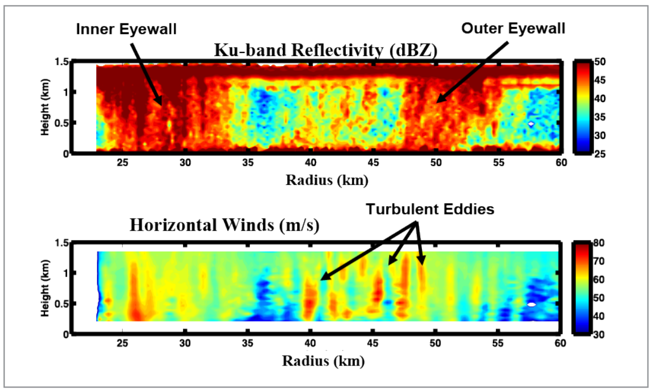
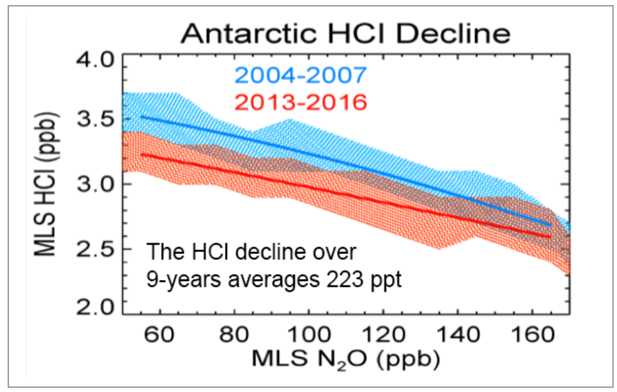
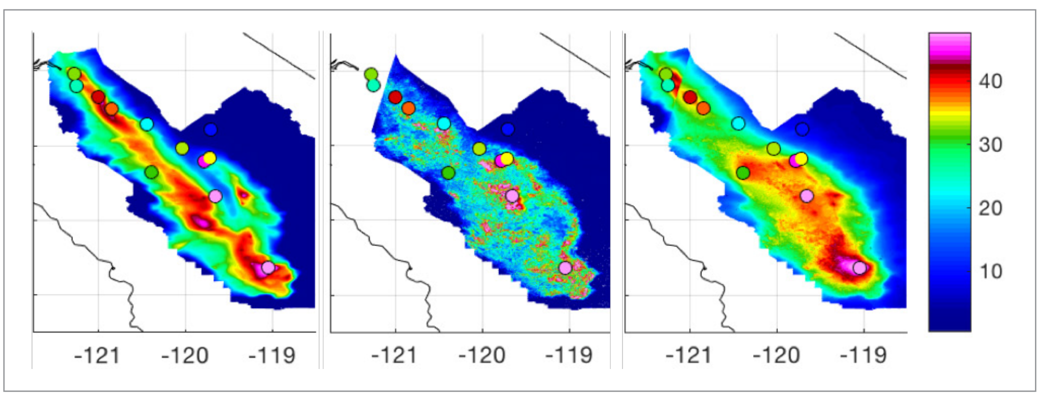
NASA/TM–2019-219038

Atmospheric Research 2018 Technical Highlights







August 2019

On the Cover:

Top left: *Radar Observations Discover Unknown Structure of Coherent Turbulence in the Hurricane Boundary Layer*

These figures show the structure of turbulent filaments with the most intense eddies located at the inner edge of the outer eyewall. Measurements of this intense and dangerous layer are difficult to make and have relied heavily on instruments dropped from aircraft, which are not optimal for capturing the full structure. New analysis of IWRAP radar data provides a first look at coherent turbulence in the boundary layer of Hurricane Rita (2005). The structure of these coherent turbulent features is different than the prevailing understanding of boundary layer rolls, which transport high momentum air downwards towards the ocean surface. *(Section 2.1.9)*

Top right: *Antarctic HCL Decline*

This study takes advantage of Antarctic chemistry that converts all of the inorganic Cl species into HCl during a brief period each spring. The MLS HCl measurements during this period represent the sum of Cl compounds that can destroy O_3. The ozone depletion calculated from MLS ozone data varies with changing chlorine levels (Cly) that were determined from MLS HCl measurements. We see that for constant values of N_2O, HCl is really declining, and that can only happen because stratospheric chlorine loading is declining. *(Section 2.3.1)*

Middle: *Surface $PM_{2.5}$ Fields & Ground Observations of San Joaquin Valley*

Traditionally, regional-level air quality in populated areas is assessed through chemical transport model (CTM) simulations, loosely constrained by observations from surface monitoring stations which typically provide limited coverage downwind of major pollution sources, or none at all. We examined the optimal application of this physical technique in the San Joaquin Valley. Surface $PM_{2.5}$ concentration maps of the regional CTM output are illustrated in the left image, the combined satellite-based output of aerosol airmass-type maps from the MISR RA and total-column aerosol optical depth from the MISR RA and MAIAC are displayed in the center. The final right image shows the physically optimized (i.e., surface observations + satellite-based observations + model output) maps. The images show that the optimized concentration maps are spatially consistent with topography, typifying localized hotspots over known urban areas, and exhibiting realistic dispersion patterns. The optimized air quality estimation accuracy identifies and quantifies specific drivers of adverse, multi-pollutant health effects. *(Section 2.2.9)*

Bottom: *NASA's Precipitation Imaging Processor (PIP)*

The unit consists of a halogen light source and a video camera that captures falling precipitation at 400 frames per second over an area of 64 mm × 48 mm (640 × 480 pixels) with 0.1 mm resolution (Courtesy of Kwonil Kim, Kyungpook National University). NASA deployed its PIP in support of the 2018 Winter Olympics in Pyeongchang, South Korea. The PIP is a Wallops-built instrument that uses high resolution video to capture falling snow. One of the unique abilities of this instrument/software package is its ability to estimate the effective density of snow, based on the observed fall speed of the snowflakes. Density is needed to retrieve the liquid water content of the falling snowflakes and hence water flux, which is critical to closing the hydrological cycle. *(Section 2.4.2)*

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

NASA/TM–2019-219038

Atmospheric Research 2018 Technical Highlights

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

August 2019

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 NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

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- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

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- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

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National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Dear Reader,

Welcome to the 2018 Atmospheric Research Highlights report, summarizing Earth atmospheric science and communication/outreach accomplishments from NASA's Goddard Space Flight Center (GSFC). As in previous years, this report is intended for a broad audience, including colleagues within NASA, scientists outside the Agency, science graduate students, and members of the public.

Organizationally, the report covers research activities under the Office of Deputy Director for Atmospheres (610AT), which is within Earth Sciences Division (610) in the Sciences and Exploration Directorate (600). Laboratories and office within 610AT include: Mesoscale Atmospheric Processes Laboratory (612), Climate and Radiation Laboratory (613), Atmospheric Chemistry and Dynamics Laboratory (614), and the Wallops Field Support Office (610.W). As of this writing, 610AT personnel are 59 civil servants and 251 cooperative agreement or contractor scientific and technical staff.

While the report provides a comprehensive summary of 610AT 2018 activities, I'm happy to highlight a few items here.

Satellite Observations: The first Earth cloud observing CubeSat, IceCube, acquired 16 months of cloud data at orbital altitudes of 200-400 km before its reentry to the atmosphere on October 3, 2018. On September 29, 2018, four days before its reentry, IceCube was able to capture cloud features from Typhoon Trami at an orbital altitude of ~200 km. The IceCube calibrated radiances produced the first 883-GHz cloud ice map, which shows consistent amplitudes with the cloud ice observed during the same period by the Microwave Limb Sounder (MLS) at 240 and 640 GHz.

