished service and steadfast leadership in establishing the GPM mission as a successful international project for scientific and societal benefit.*
Exceptional Service Medal	Steve Platnick 610	*For his remarkable record of supporting, disseminating, and interpreting NASA's climate-relevant cloud observations from space.*
Exceptional Achievement Medal	George Huffman 612	*For scientific achievements in multi-satellite global precipitation retrieval algorithm development and rain product dissemination.*
Exceptional Achievement Medal	David Wolff 610W	*For exceptional achievement, dedication and leadership in the field deployment of GPM Ground Validation radars.*
Outstanding Leadership Medal	Joanna Joiner 614	*For her leadership of retrieval efforts for retrieval of atmospheric composition and plant fluorescence, and exemplary mentoring of young scientists.*
Exceptional Public Achievement Medal	Can Li 614	*For implementation of a novel and efficient algorithm that dramatically improves sulfur dioxide retrievals for OMI and OMPS and enables improved detection of emission sources.*
GPM Post-Launch Team	Gail Skofronick-Jackson 612	*For exceeding all expectations for GPM operations, data processing, algorithm performance, science impact, and education and public outreach within one year after launch.*
Microwave Limb Sounder (MLS) Team	Dong L. Wu 613	*For the outstanding skill and dedication in extending the successful operation and science achievements of the Earth Observing System Microwave Limb Sounder instrument.*

5.4. Robert H. Goddard Awards

Atmospheric Research team members received five individual awards.

Robert H. Goddard Award	Recipient	Citation
Award of Merit	P.K. Bhartia	*For life-long leadership and intellectual contribution to NASA's monitoring of atmospheric ozone and the establishment of a long-term ozone climate record.*
Science	Alexander Marshak	*For great advancements in our understanding of the three-dimensional nature of clouds and its implications on the transfer of atmospheric solar radiation*
Science	Nai-Yung Christina Hsu	*For innovative operational algorithms that improve aerosol detection from space for air quality and climate applications*
Science	Lok Lamsal	*For exemplary satellite atmospheric composition retrieval development, scientific analysis, and promotion of NASA data to the scientific and applied sciences communities.*
Science	Matthew DeLand	*For exceptional and sustained scientific insight in understanding long-term solar spectral irradiance variability and Polar Mesospheric Cloud morphology.*

Four GPM teams received awards.

Robert H. Goddard Award	Recipient	Citation
Science: GPM Algorithm/ IMERG Team	David Bolvin, Mircea Grecu, George J. Huffman, Benjamin Johnson, Christopher Kidd, Kwo-Sen Kuo, Liang Liao, Toshihisa Matsui, Robert Meneghini, Stephen Joseph Munchak, Eric J. Nelkin, William Olson, Lin Tian	*For outstanding precipitation retrieval algorithm development to support the Global Precipitation Measurement (GPM) mission.*
Science: GPM Ground Validation Team	Gerald Heymsfield, Benjamin Johnson, Christopher Kidd, David Marks, Kenneth Morris, Stephen Joseph Munchak, Jason Pippitt, Mathew Schwaller, Ali Tokay, David Wolff, Di Wu	*For creative development and use of validation data for GPM from surface-based sensors and four highly successful field campaigns.*
Outreach: GPM Outreach Team	Dorian Janney, Jacob Reed, Kristen Weaver	*For outstanding education and public outreach activities to support the Global Precipitation Measurement (GPM) mission.*
Science: Precipitation Processing System Team	Eric Stocker and 36 recipients from Code 610.2	*For outstanding data processing development to support the Global Precipitation Measurement (GPM) mission.*

5.5. Wallops Peer Awards

Wallops Peer Award	Recipient	Citation
Climate Adaptation Science Investigation (CASI) Team	Tiffany Moisan (610.W), John Moisan (610.W), David Wolff (610.W), and Kay Rufty (610.W/GST)	*Initiation of science investigations critical to the understanding of Wallops Island's vulnerability to sea level rise and coastal flooding.*
Field Support	Technician team at Wallops Field Support Office	*Outstanding Field Support for NASA's Global Precipitation Measurement Ground Validation Program.*

5.6. Other NASA Centers

NASA's Johnson Space Center presented a Group Achievement Awad to the CATS team. The award includes the JSC people and the JAXA people who worked most closely with the GSFC CATS teams.

Affiliation	Recipient	Citation
Civil Servant	Matthew McGill, Stan Scott, John Cavanaugh, Beth Paquette, Phillip Adkins, Ellsworth Welton,	*For exemplary performance and teamwork in developing the Cloud-Aerosol Transport System for ISS.*
SSAI	Andrew Kupchock, John Yorks, Patrick Selmer, Stephen Palm, Dennis Hlavka, William Hart	
Fibertek	Andy Losee, Xung Dang, Selma Tint, Ibraheem Darab, Floyd Hovis, Ti Chuang, Pat Burns, Gary Stevenson, Bill Gavert	

5.7. External Awards and Recognition

Dr. Anne Thompson (Code 614): Anne was selected by AGU as the 2015 Roger Revelle Medalist.

Steven Platnick (610AT): The American Meteorological Society's Verner E. Suomi Award.

Jose Rodriguez (614): Elected as Fellows by the Council of the American Association for the Advancement of Science (AAAS). He will be recognized for his contributions to science at the Fellows Forum to be held on February 13, 2016 during the AAAS Annual Meeting in Washington, D.C.

Dr. Lorraine Remer, (613/UMBC-JCET): Honored by the AGU as an 2015 Fellow. The recognition ceremony was held at the 2015 AGU Fall Meeting in San Francisco, CA, December 16, 2015.

Dr. Susan Strahan (USRA/614): Received the 2014 Editor's Citation for Excellent in Refereeing for the Journal of Geophysical Research – Atmospheres.

Daniel Perez-Ramirez (USRA/612): Awarded a 2-year Marie Curie grant funded by the European Commission. The project involves use of simulations of measurements and aerosol retrievals from a space-borne multi-wavelength lidar system as anticipated for the upcoming ACE mission.

Lauren Zamora (613/ORAU): Competitively selected to be one of only 600 young scientists invited from around the world to attend the 65th Lindau Nobel Laureate Meeting, the fourth interdisciplinary meeting with Nobel Laureates from the fields of physics, physiology, medicine, and chemistry. The meeting was held from June 28 to 3 July 3, 2015, in Lindau, Germany. http://www.lindau-nobel.org/.

5.8. 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

5.9. American Meteorological Society

5.9.1. Honorary Members

Honorary members of the American Meteorological Society shall be 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

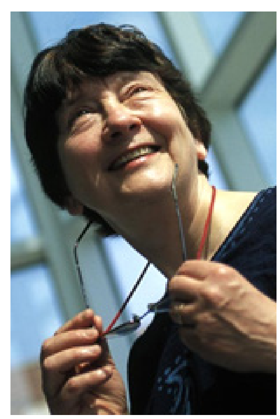

Eugenia Kalnay

Figure 5.3: Honorary AMS members

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

5.10. American Geophysical Union

5.10.1. Roger Revelle Medal: Anne Thompson, 2015 Award Recipient

Established in 1991, the Revelle Medal is named in honor of Roger Revelle, who made substantial contributions to the awareness of global change. Revelle served as an AGU section president for the Ocean Sciences section (1956–1959). Edward N. Lorenz was the first recipient of the Revelle Medal.

5.10.2. 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, and/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

Recipient	Year
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

5.10.3. 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. EDUCATION AND OUTREACH

6.1. Introduction

Atmospheric Scientists in the Earth Sciences Division actively participate in NASA's efforts to serve the education community at all levels and to reach out to the general public. Scientists seek to make their discoveries and advances broadly accessible to all members of the public, and 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

Brian Campbell (610.W, GST) presented two webinars on the Soil Moisture Active Passive (SMAP) mission in cooperation with the Wayne County (MI) Regional Education Service Agency (RESA) January 12, 2015. Applications of NASA soil moisture data, as well as hands-on activities to explore local conditions were outlined to educators in Grades 5 through 10. Wayne RESA is a GLOBE Training institution, and these presentations included an overview of the GLOBE program and a discussion of how to become involved.

On January 16, **Bryan Duncan (614)** presented "A Tale of 3 Cities: Air Quality Observations from Space" to 70 STEM teachers from south-central Maryland. Prior to the presentation, **Ginger Butcher (610)** demonstrated a lesson about how NASA instruments measure pollution in the atmosphere.

The GPM-GLOBE Student Field Campaign began February 1st, with four short kick-off webinars for students during the day on February 2. Students learned about the GPM mission and why both ground and space observations are needed, and were able to ask questions of GPM Education Specialist **Kristen Weaver (612, USRA)** and PMM Science Team member Mark Kulie of the University of Wisconsin. Over the course of the four webinars, 15 educators and approximately 75 students participated from six U.S. states as well as Poland, Puerto Rico, the Dominican Republic, and the Czech Republic.

The first two scientist blogs for the GPM-GLOBE Student Field Campaign are live and gaining views. Former GPM Ground Validation Team member Piotr Domaszczynski's blog, titled "Praying for rain: GPM rainfall measurements from the ground-up perspective," has received 410 views since being posted on February 2, 2015. Current PMM Science Team member Ali Tokay's blog, titled "How well can we measure precipitation? Why is it so important?" has already been viewed 605 times since being posted on February 9, 2015. At least 50 schools have entered precipitation data in the GLOBE database in the last week, and about 10 of those have teachers who attended the introductory field campaign webinar, the virtual campaign kick-off for students, or are otherwise affiliated with GPM as a GPM Master Teacher or Pilot Teacher.

On February 7, **Dorian Janney (612, ADNET)** presented a workshop entitled "NASA and OEEP: The Perfect Partnership" (Outdoor Environmental Education Program) to 56 educators.

On February 10, **Dorian Janney (612, ADNET)** conducted a program about GPM and measuring snow at the NIH Children's Inn. Six children and eight adults attended.

Education and Outreach

On February 18, the GPM Education and Communication Team (612) hosted two sessions of a webinar for the GPM-GLOBE Student Field Campaign, entitled “Ground Validation and Satellite Measurement.” The featured presenter at the first session was **Dr. Walter Petersen (610.W),** Deputy Project Scientist for Ground Validation, and at the second session was Dr. Stephen Nesbitt, GPM Ground Validation Team member. The audience was teachers participating in the student field campaign and CoCoRaHS citizen science observers. The 27 attendees represented seven different states and eight different countries.

On February 18, **Dorian Janney (612, ADNET)** presented to three classes (73 students, 3 teachers) about how NASA missions help us better understand our home planet at Roberto Clemente Middle School. These students came to Goddard on January 26, 2015 the to learn more about NASA’s Earth observing missions and interview scientists and others as they prepare their films for the upcoming Environmental Film Festival.

On February 20, **Dorian Janney (612, ADNET)** and **Kristen Weaver (612, USRA)** shared GPM and other NASA Earth science education resources at a table at the Global Education Resource Fair as part of the Teachers for Global Classrooms program. The program, funded by the Bureau of Educational and Cultural Affairs at the U.S. Department of State and implemented by the nonprofit International Research and Exchanges Board (IREX), brings over 100 teachers and administrators from around the United States to a Global Education Symposium in Washington, D.C., and subsequently on an international fellowship to one of six countries.

On March 2, **Robert Levy (613)** presented a talk entitled “MODIS Aerosol Remote-Sensing 101” to students attending the AOSC 625 class “Remote Inference of Atmospheric Properties by Satellite”, University of Maryland, College Park.

On March 9-10, Todd Toth (ADNET; 160) and **Dorian Janney (612, ADNET)** presented at the GLOBE Train the Trainer and North America Regional GLOBE meetings in Chicago, Illinois, about GPM, the GPM-GLOBE Student Field Campaign, and the upcoming Watershed Science Summer Institute. A total of 83 people attended the two presentations.

On March 18, the GPM Education & Communication Team held two sessions of a webinar as part of the GPM-GLOBE Student Field Campaign titled “Getting and Analyzing Precipitation Data.” Guest presenter Gary Randolph, Training Coordinator from the GLOBE Implementation Office, gave a tour of the GLOBE Science Data Visualization service, and **Kristen Weaver (612, USRA)** showed participants how to get satellite precipitation data from various sources such as “My NASA Data” and “Giovanni,” as well as giving examples of how students can analyze that data. Attendance was 16 teachers from the United States and six other countries.

On March 19, **Kristen Weaver (612, USRA)** and **Dorian Janney (612, ADNET)** hosted an activity table at the Fort Belvoir Elementary School Science Fair and STEM Evening. Attendees learned about the GPM mission and were challenged to build a tower that could resist the force of a simulated hurricane. Attendance was over 500 (military families and elementary-aged children).

On March 20, **Dorian Janney (612, ADNET)** ran a presentation, as requested by the GSFC Office of Education, for 15 pre-service teachers from Marymount University. She gave them information on the science and technology behind the GPM mission and discussed climate change.

Brian Campbell (610.W, GST) led a professional development training for seventeen Wicomico County, Maryland elementary and middle school teachers on April 14, 2015. The training was held at the James M. Bennett High School in Salisbury, Maryland, and focused on NASA Earth Science and the SMAP mission and also trained teachers in the new GLOBE SMAP Block Pattern Soil Moisture Protocol.

On Friday, May 1, two GPM-themed films were submitted to the 10th Annual Montgomery County Public Schools Environmental Film Festival. One in particular, titled "GPM," included interviews with Dalia Kirschbaum (617) **and Gail Skofronick Jackson (612)** conducted during a visit to Goddard by the Poolesville High School filmmakers. It received an honorable mention was shown at the festival screening at the AFI Silver Theater.

On May 7, **Dorian Janney (612, ADNET)** was a keynote presenter at the Family Science Night at Westland Middle School in Bethesda, Maryland, giving a talk entitled "Extreme Weather Events: How NASA is Helping us Better Understand Natural Disasters." Attendance at the event was estimated at 350.

On June 8, **Dorian Janney (612, ADNET)** and **Kristen Weaver (612, USRA)** gave presentations to sixth grade students at Roberto Clemente Middle School in Germantown, Maryland. Dorian's topic was how NASA studies climate change, and Kristen discussed NASA's Earth science missions including GPM. Each gave talks to four different groups of students, reaching about 240 students total. On June 8, Dorian Janney, Kristen Weaver, and Ray Paleg (GPM summer intern), also attended and presented at Forest Knolls Elementary School's special NASA/GPM Assembly. GPM Master Teacher Susan Michal presented awards to students who had participated in the GPM Afterschool Club and who contributed to a NASA/GPM news show produced and taped at the school as part of their communication arts program. Several students also shared their GPM-related research and projects. About 300 students and 30 adults attended the assembly, and about 50 students received awards for their GPM-related participation.

The SMD Earth Science Education Team hosted a "Summer Watershed Institute" for 30 Maryland 3rd, 4th, and 5th grade teachers on July 6–10 at Goddard. The teachers learned the science behind how NASA studies the Earth—especially the Chesapeake Bay region—and the Maryland State educational requirements related to these topics. They also met with several scientists and engineers to learn about their work and research. The teachers returned at the end of the month to present new materials they developed as part of this institute and reported on their own observations taken using GLOBE data collection protocols in the interim weeks. The facilitation team for the workshop included GPM Education Specialists **Dorian Janney (612, ADNET) and Kristen Weaver (612, USRA),** as well as summer intern Rachel (Ray) Paleg (617), **Brian Campbell (610.W, GST)**, **Valerie Casasanto (610, UMBC), Holli Riebeek (610, SSAI)**, and **Ginger Butcher (610, SSAI)**.

Dorian Janney (612, ADNET) and Kristen Weaver (612, USRA) presented a poster at the PMM Meeting in Baltimore on July 14. The poster focused on the Education and Communications work that the GPM Education and Public Outreach team has accomplished over the past year. They attended the PMM meeting on July 14–15.

On July 15, **Kristen Weaver (612, USRA)** conducted a virtual educator professional development session about how NASA studies hurricanes, past and present, including information about GPM, TRMM and HS3. About 15 educators connected remotely from Johnson Space Center to the Digital Learning Network studio at Goddard for the presentation.

On July 16, **Kristen Weaver (612, USRA)** gave a workshop presentation at the NIST Summer Institute for Middle School Science Teachers in Gaithersburg, Maryland. The presentation included information about the GPM mission and science background, as well as training in the GLOBE data collection protocols for precipitation, clouds, and surface temperature. Twenty-two middle school educators from around the United States attended.

As the creator of ClimateBits, **Stephanie Schollaert Uz (614, GST)** was invited to the White House's back-to-school climate education event on August 20. In the welcome remarks, NOAA Administrator Kathryn Sullivan highlighted ClimateBits videos as an interagency collaboration between GSFC, NOAA, and the University of Maryland that explains and visualizes key concepts in climate science. This live-broadcast event to discuss climate literacy and ways to connect students and citizens to the best-available science-based information about climate change was attended by 120 students, educators and education leaders from around the country. In conjunction with the live event, the White House Office of Science and Technology Policy published a fact sheet including "Earth to Sky" climate science and communication courses, another resource created with Goddard through an interagency partnership (Anita Davis, 610, SSAI): https://www.whitehouse.gov/sites/default/files/microsites/ostp/climate_ed_fact_sheet.pdf

On October 2, **Dorian Janney (612, ADNET) and Kristen Weaver (612, USRA)** staffed a table to share information about the GPM mission and related educational resources as part of the Academic Playground, a teacher resource fair included in a Prince George's County Public Schools teacher professional development day held at Central High School in Capitol Heights, Maryland. They spoke to about 100 middle and high school teachers.

For Earth Science Week, October 11–17, **Kristen Weaver (612, USRA)** wrote a blog about ways students could make their own visualizations of precipitation from ground station and satellite data using online tools that expand beyond simple graphs. http://svs.gsfc.nasa.gov/goto?4386

Dorian Janney (612, ADNET) held a two-hour workshop at Stranmillis University College in Belfast, Ireland, on October 14th for 8 professors and 47 education students. Dorian was invited to come and meet with the Education College Dean and Assistant Deans, and to give a two-hour workshop on how GPM studies Earth's water resources and share related STEM educational materials and hands-on activities. One of the GPM Master Teacher alumni, currently on sabbatical at the university, asked Dorian to come and speak while she was on vacation in Europe.

Brian Campbell (610W, GST) presented on the SMAP Mission-GLOBE Collaboration to the White House Subcommittee on Water Availability and Quality's Citizen Science Forum on October 15. Highlights included the current GLOBE/SMAP Soil Moisture Measurement Field Campaign and the release of Level 3 radiometer soil moisture data.

On October 17, the GPM Education and Communication Team held the second webinar with the 2015–2016 cohort of GPM Master Teachers, a group of 27 teachers from around the world—now including three from Brazil as a partnership with the Prefeitura Rio de Janiero (city government). Led by **Dorian Janney (612, ADNET) and Kristen Weaver (612, USRA),** the teachers learned about NASA Earth science missions generally and had a special presentation from **Dr. Stephanie Schollaert Uz (614, GST)** about the upcoming strong El Niño. http://svs.gsfc.nasa.gov/goto?4386

Stephanie Schollaert Uz (GST/614) wrote a blog post about El Niño https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4387.

On Tuesday, October 20, **Kristen Weaver (612, USRA)** hosted a webinar for educators about the OLYMPEX field campaign. The keynote speaker was Lynn McMurdie, PhD, the Project Manager and Senior Research Scientist for OLYMPEX, University of Washington. McMurdie explained the purpose of the project and why the Olympic Peninsula is a particularly significant locale for studying rain and snow. Kristen Weaver then gave a brief overview of the educational resources available for the campaign. The 18 participants represented eight states and six non-U.S. countries.

On October 24, 2015, **Valentina Aquila (614, USRA)** led part of a professional workshop for Maryland teachers and educators within the NSF-funded initiative called MADE CLEAR (Maryland and Delaware Climate Change Education Assessment and Research). MADE CLEAR is a cooperative agreement led by the University of Maryland and the University of Delaware that aims to bring experts in climate science and education together to provide support for middle and high school teachers.

On Thursday, November 12**, Dorian Janney (612, ADNET)** gave an online presentation to teachers in Rhode Island to share information about the GPM mission and share various educational resources. This presentation was given as a result of a request from the GSFC Office of Education and was a part of the Small Museums project. There were six teachers and two museum educational directors present.

On Friday, November 20, **Dorian Janney (612, ADNET)** worked with two groups of elementary school students at the Cedar Grove Elementary School in Maryland. She has been mentoring these two groups as they work toward designing and implementing a GLOBE investigation to submit next spring in the GLOBE Virtual Science Fair.

On December 2, **Dorian Janney (612, ADNET)** and **Kristen Weaver (612, USRA)** presented on GPM and the OLYMPEX field campaign, and she ran hands-on activities at the Goddard Visitor Center for a field trip by St. Michaels Elementary School from St. Michaels, Maryland. About 55 third grade students and 30 adult chaperones attended.

6.3. 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 2015 among the various laboratories.