610AT personnel were involved in numerous other satellite efforts. Satellite missions of special note include the Global Precipitation Measurement (GPM) mission, entering its fourth year in orbit, Deep Space Climate Observatory/Earth Polychromatic Imaging Camera (DSCOVR/EPIC) completing its third year in orbit, and the venerable Earth Observing System (EOS) missions Terra, Aqua and Aura that have provided almost two decades of science observations (19 years for Terra). Meanwhile Suomi NPP, with an instrument suite designed to provide continuity with many of the EOS data records, celebrated its seventh anniversary in 2018. 610AT scientists developed many of the atmospheric algorithms used for generating scientific data products from these satellite sensors and are actively involved in analysis and interpretation of these datasets. Physical, dynamic and chemical computers models developed in 610AT are essential to fully utilizing these data.

I'm happy to announce the following satellite project-related changes in 2018: Scott Braun (612) became the GPM Project Scientist and Robert Levy (613) became the GOES Flight Deputy Project Scientist.

Suborbital deployments: Many of our scientists were involved in major NASA suborbital (ground-based and aircraft) field campaigns during 2018.

The 2018 Winter Olympics and Paralympics took place in South Korea on February 9-25 and March 8-18, respectively. David Wolff (610.W) and the GPM Ground Validation (GV) program at Wallops along with the Mesoscale Processes Laboratory (612) were major participants. The GV observations were part of a team effort geared toward the synergistic validation of GPM satellite estimates of snowfall and the NASA Unified Weather Research and Forecast (NU-WRF) model's predictive capability for mountain snow events.

During the summer of 2018, Thomas McGee (614) and John Sullivan (614) completed the Ozone Water Land Environmental Transition Study (OWLETS-2) that took place in the northern Chesapeake Bay region between Washington, D.C. and Baltimore, Maryland. During the study they investigated air quality interactions at the coastal interface with various platforms of observations including ground based instruments from GSFC, such as TOLNet, Pandora, AeroNet, MPLNet, and additional sensors from Code 614. Aircraft flights from the UMD Cessna and NASA GeoTASO were also supported. Research vessels were also utilized to sample directly overwater pollutant concentrations.

In addition to OWLETS-2, the NASA Pandora Project (Bob Swap, 614) also supported the Long Island Sound Tropospheric Ozone Study (LISTOS) with 11 instruments, 7 of which became long-term fixed observation sites. Over 15 peer-reviewed manuscripts that utilized Pandora data were published in calendar year 2018. MPLNET supported several short-term field campaigns. A site in Bidur, Nepal was setup to support the RAJO-MEGHA field campaign. Two additional sites in Taiwan were added at Kaohsiung and Xitun to support local air quality studies and the long running 7-SEAS field campaign.

Anne Thompson (610) and the Southern Hemisphere ADditional OZonesondes (SHADOZ) teams carried out launches from 13 stations around the world during 2018. There are now more than 7500 sets of archived SHADOZ ozone and radiosonde profiles at the website https://tropo.gsfc.nasa.gov/shadoz. Work also continued on the first major reprocessing of the 20-year SHADOZ data record.

Special Recognition: As in previous years, 610AT scientists garnered professional honors and other recognition during 2018.

Paul Newman (610) was elected as president-elect for the American Geophysical Union Atmospheric Sciences Section.

James Gleason (614) received the Robert H. Goddard Award of Merit for exceptional and far-reaching career achievements, including the role of Project Scientist for critical next generation NASA-NOAA polar orbiting satellite systems.

Anne Thompson (610) received the 2018 William Nordberg Memorial Award for Earth Sciences in recognition of her wide-ranging national and international scientific research and service.

Scott Braun (612) and George Huffman (612) were named Fellows of the American Meteorological Society. They received their honors at the 99th American Meteorological Society (AMS) annual meeting in Phoenix, Ariz. during the week of January 6-10, 2019.

Ali Tokay (612, UMBC) received the AMS Editor's Award for his contribution to the *Journal of Applied Meteorology and Climatology* for his in-depth reviews of precipitation manuscripts.

Wei-Kuo Tao (612) was elected as a fellow of the Meteorological Society of Republic of China (Taiwan) for excellent scientific research in the development of cloud solving models.

Mian Chin (614) was listed in the Clarivate Analytics list of 2018 Highly Cited Researchers.

David Wolff (610W) was recognized by the National Space Club Scholars Program (sponsored by NASA in cooperation with the National Space Club and Foundation) for Student Mentoring during the summer 2018 session.

Santiago Gassó (613, UMD) was chosen by students at the Huinca Renancó Middle School in Córdoba, Argentina, as a notable Argentinean scientist in atmospheric sciences and recognized fot his work on dust transport.

Civil Servant Personnel: I was pleased to welcome Natalya Kramarova (614) in early 2018. Natalya received her Ph.D. Degree in Physics and Mathematics (2007) from Moscow State University, Moscow, Russia. She worked on developing a radiative transfer algorithm and studying long-term ozone variability caused by natural processes, such as the 11-year Solar cycle, Quasi-Biennial Oscillation, etc.

George Huffman was appointed Assistant Lab Chief for 612. George, who became a Goddard civil servant in 2012, is a recognized world-class scientist in the analysis of global satellite precipitation data and the development of highly valued multi-sensor global precipitation data sets used across the international scientific community.

Transitions: Dennis Chesters (613) retired following nearly 40 years of federal service. Dennis provided leadership over many years that successfully helped realize the goals of NASA's GOES-POES program by serving as project scientist to NOAA's geosynchronous weather and climate monitoring satellites. As GOES Project Scientist, Dennis assured the scientific integrity of the present and future GOES operational environmental sensors. He was particularly attentive to aspects that enable well-calibrated long-term environmental monitoring from GOES. Dennis was that rare combination, both scientist and technological innovator, that has provided invaluable services to the GOES program and to the scientific community over the years.

Gail Jackson (612) transferred to the NASA Headquarters Earth Sciences Division to become a program manager in the weather focus area. Gail was a highly accomplished and well-regarded scientist specializing in ice cloud particle retrievals through microwave remote sensing. While at Goddard, she was the project scientist for GPM and chief of the Mesoscale Atmospheric Processes Laboratory (612). I wish her well in her new position.

Theodore (Ted) Jackson retired after 20+ years of service at Goddard in the Mesoscale Atmospheric Processes Laboratory (612). Ted provided outstanding support of computing systems, deep technical expertise of multiple operating systems, and led development of the Laboratory computing facility. He will be greatly missed.

Lisa Madden (612, ADNET) retired in mid-October. She has had many years of service to NASA both here and at Glenn Research Center as a systems administrator. She will also be greatly missed.

We are saddened that Lin Tian passed away on May 9, though peacefully. Lin was a longtime member of Code 612, most recently working on aircraft radar data analysis for precipitation. She is sorely missed.

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

Steven Platnick
Deputy Director for Atmospheres
Earth Sciences Division, Code 610

March 2019

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

These data show that the scientific work being conducted in the Laboratories is competitive with the work being done elsewhere at 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 at 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 2018. 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 website https://atmospheres.gsfc.nasa.gov.

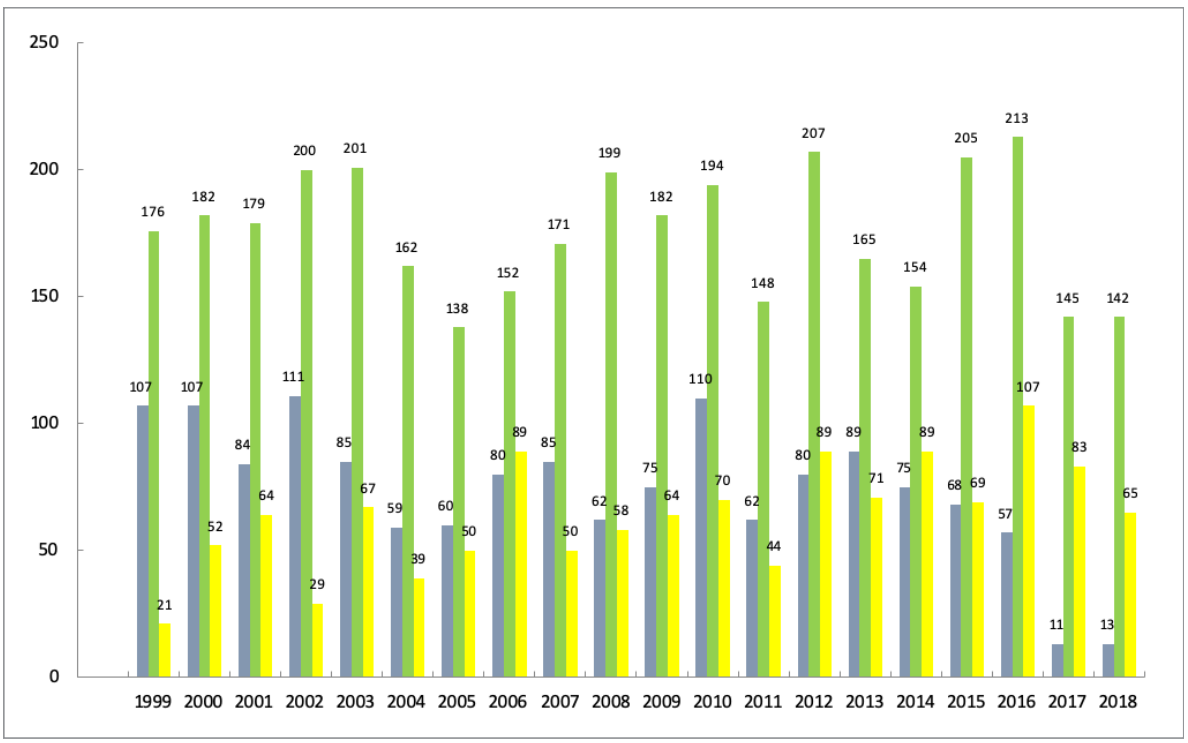


Figure 1.1: *Number of proposals and referred publications by atmospheric sciences members over the years. The green bars are the total number of publications and the blue bars the number of publications where a Laboratory member is first author. Proposals submitted are shown in yellow.*

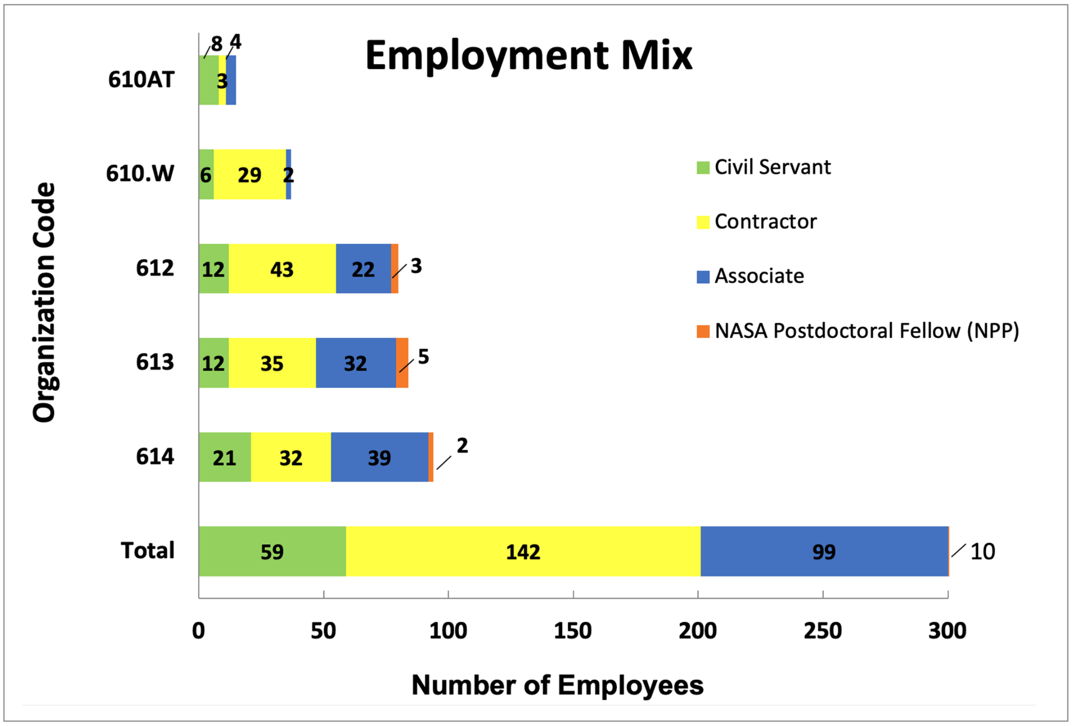


Figure 1.2: *Breakdown of the organizational employee mix.*

2. SCIENCE HIGHLIGHTS

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

The following sections summarize some of the scientific highlights of each Laboratory and the Wallops Field Office for the year 2018. The individual contributor(s) are named at the end of each summary. Additional highlights and other information may be found at the website: https://atmospheres.gsfc.nasa.gov.

2.1. Mesoscale Atmospheric Process 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. A major emphasis is placed on understanding energy exchange and conversion mechanisms; especially cloud microphysical development and latent heat release associated with atmospheric motions. The research is inherently focused on defining the atmospheric component of the global hydrologic cycle, especially precipitation, and its interaction with other components of the Earth system. The Laboratory also played a key science leadership role in the Tropical Rainfall Measurement Mission (TRMM), launched in 1997, and in developing the Global Precipitation Measurement (GPM) mission concept and continuing to lead scientific investigations. 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 as follows.

2.1.1. Using CATS near-real time data to monitor volcanic plume transport

The Cloud Aerosol Transport System (CATS) directly supports NASA's strategic goal to advance understanding of Earth and develop new technologies for future Earth Science missions by utilizing the International Space Station (ISS) as a low-cost platform for Earth Science. CATS advances the space-based lidar record that is vital to understanding the Earth's climate system by providing diurnally varying vertical profiles of clouds and aerosols to determine their transport and radiative effects, key uncertainties in predicting the Earth's radiation balance. CATS provides minimal data latency to produce near-real time data products within six hours of data collection. This enables aerosol forecast modeling that reduces economic loss and air travel-related deaths through applications such as forecasting volcanic plume transport for aviation safety. OMPS and CATS observations of the Mt. Etna SO_2 plume on December 4, 2015 are shown in Figure 2.1.1. A map of the total column SO_2 from OMPS on December 4 (A) shows a thin plume was transported towards the east. The CATS Attenuated Total Backscatter (ATB) profiles at 1064 nm (B & C) show that the Mt. Etna volcanic plume is located at an altitude of 14 km just east of the Mediterranean Sea, and 12 km further east. An asterisk (*) is used to denote CATS nighttime observations.