Table 6.5: Atmospheric Sciences Distinguished Lecture Series

Date	Speaker	Title
January 15	Dan Seidel NOAA Air Resources Laboratory, University of Maryland, College Park	*Perspectives on Climate Engineering*
February 19	Ralf Bennartz University of Wisconsin–Madison	*Recent Advances in Passive Microwave Remote Sensing of Clouds, Light Rain, and Snowfall*
March 19	Arlene Fiore Columbia University–Earth Institute	*U.S. Air Pollution and Climate Connections, from Background Variability to Extreme Events*
April 16	Randall Martin Dalhousie University, Halifax, Nova Scotia	*Insight into Global Air Quality and Public Health by Interpreting Satellite Observations*
May 21	James Crawford NASA Langley Research Center	*Challenges and opportunities for remote sensing of air quality: Insights from DISCOVER-AQ*
June 18	Masaki Satoh University of Tokyo, Atmosphere and Ocean Research Institute	*A 20-year Climatology of a NICAM AMIP-type Simulation*
July 23	Mitch Moncrieff National Center for Atmospheric Research, Boulder, Colorado	*Organized Convention Parameterization at the Weather-Climate Intersection*
September 17	Eric Maloney Colorado State University	*Recent Progress in Understanding the Dynamics of the Madden-Julian oscillation*
October 15	Renyi Zhang Texas A&M	*Formation and Regional to Global Impacts of Severe Haze in China*

Date	Speaker	Title
November 19	Yangang Liu Brookhaven National Laboratory	*Addressing Aerosol-Cloud Interaction Challenges: Buffering and Coupling*
December 10	Viviana Maggioni George Mason University, Fairfax, Virginia	*Modeling Satellite Precipitation Uncertainties Over Complex Terrain*

Table 6.6: Mesoscale Atmospheric Processes

Date	Speaker	Title
December 8	Ruben Delgado University of Maryland, Baltimore County	*Remote-Sensing and Ground Measurements of Particle Pollution at UMBC*

Table 6.7: Climate and Radiation

Date	Speaker	Title
January 22	Myong-In Lee School of Urban and Environmental Engineering, Ulsan National Institute of Science and Technology	*Prediction of the Arctic Oscillation in Boreal Winter by Dynamical Seasonal Forecasting Systems*
February 4	Benjamin Marchant GESTAR-USRA, Climate & Radiation Laboratory	*MODIS Collection 6 Cloud Thermodynamic Phase And Machine Learning Algorithms for Classification*
February 10	Daniel Murphy NOAA-ESRL Chemical Sciences Division	*Connecting Aerosol Observations to Climate Forcing*
February 18	Pengwang Zhai Department of Physics, University of Maryland, Baltimore County	*Vertical Distribution Effects on Aerosol Remote Sensing*
February 25	Ben Kravitz Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory	*What We Know About Geoengineering from Climate Models (and What We Don't)*
March 4	Prof. Alex B. Kostinski Physics Department, Michigan Technological University	*Optimal Shapes in Electromagnetic Scattering by Small Aspherical Particles*
March 16	Daniel Rosenfeld Institute of Atmospheric Sciences, The Hebrew University of Jerusalem	*What Has Prevented Us from Reducing the Uncertainty in Aerosol Cloud-Mediated Radiative Forcing and What Can We Do About It?*
March 18	Jan-Peter Muller University College London, Mullard Space Science Laboratory	*Global BRDF/Albedo, fapar and LAI from Optimal Estimation of a 35-year Record of U.S. & European EO Data: A progress report on QA4ECV*
April 1	Shaima Nasiri Texas A&M University and U.S. Department of Energy	*AIRS Version 6 Thermodynamic Phase and Ice Cloud Property Retrievals*
April 15	Boon Sze (Jackson) Tan ORAU/NASA Postdoctoral Program Fellow, Wallops Flight Facility	*The Role of Organized Deep Convection in Observed Changes in Tropical Rainfall*
May 6	Lauren Zamora ORAU/NASA Postdoctoral Program Fellow, Climate & Radiation Laboratory	*Aircraft-Measured Indirect Cloud Effects from Biomass Burning Smoke in the Arctic*

Date	Speaker	Title
May 13	Johannes Quaas Universität Leipzig, NASA/GISS	*Use of Satellite Data to Evaluate the Aerosol-Cloud Radiative Forcing in Climate Models*
May 18	Manisha Ganeshan GESTAR-USRA, Climate and Radiation Laboratory	*Investigation of Arctic Boundary Layer Processes Using Ship-Based and COSMIC RO Observations*
June 3	Trude Storelvmo Yale University	*Getting the Liquid-to-Ice Proportion In Mixed-Phase Clouds Right in Climate Models, and Why It Matters in a Warmer Climate*
August 7	Paulo Artaxo Instituto de Fisica, Universidade de Sao Paulo	*When Biogenic Aerosols Meets Urban Air Pollution Affecting Clouds and Radiative Forcing: Results from the GoAmazon Experiment*
September 2	Tianle Yuan UMBC-JCET, Climate & Radiation Laboratory	*Positive Low Cloud and Dust Feedbacks Help to Generate Tropical North Atlantic Multi-decadal Variability*
September 16	Clark J. Weaver UMD-Earth System Science Interdisciplinary Center	*Shortwave TOA cloud radiative forcing derived from a long-term record of satellite UV reflectivity and CERES measurements*
October 7	Pengwang Zhai Department of Physics, University of Maryland, Baltimore County	*Theory and Applications of Light-Particle-Interaction in Turbid Media*
October 21	J. Vanderlei Martins UMBC-JCET, Climate & Radiation Laboratory	*Optical Characterization of Aerosol and Cloud Particles with Hyper-Angular Scattering and Absorption Measurements*
November 4	Robert C. Levy GSFC, Climate & Radiation Laboratory	*Towards a comprehensive, global aerosol data record using multiple satellites and other remote sensing*
November 18	Hongbin Yu UMD-ESSIC, Climate and Radiation Laboratory	*Characterizing Trans-Atlantic Dust Transport and Deposition with CALIPSO Data*
December 2	Jaehwa Lee University of Maryland/Earth System Science Interdisciplinary Center, Climate & Radiation Laboratory	*Retrieving the height of smoke and dust aerosols by synergistic use of VIIRS, OMPS, and CALIOP observations*

6.3.1. 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? POC: Dr. Charles Gatebe, GESTAR-USRA, Climate and Radiation Laboratory.

Table 6.8: Maniac Talks

Date	Speaker	Title
January 26	Michael Mishchenko Senior Scientist, Goddard Institute for Space Studies	*How much first-principle physics do we need in remote-sensing and atmospheric-radiation research*
February 25	Paul Newman Chief Scientist for Atmospheric Sciences, Goddard Space Flight Center	*Some pretty good rules for a career: Newman's own lessons*
March 31	Eugenia Kalnay Distinguished University Professor, Department of Atmospheric and Oceanic Science, University of Maryland, College Park	*Sheer Luck: How I stumbled my way through a fantastic scientific career*

Date	Speaker	Title
April 22	Richard Stolarski Emeritus Research Scientist, Goddard Space Flight Center	*Ozone has been very, very good to me*
May 27	Richard Spinrad Chief Scientist, NOAA	*Lately It Occurs to Me, What a Long, Strange Trip It's Been: One technocrat's unguided tour through oceanography*
June 30	Richard Eckman Program Manager for the Atmospheric Composition Modeling and Analysis Program, NASA Headquarters	*Confessions of a Wannabe Meteorologist*
July 14	Marshall Shepherd Director, the University of Georgia's Atmospheric Sciences Program	*Zombies, Sports, and Cola: Implications for Communicating Weather and Climate*
August 28	Frank Cepollina Associate Director, Satellite Servicing Capabilities Office, Goddard Space Flight Center	*Servicing and NASA*
September 29	Neil Gehrels Chief, Astroparticle Physics Laboratory, Goddard Space Flight Center	*Adventures in Astrophysics*
November 18	Spiro Antiochos Senior Scientist for Space Weather, Heliophysics Science Division, Goddard Space Flight Center	*Seeing the Light*
December 2	David W. Miller NASA Chief Technologist	*Defying Gravity and Overcoming Inertia: a Systems Perspective*

Table 6.9: Atmospheric Chemistry and Dynamics

Date	Speaker	Title
January 15	Margaret Hurwitz Morgan State University, Atmospheric Chemistry and Dynamics Laboratory	*From the Middle Atmosphere to the Middle East: My Experience as a AAAS Science & Technology Policy Fellow*
January 22	Susan Strahan USRA, Atmospheric Chemistry and Dynamics Laboratory	*Modulation of Antarctic vortex composition by the quasi-biennial oscillation as seen in observations and the GEOS-CCM*
February 5	Lee Murray NASA GISS	*Lightning-driven Variability in Atmospheric Composition and Climate*
February 12	Valentina Aquila USRA, Atmospheric Chemistry and Dynamics Laboratory	*Forcing mechanisms on stratospheric temperatures: GHG, ODS, volcanic eruptions, and solar cycle*
February 26	Anne Thompson NASA/GSFC, Atmospheric Chemistry and Dynamics Laboratory	*Large Tropospheric Ozone Increases over South Africa and Reunion Island: Observations*
March 12	James Wang USRA, Atmospheric Chemistry and Dynamics Laboratory	*Journal Club/Arctic wetland methane emissions and how they've been influenced by recent climate trends*

Date	Speaker	Title
May 14	Rich Stolarski Emeritus Research Scientist, Goddard Space Flight Center	*Nitrous oxide, carbon dioxide and the future of the ozone layer*
May 21	Mark Olsen Morgan State University, Atmospheric Chemistry and Dynamics Laboratory	*Tropical and midlatitude tropospheric column ozone response to ENSO in GEOS-5 assimilation of OMI and MLS ozone data*
May 28	Michael Manyin, SSAI and Clark Weaver, University of Maryland, Atmospheric Chemistry and Dynamics Laboratory	*Electric Vehicles: Perspectives from two Early Adopters*
June 4	Paul Newman GSFC, Atmospheric Chemistry and Dynamics Laboratory	*Seasonal Evolution of the Antarctic Ozone Hole*
June 25	Sarah Strode USRA, Atmospheric Chemistry and Dynamics Laboratory	*The Implications of Model Bias in CO for Methane Lifetime*
July 16	Pete Colarco GSFC, Atmospheric Chemistry and Dynamics Laboratory	*The OMPS Limb Profiler Stratospheric Aerosol Products and Comparisons to the GEOS-5 Chemistry-Climate Model*
July 30	Elena Spinei University of Maryland, Atmospheric Chemistry and Dynamics Laboratory	*Pandora O_3 and NO_2 profiling capabilities: validation using DISCOVER-AQ measurements*
August 6	Piers Sellers GSFC, Earth Sciences Division	*614 Lab Discussions*
August 13	Junhua Liu USRA, Atmospheric Chemistry and Dynamics Laboratory	*Origins of tropospheric ozone interannual variation over Réunion: A model investigation*
August 20	John Burrows University of Bremen	*Observing the anthropocene from space*
August 27	Bryan Duncan NASA/GSFC, Atmospheric Chemistry and Dynamics Laboratory	*A space-based, high-resolution view of notable changes of urban and regional NO_x pollution around the world (2005-2014)*
September 24	Susan Strahan USRA, Atmospheric Chemistry and Dynamics Laboratory	*The impact of sudden stratospheric warmings on Artic ozone depletion*
October 1	Clark Weaver University of Maryland, Atmospheric Chemistry and Dynamics Laboratory	*Shortwave TOA cloud radiative forcing derived from a long-term record of satellite UV*
October 15	Gary Morris/ St. Edwards University	*An overview of the tropospheric ozone pollution project (TOPP): Ozone and SO_2 sondes from 2004–2015*
October 22	Yasin Elshorbany University of Maryland, Atmospheric Chemistry and Dynamics Laboratory	*The Description and Validation of a Computationally-Efficient CH_4-CO-OH (ECCOHv1.01) Chemistry Module for 3D Model Applications*
December 10	Mark Olsen Morgan State University, Atmospheric Chemistry and Dynamics Laboratory	*GU Press Conference Practice*

6.4. AeroCenter Seminars

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

In 2015, the AeroCenter held 22 seminars with typically 30 to 40 physical attendees, and 5 to 10 Vidyo attendees most from outside GSFC. Initiated by Lorrain Remer and Yoram Kaufman, the AeroCenter has played a prime role for more than 10 years, exchanging up-to-date aerosol science across NASA laboratories and other institutions since 2001. In 2015, a forum on geoengineering and the emerging aerosol remote sensors was held. For further information, please contact Tianle Yuan (tianle.yuan@nasa.gov).

6.5. Public Outreach

On January 16, 2015, approximately 70 residents from the Delaware-Maryland-Virginia (Delmarva) Peninsula plan to participated in a joint project between the GPM Ground Validation group at WFF and the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS; a national citizen science effort). The project formally ran for three months, although some training and data logging had already started, and participants were encouraged to continue submitting data for use by the GPM GV Group, the National Weather Service, and other CoCoRaHaS users.

On February 19, **Stephanie Schollaer Uz (614, GST)** ran a hands-on activity at the McKinley Fair entitled "Ocean Color measured by satellites and you!" Participants saw examples of NASA Earth satellite imagery, learned about ocean color through a hands-on spectrophotometry activity of different colored water samples (photo attached), and watched the biosphere (NDVI and ocean color) changing over time on a Magic Planet. There were about 300 visitors to the science fair, between 50-100 of whom got the chance to perform the spectrophotometry experiment with others watching. Two high school students assisted with the activity.

On February 24, the work of **Hongbin Yu (613)** was highlighted in a feature article and animation on the NASA web site. The article is "NASA satellite reveals how much Saharan dust feeds Amazon's Plants." http://www.nasa.gov/content/goddard/nasa-satellite-reveals-how-much-saharan-dust-feeds-amazon-s-plants/#.VO5HBCnTnVQ .

On February 28, an event, called "When it Rains…Citizen Science Helping Precipitation Satellites," was held at the Wallops Flight Facility Visitor Center. **Walt Petersen (610.W)** gave an overview of the GPM mission and ground validation efforts, **Tiffany Moisan (610.W)** discussed Eastern Short citizen science participation in rainfall measurement via the CoCoRaHS network and Brian Campbell (610.W, Global Science and Technology, Inc.), shared information about the recent SMAP launch and citizen science efforts related to that mission. In addition, Brian Campbell, **Dorian Janney (612, ADNET)** and **Kristen Weaver (612, USRA-GESTAR)** staffed hands-on activity tables related to precipitation and soil moisture for families attending the event. Local Salisbury and Delmarva TV station WMDT 47 recorded and aired a segment about the program on the nightly news, http://www.wmdt.com/news/more-local-news/nasa-seek-citizen-scientists-for-two-missions/31545688.

On March 15, GPM hosted the Sunday Experiment on weather, climate, and precipitation for 121 children and 107 adults at the Goddard Visitor Center. **Kristen Weaver (612, USRA)** organized the event, with assistance from **Erica McGrath-Spangler (610.1, USRA)**, Brian Shilling (GPM Master Teacher), and several high school helpers.

On March 18, **Kristen Weaver (612, USRA)** presented information about the GPM-GLOBE Student Field Campaign as part of a panel for the March Education and Communication Colloquium on the topic of "Citizen Science at Goddard." Other panelists were Marc Kuchner (667) and Elizabeth Macdonald (673).

On March 20, **Kristen Weaver (612, USRA) and Dorian Janney (612, ADNET)** ran activity tables at the Outdoor Environmental Education Program's Astronomy Night at the Lathrop E. Smith Center. Attendance was approximately 110.

On March 24**, Valentina Aquila (614)** gave a talk about volcanoes, climate, and geoengineering at the Rockville Science Café. Science Cafés are live events held in casual settings, such as a pubs, coffeehouses or restaurants, are open to everyone. They feature an engaging scientist who leads the discussion to encourage conversation, debate, and interaction. http://rocknet.org/ScienceCenter/programs/science-cafe-2/.

L**auren Zamora (613, ORA**U) is featured in a "Conversations with Goddard" segment, entitled "Lauren M. Zamora—Meeting Nobel Laureates Just Part of the Job." http://www.nasa.gov/content/goddard/lauren-m-zamora-meeting-nobel-laureates-is-part-of-her-job/#.VQmmwki7lNg .

On March 26, **Kevin Vermeesch (612, UMBC/JCET,)** volunteered at the Anne Arundel County Regional Science and Engineering Fair held on March 21 at South River High School in Edgewater, Maryland. He judged high school projects in physics and astronomy.

Gail Skafronick-Jackson (612) and George J. Huffman (612), the GPM Project Scientist and Deputy Project Scientist, provided interviews to media outlets around the country as part of a Office of Communication live-shot campaign on GPM. These live shots are intended to raise public and media awareness of and appreciation for the GPM datasets.

Qing Liang (614) was interviewed by the BBC Radio and Music for a radio program on the 30th anniversary of the discovery of the hole in the ozone layer. She was asked to comment on her recent research on carbon tetrachloride and its impact on the recovery of the stratospheric ozone layer.

The GPM Education and Communication Team, led by **Dorian Janney (612, ADNET)** and **Kristen Weaver (612, USRA),** staffed a table in the NASA tent at the Global Citizen 2015 Earth Day on the National Mall in Washington, D.C., on April 17 and 18. The team share information about GPM with arranged school groups as well as members of the general public. Attendance at the National Mall event overall was estimated to exceed 200,000, with several thousand coming through the NASA tent over the two days.

On April 29 and 30, **Dorian Janney (612, ADNET)** attended the "Education Summit: Implementing of the Next Generation Science Standards at the State Level- Networking Support in the Earth and Space Science Education Community" at NOAA in Silver Spring. Over 75 stakeholders from Federal agencies, NGOs, state offices of education, NSTA, and several other organizations came together to examine what the ESS community can do to assist states and school districts in teaching the ESS components of the NGSS.

Scott Braun (612) appeared on The Weather Channel's Weather Geeks show, along with **Jeff Halverson (UMBC/JCET),** on Sunday, May 3, 2015. Hosted by Marshall Shepherd, a former NASA employee (612) , Scott Braun discussed the TRMM and GPM missions, while Halverson talked about hurricanes. Clips from the show will be posted to http://www.weather.com/tv/shows/wx-geeks in the near future.

Scott Braun (612) provided a summary of TRMM's accomplishments at the White House Conference Center on May 13, 2015, during a briefing on TRMM's reentry. In attendance were representatives from the National Security Council, FAA, FEMA, NOAA, DHS, State Department, among others. While questions arose about the risks posed by the uncontrolled reentry, participants appeared to accept that TRMM's value for both science and applications warranted the small risk of an uncontrolled reentry

On May 16**, Kristen Weaver (612, USRA)** staffed a table at Weather & Climate Day held at the National Aquarium in Baltimore, Maryland, and shared information about the GPM mission. The booth allowed participants to compare precipitation patterns for different locations around the United States. Approximately 120 people stopped by the table in the course of the afternoon.

Dorian Janney (612, ADNET) hosted a table at the World Science Festival held in New York City from May 27 through May 31, sharing information about the GPM mission with 4,000–5,000 visitors over the five days.

The 2nd GPM Applications Workshop was held June 9–10, 2015 at the University of Maryland Conference Center in Hyattsville, Maryland. Goddard scientists who provided leadership and presentations included: **George Huffman (612), Gail Skofronick Jackson (612),** Owen Kelley (GMU/610.2), Dalia Kirschbaum (617), Christa Peters-Lidard (610). The workshop had over 125 participants from several different countries and across multiple user communities—from public and private sectors, governments, NGOs, and academia. The workshop included two introductory and research sessions on GPM products and five panel discussions that covered weather forecasting and communication, food security and water resources, ecological forecasting and public health, and disaster risk assessment and management. The poster and breakout sessions were aimed to further discuss the needs, requirements, and challenges for the user community in applying GPM data. http://pmm.nasa.gov/meetings/2015-gpm-applications-workshop.

Dr. Paul Newman (610) gave an OzonAction webinar on "Why Isn't the Ozone Hole Story Already History?" on Wednesday, June 17. Participants came from different locations in the world: Bahrain, Bangkok, Belize, Bolivia, Bulgaria, Burkina Faso, Canada, Croatia, European Union, France, Germany, Haiti, Kenya, Mexico, Micronesia, Saint Lucia, Saudi Arabia, Sierra Leone, Swaziland, Switzerland, Thailand, Ukraine, United Kingdom, and United States.

Brian Campbell (610.W, GST) was quoted in Discover Magazine's online Citizen Science Salon blog article entitled, "NASA and SciStarter Enlist Citizen Scientists for Nationwide Research that Examines Soil Moisture Conditions and Water Availability." This program is part of the ongoing Soil Moisture Active Passive (SMAP) mission's campaign to have citizen scientists take ground-based soil moisture measurements that can be compared to the SMAP satellite data and potentially be used as validation datasets for the satellite data. http://blogs.discovermagazine.com/citizen-science-salon/2015/07/15/nasa-and-scistarter-enlist-citizen-scientists-for-nationwide-research-that-examines-soil-moisture-conditions-and-water-availability/#.Va7sGLavzaF.

As one of four presentations sponsored by SSAI, **David Bolvin (612, SSAI)** and **Eric Nelkin (612, SSAI)** presented a talk, entitled "The Global Precipitation Measurement (GPM) Mission," to Prince George's County Executive Rushern Baker and Goddard's Deputy Director for Science, Operations and Program Performance, Colleen Hartman (Code 600) on June 18, 2015.

On October 2, **Scott Braun (612), George Huffman (612),** and Dalia Kirschbaum (617) provided one in-person interview and 15 remote studio interviews in a GPM live shot campaign related to Hurricane Joaquin. Goddard's Office of Communication coordinated the campaign, its Scientific Visualization Studio provided visuals, and Goddard TV provided studio support. The entire activity was arranged in less than 48 hours, an unusually speedy turn-around driven by the rapidly changing hurricane threat. Media outlets that picked up the broadcast included: The Christian Broadcasting Network, Virginia Beach, Virginia; KHOU, Houston, Texas, KXAN, Austin, Texas, NewsChannel$_8$, Washington, D.C., Prince George's County, WGME, Portland, Maine.

The following teams and individuals participated in Explore@NASAGoddard on September 26, 2015:

The GSFC/SMARTLabs (http://smartlabs.gsfc.nasa.gov/) team, **Si-Chee Tsay (613)**, **Adrian M. Loftus (613, ORAU)**, and Peter Pantina **(613, SSAI)** led tours of the Aerosol, Cloud, Humidity, Interactions Exploring and Validating Enterprise (ACHIEVE) and the Chemical, Optical, and Microphysical Measurements of In-situ Troposphere (COMMIT) mobile laboratories, provided demonstrations and explanations of the instruments and infrastructure, and summarized the laboratories' role in aerosol-cloud-precipitation interaction research. On display were the W-band (93.95 GHz) scanning cloud radar, a K-band (24 GHz) vertically pointing drizzle radar, rain gauges, a 7-channel microwave radiometer, an interferometer, an AErosol RObotic NETwork (AERONET) sunphotometer (in cloud mode), a polarized Micro-Pulse Lidar Network (MPLNET) lidar, a ceilometer (910 nm), modularized network radiometers/spectrometers, and in-situ instruments (gas monitors, aerosol particle sizers, optical extinction/absorption/scattering monitors, nephelometers). Visitors of all ages, including Center Director Christopher Scolese, learned about the applications of the mobile facilities and asked a variety of questions pertaining to the instruments and the science missions.