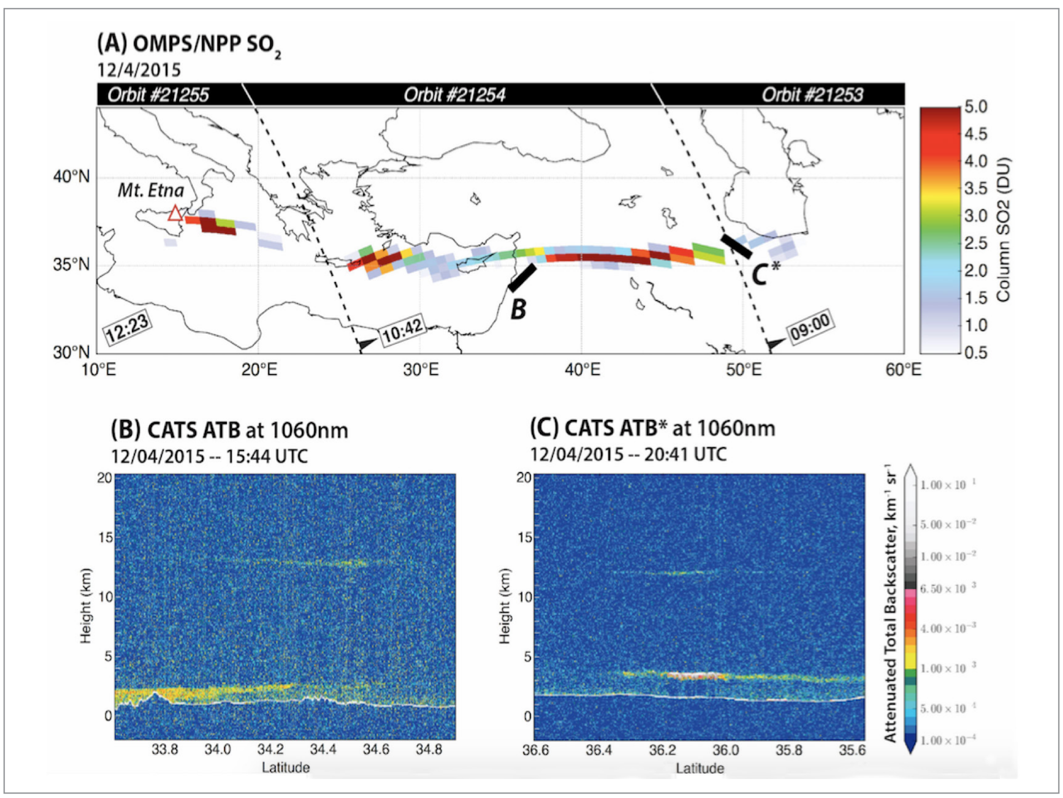


Figure 2.1.1: *CATS observed the Mt. Etna plume on December 4, 2015 at altitude of 12-14 km (B & C), higher than estimated using trajectory analysis (8-12 km.) CATS near-real time data provided an unprecedented opportunity to monitor and predict volcanic plume transport. J. Yorks (612), E. Hughes, (614, UMD); et al.*

2.1.2. The impact of hail and large ice on multi-frequency radar observations

The findings in this work, and other related papers, are the first conclusive evidence that multiple scattering can be significant in convective storms with large ice. This includes even the lowest Ku-band frequency on GPM, and it highlights the deficiencies with using higher frequencies such as Ka band for measuring strong thunderstorms. Multiple scattering is very difficult to detect with single frequency spaceborne radars (GPM DPR Ku or Ka bands, CloudSat) because of the large footprints and non-uniform beam filling. Multiple scattering signatures are now being detected in GPM DPR data, and these effects will be included in future GPM algorithms. Given the high societal impact of intense thunderstorms and hail, resolving the challenges of interpreting radar data affected by multiple scattering will increase the value of airborne and spaceborne observations of precipitation. These results are highly relevant to future missions such as Aerosol, Chemistry, and Ecosystems (ACE) in the previous *Decadal Survey*, and Clouds, Convection, and Precipitation (CCP) in the *2017 Decadal Survey*. Vertical profiles of radar reflectivity are shown in Figure 2.1.2 for one location in a storm core for the four frequencies. The shaded curves depict the observed reflectivity profiles. The dotted curves show the calculated single scattering reflectivity based on the assumption of hail, and the diamond symbols show the calculated reflectivity given the same assumptions, but including multiple scattering effects. The shapes of these profiles contain what has been called a "knee" where the reflectivity, initially decreasing toward the surface due to attenuation and non-Rayleigh scattering (dotted curve), anomalously flattens because of multiple scattering (diamonds) driven by the presence of hail and other large ice particles.

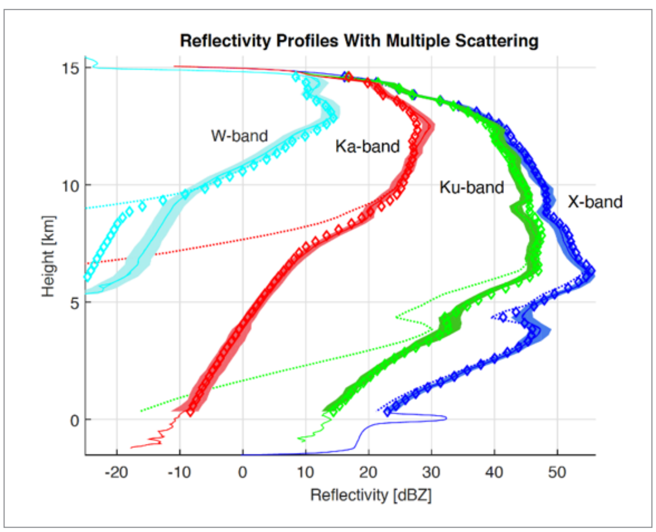


Figure 2.1.2: *Four-frequency measurements from GSFC CRS (W), HIWRAP, and EXRAD radars on the NASA ER-2 for North Carolina hailstorms.*

Contributors: G. Heymsfield (612), L. Tian (612, MSU), et al.

Reference: Heymsfield, G. M., L. Tian, L. Li, M. McLinden, and J. I. Cervantes, 2013: Airborne Radar Observations of Severe Hailstorms: Implications for Future Spaceborne Radar. *J. Appl. Meteor. Climatol.*, **52**, 1851-1867, https://doi.org/10.1175/JAMC-D-12-0144.1.

2.1.3. NASA HS3 observations of the inner-core temperature structure of hurricane Edouard (2014)

For decades, the scientific community has accepted that the maximum perturbation temperature, or "warm core," of tropical cyclones (TC) is confined to upper-levels. However, this study and other recent observational and modeling studies have suggested that the inner-core temperature structure is not as well-known; perturbation temperature maxima of approximately equal magnitude were observed in Edouard (2014) in both the mid- and upper-levels of the atmosphere by Hurricane and Severe Storm Sentinel (HS3) high-altitude dropsondes. As the ability to forecast tropical cyclones intensity, which is dominated by more chaotic inner-core processes, remains challenging, it is crucial to obtain an accurate depiction of the evolution of the inner-core temperature structure and the relationship between subsequent TC intensity changes. The results in this study demonstrate that in order to remotely sense the inner-core temperature structure of TCs, the need for both increased vertical resolution and the ability to penetrate clouds are essential. As shown in Figure 2.1.3, HS3 sampled Edouard's inner-core temperature structure through the use of high-altitude dropsondes (b) and S-HIS (c). A warm core magnitude of ~10 K was observed in both the mid- and upper-levels; AMSU-A (d) and a high-resolution model (a) were unable to resolve the magnitude or detailed vertical structure of the warm core.