Figure 6.1: Visitors lining up to learn about the science objectives and instrument operations of COMMIT (left trailer) and ACHIEVE (right trailer)

On November 13, **Dorian Janney (612, ADNET)** gave a presentation as a part of Maryland's STEM Festival activities. Broadcast via NASA's Digital Learning Network, Janney discussed how the GPM mission uses technology to measure precipitation across the globe. The presentation, given per a request from the GSFC Office of Education, was recorded and archived. During the actual event, there were 24 views of the Ustream channel from the United States, Bulgaria, and Argentina with an estimated audience of 600 viewers. Since the original webinar, there have been 7,112 on-demand requests for this segment.

Stephanie Schollaert Uz (610, GST) participated on a plenary evaluation panel at the 2015 Science On a Sphere Users Collaborative Network Meeting in Portland, Oregon, from December 2-4. There she presented results of a new study about when spherical displays convey an advantage for understanding Earth science concepts.

She also gave a Science On a Sphere presentation about helping audiences relate to big data using ClimateBits: short visualizations that convey key climate concepts. The examples she showed included the new Monsoon ClimateBits, featuring **Bryan Duncan (614)** telling the story of the monsoon rainy season and the different aspects that can be observed from space. After the video, she showed real-time GPM precipitation data and demonstrated how museum docents could point out monsoon features and then discuss any clouds and precipitation over their local area. The new monsoon piece can be seen here: https://youtu.be/Dc1Ag07UvyA .

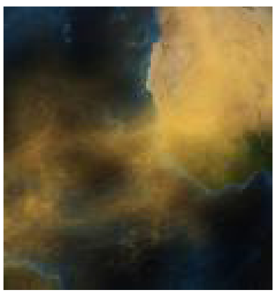
7. ATMOSPHERIC SCIENCE IN THE NEWS

The following pages contain news articles and press releases that describe some of the Laboratory's activities during 2015.

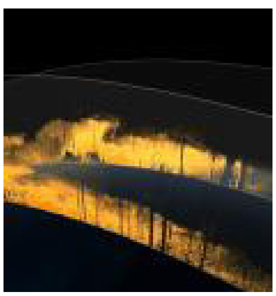
(e) Science News: Earth & Climate

Massive amounts of Saharan dust fertilize the Amazon rainforest

Published: Tuesday, February 24, 2015 - 14:35
Link to article



Conceptual Image Lab, NASA/GSFC



Conceptual Image Lab, NASA/GSFC

The Sahara Desert and the Amazon rainforest seem to inhabit separate worlds. The former is a vast expanse of sand and scrub stretching across the northern third of Africa, while the latter is a dense green mass of humid jungle covering northeast South America. And yet, they are connected: every year, millions of tons of nutrient-rich Saharan dust cross the Atlantic Ocean, bringing vital phosphorus and other fertilizers to depleted Amazon soils. For the first time, scientists have an accurate estimate of how much phosphorus makes this trans-Atlantic journey. A new paper, accepted for publication Feb. 24, 2015 in the journal *Geophysical Research Letters*, puts the number at about 22,000 tons per year, which roughly matches the amount that the Amazon loses from rain and flooding.

This phosphorus accounts for just 0.08% of the 27.7 million tons of Saharan dust that settles in the Amazon every year. The finding is part of a bigger research effort to understand the role of dust in the environment and its effects on local and global climate.

"We know that dust is very important in many ways. It is an essential component of Earth system. Dust will affect climate and, at the same time, climate change will affect dust," said lead author Hongbin Yu, an associate research scientist at the Earth System Science Interdisciplinary Center (ESSIC), a joint center of the University of Maryland and NASA's Goddard Space Flight Center.

Of particular interest is the dust picked up from the Bodélé Depression in Chad. This ancient lake bed contains huge deposits of dead microorganisms that are loaded with phosphorus. Amazonian soils, in turn, are short on phosphorus and other critical nutrients that get washed away by the basin's frequent and heavy rainfall. Thus, the entire Amazon ecosystem depends on Saharan dust to replenish these losses.

Yu and his colleagues analyzed dust transport estimates based on data collected by NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite between 2007 and 2013. The team focused on Saharan dust transported across the Atlantic Ocean to South America and beyond, to the Caribbean Sea, because it is the largest transport of dust on the planet.

The team estimated the phosphorus content of Saharan dust by studying samples from the Bodélé Depression and from ground stations on Barbados and in Miami. They then used this estimate to calculate how much phosphorus gets deposited in the Amazon basin. Although the seven-year data record is too short to make conclusions about long-term trends, it is an important step toward understanding how dust and other windborne particles, or aerosols, behave as they move across the ocean.

"We need a record of measurements to understand whether or not there is a fairly robust, fairly consistent pattern to this aerosol transport," said Chip Trepte, project scientist for CALIPSO at NASA's Langley Research Center, who was not involved in the study.

Year by year, the pattern is highly variable. There was an 86 percent change between the highest amount of dust transported in 2007 and the lowest in 2011. Yu and his colleagues believe this variation is due to conditions in the Sahel, the long strip of semi-arid land on the southern border of the Sahara. Years of high rainfall in the Sahel were typically followed by low dust transport in the next year.

Although the mechanism behind this correlation is unknown, Yu and his team have a few ideas. Increased rainfall could mean more vegetation and therefore less soil exposed to wind erosion in the Sahel. A second, more likely explanation is that the amount of rainfall is related to the wind circulation patterns that sweep dust from both the Sahel and Sahara into the upper atmosphere, where it makes the long journey across the ocean.

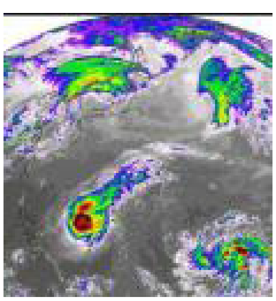
"This is a small world, and we're all connected together," Yu said.

Source: University of Maryland

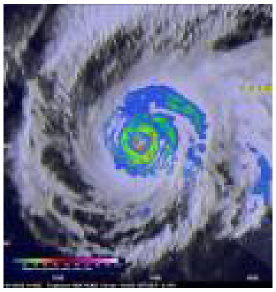
(e) Science News: Earth & Climate

TRMM satellite makes direct pass over Super Typhoon Maysak

Published: Thursday, April 2, 2015 - 17:05
Link to article



SSEC/University of Wisconsin-Madison



SSAI/NASA GSFC, Hal Pierce

The Tropical Rainfall Measuring Mission satellite delivered a remarkable image of Super Typhoon Maysak on March 31. TRMM obtained an image straight over the top of a super typhoon with a double eye-wall, Super Typhoon Maysak, as it roared through the warm waters of the West Pacific south of Guam. This image with the TRMM Precipitation Radar or PR was taken at 14:15 UTC (10:15 a.m. EDT) on March 31, 2015 and shows the rain intensities within the very heart of Super Typhoon Maysak as it undergoes an eye wall replacement cycle. Mature, intense tropical cyclones can and often do undergo what is known as an eyewall replacement cycle wherein a new eye wall or ring of convection within the outer rain bands forms further out from the storm's center, outside the radius of the original eye wall, and begins to choke off the original eye wall, starving it of moisture and momentum. Eventually, if the cycle is completed, the original eye wall dissipates and this new outer eye wall can contract and replace the old eye wall. The storm's intensity can fluctuate over this period, initially weakening as the inner eye wall dies before again strengthening as the outer eye wall contracts. Eye wall replacement cycles are hard to forecast.

Here TRMM provided a look at a classic eye wall replacement cycle in progress. At the very center is the eye of Super Typhoon Maysak, which is devoid of rain where air is descending. Immediately surrounding the eye is the original inner eye wall where air is rising in convective updrafts and releasing heat through condensation. The vast amounts of heat being released into the storm as a result is known as latent heating and is what drives the storm's circulation. The inner eye wall is identified by the nearly complete ring of very intense rainfall with rates on the order of 100 mm/hr or more (~4 inches/hr, shown by the white areas inside the light purple) in the southwestern semicircle. Outside of the inner eye wall is a very distinct ring of very weak rain (~5 mm/hr or less, shown in blue), known as the moat. The moat marks the area between the inner and outer eye walls where air that has already risen through the updrafts in the eye walls is now subsiding, suppressing rain. Next, outside of the moat is the new outer eye wall, shown by the nearly perfect concentric ring of moderate (shown in green) to heavy (shown in red) rain rates. Additional bands of light to moderate rain (blue and green areas, respectively) wrap around the northeast quadrant Maysak.

Another key aspect of Maysak's features as revealed by TRMM is their near perfect symmetry around the storm's center. This is a clear sign of the storm's intensity. The more intense the circulation, the more uniformly rain features are wrapped around the center. Indeed, at the time this image was taken by TRMM, Maysak's maximum sustained winds were estimated to be 140 knots (~161 mph) by the Joint Typhoon Warning Center, making it a Category 5 super typhoon (equivalent to a Category 5 hurricane on the U.S. Saffir-Simpson scale).

Maysak is the first super typhoon of the season in the Northwest Pacific Basin. The storm is forecast to weaken before approaching the northern Philippines in the next couple of days. TRMM is a joint mission between NASA and the Japanese space agency JAXA.

Source: NASA/Goddard Space Flight Center

M15-029

NASA Briefing to Highlight Early Results from New Earth Science Missions

Feb. 23, 2015

Over the past 12 months NASA has added five missions to its orbiting Earth-observing fleet – the biggest one-year increase in more than a decade. NASA scientists will discuss early observations from the new missions and their current status during a media teleconference at 2 p.m. EST Thursday, Feb. 26.

New views of global carbon dioxide, rain and snowfall, ocean winds, and aerosol particles in the atmosphere will be presented during the briefing.

The first of the five new missions – the Global Precipitation Measurement (GPM) core observatory – was launched from Japan one year ago on Feb. 27, 2014. The most recent – the Soil Moisture Active Passive (SMAP) mission – was launched from California on Jan. 31 and is in its checkout phase before starting to collect data. Two missions are collecting NASA's first ongoing Earth observations from the International Space Station (ISS).

The teleconference panelists are:

- *Peg Luce, deputy director of the Earth Science Division in NASA's Science Mission Directorate, Headquarters, Washington*
- *Gail Skofronick-Jackson, GPM project scientist, NASA's Goddard Space Flight Center, Greenbelt, Maryland*
- *Ralph Basilio, Orbiting Carbon Observatory-2 project manager, NASA's Jet Propulsion Laboratory, Pasadena, California*
- *Ernesto Rodriguez, ISS-RapidScat project scientist, NASA's Jet Propulsion Laboratory*
- *Matthew McGill, Cloud Aerosol Transport System (CATS) principal investigator, NASA's Goddard Space Flight Center*

For dial-in information, media representatives should email their name and affiliation to Steve Cole at stephen.e.cole@nasa.gov by noon Thursday. Media and the public also may ask questions during the briefing on Twitter using the hashtag #askNASA.

Supporting graphics for the briefing will be posted at the start of the event at:

http://svs.gsfc.nasa.gov/Gallery/EarthNowBriefing.html

Audio of the briefing, as well as supporting graphics, will stream live at:

http://www.nasa.gov/newsaudio

For more information about NASA's Earth science programs, visit:

http://www.nasa.gov/earthrightnow

Charles Gatebe—Pushing the Limits of Curiosity

April 8, 2015

Taken in June 2007 onboard a Jetstream 31 aircraft in Oklahoma. Gatebe was supporting the Cloud and Land Surface Interaction Campaign, focusing on advancing the understanding of how land surface processes influence cumulus convection. Credits: Courtesy of C. Gatebe

Name: Charles K. Gatebe
Title: Research scientist
Organization: Code 613, Climate and Radiation Laboratory, Earth Sciences Division
Earth Sciences Directorate

Climate scientist Charles K. Gatebe always pushes the limits and encourages others to be as curious.

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

I'm a climate scientist. I study reflected sunlight to improve our understanding of the composition of the atmosphere and surface properties, including land and ocean, and impact on Earth's radiation budget and climate. I conduct elaborate airborne experiments in different places in the world and use data from these experiments to validate information from satellites.

Why is it important to measure reflected sunlight?

Sunlight is sensitive to the changing composition of the atmosphere, including its greenhouse gases and aerosol content, cloud and surface properties. We study the reflected sunlight to monitor changes in the atmospheric composition, plant life, vegetation over land and in marine ecosystems.

How did you become interested in studying climate?

I was born and raised in central Kenya, in the same area as Wangari Maathai, who won the Nobel Peace Prize in 2004 for "her contribution to sustainable development, democracy and peace." I grew up in a thatched hut in a village owned by a coffee farmer. I come from humble beginnings.

Our village is on a plateau about 6,000 feet above sea level. When I woke up, I saw Mt. Kenya, which, at more than 17,000 feet, is the second-highest mountain in Africa. I am a member of the Kenyan Kikuyu tribe. In our mythology, our God lives in the sky or in the clouds, but when he comes down to Earth, he rests on top of Mt. Kenya. Although Kenya is in the tropics, the top of Mt. Kenya has a snow and ice cap. The mysteries of the mountain are embedded in our culture.

I was educated in Kenya and in South Africa. When I first went to college at the University of Nairobi, Kenya, I was shocked that even on a sunny day, the sky was tinted gray, not blue. I wanted to know why the color of the sky had changed. So I became interested in air pollution and climate. I got a bachelor's concentrating in meteorology, mathematics and physics, and then a masters in meteorology also from the University of Nairobi. I did some of the early work on air pollution monitoring in Kenya using hand-held air samplers. Then I got a doctorate in atmospheric physics from The University of Witwatersrand in South Africa. My doctorate work established the first climatology of air pollution corridors in eastern Africa.

What brought you to Goddard?

In 1998, NASA wanted to validate the information from their satellites. I was just finishing my doctorate at that time and met Dr. Michael King, who was the Earth Observing System project scientist. Dr. King invited me to work at Goddard to help prepare for a field campaign in southern Africa. I came to Goddard in 1999. The following year, NASA began the Southern African Regional Science Initiative-2000 airborne field campaign in southern Africa. I operated NASA's Cloud Absorption Radiometer on the University of Washington's CV-580 aircraft. I took reflectance measurements over various types of surfaces such as savanna, clouds, salt pans, ocean and smoke from biomass burning for satellite validation.

How has your research evolved?

The platforms and instruments for our measurements have greatly improved. When I first started studying air pollution and climate in college, I would physically go to different areas and take measurements from the ground using hand-held instruments. It took me a long time. I realized that I was only getting samples from very near the ground, so I decided to take some samples from a mountain. I went to Mt. Kenya and took measurements using battery operated instruments at 14,500 feet, which represented air from a much larger area transported by different air masses.

Once I joined NASA, we were able to use an aircraft as our platform and sensors that detect and measure the radiation reflected or backscattered from a remote target. Our measurements of pollution represented a much wider area. It was very important to us to cover a lot of area and height to get the biggest and most representative picture.

Eventually, it became important for NASA to validate the data coming from the Earth observing satellites. So the satellites became our next platform and covered the entire Earth. My role was helping to make sure that the information from the satellites was accurate so that other scientists could then use that information to improve weather and climate models.

Gatebe preparing the CAR instrument (on the cart) for calibration with an integrating sphere in Goddard's Calibration Facility in Building 33.

What was one of your most memorable field campaigns?

In 2008, we were involved in the Arctic Research of the Composition of the Troposphere field campaign in Alaska, Canada and Greenland. We studied emissions coming from wildfires. The plumes carried the smoke and soot. Our platform was an airplane. Our instrument measured the radiation inside the smoke plumes. I didn't realize that these large plumes are so very, very dark. There we were, flying through plumes that you couldn't see through, knowing that the fires were not that far below us. No one had ever done that before. As a scientist, I wanted to find out what was happening.

All of a sudden, I thought that our instrument had died. It turned out that there was very low radiation at that particular point so there was almost nothing for the instrument to measure. Then we flew over some radiation and the instrument resumed giving measurements. I never imagined that the smoke plume would not constantly emit radiation.

These smoke plumes can transport smoke and pollutants all the way to the upper troposphere and lower stratosphere. These pollutants can be dispersed by winds and affect air quality over a broad area.

What makes a good scientist?

I always want to know about things. I'm very curious. It happened that I became a climate scientist, but I'm always interested in knowing about everything.

To be good at what you do, you must be passionate. If you don't have passion, you can't be a good scientist, or good at anything else for that matter.

I always push the limits. When I was very young, my father had an old radio that no one else was allowed to touch. This old radio was very precious to us. We had no TV. One day he asked me to turn up the volume. He couldn't hear well, so he asked me to increase the volume again. When I reached the limit of the switch, I asked myself, "What is next?" So I continued turning the switch until it broke. That's what makes a good scientist. That's what makes an inventor. I need to see, touch and feel everything rather than just read about it in a textbook. I need to feel the science.

I was always asking questions in school and I enjoyed working independently. My high school physics teacher allowed me to conduct my own experiments in the lab alone at night or on weekends. Based on this independent work, I won a physics prize in high school in 1984 from the Kenya Secondary Schools Science Congress. I was a president of our school's science club and led other students in trying to discover new things.

I love being criticized because I love debating the merits of what I am doing. They could be right, I could be wrong and then I'll make the adjustments. I tell people that we at NASA are here to push boundaries. Even if we fail, we have tried to push the limits. This theme has echoed throughout my life.

I never throw away untried ideas. I write them all down. Eventually, I usually manage to make connections with other ideas. I don't want to lose any of them.

You have to question the status quo to progress. This is true of science and of life.

What are your latest big ideas?

I'm really interested in seasonal snow cover because of its critical influence on the water cycle, climate and weather of our planet. Scientists are challenged with accurately quantifying the seasonal variability of fresh water stored in the snow cover. A better understanding of regional snow water equivalent before the onset of the spring melt would contribute to informed planning to save lives and resources. A better characterization of snow albedo or reflectivity and energy balance during snowmelt will lead to improvements in climate and hydrologic models. I want to help advance remote snow characterization and estimation of snow water equivalent.

Another big idea is using small satellites, like nanosatellites or Smallsats, to study climate change. These satellites are the size of a soccer ball or shoebox and can be launched in the unused cargo space in launches of larger satellites. Smallsats can now perform functions such as snapping photos of Earth from space that used to be possible only with large expensive spacecraft. The main challenge for small spacecraft today is proving that they can be trusted as part of an Earth-observing system.

Are you a mentor?

I mentor a lot of students. I love the students who are independent, creative and like to ask questions. I want to help the next generation, to plant seeds for tomorrow. That's why I mentor.

How did you come up with the Maniac Talks, the inspiring, one-hour talks in which people talk about how they achieved successful careers?

After college graduation, my parents threw a party which we called a tea party. Kenya is a former colony of Great Britain. I was the first person in my family and in my village to get a college degree. The villagers never thought that anyone so poor could get a college degree. Everyone from the village came. My mother insisted that I wear the graduation gown for the tea party. Some people actually came to touch my gown. My mother also made me give a talk to tell the parents to educate their kids.

Seven years later, I was teaching at the University of Nairobi. A boy from my village came to me. He had just graduated from a university and thanked me for my tea party talk. My mother served tea and bread, which was very rare in our village as we lived on corn and beans. His mother told him he had to do what I had done. I hadn't realized that anyone in the audience had listened to me.

In 2011, I started Goddard's Maniac Talks. The talks were inspired by younger colleagues from Goddard's Earth Sciences Technology and Research program. I wanted people to tell their own stories to inspire others the same as I had inspired, unknowingly, the little boy from my village. It is very important. Maniac Talks are about what inspired people to do what they are doing now in their career. It's about their driving forces and motivators and what keeps them going. It's about how they overcome obstacles. The speakers have one hour to summarize their whole life.

When I introduce people, I like to tell a story about animals. My stories are allegories with many layers of messages. It's always safe to talk about animals, but it isn't always so safe to mention people by name.

It can be hard to prepare a Maniac Talk, but speakers are always very glad that they did. All the talks are available here.

Taken in April 2008 at Thule Air Base/Pituffik Airport, the United States Air Force's northernmost base, located on the northwest side of the island of Greenland.

What quality do you most appreciate from others?

Bravery. I like people who can face tough and complicated situations or can deal with the most difficult of things with ease.

What one word do you wish people would use to describe you?

Curious.

You grew up in a thatched hut in a small village in central Kenya owned by a coffee farmer. You are now a world-class climate scientist. What goes through your mind when you reflect back?

I've been blessed. Looking back, I can't think of anyone else that I knew as a child who has made it this far. In anything that I've ever done, I've always been extremely focused and absolutely determined. When

I want to do something, I just do it. My least favorite word is “no.” Once someone explains why something is important, then I will probably agree with them or at least accept their position. But I don’t like a flat-out “no.”

Life has a lot of twists and turns. Everyone I have known, whether they supported or opposed me, has helped me get to where I am today. Everyone has been important. I learned at an early age that I could not leave my fate to others, that I had to take charge of my own fate. I have always been concerned about the big things, not the small stuff. At the end of the day, I always ask myself what I have done to help benefit others and advance science. That’s the final test for me.

Do you still have ties to your old village?

Yes, my wife or I try to return once a year for a few weeks. My two sons visit Kenya occasionally. My wife and I informally adopted three abandoned girls. We support them financially. They now live with my brother and his wife, whom they call father and mother.

Awards:

2014 Robert H. Goddard Award for Outreach.

2000 World Meteorological Organization’s Young Scientist Award.

1979: Selected to participate in a national convention celebrating the United Nations Educational, Scientific and Cultural Organization’s International Year of the Child.

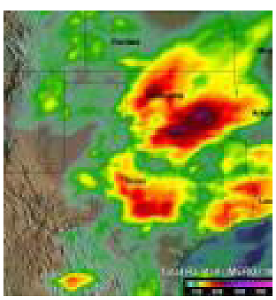
Last Updated: July 30, 2015
Editor: Lynn Jenner

Tags: Goddard Space Flight Center

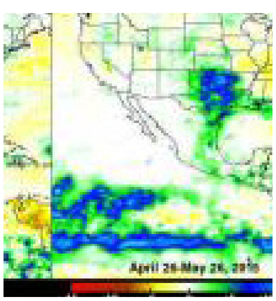
(e) Science News: Earth & Climate

Severe flooding hits central Texas, Oklahoma

Published: Friday, May 29, 2015 - 12:33
Link to article



Credits: Hal Pierce (SSAI/NASA GSFC)



Credits: Hal Pierce (SSAI/NASA GSFC)

A stagnant upper-air pattern that spread numerous storms and heavy rains from central Texas up into Oklahoma has resulted in record flooding for parts of the Lone Star State. One of the hardest hit areas was in Hays County Texas south of Austin where the Blanco River rose rapidly and set a new record crest at over 40 feet, 13 feet above flood stage, following a night of very heavy rain in the area, with over 12 inches reported locally in a short period of time, in an area already wet from previous storms. The combination of high pressure over the southeastern United States and a persistent southerly flow of moisture up out of the Gulf of Mexico ahead of a deep upper-level trough that was slow to leave the central and southern Rockies set the stage for persistent widespread storms across the Southern Plains from the eastern half of Texas, through Oklahoma, and into southern Kansas. The Integrated Multi-satellitE Retrievals for GPM, known simply as IMERG, is a new rainfall product that produces estimates of precipitation from a combination of passive microwave sensors, including the GMI microwave sensor onboard the GPM satellite, and geostationary IR (infrared) data. This first image shows IMERG rainfall estimates for the week-long period 19 to 26 May 2015 for the south central US. IMERG shows upwards of 200 mm of rain (~8 inches, orange and red areas) across central and southeastern Texas and a large portion of Oklahoma with locally higher amounts exceeding 300 mm (~12 inches, shown in brown) in central Texas and 400 mm (~16 inches, purple areas) over south central Oklahoma, where early in the period a stationary front provided the focus for storms. So far at least 18 fatalities are being blamed on the recent flooding across the region.

The recent rains drove monthly average rainfall totals well in access of the seasonal averages for this period. The panel on the right shows the current monthly TRMM-based average rainfall (which has a much longer climatology than IMERG) is well above the typical amount (shown in blue) for this time of year across most of the eastern two thirds of Texas and almost all of Oklahoma. The northern Gulf Coast also has above normal rainfall (shown in green) while at the same time the Tennessee and Ohio Valleys are showing below normal rainfall (yellow area). This type of pattern along with the excessive rainfall anomalies evident over the eastern equatorial Pacific offers a strong clue as to a potential culprit--El Nino. Anomalous rainfall over the eastern equatorial Pacific with alternating areas of above and below normal rainfall extending into midlatides is a classic El Nino teleconnection pattern. Rainfall anomalies were somewhat similar for this same time last year (left panel), but although there was an inkling, El Nino failed to materialize. This year El Nino appears to be alive and well.

TRMM/GPM are a joint missions between NASA and the Japanese space agency JAXA.

Images produced by Hal Pierce (SSAI/NASA GSFC) and caption by Steve Lang (SSAI/NASA GSFC).

Source: NASA/Goddard Space Flight Center

The Baltimore Sun

At Goddard, NASA scientists turn their gaze Earthward

Yvonne Wenger, Contact Reporter
ywenger@baltsun.com
twitter.com/yvonnewenger

Teams of scientists at NASA's Goddard Space Flight Center focused on Earth, not space.

Greenbelt NASA scientist George J. Huffman sometimes watches in awe as bands of greens and yellows and reds float across a map of the world on a 20-foot screen at Goddard Space Flight Center.

The technology he helped develop uses satellites to track rain, hurricanes and blizzards — information that allows people on the West Coast to gauge their water supply from the Sierra Nevada snowpack, students to track zebra migrations in Africa and researchers to monitor the threat of Japanese encephalitis in Australia.

Like many of the 9,000 people who work for the space agency at Goddard in Greenbelt, Huffman is charged with developing technology to study the Earth from above.

The more advances they make, Huffman said, the better people will be able to understand weather patterns and climate change in the decades to come.

"The mission is to step into the future and say, 'What is it we could do, particularly from a spaceborne perspective?'" said Huffman, of Bowie. "How can we use space assets and the viewpoint to learn more about this place where we live and make life better and increase our understanding of what is and what will be?"

Huffman, who earned a doctorate in meteorology from the Massachusetts Institute of Technology, helps lead Goddard's work using satellites, microwave data and advanced algorithms to track precipitation across the globe.

He's worked at Goddard for nearly 30 years, as a contractor and as an employee. Two-thirds of the workers at Goddard are contractors.

NASA bills the facility as the nation's largest organization to use scientists and engineers to build "spacecraft, instruments and new technology to study Earth, the sun, our solar system and the universe."

Of all the worlds NASA studies, a Goddard spokeswoman said, Earth is the most important.

"It's really about understanding our planet," Rani C. Gran said. "Our planet is really beautiful. How does it work? That's what our scientists find out."

Huffman, who was born in Iowa and grew up in Ohio, said he's been fascinated since childhood with the "amazing complexity" of tornadoes, hurricanes, typhoons, thunderstorms, blizzards and rainbows.

"It's like the baseball player who says he was overjoyed to find out that he could get paid to do this," Huffman said.

He came to the area to teach meteorology at the University of Maryland, and is now deputy project scientist for an international satellite mission that observes rain and snow throughout the world.

He also leads another project that combines data from about 10 satellites and merges them into a single map.

The work of Huffman and others gives emergency managers and crop forecasters information to monitor water levels — whether there will be enough in California, which is suffering a four-year drought, or too much in India, where monsoons can cause landslides and flooding.

The information they produce is available online for the taking and explained during NASA workshops for various groups.

"It helps a lot of different non-governmental groups," Goddard scientist Dalia Kirschbaum said. "We talk to everyone. One of the goals is to provide the real-time as well as research versions to scientists and the public."

Huffman said studying precipitation from space gives a broader picture than could be created from the ground alone.

From the Earth, radar provides snapshots of weather systems in certain areas, but has limitations: it can't see storms as they move off the coast and out into the ocean.

There's also a lack of coverage over developing countries or those with civil strife, Huffman said.

The satellites that create the images see microwave energy released by the Earth's surface and atmosphere. The snow — the latest form of precipitation added to the global project — is shown in blues on NASA's map. Rain is depicted in warm colors, such as red.

"We don't measure precipitation by satellite," Huffman explained."What we measure is the radiant energy coming up from the Earth and the atmosphere and things in the atmosphere."

Huffman said NASA uses satellites in low orbit, about 250 to 500 miles from the Earth's surface, from U.S. agencies, including the National Oceanic and Atmospheric Administration and the Department of Defense, and from Japan and Europe.

Each satellite sees a given point on Earth about two times a day. Huffman said NASA merges the images from various satellites and combines the data into a seamless map.

"What these data allow us to do is look through the clouds," Huffman said. "This is the not the first time we've been able to do this, but it's the best, so far."

The team produces several versions of the global precipitation map, including a highly refined version that shows data from three months ago and one from 16 hours ago. Scientists are working to release a 6-hour version in the coming weeks and eventually a 4-hour one, Huffman said.

The project will give scientists a better sense of the water-to-energy cycle across the globe**,** Huffman said. Those patterns lay a foundation for understanding long-term climate change, he said.

"That's what California is worried about," he said. "It's not a degree increase in temperature. If they don't have rain for the next three years, they're in deep, deep trouble."

Learning about Earth from space

NASA's Goddard Space Flight Center in Greenbelt employs engineers and scientists to further understanding of Earth from space. Here's a look at some of their advances:

- *Measured the depletion of groundwater storage around the world by calculating how much water has been lost in natural aquifers.*
- *Published the first satellite images of the Antarctic ozone hole, among other efforts to help further the world's understanding of the stratospheric ozone layer. Goddard provides daily updates on the condition of the ozone layer and projects levels in the future.*
- *Using various satellites, NASA scientists track changes in the growing seasons with three-dimensional surveys of forest height from space. The information is essential to understanding how much carbon the forest can absorb from the atmosphere.*
- *Monitoring the Earth's cryosphere — the planet's frozen areas, such as the Arctic sea ice, land ice on Antarctica and Greenland, and mountain glaciers. Tracking those measurements helps chart climate change.*

Source: Goddard Space Flight Center

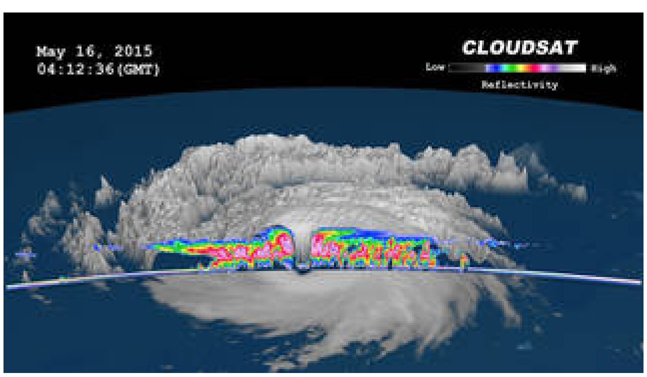
How Does NASA Study Hurricanes?

Aug. 14, 2015

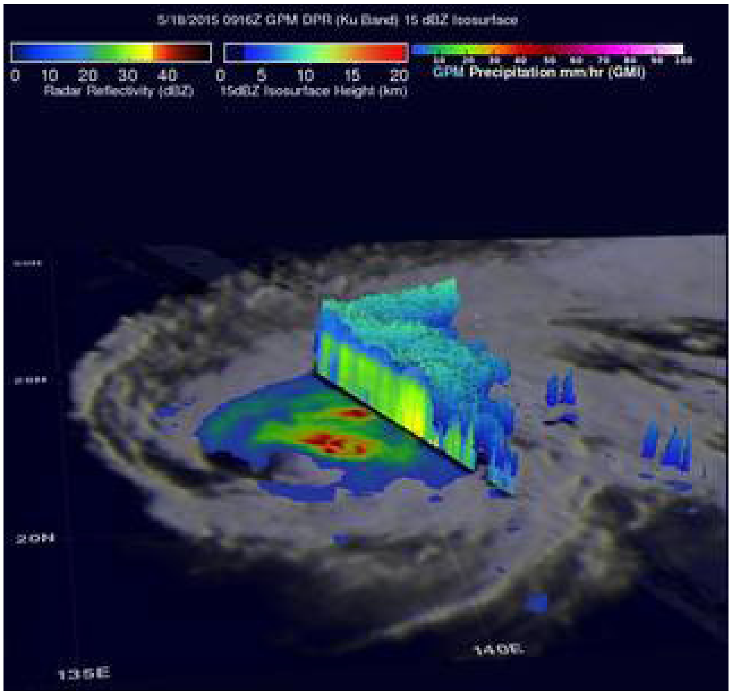
Hurricanes are the most powerful weather event on Earth. NASA's expertise in space and scientific exploration contributes to essential services provided to the American people by other federal agencies, such as hurricane weather forecasting.

The National Oceanic and Atmospheric Administration and the National Hurricane Center (NHC) use a variety of tools to predict these storms' paths. These scientists need a wealth of data to accurately forecast hurricanes. NASA satellites, computer modeling, instruments, aircraft and field missions contribute to this mix of information to give scientists a better understanding of these storms.

This visible image of Hurricane Katrina was taken on August 29 at 05:16 UTC (1:16 a.m. EDT) by the MODIS instrument that flies aboard NASA's Aqua satellite as it approached landfall in Louisiana. Credits: NASA Goddard MODIS Rapid Response Team



MTSTAT and CloudSat imagery of Typhoon Dolphin. Credits: Natalie D. Tourville/Colorado State University



This 3-D view of the area northeast of Typhoon Dolphin's eye on May 16 created by data from NASA/JAXA's GPM core satellite shows heaviest rain over the open waters of the Pacific Ocean at a rate of over 65 mm (2.6 inches) per hour. Credits: NASA/SSAI/JAXA, Hal Pierce

NASA's Research Role

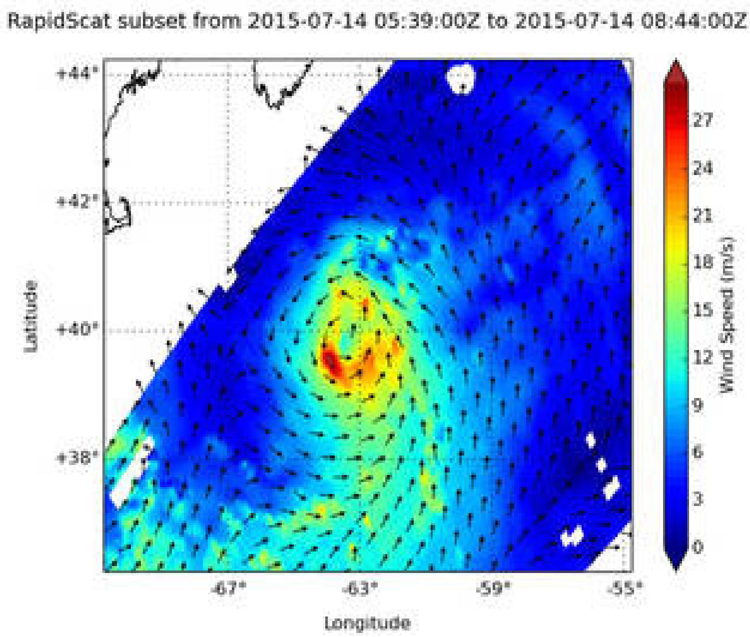
NASA's role as a research agency is to bring new types of observational capabilities and analytical tools to learn about the fundamental processes that drive hurricanes and work to help incorporate that data into forecasts. NASA collaborates with its interagency partners so that the nation benefits from our respective capabilities.

"Before we had satellites and aircraft, hurricanes would destroy entire cities, like the Labor Day Hurricane in Key West back in 1935," said Gail Skofronick-Jackson, the project scientist for NASA's Global Precipitation Measurement mission at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "You would have no idea if a hurricane was coming until it was too late."

Hurricanes in the Atlantic Ocean can form when sub-Saharan thunderstorms travel westward with areas of lower pressure. These troughs are known as African Easterly Waves. Warm, moist air rises within the storm clouds, drawing air into the thunderstorms. Like an ice skater pulling in her arms to increase her spin, this inward moving air increases the rotation of the air within the storm cloud. Moving across the warm Atlantic, this cycle repeats ona daily basis, and, with a favorable environment, potentially accelerates to create a monstrous vortex powered by oceanic heat.

NASA uses an arsenal of instruments to learn more about how these storms progress as they form. These devices orbit Earth on a fleet of spacecraft, including Aqua, Terra, the Global Precipitation Measurement core observatory, NASA-NOAA's Suomi NPP satellite, Calipso, Jason-2 and CloudSat.

"There are typically multiple instruments on every spacecraft with various purposes that often complement each other," said Eric Moyer, the Earth science operations manager at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "We can see the progression of a storm from one day to the next using the Terra and Aqua satellites—a morning and afternoon view of every storm system, every day."



On July 14, RapidScat saw the sustained winds surrounding Claudette's center of circulation were no stronger than 21 meters per second with the exception of stronger winds in the southwestern quadrant.

Credits: NASA JPL/Doug Tyler

What NASA Studies

These instruments analyze different aspects of these storms, such as rainfall rates, surface wind speed, cloud heights, ocean heat and environmental temperature and humidity. Observing these factors helps identify the potential for storm formation or intensification. Similarly, the data allows meteorologists to better predict where, when and how hard hurricanes will strike land.

NASA's RapidScat instrument that flies aboard the International Space Station measures surface winds over the ocean and is used to gather data on tropical cyclones. This can show where in a hurricane the strongest winds occur. RapidScat continues a long satellite record of these observations that began with NASA's QuikScat satellite.

Scientists must completely understand a hurricane to predict its trajectory and strength. This means meteorologists must peer inside the cloud itself.

"Looking at the cloud structure can help us understand the storm's structure and location, which improves our forecasts," said Michael Brennan, a senior hurricane specialist at the National Oceanic and Atmospheric Administration's National Hurricane Center. "We heavily rely on the passive microwave imagers from satellites to see what is happening in the core of the storm."

Passive microwave imagers aboard NASA's Global Precipitation Measurement and NASA-NOAA's Suomi National Polar-orbiting Partnership missions can peer through cloud canopies, allowing scientists to observe where the water is churning in the clouds.

"Just like a doctor using x-rays to understand what's happening in the human body, our radiometers can pierce the clouds and understand the cyclone's structure," Skofronick-Jackson said. "We learn about the amount of liquid water and falling snow in the cloud. Then we know how much water may fall out over land and cause floods."

"Having satellites to watch the oceans is critical, and that will never change," Skofronick-Jackson said. "Radars on Earth can only see a certain distance out in the ocean, so without spacecraft, you would need radars on every ship. With satellite data informing computer models, we can predict the storms' paths, to the point where regions only need to evacuate half as much coastline as before. That's important, because it costs a lot of money to pack up, move to a hotel and close down businesses."

Computer Modeling

Computer modeling is another powerful NASA research tool.

NASA's Global Modeling and Assimilation Office, or GMAO works to improve the understanding of hurricanes and assess models and procedures for quality. GMAO helps to identify information that was missing and determines what services could be added to help future investigation and prediction of hurricane systems.

As NASA launches more sophisticated Earth-observing instruments, teams produce models with higher and higher resolutions, the ability to ingest such data, or the data assimilation procedure, increases. Each new instrument provides scientists and modelers a closer and more varied look at tropical cyclones. The higher the resolution of models and the capability of data assimilation systems, the easier it is to exploit data from satellite-borne instruments and to determine a hurricane's intensity and size in terms of things such as the wind field and cloud extent.

Airborne Missions

NASA also conducts field missions to study hurricanes. With an arsenal of instruments, ranging from radiometers that read moisture levels; lidars that measure aerosols, moisture, and winds; dropsonde systems to measure high-resolution profiles of temperature, pressure, moisture, and winds; to Doppler radar systems to map the 3-D precipitation and winds within storms. These instruments monitor the structure and environment of hurricanes and tropical storms as they evolve.

The most recent NASA field mission to study hurricanes was the Hurricane and Severe Storm Sentinel or HS3. For three consecutive years, the HS3 mission investigated the processes that underlie hurricane formation and intensity change in the Atlantic Ocean basin. The mission used the Global Hawk, a high-altitude long-endurance aircraft capable of flights of 26 hours at altitudes above 55,000 ft. Flying from the Wallops Flight Facility in Virginia, the uninhabited Global Hawks could cover the entire Atlantic Ocean, enabling measurements of storms at early stages in the central or eastern Atlantic or spending 12-18 hours over storms in the western Atlantic.

A Future Mission

In 2016, NASA is launching the Cyclone Global Navigation Satellite System, a constellation of eight small satellites. CYGNSS will probe the inner core of hurricanes in such detail to better understand their rapid intensification. One advantage of CYGNSS is that it can get frequent measurements within storms. This allows CYGNSS to make accurate measurements of ocean surface winds both in and near the eye of the storm throughout the lifecycle of tropical cyclones. The goal is to improve hurricane intensity forecasts.

NASA data and research allows scientists to observe the fundamental processes that drive hurricanes. Meteorologists incorporate this satellite, aircraft and computer modeling data into forecasts in the United States and around the world.

For more on NASA's hurricane observations and research, visit: www.nasa.gov/hurricane

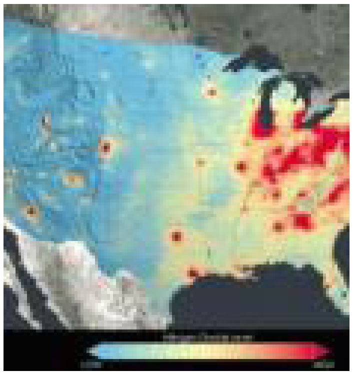
Max Gleber
NASA's Goddard Space Flight Center
Last Updated: Aug. 14, 2015
Editor: Karl Hille

Tags: Benefits to You, Earth, Goddard Space Flight Center, Hurricanes

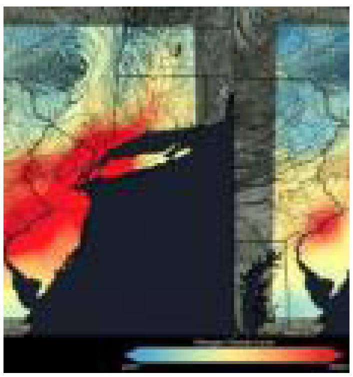
(e) Science News: Earth & Climate

New NASA images highlight US air quality improvement

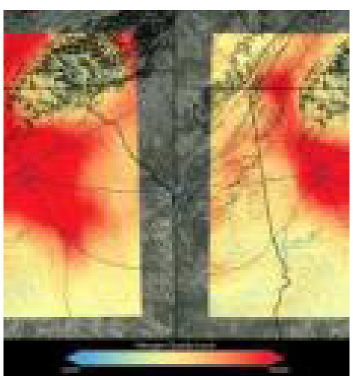
Published: Thursday, June 26, 2014 - 13:59
Link to article



NASA Goddard's Scientific Visualization Studio/T. Schindler



NASA Goddard's Scientific Visualization Studio/T. Schindler



NASA Goddard's Scientific Visualization Studio/T. Schindler

Anyone living in a major U.S. city for the past decade may have noticed a change in the air. The change is apparent in new NASA satellite images unveiled this week that demonstrate the reduction of air pollution across the country. After ten years in orbit, the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite has been in orbit sufficiently long to show that people in major U.S. cities are breathing less nitrogen dioxide -- a yellow-brown gas that can cause respiratory problems.

Atmospheric Sciences in the News

Nitrogen dioxide is one of the six common pollutants regulated by the U.S. Environmental Protection Agency (EPA) to protect human health. Alone it can impact the respiratory system, but it also contributes to the formation of other pollutants including ground-level ozone and particulates, which also carry adverse health effects. The gas is produced primarily during the combustion of gasoline in vehicle engines and coal in power plants. It's also a good proxy for the presence of air pollution in general.

Air pollution has decreased even though population and the number of cars on the roads have increased. The shift is the result of regulations, technology improvements and economic changes, scientists say.

In fact, about 142 million people still lived in areas in the United States with unhealthy levels of air pollution, according to the EPA. Also, high levels of air pollution remain an issue in many other parts of the world, according to the global view from satellites.

"While our air quality has certainly improved over the last few decades, there is still work to do -- ozone and particulate matter are still problems," said Bryan Duncan, an atmospheric scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Decision makers and regulatory agencies like EPA have long relied on data from ground sites to inform air quality science and forecasts. NASA, while not directly involved with regulation or making forecasts, provides a consistent, global, space-based view -- not possible from any other source -- of when and where air pollution occurs.