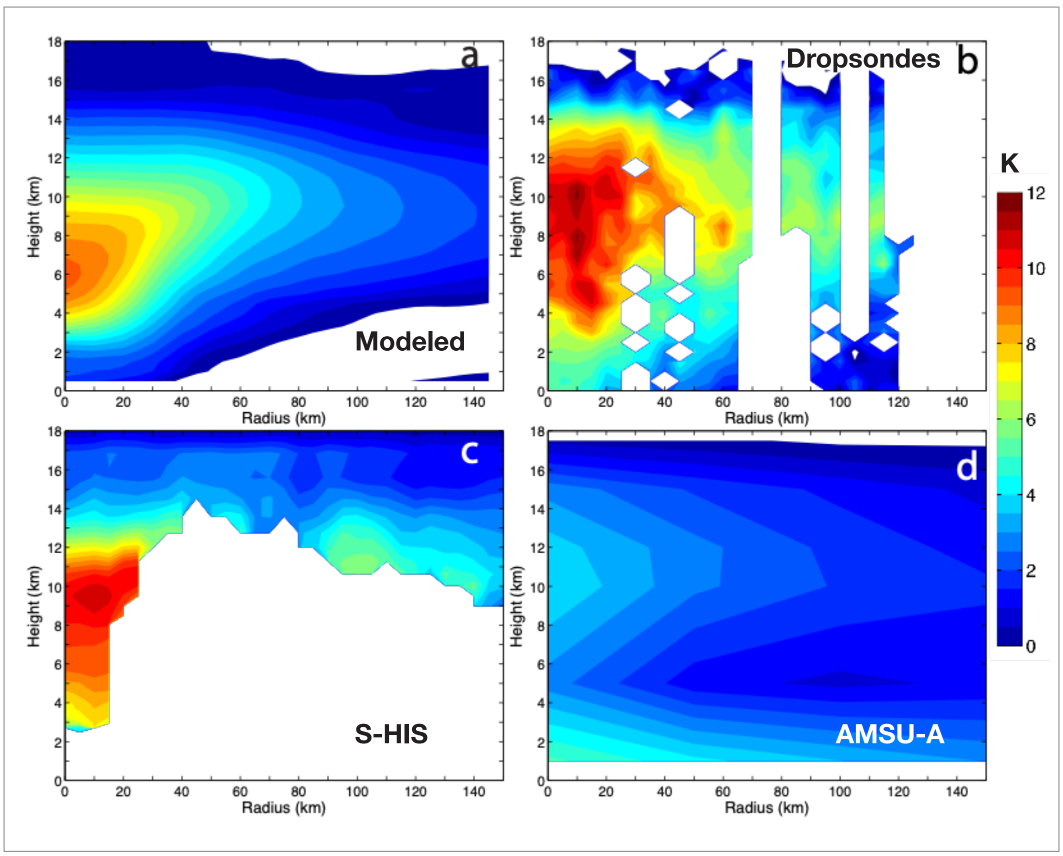


Figure 2.1.3: *A comparison between Hurricane Edouard's (2014) modeled and observed inner-core temperature structure highlights the need for direct measurements of the magnitude and vertical structure of the warm core of tropical cyclones.*

Contributors: E. B. Munsell (612, USRA), F. Zhang (PSU), S. A. Braun (612), J. A. Sippel (NOAA/AOML/HRD), and A. C. Didlake (PSU)

Reference: Munsell, E. B., F. Zhang, S. A. Braun, J. A. Sippel, and A. C. Didlake, 2018: The inner-core temperature structure of Hurricane Edouard (2014): Observations and ensemble variability. *Mon. Wea. Rev.*, **146**, 135-155, https://doi.org/10.1175/MWR-D-17-0095.1.

2.1.4. Numerical weather prediction models show both challenges and improvements in simulating intense wintertime cyclones

High-impact winter time events that occur in the northeastern U.S. (i.e., nor'easters) several times during a typical winter and can cause billions of U.S. dollars in damage per event. Nor'easter events are a high-level target of interest for precipitation- and cloud-focused missions including GPM and CloudSAT. Simulating nor'easters with numerical weather prediction models, such as weather research and forecasting (WRF), NU-WRF, and GEOS-5, provide a unique means to tease out the processes underpinning these power cyclones at time and spatial scales not yet addressed sufficiently from space-based platforms. WRF simulations of seven intense wintertime cyclones in January 2015 demonstrate minimal sensitivity between five: cloud physics parameterizations and broader cyclone characteristics (intensity, winds, timing, precipitation coverage, etc.); yet cyclone radar reflectivity structures are highly sensitive to cloud physics. Simulated radar reflectivity probability distribution function (PDF) overlap scores (calculated hourly and every 250 m vertically) indicate a tendency for lower model predictive skill near and just above the freezing level (~3,000 m) when evaluated against observed radar reflectivity (Multi-Radar/Multi-Sensor, MRMS). Lower reflectivity PDF scores stem from excessive generation of snow and especially highly reflective graupel hydrometeors off the U.S. coast. Improvements in PDF overlap scores and simulated reflectivity underscore recent Goddard Cumulus Ensemble (GCE) cloud physics improvements.

Contributors: S. D. Nicholls (612, UMBC), S. G. Decker (RU), et al.

Reference: Nicholls, S. D., S. G. Decker, W.-K. Tao, S. E. Lang, J. J. Shi, and K. I. Mohr, 2017: Influence of bulk microphysics schemes upon Weather Research and Forecasting (WRF) version 3.6.1 nor'easter simulations. *Geosci. Model Dev.*, **10**, 1033-1049, https://doi.org/10.5194/gmd-10-1033-2017.

2.1.5. Improved ocean wind retrievals from combined active-passive microwave remote sensing

The ability of passive microwave radiometers to estimate ocean winds has long been recognized, and dedicated wind vector missions using passive microwave radiometry (e.g., WindSat) or active scatterometry (e.g., QuikSCAT, RapidScat) have proven valuable for numerical weather prediction and as climate data records. While not designed as a wind mission, the instrument suite is also well-equipped to retrieve ocean surface winds in clear skies and light-to-moderate precipitation, owing to the stability, accuracy, and high resolution of the GPM Microwave Imager (GMI) and the sensitivity of DPR-measured surface backscatter to ocean roughness. Wind retrievals were implemented in version 5 of the combined DPR-GMI precipitation product. The GPM retrievals offer comparable performance to these dedicated missions, particularly in the presence of precipitation (made possible in the combined radar-radiometer framework), which has long been a challenge for single-instrument retrievals. These results highlight that innovative use of measurements can provide useful information about geophysical parameters beyond the mission primary objectives, and that seemingly unrelated observables can be targeted by the same instrumentation in future missions if similar overlaps can be identified. The data provided by the combined radar-radiometer wind and precipitation retrievals can also be used in scientific studies that require co-located, high resolution (5 km) wind and precipitation fields, such as cold pool dynamics studies, small-scale structure of the Intertropical Convergence Zone (ITCZ), and wind fields in extratropical cyclones.

Contributors: S. J. Munchak (612), R. Meneghini, (612) W. S. Olson (612, UMBC), M. Grecu (612, MSU)

Reference: Munchak, S. J., R. Meneghini, M. Grecu, and W. S. Olson, 2016: A Consistent Treatment of Microwave Emissivity and Radar Backscatter for Retrieval of Precipitation over Water Surfaces. *J. Atmos. Oceanic Technol.*, **33**, 215-229, https://doi.org/10.1175/JTECH-D-15-0069.1.

2.1.6. Assimilation of NASA satellite observations of precipitation brings crucial information into modeling of West Africa monsoon in data sparse regions

GPM provides global coverage of precipitation observations. Assimilation of this data brings crucial information about precipitation and hydrological cycles into our Earth environment modeling systems and is particularly significant in data sparse regions. The experiments of assimilating GPM multi-sensor, multi-channel, precipitation-sensitive radiances into the NASA NU-WRF model show remarkable improvement to West African monsoon rain band location and intensity. It also has a better representation of continental tropical convective cloud systems that enhances the connection between tropical waves and storm initiation and propagation. The precipitation of the West African monsoon (WAM) not only provides vital water resources to the region, but also modulates tropical climate, influences the initiation of tropical cyclones, and is potentially impacted by global climate change. GPM provides crucial observations over the data sparse continent. We developed an innovative, ensemble-based data assimilation technique to optimally integrate a high-resolution numerical model prediction and observed precipitation-sensitive radiances from GPM constellation satellites, where the resulting forecast error covariance can propagate observation information into regions where it matters most: storms and severe weather areas. This data assimilation system, developed for GPM science applications, pioneered the direct assimilation of precipitation-sensitive radiances over land surfaces into cloud-resolving forecast, and results obtained from this study verified the positive data impact of precipitation-sensitive microwave observations. Satellite observations and cloud-resolving prediction models allow us to forecast and study the evolution of precipitating systems such as the WAM, providing timely data to impacted populations and expanding our knowledge of the Earth system. Cloud-scale dynamical models will benefit from the CCP targeted observable designated by the National Academies *Decadal Survey*.

Contributors: S. Q. Zhang (612, SAIC), T. Matsui, (612, UMD) S. Cheung (UC-Davis), M. Zupanski (CSU/CIRA), C. Peters-Lidard (610)

Reference: Zhang, S. Q., T. Matsui, S. Cheung, M. Zupanski, and C. Peters-Lidard, 2017: Impact of Assimilated Precipitation-Sensitive Radiances on the NU-WRF Simulation of the West African Monsoon. *Mon. Wea. Rev.*, **145**, 3881-3900, https://doi.org/10.1175/MWR-D-16-0389.1.

2.1.7. Next-generation tropical and warm season convective-stratiform heating algorithm for GPM improves low- and mid-level heating estimates

The Goddard Convective-Stratiform Heating Algorithm has been used to estimate cloud heating since TRMM's launch and is being used to estimate cloud heating from GPM. The latest version uses newer cloud-resolving simulations from the Goddard cumulus ensemble (GCE) model to build look-up tables and adopts two new metrics for mapping simulated heating structures to the satellite: echo top heights and low-level echo gradients. The new retrievals have a smaller heating bias versus input surface rainfall than previous versions.

Cloud latent heating is an important driver for a range of atmospheric circulations, especially in the tropics. It is the primary driver for the large-scale Hadley circulation, provides import feedbacks to monsoon circulations, and strongly influences the Madden-Julian Oscillation (MJO). At smaller scales, it is the main energy source for the maintenance and intensification of tropical cyclones. Its estimation was one of the primary objectives of TRMM and is still a key objective of GPM. Being able to estimate cloud heating from TRMM and now GPM satellite data allows us to improve our understanding of its relationship to tropical circulations and weather and assist in the numerical simulation of such events by providing a framework for the cloud effects that must be accounted for in those models. On longer time scales, changes in rainfall or its characteristics can be connected to changes in heating, and thus to potential changes in atmospheric circulations.

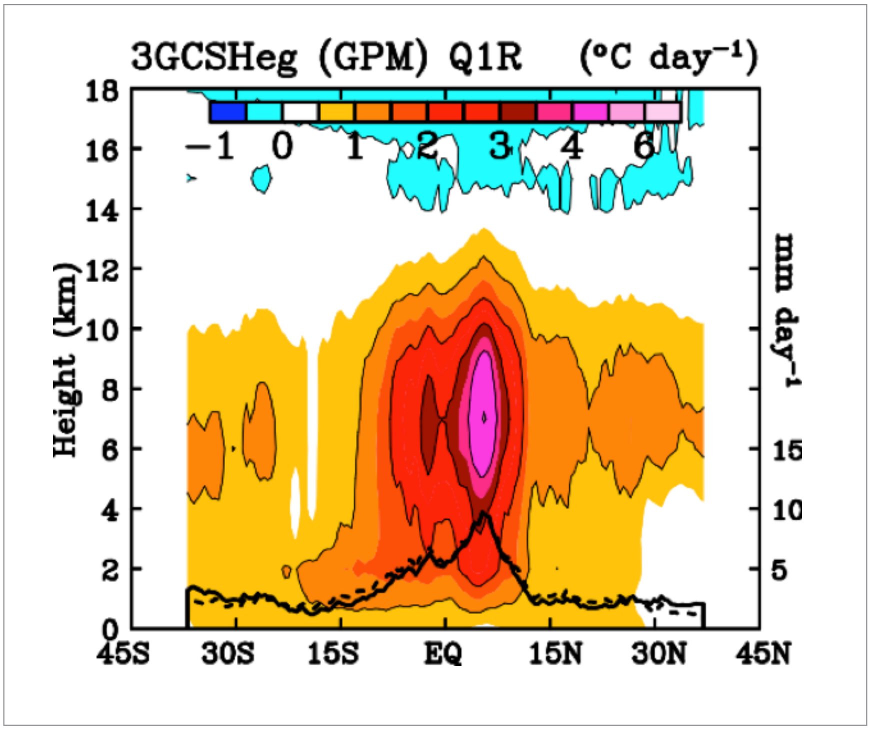


Figure 2.1.7: *Zonal cross section (latitude vs height) of mean cloud heating (latent heating + cloud eddy effects) retrieved from the latest version of the Goddard Convective-Stratiform Heating (CSH) algorithm for the 3 month period, April-June 2014. Overlaid are zonal mean surface rainfall (solid black line) and zonal mean equivalent surface rainfall.*

Contributors: S. Lang (612, SSAI) and W.-K. Tao (612)

Reference: Lang, S. E., and W.-K. Tao, 2018: The next-generation Goddard Convective-Stratiform Heating Algorithm: New Tropical and Warm Season Retrievals for GPM. *J. Clim.*, Early Online Release (April 25, 2018), Global Precipitation Measurement Special Collection, https://doi.org/10.1175/JCLI-D-17-0224.1.

2.1.8. Microphysics and radiation effect of dust on the Saharan air layer (SAL)—A HS3 case study

This study uses HS3 observations and simulations to examine Saharan air layer (SAL) structure and the impact of dust on environmental structure. Changes in temperature vertical motion specific humidity and relative humidity associated with the radiative and microphysical impacts of dust aerosols were observed. The difference between the simulation with radiative and microphysical effects (AMR) and the simulation without radiative and microphysical interactions (NoAMR) was also determined. The Global Hawk provides a valuable capability for mapping out large regions of the SAL and its environment. Observations of this SAL event are discussed in a paper (see reference) and are used to validate the numerical simulation. While HS3 was focused on tropical cyclones, this study addresses one of its secondary objectives, to characterize the structure and impacts of the SAL. Using the NUWRF model with interactive dust, we assess the impact of Saharan dust on the thermodynamic and kinematic structure of the SAL and its environment. These effects can have implications for the interaction of the SAL with African easterly wave disturbances that are often the precursors for Atlantic hurricanes.

Contributors: Z. Tao (614, USRA), S. A. Braun (612), J. J. Shi (612, MSU), M. Chin (614), D. Kim (614), T. Matsui (612, UMD), C. D. Peters-Lidard (610)

Reference: Tao, Z., Tao, S. A. Braun, J. J. Shi, M. Chin, D. Kim, T. Matsui, and C. Peters-Lidard, 2018: Microphysics and radiation effect of dust on Saharan Air Layer—A HS3 case study. *Mon. Wea. Rev.*, **146**, 1813-1835, https://doi.org/10.1175/MWR-D-17-0279.1.

2.1.9. Radar observations discover unknown structure of coherent turbulence in the hurricane boundary layer

Observations of the hurricane boundary layer (ocean surface to ~1 km height) are important for vulnerable coastal communities and making predictions of storm intensity. These observations are difficult to obtain and have relied on point measurements taken from "dropsondes." New analysis of Imaging Wind and Rain Airborne Profiler (IWRAP) radar data provides a first look at coherent turbulence in the boundary layer of Hurricane Rita (2005). Intense turbulent eddies with new circulation signatures are connected to the evolution of the "eyewall replacement cycle" where an outer eyewall contracts and merges with the inner eyewall. The destructive power of hurricanes is unlike anything else on Earth with the proven capability to significantly damage the U.S. economy, destroy entire regions and kill thousands of people even in the modern era. The boundary layer of a hurricane (ocean surface to ~1 km height) is of prime importance for vulnerable coastal communities and for making accurate forecasts of storm intensity that can help mitigate the loss to life and property. Measurements of this intense and dangerous layer are difficult to make and have relied heavily on instruments dropped from aircraft, which are not optimal for capturing the full structure. New processing and analysis of data from the IWRAP in intense Hurricane Rita (2005) are able to provide the nearly full structure of the turbulent boundary layer at very high resolution, filling a crucial measurement gap.

Contributors: S. Guimond (612, UMBC), J. Zhang (NOAA/HRD, UMIAMI), J. Sapp (NOAA/NESDIS, GST) and S. Frasier (UMASS)

Reference: Guimond, S. R., J. A. Zhang, J. W. Sapp and S. J. Frasier, 2018: Coherent turbulence in the boundary layer of Hurricane Rita (2005) during an eyewall replacement cycle. *J. Atmos. Sci.*, **75**, 3071-3093, https://doi.org/10.1175/JAS-D-17-0347.1.