Another ongoing effort by NASA to study air quality is Discover-AQ, a multi-year airborne mission flying this summer in Denver to learn more about how the wide range of air pollutants viewed from satellites relates to what's happening close to the ground where people live and breathe. The mission flew previously in 2011 over Baltimore, Maryland and Washington, D.C.; in 2013 over the San Joaquin Valley, California; and in 2013 over Houston, Texas.

"You can't control what you don't measure," said Russ Dickerson of the University of Maryland, College Park, and member of the NASA Air Quality Applied Sciences Team -- created in 2011 by the NASA Applied Sciences Program to serve the needs of U.S. air quality management through the use of Earth Science satellite data, suborbital, and models. "NASA measurements of air quality have value to the people with the authority to control emissions and develop policy."

The new NASA images also take a close up look at the Ohio River Valley, Northeast Corridor, and some populous U.S. cities. They show how nitrogen dioxide concentrations during spring and summer months, averaged from 2005-2007, compare to the average from 2009-2011.

Measurements of nitrogen dioxide from OMI depict the concentration of the gas throughout a column of air in the troposphere, Earth's lowest atmospheric layer. The images are color-coded: Blue and green denote lower concentrations and orange and red denote higher concentrations, ranging from 1x1015 to 5x1015 molecules per square centimeter, respectively.

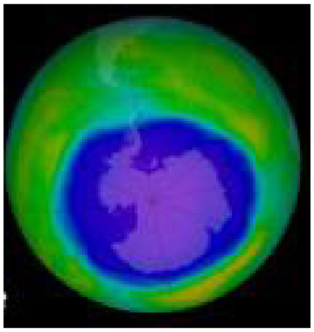
Images were composed by NASA's Scientific Visualization Studio based on data and input provided by atmospheric scientists Yasuko Yoshida, Lok Lamsal, and Bryan Duncan, all of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Source: NASA

(e) Science News: Earth & Climate

Annual Antarctic ozone hole larger and formed later in 2015

Published: Thursday, October 29, 2015 - 21:48 (e) Science News: Earth & Climate
Link to article



Credits: NASA/GSFC

The 2015 Antarctic ozone hole area was larger and formed later than in recent years, said scientists from NASA and the National Oceanic and Atmospheric Administration (NOAA). On Oct. 2, 2015, the ozone hole expanded to its peak of 28.2 million square kilometers (10.9 million square miles), an area larger than the continent of North America. Throughout October, the hole remained large and set many area daily records. Unusually cold temperature and weak dynamics in the Antarctic stratosphere this year resulted in this larger ozone hole. In comparison, last year the ozone hole peaked at 24.1 million square kilometers (9.3 million square miles) on Sept. 11, 2014. Compared to the 1991-2014 period, the 2015 ozone hole average area was the fourth largest.

"While the current ozone hole is larger than in recent years, the area occupied by this year's hole is consistent with our understanding of ozone depletion chemistry and consistent with colder than average weather conditions in Earth's stratosphere, which help drive ozone depletion," said Paul A. Newman, chief scientist for Earth Sciences at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

The ozone hole is a severe depletion of the ozone layer above Antarctica that was first detected in the 1980s. The Antarctic ozone hole forms and expands during the Southern Hemisphere spring (August and September) because of the high levels of chemically active forms of chlorine and bromine in the stratosphere. These chlorine- and bromine-containing molecules are largely derived from man-made chemicals that steadily increased in Earth's atmosphere up through the early 1990s.

"This year, our balloon-borne instruments measured nearly 100 percent ozone depletion in the layer above South Pole Station, Antarctica, that was 14 to 19 kilometers (9 to 12 miles) above Earth's surface," said Bryan Johnson, a researcher at NOAA's Earth System Research Laboratory in Boulder, Colorado. "During September we typically see a rapid ozone decline, ending with about 95 percent depletion in that layer by October 1. This year the depletion held on an extra two weeks resulting in nearly 100 percent depletion by October 15."

The ozone layer helps shield Earth from potentially harmful ultraviolet radiation that can cause skin cancer, cataracts, and suppress immune systems, as well as damage plants. The large size of this year's ozone hole will likely result in increases of harmful ultraviolet rays at Earth's surface, particularly in Antarctica and the Southern Hemisphere in the coming months.

Ozone depletion is primarily caused by man-made compounds that release chlorine and bromine gases in the stratosphere. Beginning in 1987, the internationally agreed-upon Montreal Protocol on Substances that Deplete the Ozone Layer has regulated these ozone-depleting compounds, such as chlorine-containing chlorofluorocarbons used in refrigerants and bromine-containing halon gases used as fire suppressants. Because of the Protocol, atmospheric levels of these ozone depleting compounds are slowly declining. The ozone hole is expected to recover back to 1980 levels in approximately 2070.

This year, scientists recorded the minimum thickness of the ozone layer at 101 Dobson units on October 4, 2015, as compared to 250-350 Dobson units during the 1960s, before the Antarctic ozone hole occurred. Dobson units are a measure of the overhead amount of atmospheric ozone.

The satellite ozone data come from the Dutch-Finnish Ozone Monitoring Instrument on NASA's Aura satellite, launched in 2004, and the Ozone Monitoring and Profiler Suite instrument on the NASA-NOAA Suomi National Polar-orbiting Partnership satellite, launched in 2011. NOAA scientists at the South Pole station monitor the ozone layer above that location by using a Dobson spectrophotometer and regular ozonesonde balloon launches that record the thickness of the ozone layer and its vertical distribution. Chlorine amounts are estimated using NOAA and NASA ground measurements and observations from the Microwave Limb Sounder aboard NASA's Aura satellite. These satellites continue a data record dating back to the early 1970s.

Source: NASA/Goddard Space Flight Center

(e) Science News: Earth & Climate

New NASA satellite maps show human fingerprint on global air quality

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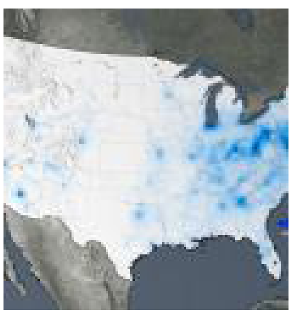
Link to article



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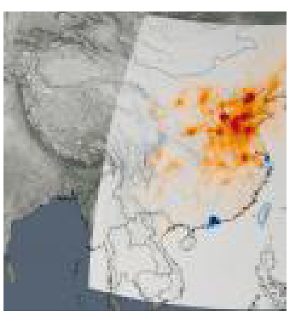

NASA

Using new, high-resolution global satellite maps of air quality indicators, NASA scientists tracked air pollution trends over the last decade in various regions and 195 cities around the globe. The findings were presented Monday at the American Geophysical Union meeting in San Francisco and published in the *Journal of Geophysical Research*. "These changes in air quality patterns aren't random," said Bryan Duncan, an atmospheric scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland, who led the research. "When governments step in and say we're going to build something here or we're going to regulate this pollutant, you see the impact in the data."

Duncan and his team examined observations made from 2005 to 2014 by the Dutch-Finnish Ozone Monitoring Instrument aboard NASA's Aura satellite. One of the atmospheric gases the instrument detects is nitrogen dioxide, a yellow-brown gas that is a common emission from cars, power plants and industrial activity. Nitrogen dioxide can quickly transform into ground-level ozone, a major respiratory pollutant in urban smog. Nitrogen dioxide hotspots, used as an indicator of general air quality, occur over most major cities in developed and developing nations.

The science team analyzed year-to-year trends in nitrogen dioxide levels around the world. To look for possible explanations for the trends, the researchers compared the satellite record to information about emission controls regulations, national gross domestic product and urban growth.

"With the new high-resolution data, we are now able to zoom down to study pollution changes within cities, including from some individual sources, like large power plants," said Duncan.

Previous work using satellites at lower resolution missed variations over short distances. This new space-based view offers consistent information on pollution for cities or countries that may have limited ground-based air monitoring stations. The resulting trend maps tell a unique story for each region.

The United States and Europe are among the largest emitters of nitrogen dioxide. Both regions also showed the most dramatic reductions between 2005 and 2014. Nitrogen dioxide has decreased from 20 to 50 percent in the United States, and by as much as 50 percent in Western Europe. Researchers concluded that the reductions are largely due to the effects of environmental regulations that require technological improvements to reduce pollution emissions from cars and power plants.

China, the world's growing manufacturing hub, saw an increase of 20 to 50 percent in nitrogen dioxide, much of it occurring over the North China Plain. Three major Chinese metropolitan areas -- Beijing, Shanghai, and the Pearl River Delta -- saw nitrogen dioxide reductions of as much as 40 percent.

The South African region encompassing Johannesburg and Pretoria has the highest nitrogen dioxide levels in the Southern Hemisphere, but the high-resolution trend map shows a complex situation playing out between the two cities and neighboring power plants and industrial areas.

"We had seen seemingly contradictory trends over this area of industrial South Africa in previous studies," said Anne Thompson, co-author and chief scientist for atmospheric chemistry at Goddard. "Until we had this new space view, it was a mystery."

The Johannesburg-Pretoria metro area saw decreases after new cars were required in 2008 to have better emissions controls. The heavily industrialized area just east of the cities, however, shows both decreases and increases. The decreases may be associated with fewer emissions from eight large power plants east of the cities since the decrease occurs over their locations. However, emissions increases occur from various other mining and industrial activities to the south and further east.

In the Middle East, increased nitrogen dioxide levels since 2005 in Iraq, Kuwait and Iran likely correspond to economic growth in those countries. However, in Syria, nitrogen dioxide levels decreased since 2011, most likely because of the civil war, which has interrupted economic activity and displaced millions of people.

Source: NASA/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 2015, Atmospheric Research published 158 peer-reviewed publications listed below.

Arnold, S. R., L. K. Emmons, S. A. Monks, K. S. Law, D. A. Ridley, S. Turquety, S. Tilmes, J. L. Thomas, I. Bouarar, J. Flemming, V. Huijnen, J. Mao, B. N. Duncan, S. Steenrod, Y. Yoshida, J. Langner, and Y. Long. 2015. "Biomass burning influence on high-latitude tropospheric ozone and reactive nitrogen in summer 2008: a multi-model analysis based on POLMIP simulations." *Atmos. Chem. Phys.*, 15 (11): 6047-6068 (10.5194/acp-15-6047-2015).

Barth, M. C., C. A. Cantrell, W. H. Brune, S. A. Rutledge, J. H. Crawford, H. Huntrieser, L. D. Carey, D. MacGorman, M. Weisman, K. E. Pickering, E. Bruning, B. Anderson, E. Apel, M. Biggerstaff, T. Campos, P. Campuzano-Jost, R. Cohen, J. Crounse, D. A. Day, G. Diskin, F. Flocke, A. Fried, C. Garland, B. Heikes, S. Honomichl, R. Hornbrook, L. G. Huey, J. L. Jimenez, T. Lang, M. Lichtenstern, T. Mikoviny, B. Nault, D. O'Sullivan, L. L. Pan, J. Peischl, I. Pollack, D. Richter, D. Riemer, T. Ryerson, H. Schlager, J. St. Clair, J. Walega, P. Weibring, A. Weinheimer, P. Wennberg, A. Wisthaler, P. J. Wooldridge, and C. Ziegler. 2015. "The Deep Convective Clouds and Chemistry (DC3) Field Campaign." *BAMS*, 96 (8): 1281-1309 (10.1175/bams-d-13-00290.1).

Bernard, F., M. R. McGillen, E. L. Fleming, C. H. Jackman, and J. B. Burkholder. 2015. "CBrF3 (Halon-1301): UV absorption spectrum between 210 and 320K, atmospheric lifetime, and ozone depletion potential." *J. of Photochemistry and Photobiology A: Chemistry*, 306: 13-20 (10.1016/j.jphotochem.2015.03.012).

Best, M. J., G. Abramowitz, H. R. Johnson, A. J. Pitman, G. Balsamo, A. Boone, M. Cuntz, B. Decharme, P. A. Dirmeyer, J. Dong, M. Ek, Z. Guo, V. Haverd, B. J. van den Hurk, G. S. Nearing, B. Pak, C. D. Peters-Lidard, J. A. Santanello, L. Stevens, and N. Vuichard. 2015. "The Plumbing of Land Surface Models: Benchmarking Model Performance." *J. of Hydrometeorology, vol. 16, issue 3, pp. 1425-1442*, 16: 1425 (Full Text (Link)) (10.1175/JHM-D-14-0158.1).

Bi, J., Y. Knyazikhin, S. Choi, T. Park, J. Barichivich, P. Ciais, R. Fu, S. Ganguly, F. G. Hall, T. Hilker, A. Huete, M. Jones, J. Kimball, A. I. Lyapustin, M. Mõttus, R. R. Nemani, S. Piao, B. Poulter, S. R. Saleska, S. S. Saatchi, L. Xu, L. Zhou, and R. B. Myneni. 2015. "Sunlight mediated seasonality in canopy structure and photosynthetic activity of Amazonian rainforests." *Environmental Research Letters*, 10 (6): 064014 (10.1088/1748-9326/10/6/064014).

Boisvert, L. N., D. L. Wu, T. Vihma, and J. Susskind. 2015. "Verification of air/surface humidity differences from AIRS and ERA-Interim in support of turbulent flux estimation in the Arctic." *J. Geophys. Res. Atmos.*, 120 (3): 945–963 (10.1002/2014JD021666).

Bosilovich, M. G., J.-D. Chern, D. M. Mocko, and A. M. Da Silva. 2015. "Evaluating Observation Influence on Regional Water Budgets in Reanalyses." *J. Climate*, 28 (9): 3631–3649 (10.1175/JCLI-D-14-00623.1).

Brindley, H., S. Osipov, R. Bantges, A. Smirnov, J. Banks, R. C. Levy, P.-J. Prakash, and G. Stenchikov. 2015. "An assessment of the quality of aerosol retrievals over the Red Sea and evaluation of the climatological cloud-free dust direct radiative effect in the region." *J. Geophys. Res.-Atmos*, 120 (20): 10,862–10,878 (10.1002/2015JD023282).

Bringi, V. N., L. Tolstoy, M. Thurai, and W. A. Petersen. 2015. "Estimation of Spatial Correlation of Drop Size Distribution Parameters and Rain Rate Using NASA's S-Band Polarimetric Radar and 2D Video Disdrometer Network: Two Case Studies from MC3E." *J. of Hydrometeorology*, 16 (3): 1207-1221 (10.1175/jhm-d-14-0204.1).

Buchard, V. J., A. M. Da Silva, P. R. Colarco, A. S. Darmenov, C. A. Randles, R. C. Govindaraju, O. Torres, J. Campbell, and R. Spurr. 2015. "Using the OMI aerosol index and absorption aerosol optical depth to evaluate the NASA MERRA Aerosol Reanalysis." *Atmos. Chem. Phys.*, 15: 5743-5760 (10.5194/acp-15-5743-2015).

Appendix 1: Refereed Articles

Canty, T. P., L. Hembeck, T. P. Vinciguerra, D. C. Anderson, D. L. Goldberg, S. F. Carpenter, D. J. Allen, C. P. Loughner, R. J. Salawitch, and R. R. Dickerson. 2015. "Ozone and NO*x* chemistry in the eastern US: evaluation of CMAQ/CB05 with satellite (OMI) data." *Atmos. Chem. Phys.*, 15 (19): 10965-10982 (10.5194/acp-15-10965-2015).

Carey, L. D., and W. A. Petersen. 2015. "Sensitivity of C-Band Polarimetric Radar–Based Drop Size Estimates to Maximum Diameter." J. of Applied Meteorology and Climatology, 54 (6): 1352-1371 (10.1175/jamc-d-14-0079.1).

Carn, S. A., K. Yang, A. J. Prata, and N. A. Krotkov. 2015. "Extending the long-term record of volcanic SO_2 emissions with the Ozone Mapping and Profiler Suite nadir mapper." *Geophysical Research Letters*, 42 (3): 925-932 (10.1002/2014gl062437).

Carr, N., P.-E. Kirstetter, Y. Hong, J. J. Gourley, M. Schwaller, W. Petersen, N.-Y. Wang, R. R. Ferraro, and X. Xue. 2015. "The Influence of Surface and Precipitation Characteristics on TRMM Microwave Imager Rainfall Retrieval Uncertainty." *J. of Hydrometeorology*, 16 (4): 1596-1614 (10.1175/jhm-d-14-0194.1).

Castellanos, P., K. F. Boersma, O. Torres, and J. F. de Haan. 2015. "OMI tropospheric NO_2 air mass factors over South America: effects of biomass burning aerosols." *Atmos. Meas. Tech.*, 8 (9): 3831-3849 (10.5194/amt-8-3831-2015).

Cazorla, M., G. M. Wolfe, S. A. Bailey, A. K. Swanson, H. L. Arkinson, and T. F. Hanisco. 2015. "A new airborne laser-induced fluorescence instrument for in situ detection of formaldehyde throughout the troposphere and lower stratosphere." *Atmos. Meas. Tech.*, 8: 541-552 (10.5194/amt-8-541-2015).(Atmospheric Chemistry, Atmospheric Dynamics, Atmospheric Measurement, Pollution, Technology & Missions)

Chao, W. C. 2015. "Correction of Excessive Precipitation over Steep and High Mountains in a GCM: A Simple Method of Parameterizing the Thermal Effects of Subgrid Topographic Variation." J. Atmos. Sci., 72 (6): 2366-2378 (10.1175/JAS-D-14-0336.1).

Cho, H.-M., Z. Zhang, K. G. Meyer, M. Lebsock, S. E. Platnick, A. S. Ackerman, L. Di Girolamo, L. C. Labonnote, C. Cornet, J. Riedi, and R. E. Holz. 2015. "Frequency and causes of failed MODIS cloud property retrievals for liquid phase clouds over global oceans." *J. Geophys. Res.-Atmos*, 120 (9): 4132-4154 (10.1002/2015JD023161).

Chretien, J., A. Anyamba, J. L. Small, S. Britch, J. L. Sanchez, A. C. Halbach, C. J. Tucker, and K. J. Linthicum. 2015. "Global Climate Anomalies and Potential Infectious Disease Risks: 2014-2015." *PLOS Currents Outbreaks*, Edition 1: (10.1371/currents.outbreaks.95fbc4a8fb4695e049baabf).

Chu, D.-C. A., R. Ferrare, J. Szykman, J. R. Lewis, A. Scarino, J. Hains, S. Burton, G. Chen, T. Tsai, C. Hostetler, J. Hair, B. N. Holben, and J. Crawford. 2015. "Regional characteristics of the relationship between columnar AOD and surface PM2.5: Application of lidar aerosol extinction profiles over Baltimore–Washington Corridor during DISCOVER-AQ." *Atmospheric Environment*, 101: 338-349 (10.1016/j.atmosenv.2014.11.034).

Coldewey-Egbers, M., D. G. Loyola, M. Koukouli, D. Balis, J.-C. Lambert, T. Verhoelst, J. Granville, M. van Roozendael, C. Lerot, R. Spurr, S. M. Frith, and C. Zehner. 2015. "The GOME-type Total Ozone Essential Climate Variable (GTO-ECV) data record from the ESA Climate Change Initiative." *Atmos. Meas. Tech.*, 8 (9): 3923-3940 (10.5194/amt-8-3923-2015).

Cook, M. B., K. E. Pickering, J. H. Crawford, B. N. Duncan, C. P. Loughner, G. S. Diskin, A. Fried, and A. J. Weinheimer. 2015. "Spatial and temporal variability of trace gas columns derived from WRF/Chem regional model output: Planning for geostationary observations of atmospheric composition." *Atmospheric Environment*, 118: 28–44 (10.1016/j.atmosenv.2015.07.024).

D'Adderio, L. P., F. Porcü, and A. Tokay. 2015. "Identification and Analysis of Collisional Breakup in Natural Rain." *J. of the Atmospheric Sciences*, 72 (9): 3404-3416 (10.1175/jas-d-14-0304.1).

Dawson, K. W., N. Meskhidze, D. Josset, and S. Gassó. 2015. “Spaceborne observations of the lidar ratio of marine aerosols.” *Atmos. Chem. Phys.*, 15: 3241-3255 (10.5194/acp-15-3241-2015).(Aerosols)

de Foy, B., Z. Lu, D. G. Streets, L. N. Lamsal, and B. N. Duncan. 2015. “Estimates of power plant NOx emissions and lifetimes from OMI NO_2 satellite retrievals.” *Atmospheric Environment*, 116: 1-11 (10.1016/j.atmosenv.2015.05.056).

De Lannoy, G. J., R. H. Reichle, J. Peng, Y. Kerr, R. Castro, E. Kim, and Q. Liu. 2015. “Converting Between SMOS and SMAP Level-1 Brightness Temperature Observations Over Nonfrozen Land.” *IEEE Geosci. Remote Sens. Lett*, 12: 1-5 (10.1109/LGRS.2015.2437612).

de Moura, Y. M., T. Hilker, A. I. Lyapustin, L. S. Galv o, J. R. dos Santos, L. O. Anderson, C. H. de Sousa, and E. Arai. 2015. “Seasonality and drought effects of Amazonian forests observed from multi-angle satellite data.” *Remote Sensing of Environment*, 171: 278-290 (10.1016/j.rse.2015.10.015).

deGouw, J. A., S. A. McKeen, K. C. Aikin, C. A. Brock, S. S. Brown, J. B. Gilman, M. Graus, T. F. Hanisco, J. S. Holloway, J. Kaiser, F. N. Keutsch, B. M. Lerner, J. Liao, M. Z. Markovic, A. M. Middlebrook, K.-E. Min, J. A. Neuman, J. B. Nowak, J. Peisch, I. B. Pollack, J. M. Roberts, T. B. Ryerson, M. Trainer, P. R. Veres, C. Warneke, A. Welti, and G. M. Wolfe. 2015. “Airborne measurements of the atmospheric emissions from a fuel ethanol refinery.” *J. Geophys. Res. Atmos.*, 120: 4385–4397 (10.1002/2015JD023138).

Demir, I., H. Conover, W. F. Krajewski, B.-C. Seo, R. Goska, Y. He, M. F. McEniry, S. J. Graves, and W. Petersen. 2015. “Data-Enabled Field Experiment Planning, Management, and Research Using Cyber infrastructure.” *J. of Hydrometeorology*, 16 (3): 1155-1170 (10.1175/jhm-d-14-0163.1).