2.1.10. Simulations and observations demonstrating remote horizontal detection of supercooled liquid clouds

Observations of a frontal system approaching Boulder, Colorado (Nov. 30-Dec. 1, 2014) by a horizontally-pointing radiometer showed a spectral response to temperature, humidity, and cloud liquid water. This response, verified by simulations, demonstrated the feasibility of radiometers for detecting supercooled liquid water in clouds, supporting Earth science, and aviation safety. Supercooled water, or water that remains in liquid state below the freezing temperature, has considerable impact to society due to its role in the global radiation budget, cloud microphysics, and aviation safety. Originally conceived as a technology to protect unmanned aerial systems—which lack pilot situational awareness and often are not equipped with deicing equipment—from icing due supercooled liquid water droplets, horizontally-viewing radiometers have the potential to improve observations of cloud systems. Aircraft equipped with such sensors would have indicators of hazardous flying conditions while also providing meteorological information on clouds, water vapor, and temperature. Moreover, these sensors could be used to allow aircraft in field campaigns to either locate clouds of interest for further observation or avoid these clouds when not equipped for such conditions.

Contributors: I. S. Adams (612), J. Bobak (NRL DC), R. "Stick" Ware (Radiometrics)

Reference: Adams, I. S. and J. Bobak, 2018: The feasibility of detecting supercooled liquid with a forward-looking radiometer. *J. Sel. Topics Appl. Earth Observ. Remote Sens.*, **11**, 1932-1938, https://doi.org/10.1109/JSTARS.2018.2844684.

2.1.11. Advanced snow water path retrieval algorithm for the GPM Microwave Imager provides wide-swath snowfall detection over all surfaces

Snow plays a central role in the Earth climate system (water cycle, Earth radiative budget), and global snowfall can only be monitored by spaceborne instruments. Spaceborne cloud radars, e.g., Cloud Profiling Radar (CPR), have the sensitivity to detect and quantify snowfall profiles but on a narrow swath, while spaceborne radiometers, e.g., GMI, available on a large swath, are sensitive to snowfall but are subject to background surface contamination and are indirectly linked to surface snowfall. In particular, radiometer snowfall detection capabilities strongly depend on the interconnection between background surface characteristics, atmospheric water vapor content, and occurrence and vertical distribution of supercooled liquid water clouds, which tend to mask the scattering signal related to snowfall. The Snow retrievaL ALgorithm fOr gMi (SLALOM) leverages strengths of both CPR and GMI instruments to detect snowfall and retrieve associated snow water path on the GMI swath. The SLALOM algorithm is also able to detect supercooled liquid water clouds, which play important roles in the radiative budget and in cloud microphysics. For detecting the occurrence of these clouds, probability of detection is 97% and false alarm rate is 5%. Through the exploitation of all 13 GMI channels, and the optimal use of ancillary variables describing atmospheric conditions (with no ancillary information on the background surface), SLALOM is able to predict snowfall occurrence and snow water path in very good agreement with the CloudSat CPR, with the advantage of ensuring a much larger spatial coverage corresponding to the GMI swath.

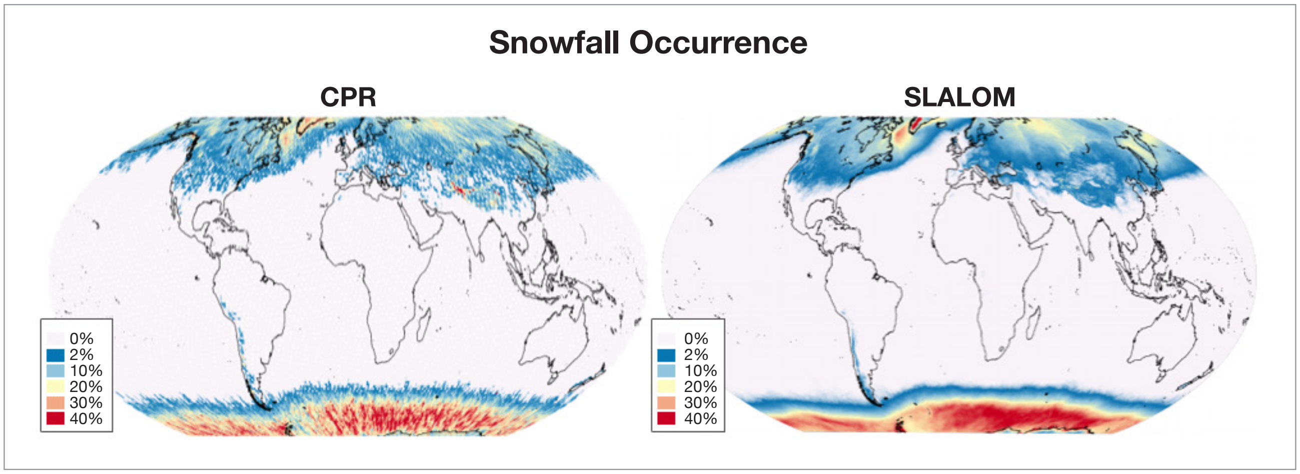


Figure 2.1.11: *Caption: Snowfall percentage of occurrence as given by CPR and SLALOM, May 2014 to 2016.*

Contributors: L. Milani (612, UMD), J.-F. Rysman (CNR-ISAC), G. Panegrossi (CNR-ISAC), P. Sanò (CNR-ISAC), A. C. Marra (CNR-ISAC), S. Dietrich (CNR-ISAC); M. S. Kulie (MTU)

Reference: Rysman, J.-F., G. Panegrossi, P. Sanò, A. C. Marra, S. Dietrich, L. Milani, and M. S. Kulie, 2018: SLALOM: An All-Surface Snow Water Path Retrieval Algorithm for the GPM Microwave Imager. *Remote Sens.*, **10**, 1278, https://doi.org/10.3390/rs10081278.

2.2. Climate and Radiation Laboratory

One of the most pressing issues humans face is to understand the Earth's climate system and how it is affected by human activities now and in the future. This has been the driving force behind many of the activities in the Climate and Radiation Laboratory. 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 are updated regularly on the Code 613 Laboratory website 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 International Satellite Cloud Climatology Project (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 PIs on research studies and experiments; and make strides in many areas of science leadership, education, and outreach. These cover the areas aerosol-cloud-precipitation interactions, aerosol effects on climate, reflected solar radiation, land 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 website contains recent significant findings in these and other areas.

The study of aerosols is important to Laboratory scientists for many reasons: (1) their direct and indirect effects on climate are complicated and not well-quantified; (2) poor air quality due to high aerosol loadings in urban areas has adverse effects on human health; (3) transported aerosols provide nutrients such as iron (from mineral dust and volcanic ash), important for fertilization of parts of the world's oceans and tropical rainforests; and (4) knowledge of aerosol loading is important to determine the potential yield from the green solar energy sources. Highlights of Laboratory research activities carried out during the year 2018 are summarized below.

2.2.1. How different cloud vertical configurations affect Earth's radiation budget

So-called "active" sensors (satellite instruments emitting pulses of radiation toward Earth) such as the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite and CPR aboard CloudSat can be used to derive, classify, and understand how clouds are stratified vertically in the atmosphere. The stratification is important for the Earth's energy budget. We show that the various major cloud vertical structures (CVS) affect the propagation of solar and thermal radiation in distinct ways: (1) Only two CVS classes, both containing high clouds warm the planet (TOA) (2) All CVS classes cool the surface; (3) Three CVS classes, all containing low clouds cool the atmosphere; (4) Contrary to prevailing descriptions, isolated high clouds ("cirrus") do not warm (at least directly) the surface, but do warm the atmosphere; (5) Isolated low clouds, being so prevalent (~35% of all clouds), are the biggest contributors to LW surface warming. The study demonstrates the power of active observations: while clouds were previously classified based only on cloud top location, the ability of active sensors to extract cloud vertical extent provides the means for better identification of cloud vertical configuration, which is essential for full appreciation of cloud radiative effects. It is therefore imperative that cloud probing from space continues as a multifaceted endeavor that involves instruments with a wide range of capabilities and sensitivities.