D’Errico, M., C. Cagnazzo, P. G. Fogli, W. K. Lau, J. von Hardenberg, F. Fierli, and A. Cherchi. 2015. “Indian monsoon and the elevated-heat-pump mechanism in a coupled aerosol-climate model.” *J. Geophys. Res. Atmos.*, 120 (17): 8712-8723 (10.1002/2015jd023346).

Diaz, J. A., D. Pieri, K. Wright, P. Sorensen, R. Kline-Shoder, C. Arkin, M. Fladeland, G. Bland, M. Buongiorno, C. Ramirez, E. Corrales, A. Alan, O. Alegria, D. Diaz, and J. Linick. 2015. “Unmanned aerial mass spectrometer systems for in-situ volcanic plume analysis.” *J Am Soc Mass Spectrom*, 26 (2): 292-304 (10.1007/s13361-014-1058-x).

Dickinson, M. B., A. T. Hudak, T. Zajkowski, E. L. Loudermilk, W. Schroeder, L. Ellison, R. L. Kremens, W. Holley, O. Martinez, A. Paxton, B. C. Bright, J. J. O’Brien, B. Hornsby, C. Ichoku, J. Faulring, A. Gerace, D. Peterson, and J. Mauceri. 2015. “Measuring radiant emissions from entire prescribed fires with ground, airborne and satellite sensors – RxCADRE 2012.” *Int. J. Wildland Fire*, 25 (1): 48 (10.1071/wf15090).

Didlake, A. C., G. M. Heymsfield, L. Tian, and S. R. Guimond. 2015. “The Coplane Analysis Technique for Three-Dimensional Wind Retrieval Using the HIWRAP Airborne Doppler Radar.” *J. Appl. Meteor. Climatol.*, 54 (3): 605–623 (10.1175/JAMC-D-14-0203.1).

Draper, D. W., D. A. Newell, F. J. Wentz, S. Krimchansky, and G. M. Skofronick-Jackson. 2015. “The Global Precipitation Measurement (GPM) Microwave Imager (GMI): Instrument Overview and Early On-Orbit Performance.” *IEEE J. Sel. Top. Appl. Earth Observations Remote Sensing*, 8 (7): 3452-3462 (10.1109/jstars.2015.2403303).

Duncan, B. N., L. N. Lamsal, A. M. Thompson, Y. Yoshida, Z. Lu, D. G. Streets, M. M. Hurwitz, and K. E. Pickering. 2015. “A space-based, high-resolution view of notable changes in urban NO x pollution around the world (2005-2014).” *J. Geophys. Res. Atmos.*, (10.1002/2015jd024121).

El-Askary, H., S. K. Park, S. Nickovic, and M. Chin. 2015. “Remote Sensing and Modeling of Atmospheric Dust and Studying Its Impact on Environment, Weather, and Climate.” *Advances in Meteorology*, 2015: 1-2 (10.1155/2015/854968).

Emde, C., V. Barlakas, C.-E. Cornet, K. F. Evans, S. V. Korkin, Y. Ota, L. C. Labonnote, A. I. Lyapustin, A. Macke, B. Mayer, and M. Wendisch. 2015. “IPRT polarized radiative transfer model intercomparison project - phase A.” *J. Quant. Spect. Rad. Trans*, 164: 8-36 (10.1016/j.jqsrt.2015.05.007).

Appendix 1: Refereed Articles

Emmons, L. K., S. R. Arnold, S. A. Monks, V. Huijnen, S. Tilmes, K. S. Law, J. L. Thomas, J.-C. Raut, I. Bouarar, S. Turquety, Y. Long, B. N. Duncan, S. D. Steenrod, S. A. Strode, J. Flemming, J. Mao, J. Langner, A. M. Thompson, D. Tarasick, E. C. Apel, D. R. Blake, R. C. Cohen, J. Dibb, G. S. Diskin, A. Fried, S. R. Hall, L. G. Huey, A. J. Weinheimer, A. Wisthaler, T. Mikoviny, J. Nowak, J. Pieschl, J. M. Roberts, T. Ryerson, C. Warneke, and D. Helmig. 2015. "The POLARCAT Model Intercomparison Project (POLMIP): overview and evaluation with observations." *Atmos. Chem. Phys.*, 15: 6721-6744 (10.5194/acp-15-6721-2015).

Engelbrecht, F., J. Adegoke, M.-J. Bopape, M. Naidoo, R. Garland, M. Thatcher, J. McGregor, J. Katzfey, M. Werner, C. M. Ichoku, and C. K. Gatebe. 2015. "Projections of rapidly rising surface temperatures over Africa under low mitigation." *Environ. Res. Lett.*, 10 (085004): (doi:10.1088/1748-9326/10/8/085004).

Ferraro, R., J. Beauchamp, D. Cecil, and G. Heymsfield. 2015. "A prototype hail detection algorithm and hail climatology developed with the advanced microwave sounding unit (AMSU)." *Atmospheric Research*, 163: 24-35 (10.1016/j.atmosres.2014.08.010).

Fioletov, V. E., C. A. McLinden, N. Krotkov, and C. Li. 2015. "Lifetimes and emissions of SO 2 from point sources estimated from OMI." *Geophysical Research Letters*, 42 (6): 1969-1976 (10.1002/2015gl063148).

Fleming, E. L., C. George, D. E. Heard, C. H. Jackman, M. J. Kurylo, W. Mellouki, V. L. Orkin, W. H. Swartz, T. J. Wallington, P. H. Wine, and J. B. Burkholder. 2015. "The impact of current CH_4 and N_2O atmospheric loss process uncertainties on calculated ozone abundances and trends." *J. Geophys. Res. Atmos.*, 120 (10): 5267–5293 (10.1002/2014JD022067).

Ganeshan, M., and D. L. Wu. 2015. "An investigation of the Arctic inversion using COSMIC RO observations." *J. Geophys. Res. Atmos*, 120 (18): 9338-9351 (10.1002/2015JD023058).

Ganeshan, M., and R. Murtugudde. 2015. "Nocturnal propagating thunderstorms may favor urban "hot-spots": A model-based study over Minneapolis." *Urban Climate*, 14 (Part 4): 606-621 (10.1016/j.uclim.2015.10.005).

Garfinkel, C. I., M. M. Hurwitz, and L. D. Oman. 2015. "Effect of recent sea surface temperature trends on the Arctic stratospheric vortex." *J. Geophys. Res. Atmos.*, 120 (11): 5404-5416 (10.1002/2015jd023284).

Gatlin, P. N., M. Thurai, V. N. Bringi, W. Petersen, D. Wolff, A. Tokay, L. Carey, and M. Wingo. 2015. "Searching for Large Raindrops: A Global Summary of Two-Dimensional Video Disdrometer Observations." *J. of Applied Meteorology and Climatology*, 54 (5): 1069-1089 (10.1175/jamc-d-14-0089.1).

Gkikas, A., N. Hatzianastassiou, N. Mihalopoulos, and O. Torres. 2015. "Characterization of aerosol episodes in the greater Mediterranean Sea area from satellite observations (2000–2007)." *Atmospheric Environment*, (In Press) (10.1016/j.atmosenv.2015.11.056).

Gong, J., D. L. Wu, and V. Limpasuvan. 2015. "Meridionally tilted ice cloud structures in the tropical Upper Troposphere as seen by CloudSat." *Atmos. Chem. Phys.*, 15: 6271-6281 (10.5194/acp-15-6271-2015).

Gong, J., J. Yue, and D. L. Wu. 2015. "Global survey of concentric gravity waves in AIRS images and ECMWF analysis." *J. Geophys. Res. Atmos*, 120: 2210-2228 (10.1002/2014JD022527).

Gu, G., R. F. Adler, and G. J. Huffman. 2015. "Long-term changes/trends in surface temperature and precipitation during the satellite era (1979–2012)." *Climate Dynamics*, 1-15 (10.1007/s00382-015-2634-x).

Guan, K., J. A. Berry, Y. Zhang, J. Joiner, L. Guanter, G. Badgley, and D. B. Lobell. 2015. "Improving the monitoring of crop productivity using spaceborne solar-induced fluorescence." *Global Change Biology*, (In Press) (10.1111/gcb.13136).

Guan, K., M. Pan, H. Li, A. Wolf, J. Wu, D. Medvigy, K. K. Caylor, J. Sheffield, E. F. Wood, Y. Malhi, M. Liang, J. S. Kimball, S. R. Saleska, J. Berry, J. Joiner, and A. I. Lyapustin. 2015. "Photosynthetic seasonality of global tropical forests constrained by hydroclimate." *Nature Geoscience*, 8: 284–289 (10.1038/ngeo2382).

Guanter, L., I. Aben, P. Tol, J. M. Krijger, A. Hollstein, P. Köhler, A. Damm, J. Joiner, C. Frankenberg, and J. Landgraf. 2015. "Potential of the TROPOspheric Monitoring Instrument (TROPOMI) onboard the Sentinel-5 Precursor for the monitoring of terrestrial chlorophyll fluorescence." *Atmos. Meas. Tech.*, 8: 1337-1352 (10.5194/amt-8-1337-2015).

Harris, N. R., B. Hassler, F. Tummon, G. E. Bodeker, D. Hubert, I. Petropavlovskikh, W. Steinbrecht, J. Anderson, P. K. Bhartia, C. D. Boone, A. Bourassa, S. M. Davis, D. Degenstein, A. Delcloo, S. M. Frith, L. Froidevaux, S. Godin-Beekmann, N. Jones, M. J. Kurylo, E. Kyrölä, M. Laine, S. T. Leblanc, J.-C. Lambert, B. Liley, E. Mahieu, A. Maycock, M. de Mazi re, A. Parrish, R. Querel, K. H. Rosenlof, C. Roth, C. Sioris, J. Staehelin, R. S. Stolarski, R. Stübi, J. Tamminen, C. Vigouroux, K. A. Walker, H. J. Wang, J. Wild, and J. M. Zawodny. 2015. "Past changes in the vertical distribution of ozone – Part 3: Analysis and interpretation of trends." *Atmos. Chem. Phys.*, 15 (17): 9965-9982 (10.5194/acp-15-9965-2015).

Heidinger, A., Y. Li, B. Baum, R. Holz, S. Platnick, and P. Yang. 2015. "Retrieval of Cirrus Cloud Optical Depth under Day and Night Conditions from MODIS Collection 6 Cloud Property Data." *Remote Sensing*, 7 (6): 7257-7271 (10.3390/rs70607257).

Herman, J. R., R. Evans, A. M. Cede, N. K. Abuhassan, I. Petropavlovskikh, and G. McConville. 2015. "Comparison of ozone retrievals from the Pandora spectrometer system and Dobson spectrophotometer in Boulder, Colorado." *Atmos. Meas. Tech.*, 8: 3407-3418 (10.5194/amt-8-3407-2015).

Hilker, T., A. I. Lyapustin, F. G. Hall, R. Myneni, Y. Knyazikhin, Y. Wang, C. J. Tucker, and P. J. Sellers. 2015. "On the measurability of change in Amazon vegetation from MODIS." *Remote Sensing of Environment*, 166: 233–242 (10.1016/j.rse.2015.05.020).

Huang, G.-J., V. Bringi, D. Moisseev, W. Petersen, L. Bliven, and D. Hudak. 2015. "Use of 2D-video disdrometer to derive mean density–size and Ze–SR relations: Four snow cases from the light precipitation validation experiment." *Atmospheric Research*, 153: 34-48 (10.1016/j.atmosres.2014.07.013).

Huang, J., H. Liu, J. H. Crawford, C. Chan, D. B. Considine, Y. Zhang, X. Zheng, C. Zhao, V. Thouret, S. J. Oltmans, S. C. Liu, D. B. Jones, S. D. Steenrod, and M. R. Damon. 2015. "Origin of springtime ozone enhancements in the lower troposphere over Beijing: in situ measurements and model analysis." *Atmos. Chem. Phys.*, 15 (9): 5161-5179 (10.5194/acp-15-5161-2015).

Ialongo, I., J. Hakkarainen, R. Kivi, P. Anttila, N. A. Krotkov, K. Yang, C. Li, S. Tukiainen, S. Hassinen, and J. Tamminen. 2015. "Comparison of operational satellite SO_2 products with ground-based observations in northern Finland during the Icelandic Holuhraun fissure eruption." *Atmos. Meas. Tech.*, 8 (6): 2279-2289 (10.5194/amt-8-2279-2015).

Jakel, E., B. Mey, R. C. Levy, X. Gu, T. Yu, Z. Li, D. Althausen, B. Heese, and M. Wendisch. 2015. "Adaption of the MODIS aerosol retrieval algorithm by airborne spectral surface reflectance measurements over urban areas: A case study." *Atmos. Meas. Tech*, 8: 5237-5249 (10.5194/amt-8-5237-2015).

Just, A. C., R. O. Wright, J. Schwartz, B. A. Coull, A. A. Baccarelli, M. M. Tellez-Rojo, E. Moody, Y. Wang, A. I. Lyapustin, and I. Kloog. 2015. "Using High-Resolution Satellite Aerosol Optical Depth To Estimate Daily PM2.5 Geographical Distribution in Mexico City." *Environ. Sci. Technol.*, 49 (14): 8576–8584 (10.1021/acs.est.5b00859).

Kahn, R. A. 2015. "Satellites and Satellite Remote Sensing: Aerosol Measurements." *Encyclopedia of Atmospheric Sciences*, 5 (2nd Edition): Elsevier Ltd., 51-66, ISBN: 9780123822253.(10.1016/B978-0-12-382225-3.00347) (Book)

Kahn, R. A., and B. Gaitley. 2015. "An analysis of global aerosol type as retrieved by MISR." *J. Geophys. Res.-Atmos*, 120 (9): 4248-4281 (10.1002/2015JD023322).

Kaiser, J., G. M. Wolfe, K. E. Min, S. S. Brown, C. C. Miller, D. J. Jacob, J. A. deGouw, M. Graus, T. F. Hanisco, J. Holloway, J. Peischl, I. B. Pollack, T. B. Ryerson, C. Warneke, R. A. Washenfelder, and F. N. Keutsch. 2015. "Reassessing the ratio of glyoxal to formaldehyde as an indicator of hydrocarbon precursor speciation." *Atmospheric Chemistry and Physics*, 15: 7571-7583 (10.5194/acp-15-7571-2015).

Kharol, S., R. Martin, S. Philip, B. Boys, L. Lamsal, M. Jerrett, M. Brauer, D. Crouse, C. McLinden, and R. Burnett. 2015. "Assessment of the magnitude and recent trends in satellite-derived ground-level nitrogen dioxide over North America." *Atmospheric Environment*, 118: 236-245 (10.1016/j.atmosenv.2015.08.011).

Kidd, C. 2015. "Erratum." *Weather*, 70 (10): 302 (10.1002/wea.2657).

Kidd, C. 2015. "The narrow cold-frontal rainband of 22/23 November 2013." *Weather*, 70 (8): 246 (10.1002/wea.2505).

Kiemle, C., G. Ehret, S. Kawa, and E. Browell. 2015. "The global distribution of cloud gaps in CALIPSO data." *J. of Quantitative Spectroscopy and Radiative Transfer*, 153: 95-101 (10.1016/j.jqsrt.2014.12.001).

Kim, M.-K., W. K. Lau, K.-M. Kim, J. Sang, Y.-H. Kim, and W.-S. Lee. 2015. "Amplification of ENSO effects on Indian summer monsoon by absorbing aerosols." *Climate Dynamics*, (10.1007/s00382-015-2722-y).

Kim, S., S.-Y. Kim, M. Lee, H. Shim, G. M. Wolfe, A. B. Guenther, A. He, Y. Hong, and J. Han. 2015. "Impact of isoprene and HONO chemistry on ozone and OVOC formation in a semirural South Korean forest." *Atmos. Chem. Phys.*, 15 (8): 4357-4371 (10.5194/acp-15-4357-2015).

Kirschbaum, D. B., T. Stanley, and Y. Zhou. 2015. "Spatial and temporal analysis of a global landslide catalog." *Geomorphology*, 249 (Geohazard Databases): 4-15 (Full Text (Link)) (10.1016/j.geomorph.2015.03.016). (Remote Sensing, Earth, Hurricanes, Geomorphology)

Kirstetter, P.-E., Y. Hong, J. J. Gourley, M. Schwaller, W. Petersen, and Q. Cao. 2015. "Impact of sub-pixel rainfall variability on spaceborne precipitation estimation: evaluating the TRMM 2A25 product." *Q.J.R. Meteorol. Soc.*, 141 (688): 953-966 (10.1002/qj.2416).

Kishcha, P., A. da Silva, B. Starobinets, C. Long, O. Kalashnikova, and P. Alpert. 2015. "Saharan dust as a causal factor of hemispheric asymmetry in aerosols and cloud cover over the tropical Atlantic Ocean." *International J. of Remote Sensing*, 36 (13): 3423-3445 (10.1080/01431161.2015.1060646).

Kloog, I., M. Sorek-Hamer, A. I. Lyapustin, B. Couli, Y. Wang, A. C. Just, J. Schwartz, and D. M. Broday. 2015. "Estimating daily PM2.5 and PM10 across the complex geo-climate region of Israel using MAIAC satellite-based AOD data." *Atmospheric Environment*, 122: 409–416 (10.1016/j.atmosenv.2015.10.004).

Knobelspiesse, K., B. Van Diedenhoven, A. Marshak, S. Dunagan, B. N. Holben, and I. Slutsker. 2015. "Cloud thermodynamic phase detection with polarimetrically sensitive passive sky radiometers." *Atmos. Meas. Tech*, 8: 1537-1554 (10.5194/amt-8-1537-2015).

Köhler, P., L. Guanter, and J. Joiner. 2015. "A linear method for the retrieval of sun-induced chlorophyll fluorescence from GOME-2 and SCIAMACHY data." *Atmos. Meas. Tech.*, 8 (6): 2589-2608 (10.5194/amt-8-2589-2015).

Kumar, S. V., C. D. Peters-Lidard, J. A. Santanello, R. H. Reichle, C. S. Draper, R. D. Koster, G. S. Nearing, and M. F. Jasinski. 2015. "Evaluating the utility of satellite soil moisture retrievals over irrigated areas and the ability of land data assimilation methods to correct for unmodeled processes." *Hydrology and Earth System Sciences Discussions*, 12: 5967 (Full Text (Link)) (10.5194/hessd-12-5967-2015).

Kumar, S. V., C. D. Peters-Lidard, K. R. Arsenault, A. Getirana, D. M. Mocko, and Y. Liu. 2015. "Quantifying the Added Value of Snow Cover Area Observations in Passive Microwave Snow Depth Data Assimilation." *J. Hydrometeor.*, 16 (4): 1736-1741 (10.1175/JHM-D-15-0021.1).

Labow, G. J., J. R. Ziemke, R. D. McPeters, D. P. Haffner, and P. K. Bhartia. 2015. "A total ozone-dependent ozone profile climatology based on ozonesondes and Aura MLS data." *J. Geophys. Res. Atmos.*, 120 (6): 2537-2545 (10.1002/2014jd022634).

Lamsal, L. N., B. N. Duncan, Y. Yoshida, N. A. Krotkov, K. E. Pickering, D. G. Streets, and Z. Lu. 2015. "U.S. NO_2 trends (2005–2013): EPA Air Quality System (AQS) data versus improved observations from the Ozone Monitoring Instrument (OMI)." *Atmos. Env.*, 110: 130-143 (10.1016/j.atmosenv.2015.03.055).

Lau, K.-M., and S. Yang. 2015. "TROPICAL METEOROLOGY & CLIMATE | Walker Circulation." *Encyclopedia of Atmospheric Sciences*, 177-181 (10.1016/b978-0-12-382225-3.00450-3) (Article in Book)

Lau, W. K., and K.-M. Kim. 2015. "Robust Hadley Circulation changes and increasing global dryness due to CO_2 warming from CMIP5 model projections." *PNAS*, 112 (12): 3630–3635 (10.1073/pnas.1418682112).

L'Ecuyer, T. S., M. Rodell, W. S. Olson, B. Lin, S. Kato, C. A. Clayson, E. Wood, J. Sheffield, R. F. Adler, G. J. Huffman, M. G. Bosilovich, G. Gu, F. Robertson, P. R. Houser, D. Chambers, J. S. Famiglietti, E. Fetzer, W. T. Liu, X. Gao, C. A. Schlosser, E. Clark, D. P. Lettenmaier, and K. Hilburn. 2015. "The Observed State of the Energy Budget in the Early Twenty-First Century." *J. Clim.*, 28 (21): 8319–8346 (10.1175/JCLI-D-14-00556.1).

Lee, H., T. Yuan, H. Jung, and E. Beighley. 2015. "Mapping wetland water depths over the central Congo basin using PALSAR ScanSAR, Envisat altimetry, and MODIS VCF data." *Remote Sensing of Environment*, 159: 70-79 (doi:10.1016/j.rse.2014.11.030).

Lee, J. N., R. F. Cahalan, and D. L. Wu. 2015. "The 27-Day Rotational Variations in Total Solar Irradiance Observations: from SORCE/TIM, ACRIM III, and SOHO/VIRGO." *J. of Atmospheric and Solar-Terrestrial Physics*, (132): 64-73 (10.1016/j.jastp.2015.07.001).

Lee, J., N. C. Hsu, C. Bettenhausen, A. M. Sayer, C. J. Seftor, and M.-J. Jeong. 2015. "Retrieving the height of smoke and dust aerosols by synergistic use of VIIRS, OMPS, and CALIOP observations." *J. Geophys. Res. Atmos.*, 120 (16): 8372-8388 (10.1002/2015jd023567).

Lee, M., I. Kloog, A. Chudnovsky, A. I. Lyapustin, Y. Wang, S. Melly, B. Couli, P. Koutrakis, and J. Schwartz. 2015. "Spatiotemporal prediction of fine particulate matter using high-resolution satellite images in the Southeastern US 2003–2011." *J. of Exposure Science and Environmental Epidemiology*, 1-8 (In Press) (10.1038/jes.2015.41).

Lettenmaier, D. P., D. Alsdor, J. Dozier, G. J. Huffman, M. Pan, and E. F. Wood. 2015. "Inroads of Remote Sensing into Hydrologic Science During the WRR Era." *Water Resources Research*, 51 (9): 7309–7342 (10.1002/2015WR017616).

Levy, R. C., L. A. Munchak, S. Mattoo, F. Patadia, L. A. Remer, and R. E. Holz. 2015. "Towards a long-term global aerosol optical depth record: Applying a consistent aerosol retrieval algorithm to MODIS and VIIRS observed reflectance." *Atmos. Meas. Tech*, 8: 4083-4110 (10.5194/amt-8-4083-2015).

Li, C., J. Joiner, N. A. Krotkov, and L. Dunlap. 2015. "A new method for global retrievals of HCHO total columns from the Suomi National Polar-orbiting Partnership Ozone Mapping and Profiler Suite." *Geophysical Research Letters*, 42 (7): 2515-2522 (10.1002/2015gl063204).

Li, S., R. A. Kahn, M. Chin, M. J. Garay, and Y. Liu. 2015. "Improving satellite-retrieved aerosol microphysical properties using GOCART data." *Atmos. Meas. Tech.*, 8: 1157-1171 (10.5194/amt-8-1157-2015).

Liaskos, C. E., D. J. Allen, and K. E. Pickering. 2015. "Sensitivity of tropical tropospheric composition to lightning NO x production as determined by replay simulations with GEOS-5." *J. Geophys. Res. Atmos.*, 120 (16): 8512-8534 (10.1002/2014jd022987).

Lim, Y.-K., S. D. Schubert, O. Reale, M.-I. Lee, A. M. Molod, and M. J. Suarez. 2015. "Sensitivity of tropical cyclones to parameterized convection in the NASA GEOS-5 model." *J. Climate*, 28 (2): 551-573 (10.1175/JCLI-D-14-00104.1).

Limbacher, J. A., and R. A. Kahn. 2015. "MISR empirical stray light corrections in high-contrast scenes." *Atmos. Meas. Tech*, 8: 2927-2943 (10.5194/amt-8-2927-2015).

Lin, Z., S. Stamnes, Z. Jin, I. Laszlo, S.-C. Tsay, W. J. Wiscombe, and K. Stamnes. 2015. "Improved discrete ordinate solutions in the presence of an anisotropically reflecting lower boundary: Upgrades of the DISORT computational tool." *J. Quant. Spectrosc. Radiat. Trans*, 157: 119-134 (10.1016/j.jqsrt.2015.02.014).

Liu, C., P. Yang, S. L. Nasiri, S. Platnick, K. G. Meyer, C. Wang, and S. Ding. 2015. "A fast Visible Infrared Imaging Radiometer Suite simulator for cloudy atmospheres." *J. Geophys. Res. Atmos.*, 120 (1): 240-255 (10.1002/2014jd022443).

Liu, C., X. Liu, M. G. Kowalewski, S. J. Janz, G. González Abad, K. E. Pickering, K. Chance, and L. N. Lamsal. 2015. "Analysis of ACAM Data for Trace Gas Retrievals during the 2011 DISCOVER-AQ Campaign." *J. of Spectroscopy*, 2015: 1-7 (10.1155/2015/827160).

Liu, C., X. Liu, M. G. Kowalewski, S. J. Janz, G. González Abad, K. E. Pickering, K. Chance, and L. N. Lamsal. 2015. "Characterization and verification of ACAM slit functions for trace-gas retrievals during the 2011 DISCOVER-AQ flight campaign." *Atmos. Meas. Tech.*, 8 (2): 751-759 (10.5194/amt-8-751-2015).

Liu, Y., C. D. Peters-Lidard, S. V. Kumar, K. R. Arsenault, and D. M. Mocko. 2015. "Blending satellite-based snow depth products with in situ observations for streamflow predictions in the Upper Colorado River Basin." *Water Resour. Res.*, 51 (2): 1182-1202 (10.1002/2014WR016606).

Liu, Z. 2015. "Comparison of precipitation estimates between Version 7 3-hourly TRMM Multi-Satellite Precipitation Analysis (TMPA) near-real-time and research products." *Atmos. Res.*, 153: 119-133 (10.1016/j.atmosres.2014.07.032).

Liu, Z. 2015. "Comparison of versions 6 and 7 3-hourly TRMM multi-satellite precipitation analysis (TMPA) research products." *Atmospheric Research*, 163: 91-101 (10.1016/j.atmosres.2014.12.015).

Lolli, S., and P. Di Girolamo. 2015. "Principal component analysis approach to evaluate instrument performances in developing a cost-effective reliable instrument network for atmospheric measurements." *J. of Atmospheric and Oceanic Technology*, 32 (9): 1642-1649..

Long, M. S., R. Yantosca, J. E. Nielsen, et al. 2015. "Development of a grid-independent GEOS-Chem chemical transport model (v9-02) as an atmospheric chemistry module for Earth system models." *Geosci. Model Dev.*, 8 (3): 595-602 (10.5194/gmd-8-595-2015).

Loughman, R., D. Flittner, E. Nyaku, and P. K. Bhartia. 2015. "Gauss–Seidel limb scattering (GSLS) radiative transfer model development in support of the Ozone Mapping and Profiler Suite (OMPS) limb profiler mission." *Atmos. Chem. Phys.*, 15 (6): 3007-3020 (10.5194/acp-15-3007-2015).

Lu, X., C. Cao, W. Huang, J. Smith, X. Chu, T. Yuan, D. Pautet, M. Taylor, J. Gong, and C. Cullens. 2015. "A Coordinated Study of 1-h Mesoscale Gravity Waves Propagating from Logan to Boulder with CRRL Na Doppler Lidars and Temperature Mapper." *J. of Geophysical Research - Atmosphere*, 120: (10.1002/2015JD023604).

Lu, Z., D. G. Streets, B. de Foy, L. N. Lamsal, B. N. Duncan, and J. Xing. 2015. "Emissions of nitrogen oxides from US urban areas: estimation from Ozone Monitoring Instrument retrievals for 2005–2014." *Atmos. Chem. Phys.*, 15: 10367-10383 (10.5194/acp-15-10367-2015).

Lyapustin, A. I., X. Xiong, Y. Wang, G. Meister, S. E. Platnick, R. C. Levy, B. A. Franz, A. Wu, and A. A. Angal. 2015. "MODIS Terra-Aqua C6+ Cross-Calibration Improvements." *GSICS Quarterly*, 9 (2): (10.7289/V5XK8CHN) (Newsletter)

Ma, Z., X. Hu, A. M. Sayer, R. C. Levy, Q. Zhang, Y. Xue, S. Tong, J. Bi, L. Huang, and Y. Liu. 2015. "Satellite-Based Spatiotemporal Trends in PM2.5 Concentrations: China, 2004–2013." *Environmental Health Perspectives*, (10.1289/ehp.1409481).

Marchenko, S., N. A. Krotkov, L. N. Lamsal, E. A. Celarier, W. H. Swartz, and E. J. Bucsela. 2015. "Revising the slant column density retrieval of nitrogen dioxide observed by the Ozone Monitoring Instrument." *J. Geophys. Res. Atmos.*, 120 (11): 5670-5692 (10.1002/2014jd022913).

Matsui, T., W.-K. Tao, S. J. Munchak, M. Grecu, and G. J. Huffman. 2015. "Satellite view of quasi-equilibrium states in tropical convection and precipitation microphysics." *Geophysical Research Letters*, 42 (6): 1959–1968 (10.1002/2015GL063261).

Mazrooei, A., T. Sinha, A. Sankarasubramanian, S. V. Kumar, and C. D. Peters-Lidard. 2015. "Decomposition of Sources of Errors in Seasonal Streamflow Forecasting over the US Sunbelt." *J. Geophys. Res. Atmos.*, 120 (23): 11,809–11,825 (10.1002/2015jd023687).

McGillen, M. R., F. Bernard, E. L. Fleming, and J. B. Burkholder. 2015. "HCFC-133a (CF 3 CH 2 Cl): OH rate coefficient, UV and infrared absorption spectra, and atmospheric implications." *Geophysical Research Letters*, 42 (14): 6098-6105 (10.1002/2015gl064939).

McGrath-Spangler, E. L., A. M. Molod, L. E. Ott, and S. Pawson. 2015. "Impact of planetary boundary layer turbulence on model climate and tracer transport." *Atmos. Chem. Phys.*, 15 (13): 7269-7286 (10.5194/acp-15-7269-2015).(Theory & Modeling)

McLinden, M. L., E. J. Wollack, G. M. Heymsfield, and L. Li. 2015. "Reduced Image Aliasing With Microwave Radiometers and Weather Radar Through Windowed Spatial Averaging." *IEEE Transactions on Geoscience and Remote Sensing*, 53 (12): 6639-6649 (10.1109/tgrs.2015.2445100).

McNally, A. L., G. J. Husak, M. Brown, M. Carroll, C. Funk, S. '. Yatheendradas, K. R. Arsenault, C. D. Peters-Lidard, and J. P. Verdin. 2015. "Calculating Crop Water Requirement Satisfaction in the West Africa Sahel with Remotely Sensed Soil Moisture." *J. of Hydrometerology*, 16: 295-305 (10.1175/JHM-D-14-0049.1).

McPartland, L. B., D. L. Wu, and C.-L. Shie. 2015. "Increasing evaporation amounts seen in the Arctic between 2003 and 2013 from AIRS data." *J. Geophy Res. - Atmos*, 120 (14): 6865-6881 (doi:10.1002/2015JD023258).

McPeters, R., and R. Stolarski. 2015. "SATELLITES AND SATELLITE REMOTE SENSING | Measuring Ozone from Space – TOMS and SBUV." *Encyclopedia of Atmospheric Sciences*, 87-94 (10.1016/b978-0-12-382225-3.00351-0) (Article in Book)

Melroy, H. R., E. L. Wilson, G. B. Clarke, L. E. Ott, J. Mao, A. K. Ramanathan, and M. L. McLinden. 2015. "Autonomous field measurements of CO_2 in the atmospheric column with the miniaturized laser heterodyne radiometer (Mini-LHR)." *Appl. Phys. B*, 120 (4): 609-615 (10.1007/s00340-015-6172-3).

Meyer, K. G., and S. E. Platnick. 2015. "Simultaneously inferring above-cloud absorbing aerosol optical thickness and underlying liquid phase cloud optical and microphysical properties using MODIS." *J. Geophys. Res. Atmos*, 120 (11): 5524–5547 (10.1002/2015JD023128).

Minschwaner, K., G. L. Manney, I. Petropavlovskikh, L. A. Torres, Z. D. Lawrence, B. Sutherland, A. M. Thompson, B. J. Johnson, Z. Butterfield, M. K. Dubey, L. Froidevaux, A. Lambert, W. G. Read, and M. J. Schwartz. 2015. "Signature of a tropical Pacific cyclone in the composition of the upper troposphere over Socorro, NM." *Geophysical Research Letters*, 42 (21): 9530-9537 (10.1002/2015gl065824).

Monks, S. A., S. R. Arnold, L. K. Emmons, K. S. Law, S. Turquety, B. N. Duncan, J. Flemming, V. Huijnen, S. Tilmes, J. Langner, J. Mao, Y. Long, J. L. Thomas, S. D. Steenrod, J. C. Raut, C. Wilson, M. P. Chipperfield, G. S. Diskin, A. Weinheimer, H. Schlager, and G. Ancellet. 2015. "Multi-model study of chemical and physical controls on transport of anthropogenic and biomass burning pollution to the Arctic." *Atmos. Chem. Phys.*, 15 (6): 3575-3603 (10.5194/acp-15-3575-2015).

Muller, C., L. Chapman, S. Johnston, C. Kidd, S. Illingworth, G. Foody, A. Overeem, and R. Leigh. 2015. "Crowdsourcing for climate and atmospheric sciences: current status and future potential." *Int. J. Climatol.*, 35 (11): 3185-3203 (10.1002/joc.4210).

Munchak, S. J., R. Meneghini, M. Grecu, and W. S. Olson. 2015. "A Consistent Treatment of Microwave Emissivity and Radar Backscatter for Retrieval of Precipitation over Water Surfaces." *J. of Atmospheric and Oceanic Technology*, 151130150635007 (In Press) (10.1175/jtech-d-15-0069.1).

Appendix 1: Refereed Articles

Munsell, E. B., J. A. Sippel, S. A. Braun, Y. Weng, and F. Zhang. 2015. "Dynamics and Predictability of Hurricane Nadine (2012) Evaluated through Convection-Permitting Ensemble Analysis and Forecasts." *Monthly Weather Review*, 143 (11): 4514-4532 (10.1175/mwr-d-14-00358.1).

Murphy, K. J., D. K. Davies, K. Michael, C. O. Justice, J. E. Schmaltz, R. A. Boller, B. D. McLemore, F. Ding, B. E. Vollmer, and M. Wong. 2015. "LANCE, NASA's Land, Atmosphere Near Real-Time Capability for EOS." *Time-Sensitive Remote Sensing*, New York: 113-127, ISBN: 978-1-4939-2601-5.(10.1007/978-1-4939-2602-2_8) (Article in Book)

Naeger, A. R., P. Gupta, B. Zavodsky, and K. M. McGrath. 2015. "Monitoring and tracking the trans-Pacific transport of aerosols using multi-satellite aerosol optical depth retrievals." *Atmospheric Measurement Techniques Discussions*, 8 (10): 10319-10360 (10.5194/amtd-8-10319-2015).

Nag, S., C. K. Gatebe, and O. d'Weck. 2015. "Observing system simulations for small satellite formations estimating bidirectional reflectance." *International J. of Applied Earth Observation and Geoinformation*, 43: 102-118 (doi:10.1016/j.jag.2015.04.022).

Nguyen, T. B., J. D. Crounse, A. P. Teng, J. M. St. Clair, F. Paulot, G. M. Wolfe, and P. O. Wennberg. 2015. "Rapid deposition of oxidized biogenic compounds to a temperate forest." *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, 112 (5): E392–E401 (10.1073/pnas.1418702112).

Nowottnick, E. P., P. R. Colarco, E. J. Welton, and A. M. Da Silva. 2015. "Use of the CALIOP vertical feature mask for evaluating global aerosol models." *Atmospheric Measurement Techniques*, 8: 3647-3669 (10.5194/amt-8-3647-2015).

O'Halloran, T. L., J. D. Fuentes, W. K. Tao, and X. Li. 2015. "Sensitivity of convection to observed variation in aerosol size distributions and composition at a rural site in the southeastern United States." *J Atmos Chem*, 72 (3-4): 441-454 (10.1007/s10874-015-9300-x).

Okonkwo, C., B. B. Demoz, R. Sakai, C. M. Ichoku, C. Anarado, J. O. Adegoke, A. Amadou, S. I. Abdullahi, and N. Krakauer. 2015. "Combined effect of El Niño southern oscillation and Atlantic multidecadal oscillation on Lake Chad level variability." *Cogent Geoscience*, 1 (1): 1117829 (10.1080/23312041.2015.1117829).

Orbe, C., D. W. Waugh, and P. A. Newman. 2015. "Air-mass origin in the tropical lower stratosphere: The influence of Asian boundary layer air." *Geophysical Research Letters*, 42 (10): 4240-4248 (10.1002/2015gl063937).

Orbe, C., P. A. Newman, D. W. Waugh, M. Holzer, L. D. Oman, F. Li, and L. M. Polvani. 2015. "Air-mass Origin in the Arctic. Part I: Seasonality." *J. Climate*, 28 (12): 4997-5014 (10.1175/jcli-d-14-00720.1).

Orbe, C., P. A. Newman, D. W. Waugh, M. Holzer, L. D. Oman, F. Li, and L. M. Polvani. 2015. "Air-Mass Origin in the Arctic. Part II: Response to Increases in Greenhouse Gases." *J. Climate*, 28 (23): 9105–9120 (10.1175/jcli-d-15-0296.1).

Ott, L. E., S. Pawson, G. J. Collatz, W. W. Gregg, D. Menemenlis, H. Brix, C. S. Rousseaux, K. W. Bowman, J. Liu, A. Eldering, M. R. Gunson, and S. R. Kawa. 2015. "Assessing the magnitude of CO_2 flux uncertainty in atmospheric CO_2 records using products from NASA's Carbon Monitoring Flux Pilot Project." *J. of Geophysical Research - Atmospheres*, 120: 734-765 (doi:10.1002/2014JD022411).

Pan, X., M. Chin, R. Gautam, H. Bian, D. Kim, P. R. Colarco, T. L. Diehl, T. Takemura, L. Pozzoli, K. Tsigaridis, S. E. Bauer, and N. Bellouin. 2015. "A multi-model evaluation of aerosols over South Asia: common problems and possible causes." *Atmos. Chem. Phys.*, 15: 5903-5928 (10.5194/acp-15-5903-2015).(Aerosols, Theory & Modeling, Pollution)

Pauwels, V. R., and G. J. De Lannoy. 2015. "Error covariance calculation for forecast bias estimation in hydrologic data assimilation." *Advances in Water Resources*, 86: 284-296 (10.1016/j.advwatres.2015.05.013).

Perez Ramirez, D., I. A. Veselovskiy, D. N. Whiteman, A. Suvorina, M. Korenskiy, A. Kolgotin, B. N. Holben, O. Dubovik, A. Siniuk, and L. Alados-Arboledas. 2015. "High temporal resolution estimates of columnar aerosol microphysical parameters from spectrum of aerosol optical depth by linear estimation: application to long-term AERONET and star-photometry measurements." *Atmos. Meas. Tech.*, 8: 3117-3133 (10.5194/amt-8-3117-2015).

Pincus, R., E. J. Mlawer, L. Oreopoulos, A. S. Ackerman, S. Baek, M. Brath, S. A. Buelhler, K. E. Cady-Pereira, J. N. Cole, J.-L. Dufresne, M. Kelley, J. Li, J. Manners, D. J. Paynter, R. Roehrig, M. Sekiguchi, and M. D. Schwarzkopf. 2015. "Radiative flux and forcing parameterization error in aerosol-free clear skies." *Geophys. Res. Lett*, 42 (13): 5485-5492 (10.1002/2015GL064291).

Prather, M. J., J. Hsu, N. M. DeLuca, C. H. Jackman, L. D. Oman, A. R. Douglass, E. L. Fleming, S. E. Strahan, S. D. Steenrod, O. A. S vde, I. S. Isaksen, L. Froidevaux, and B. Funke. 2015. "Measuring and modeling the lifetime of nitrous oxide including its variability." *J. Geophys. Res. Atmos.*, 120 (11): 5693-5705 (10.1002/2015jd023267).

Privé, N. C., and R. M. Errico. 2015. "Spectral analysis of forecast error investigated with an observing system simulation experiment." *Tellus A*, 67: 25977 (10.3402/tellusa.v67.25977).(Theory & Modeling)

Qian, Y., T. J. Yasunari, S. J. Doherty, M. G. Flanner, W. K. Lau, J. Ming, H. Wang, M. Wang, S. G. Warren, and R. Zhang. 2015. "Light-absorbing Particles in Snow and Ice: Measurement and Modeling of Climatic and Hydrological Impact." *Adv. Atmos. Sci*, 32 (1): 64-91 (10.1007/s00376-014-0010-0).

Ringerud, S., C. D. Kummerow, and C. D. Peters-Lidard. 2015. "A Semi-Empirical Model for Computing Land Surface Emissivity in the Microwave Region." *IEEE Transactions on Geoscience and Remote Sensing*, 53 (4): 1935-1946 (Full Text (Link)) (10.1109/TGRS.2014.2351232).

Rodell, M., H. K. Beaudoing, T. S. L'Ecuyer, W. S. Olson, J. S. Famiglietti, P. R. Houser, R. F. Adler, M. G. Bosilovich, C. A. Clayson, D. Chambers, E. Clark, E. J. Fetzer, X. Gao, G. Gu, K. Hilburn, G. J. Huffman, D. P. Lettenmaier, W. T. Liu, F. R. Robertson, C. A. Schlosser, J. Sheffield, and E. F. Wood. 2015. "The Observed State of the Water Cycle in the Early Twenty-First Century." *J. of Climate*, 28 (21): 8289–8318 (10.1175/JCLI-D-14-00555.1).

Rodriguez-Fonseca, B., E. Mohino, C. R. Mechoso, C. Caminade, M. Biasutti, M. Gaetani, J. Garcia-Serrano, E. K. Vizy, K. Cook, Y. Xue, I. Polo, T. Losada, L. M. Druyan, B. Fontaine, J. Bader, F. J. Doblas-Reyes, L. Goddard, S. Janicot, A. Arribas, W. K. Lau, A. Colman, M. Vellinga, D. P. Rowell, F. Kucharski, and A. Voldoire. 2015. "Variability and predictability of West African droughts: A review of the role of sea surface temperature anomalies." *J. Climate*, 28 (10): 4034-4060 (10.1175/JCLI-D-14-00130.1).

Rong, P. P., J. Yue, J. M. Russell III, J. D. Lumpe, J. Gong, D. L. Wu, and C. E. Randall. 2015. "Horizontal winds derived from the polar mesospheric cloud images as observed by the CIPS instrument on the AIM satellite." *J. Geophys. Res. Atmos.*, 120 (11): 5564-5584 (10.1002/2014JD022813).

Rosette, J., B. Cook, R. Nelson, Chengquan Huang, J. Masek, C. Tucker, Guoqing Sun, Wenli Huang, P. Montesano, J. Rubio-Gil, and J. Ranson. 2015. "Sensor Compatibility for Biomass Change Estimation Using Remote Sensing Data Sets: Part of NASA's Carbon Monitoring System Initiative." *IEEE Geosci. Remote Sensing Lett.*, 12 (7): 1511-1515 (10.1109/lgrs.2015.2411262).

Savtchenko, A. K., G. J. Huffman, and B. E. Vollmer. 2015. "Assessment of precipitation anomalies in California using TRMM and MERRA data." *J. of Geophysical Research, Atmospheres*, 120: 8206–8215 (doi:10.1002/2015JD023573).

Sayer, A. M., N.-Y. C. Hsu, and C. Bettenhausen. 2015. "Implications of MODIS bow-tie distortion on aerosol optical depth retrievals, and techniques for mitigation." *Atmos. Meas. Tech*, 8: 5277-5288 (10.5194/amt-8-5277-2015).

Sayer, A. M., N.-Y. C. Hsu, C. Bettenhausen, M.-J. Jeong, and G. Meister. 2015. “Effect of MODIS Terra radiometric calibration improvements on Collection 6 Deep Blue aerosol products: validation and Terra/Aqua consistency.” *J. Geophys. Res*, 120: (10.1002/2015JD023878).

Schnell, J. L., M. J. Prather, B. Josse, V. Naik, L. W. Horowitz, P. Cameron-Smith, D. Bergmann, G. Zeng, D. A. Plummer, K. Sudo, T. Nagashima, D. T. Shindell, G. S. Faluvegi, and S. A. Strode. 2015. “Use of North American and European air quality networks to evaluate global chemistry-climate modeling of surface ozone.” *Atmos. Chem. Phys.*, 15: 10581-10596 (10.5194/acp-15-10581-2015).

Schoeberl, M. R., H. B. Selkirk, H. Vömel, and A. R. Douglass. 2015. “Sources of seasonal variability in tropical upper troposphere and lower stratosphere water vapor and ozone: Inferences from the Ticosonde data set at Costa Rica.” *J. Geophys. Res. Atmos.*, 120 (18): 9684-9701 (10.1002/2015jd023299).

Schoeberl, M., and P. Newman. 2015. “MIDDLE ATMOSPHERE | Polar Vortex.” *Encyclopedia of Atmospheric Sciences*, 12-17 (10.1016/b978-0-12-382225-3.00228-0) (Article in Book)

Schwantes, R. H., A. P. Teng, T. B. Nguyen, M. M. Coggon, J. D. Crounse, J. M. St. Clair, X. Zhang, K. A. Schilling, J. H. Seinfeld, and P. O. Wennberg. 2015. “Isoprene NO 3 Oxidation Products from the RO 2 + HO 2 Pathway.” *The J. of Physical Chemistry A*, 119 (40): 10158-10171 (10.1021/acs.jpca.5b06355).

Sessions, W. R., J. S. Reid, A. Benedetti, P. R. Colarco, A. da Silva, S. Lu, T. Sekiyama, T. Y. Tanaka, J. M. Baldasano, S. Basart, M. E. Brooks, T. F. Eck, M. Iredell, J. A. Hansen, O. C. Jorba, H.-M. H. Juang, P. Lynch, J.-J. Morcrette, S. Moorthi, J. Mulcahy, Y. Pradhan, M. Razinger, C. B. Sampson, J. Wang, and D. L. Westphal. 2015. “Corrigendum to “Development towards a global operational aerosol consensus: basic climatological characteristics of the International Cooperative for Aerosol Prediction Multi-Model Ensemble (ICAP-MME)” published in Atmos. Chem. Phys., 15, 335–362, 2015.” *Atmos. Chem. Phys.*, 15 (5): 2533-2534 (10.5194/acp-15-2533-2015).

Sessions, W., J. S. Reid, A. Benedetti, P. Colarco, A. da Silva, S. Lu, T. Sekiyama, T. Y. Tanaka, J. M. Baldasano, S. Basart, M. Brooks, T. F. Eck, M. Iredell, J. A. Hansen, O. Jorba, H.-M. Juang, P. Lynch, J.-J. Morcrette, S. Moorthi, J. Mulcahy, Y. Pradhan, M. Razinger, C. B. Sampson, J. Wang, and D. L. Westphal. 2015. “Development towards a global operational aerosol consensus: Basic climatological characteristics of the International Cooperative for Aerosol Prediction Multi-Model Ensemble (ICAP-MME).” *Atmos. Chem. Phys*, 15: 335-362 (10.5194/acp-15-335-2015).

Short, D. A., R. Meneghini, A. E. Emory, and M. R. Schwaller. 2015. “Reduction of Nonuniform Beamfilling Effects by Multiple Constraints: A Simulation Study.” *J. Atmospheric and Oceanic Technology*, 32 (11): 2114-2124 (10.1175/jtech-d-15-0021.1).

Sinha, P., P. Gupta, D. Kaskaoutis, L. Sahu, N. Nagendra, R. K. Manchanda, Y. B. Kumar, and S. Sreenivasan. 2015. “Estimation of particulate matter from satellite- and ground-based observations over Hyderabad, India.” *International J. Remote Sens.*, 36 (24): 6192-6213 (10.1080/01431161.2015.1112929).

Skofronick-Jackson, G., D. Hudak, W. Petersen, S. W. Nesbitt, V. Chandrasekar, S. Durden, K. J. Gleicher, G.-J. Huang, P. Joe, P. Kollias, K. A. Reed, M. R. Schwaller, R. Stewart, S. Tanelli, A. Tokay, J. R. Wang, and M. Wolde. 2015. “Global Precipitation Measurement Cold Season Precipitation Experiment (GCPEX): For Measurement’s Sake, Let It Snow.” *BAMS*, 96 (10): 1719-1741 (10.1175/bams-d-13-00262.1).

Snider, G., C. L. Weagle, R. V. Martins, A. van Donkelaar, K. Conrad, D. Cunningham, C. Gordon, M. Zwicker, C. Akoshile, P. Artaxo, N. X. Anh, J. Brooks, J. Dong, R. M. Garland, R. Greenwald, D. Griffith, K. He, B. N. Holben, R. A. Kahn, I. Koren, N. Lagrosas, P. Lestari, Z. Ma, J. V. Martins, E. J. Quel, Y. Rudich, A. Salam, S. N. Tripathi, C. Yu, Q. Zhang, Y. Zhang, M. Brauer, A. Cohen, M. D. Gibson, and Y. Liu. 2015. “SPARTAN: a global network to evaluate and enhance satellite-based estimates of ground-level particulate matter for global health applications.” *Atmos. Meas. Tech.*, 8: 505-521 (10.5194/amt-8-505-2015).

Solomos, S., V. Amiridis, P. Zanis, E. Gerasopoulos, F. I. Sofiou, T. Herekakis, J. Brioude, A. Stohl, R. A. Kahn, and C. Kontoes. 2015. "Smoke dispersion modeling over complex terrain using high resolution meteorological data and satellite observations—the FireHub platform." *Atmospheric Environment*, 119: 348-361 (10.1016/j.atmosenv.2015.08.066).

Sorek-Hamer, M., I. Kloog, P. Koutrakis, A. W. Strawa, R. Chatfield, A. Cohen, W. L. Ridgway, and D. M. Broday. 2015. "Assessment of PM2.5 concentrations over bright surfaces using MODIS satellite observations." *Remote Sensing of Environment*, 163: 180-185 (10.1016/j.rse.2015.03.014).

Spinei, E., A. Cede, J. Herman, G. H. Mount, E. Eloranta, B. Morley, S. Baidar, B. Dix, I. Ortega, T. Koenig, and R. Volkamer. 2015. "Ground-based direct-sun DOAS and airborne MAX-DOAS measurements of the collision-induced oxygen complex, O_2O_2, absorption with significant pressure and temperature differences." *Atmospheric Measurement Techniques*, 8 (2): 793-809 (10.5194/amt-8-793-2015).

Stolarski, R. S., A. R. Douglass, L. D. Oman, and D. W. Waugh. 2015. "Impact of future nitrous oxide and carbon dioxide emissions on the stratospheric ozone layer." *Environmental Research Letters*, 10 (3): 034011 (10.1088/1748-9326/10/3/034011).

Strahan, S. E., L. D. Oman, A. R. Douglass, and L. Coy. 2015. "Modulation of Antarctic vortex composition by the quasi-biennial oscillation." *Geophysical Research Letters*, 42 (10): 4216-4223 (10.1002/2015gl063759).

Strode, S. A., B. N. Duncan, E. A. Yegorova, J. Kouatchou, J. R. Ziemke, and A. R. Douglass. 2015. "Implications of carbon monoxide bias for methane lifetime and atmospheric composition in chemistry climate models." *Atmospheric Chemistry and Physics*, 15: 11789–11805 (10.5194/acp-15-11789-2015).

Strode, S. A., J. M. Rodriguez, J. A. Logan, O. R. Cooper, J. C. Witte, L. N. Lamsal, M. R. Damon, B. H. Van Aartsen, S. D. Steenrod, and S. E. Strahan. 2015. "Trends and variability in surface ozone over the United States." *J. Geophys. Res. Atmos.*, 120: (10.1002/2014JD022784).

Sullivan, J. T., T. J. McGee, R. DeYoung, L. W. Twigg, G. K. Sumnicht, D. Pliutau, T. Knepp, and W. Carrion. 2015. "Results from the NASA GSFC and LaRC Ozone Lidar Intercomparison: New Mobile Tools for Atmospheric Research." *J. Atmospheric and Oceanic Technology*, 32 (10): 1779-1795 (10.1175/jtech-d-14-00193.1).

Sun, Y., K. P. Bowman, M. G. Genton, and A. Tokay. 2015. "A Matérn model of the spatial covariance structure of point rain rates." *Stoch Environ Res Risk Assess*, 29 (2): 411-416 (10.1007/s00477-014-0923-2).

Sun, Y., R. Fu, R. Dickinson, J. Joiner, C. Frankenberg, L. Gu, Y. Xia, and N. Fernando. 2015. "Drought onset mechanisms revealed by satellite solar-induced chlorophyll fluorescence: Insights from two contrasting extreme events." *J. Geophys. Res. Biogeosci.*, 120 (11): 2427–2440 (10.1002/2015jg003150).

T. Wagner, H. Harder, J. Joiner, P. Laj, and A. Richter 2015 Editoral Note "A novel Whole Air Sample Profiler (WASP) for the quantification of volatile organic compounds in the boundary layer" published in Atmos. Meas. Tech., 6, 2703–2712, 2013." Atmospheric Measurement Techniques, 8 (8): 3405-3406 (10.5194/amt-8-3405-2015).

Tao, Z., H. Yu, and M. Chin. 2015. "The Role of Aerosol-Cloud-Radiation Interactions in Regional Air Quality—A NU-WRF Study over the United States." *Atmosphere*, 6 (8): 1045-1068 (10.3390/atmos6081045).

Taylor, M., S. Kazadzis, V. Amiridis, and R. A. Kahn. 2015. "Global aerosol mixtures and their multiyear and seasonal characteristics." *Atmospheric Environment*, 116: 112--129 (10.1016/j.atmosenv.2015.06.029). (Aerosols)

Theys, N., I. De Smedt, J. van Gent, T. Danckaert, T. Wang, F. Hendrick, T. Stavrakou, S. Bauduin, L. Clarisse, C. Li, N. Krotkov, H. Yu, H. Brenot, and M. Van Roozendael. 2015. "Sulfur dioxide vertical column DOAS retrievals from the Ozone Monitoring Instrument: Global observations and comparison to ground-based and satellite data." *J. Geophys. Res. Atmos.*, 120 (6): 2470-2491 (10.1002/2014jd022657).

Tian, L., G. M. Heymsfield, A. C. Didlake, S. Guimond, and L. Li. 2015. "Velocity–Azimuth Display Analysis of Doppler Velocity for HIWRAP." *J. Applied Meteorology and Climatology*, 54 (8): 1792-1808 (10.1175/jamc-d-14-0054.1).

Tian, Y., C. D. Peters-Lidard, S. E. Finn, and S. V. Kumar. 2015. "Calibration to improve forward model simulation of microwave emissivity at GPM frequencies over the U.S. Southern Great Plains." *IEEE Trans. Geosci. Remote Sens.,* 54 (2): (10.1109/TGRS.2015.2474120).

Tong, D. Q., L. Lamsal, L. Pan, C. Ding, H. Kim, P. Lee, T. Chai, K. E. Pickering, and I. Stajner. 2015. "Long-term NOx trends over large cities in the United States during the great recession: Comparison of satellite retrievals, ground observations, and emission inventories." *Atmospheric Environment*, 107: 70-84 (10.1016/j.atmosenv.2015.01.035).

Tummon, F., B. Hassler, N. R. Harris, J. Staehelin, W. Steinbrecht, J. Anderson, G. E. Bodeker, A. Bourassa, S. M. Davis, D. Degenstein, S. M. Frith, L. Froidevaux, E. Kyrölä, M. Laine, C. Long, A. A. Penckwitt, C. E. Sioris, K. H. Rosenlof, C. Roth, H.-J. Wang, and J. Wild. 2015. "Intercomparison of vertically resolved merged satellite ozone data sets: interannual variability and long-term trends." *Atmos. Chem. Phys.*, 15 (6): 3021-3043 (10.5194/acp-15-3021-2015).

Varnai, T., and A. Marshak. 2015. "Effect of cloud fraction on near-cloud aerosol behavior in the MODIS atmospheric correction ocean color product." *Rem. Sens*, 7: 5283-5299 (10.3390/rs70505283).

Veselovskii, I., D. N. Whiteman, M. Korenskiy, A. Suvorina, and D. Pérez-Ramírez. 2015. "Use of rotational Raman measurements in multi-wavelength aerosol lidar for evaluation of particle backscattering and extinction." *Atmospheric Measurement Techniques*, 8 (10): 4111-4122 (10.5194/amt-8-4111-2015).

Wang, L., M. B. Follette-Cook, M. Newchurch, K. E. Pickering, A. Pour-Biazar, S. Kuang, W. Koshak, and H. Peterson. 2015. "Evaluation of lightning-induced tropospheric ozone enhancements observed by ozone lidar and simulated by WRF/Chem." *Atmospheric Environment*, 115: 185-191 (10.1016/j.atmosenv.2015.05.054).

Wang, S.-H., E. J. Welton, B. N. Holben, S.-C. Tsay, N.-H. Lin, D. M. Giles, S. A. Stewart, S. Janjai, X. A. Nguyen, T.-C. Hsiao, W.-N. Chen, T.-H. Lin, S. Buntoung, S. Chantara, and W. Wiriya. 2015. "Vertical Distribution and Columnar Optical Properties of Springtime Biomass-Burning Aerosols over Northern Indochina during 2014 7-SEAS Campaign." *Aerosol and Air Quality Research*, 15: 2037-2050 (10.4209/aaqr.2015.05.0310).

Wang, S.-Y. S., J. Santanello, H. Wang, D. Barandiaran, R. T. Pinker, S. Schubert, R. R. Gillies, R. Oglesby, K. Hilburn, A. Kilic, and P. Houser. 2015. "An intensified seasonal transition in the Central U.S. that enhances summer drought." *J. Geophys. Res. Atmos.*, 120 (17): 8804-8816 (10.1002/2014jd023013).

Wargan, K., S. Pawson, M. A. Olsen, J. C. Witte, A. R. Douglass, J. R. Ziemke, S. E. Strahan, and J. E. Nielsen. 2015. "The Global Structure of Upper Troposphere-Lower Stratosphere Ozone in GEOS-5: A Multi-Year Assimilation of EOS Aura Data." *J. Geophys. Res. - Atmos*, 120: 2013-2036 (10.1002/2014JD022493).

Weaver, C. J., J. R. Herman, G. J. Labow, D. Larko, and L.-K. Huang. 2015. "Shortwave TOA cloud radiative forcing derived from a long-term (1980-present) record of satellite UV reflectivity and CERES measurements." *J. Climate*, 28 (23): 9473-9488 (10.1175/jcli-d-14-00551.1).

Williams, C. R., V. N. Bringi, L. D. Carey, V. Chandrasekar, P. N. Gatlin, Z. S. Haddad, R. Meneghini, S. Joseph Munchak, S. W. Nesbitt, W. A. Petersen, S. Tanelli, A. Tokay, A. Wilson, and D. B. Wolff. 2015. "Reply to "Comments on 'Describing the Shape of Raindrop Size Distributions Using Uncorrelated Raindrop Mass Spectrum Parameters'"." *J. Applied Meteorology and Climatology*, 54 (9): 1977-1982 (10.1175/jamc-d-15-0058.1).

Wilson, M., M. Durand, H. Jung, and D. Alsdorf. 2015. "Swath altimetry measurements of the mainstem Amazon River: measurement errors and hydraulic implications." *Hydrol. Earth Syst. Sci.*, 19: 1943-1959 (10.5194/hess-19-1943-2015).

Wolfe, G. M., T. F. Hanisco, H. L. Arkinson, T. P. Bui, J. D. Crounse, J. Dean-Day, A. Goldstein, A. Guenther, S. R. Hall, G. Huey, D. J. Jacob, T. Karl, P. S. Kim, X. Liu, M. R. Marvin, T. Mikoviny, P. K. Misztal, T. B. Nguyen, J. Peischl, I. Pollack, T. Ryerson, J. M. St. Clair, A. Teng, K. R. Travis, K. Ullmann, P. O. Wennberg, and A. Wisthaler. 2015. "Quantifying sources and sinks of reactive gases in the lower atmosphere using airborne flux observations." *Geophysical Research Letters*, 42 (19): 8231-8240 (10.1002/2015gl065839).

Wolff, D. B., D. A. Marks, and W. A. Petersen. 2015. "General Application of the Relative Calibration Adjustment (RCA) Technique for Monitoring and Correcting Radar Reflectivity Calibration." *J. of Atmospheric and Oceanic Technology*, 32 (3): 496-506 (10.1175/JTECH1700.1).

Xiao, Q., H. Zhang, M. Choi, S. Li, S. Kondragunta, J. Kim, B. N. Holben, R. C. Levy, and Y. Liu. 2015. "Evaluation of VIIRS, GOCI and MODIS Collection 6 AOD retrievals against ground sunphotometer measurements over East Asia." *Atmos. Chem. Phys. Discuss*, 15: 20709-20741 (10.5194/acpd-15-20709-2015).

Xiong, X., Aisheng Wu, B. N. Wenny, S. Madhavan, Zhipeng Wang, Yonghong Li, Na Chen, W. Barnes, and V. V. Salomonson. 2015. "Terra and Aqua MODIS Thermal Emissive Bands On-Orbit Calibration and Performance." *IEEE Transactions on Geoscience and Remote Sensing*, 53 (10): 5709-5721 (10.1109/tgrs.2015.2428198).

Xiong, X., L. Chen, Y. Liu, U. Cortesi, and P. Gupta. 2015. "Satellite Observation of Atmospheric Compositions for Air Quality and Climate Study." *Advances in Meteorology*, 2015: 1-2 (10.1155/2015/932012).

Yang, X., J. Tang, J. F. Mustard, J.-E. Lee, M. Rossini, J. Joiner, J. W. Munger, A. Kornfeld, and A. D. Richardson. 2015. "Solar-induced chlorophyll fluorescence that correlates with canopy photosynthesis on diurnal and seasonal scales in a temperate deciduous forest." *Geophysical Research Letters*, 42 (8): 2977-2987 (10.1002/2015gl063201).

Yasunari, T. J., R. D. Koster, W. K. Lau, and K.-M. Kim. 2015. "Impact of snow darkening via dust, black carbon, and organic carbon on boreal spring climate in the Earth system." *J. Geophys. Res. Atmos*, 120 (11): 5485–5503 (10.1002/2014JD022977).

Yava l , D. D., C. J. Tucker, and K. A. Melocik. 2015. "Change in the glacier extent in Turkey during the Landsat Era." *Remote Sensing of Environment*, 163: 32–41 (10.1016/j.rse.2015.03.002).(Glaciers)

Yoshida, Y., J. Joiner, C. J. Tucker, J. Berry, J. E. Lee, G. K. Walker, R. H. Reichle, R. D. Koster, A. I. Lyapustin, and Y. Wang. 2015. "The 2010 Russian drought impact on satellite measurements of solar-induced chlorophyll fluorescence: Insights from modeling and comparisons with parameters derived from satellite reflectances." *Remote Sensing of Environment*, 166: 163–177 (10.1016/j.rse.2015.06.008).(Theory & Modeling, Vegetation & Soil)

Yu, H., M. Chin, H. Bian, T. L. Yuan, J. M. Prospero, A. H. Omar, L. A. Remer, D. M. Winker, Y. Yang, Y. Zhang, and Z. Zhang. 2015. "Quantification of Trans-Atlantic Dust Transport from Seven-year (2007-2013) Record of CALIPSO Lidar Measurements." *Remote Sens. Environ*, 159: 232-249 (10.1016/j.rse.2014.12.010).

Yu, H., M. Chin, T. L. Yuan, H. Bian, L. A. Remer, J. M. Prospero, A. Omar, D. Winker, Y. Yang, Y. Zhang, Z. Zhang, and C. Zhao. 2015. "The fertilizing role of African dust in the Amazon rainforest: A first multiyear assessment based on data from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations." *Geophysical Research Letters*, 42 (6): 1984-1991 (10.1002/2015GL063040).

Yuan, T., H. Lee, and H. Jung. 2015. "Toward estimating wetland water level changes based on hydrological sensitivity analysis of PALSAR backscattering coefficients over different vegetation fields." *Remote Sensing*, 7: 3153-3183 (10.3390/rs70303153).

Zhang, L., D. K. Henze, G. A. Grell, G. R. Carmichael, N. Bousserez, Q. Zhang, O. Torres, C. Ahn, Z. Lu, J. Cao, and Y. Mao. 2015. "Constraining black carbon aerosol over Asia using OMI aerosol absorption optical depth and the adjoint of GEOS-Chem." *Atmos. Chem. Phys.*, 15 (18): 10281-10308 (10.5194/acp-15-10281-2015).

Appendix 1: Refereed Articles

Zhang, Q., Y.-B. Cheng, A. I. Lyapustin, Y. Wang, X. Zhang, A. Suyker, S. Verma, Y. Shuai, and E. M. Middleton. 2015. "Estimation of crop gross primary production (GPP): II. Do scaled MODIS vegetation indices improve performance?" *Agricultural and Forest Meteorology*, 200: 1-8 (10.1016/j.agrformet.2014.09.003).

Zhou, Y., W. K. Lau, and G. J. Huffman. 2015. "Mapping TRMM TMPA Into Average Recurrence Interval for Monitoring Extreme Precipitation Events." *J. Appl. Meteor. & Climatol*, 54 (5): 979-995 (10.1175/JAMC-D-14-0269.1).

Ziemke, J. R., A. R. Douglass, L. D. Oman, S. E. Strahan, and B. N. Duncan. 2015. "Tropospheric ozone variability in the tropics from ENSO to MJO and shorter timescales." *Atmos. Chem. Phys.*, 15 (14): 8037-8049 (10.5194/acp-15-8037-2015).