Contributors: L. Oreopoulos (613), N. Cho (613, USRA), and D. Lee (613, MSU)

Reference: Oreopoulos, L., N. Cho, and D. Lee, 2017: New insights about cloud vertical structure from CloudSat and CALIPSO observations. *J. Geophys. Res.: Atmos.*, **122**, 9280-9300, https://doi.org/10.1002/2017JD026629.

2.2.2. DSCOVR EPIC calibration using MODIS and lunar observations

EPIC's position at the Lagrange-1 point and unique observational geometry makes it an important complement to low Earth orbit (LEO) remote sensing instruments. Measurements in the backscattering region allow observations and characterizations of the glint caused by oriented ice crystals in clouds, and also facilitate better vegetation monitoring. Moreover, the EPIC instrument offers an improved temporal sampling compared to instruments on sun-synchronous orbits, with the entire sunlit hemisphere being sampled 10-20 times per day. It thus has the potential to augment remote sensing observations in such applications as determination of aerosol, cloud, sulfur dioxide (SO_2), and ozone amounts, as well as vegetation properties. Radiometric calibration of the measurements is a required first step for many of the above applications. Because the EPIC instrument does not have in-flight calibration capabilities, it is necessary to determine the calibration coefficients and monitor their stability by means of vicarious calibration. Figure 2.2.2 shows the results of four EPIC visible and NIR channels calibrated via MODIS reflectances. The two EPIC O_2 absorbing channels were calibrated via Lunar observations.

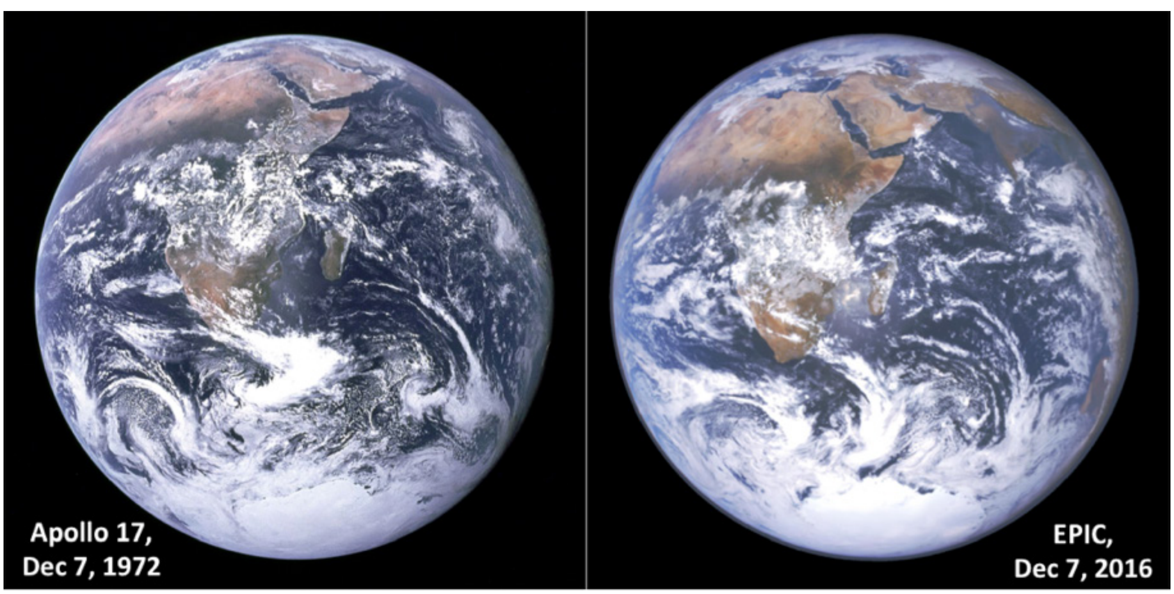


Figure 2.2.2: *DSCOVR's EPIC instrument, uniquely positioned at the Lagrange-1 point, is an important addition to the observations from currently operating low Earth orbit observing instruments.*

Contributors: A. Marshak (613), I. Geogdzhayev (Columbia University/NASA GISS)

Reference: Geogdzhayev, I. V., and A. Marshak, 2018: Calibration of the DSCOVR EPIC visible and NIR channels using MODIS Terra and Aqua data and EPIC lunar observations. *Atmos. Meas. Tech.*, **11**, 359-368, https://doi.org/10.5194/amt-11-359-2018.

2.2.3. High-frequency polarized microwave measurements show that ice crystal microphysics vary diurnally

High-frequency microwave polarization difference (PD) measurements contain valuable microphysics information about ice clouds. We found that PD measurements from GPM's GMI instrument exhibit a systematic diurnal cycle over tropical land that likely impact the evolution of the amount and thickness of ice clouds at a later time. The study demonstrates the power of passive microwave polarimetry for remotely sensing ice cloud microphysical properties. 166 GHz is the highest frequency of polarized channels in GMI. Because ice cloud scattering is more significant at high frequencies, the careful fusion of observations from multi-frequency polarized microwave/IR channels allows us to simultaneously infer bulk ice particle size and shape, paving thus the way for global studies of ice cloud microphysics on diurnal, seasonal, and inter-annual time scales. While it has been well-known that ice microphysics are strongly tied with the evolution of ice cloud macro-properties, this work reveals that understanding the variations in ice microphysics is necessary to predict, infer and model the bulk properties of the ice clouds and their overall evolution linked to precipitation processes. Furthermore, this study combined use of new satellite instrumentation (e.g., GMI) and novel observational techniques (e.g., pairing of high-frequency microwave channels), which offers a promising path for observing and understanding the entire cycle of cloud-precipitation processes.

Contributors: J. Gong (613, USRA), D. L. Wu (613) and X. Li (612, MSU)

Reference: Gong, J., X. Zeng, D. L. Wu and X. Li, 2017: Diurnal Variation of Tropical Ice Cloud Microphysics: Evidence from Global Precipitation Measurement Microwave Imager (GPM-GMI) Polarimetric Measurements. *Geophys. Res. Lett.,* **45**, 1185-1193, https://doi.org/10.1002/2017gl075519.

2.2.4. Studying volcanic eruptions with Terra and the A-Train

Space-based instruments can monitor volcanic activity globally, which is especially important in remote locations or where in situ observing conditions are hazardous. Karymsky volcano (Kamchatka, in eastern Russia) was used as a test case for identifying changes in the underlying volcano geology, solely from satellite-based remote-sensing observations. Observations from the Multi-angle Imaging SpectroRadiometer (MISR) provide volcanic plume altitude and particle microphysical properties. MISR stereo-derived plume injection heights relate to eruptive intensity and volatile content. MISR research algorithm aerosol-type retrievals distinguish sulfate- and ash-rich eruptions. The MISR plume assessments were combined with thermal anomaly observations from coincident MODerate resolution Imaging Spectroradiometer (MODIS) imagery, which tend to indicate lava flow events. Plumes ranged in length from 30 to 220 km, primarily dispersing at an altitude of 2-4 km.

The analysis of Karymsky led to the distinction of plume components (e.g., sulfate proxy, ash proxy) and plume evolution (e.g., post-2010 absorbing fraction development) using MISR. We derived a more complete picture of eruptive dynamics by combining the MISR results with lava flow constraints from MODIS. Shifts in particle properties (e.g., in 2007) correspond with changes in the MODIS thermal anomaly record, reflecting eruption phases. After 2010, large, absorbing aerosol components were retrieved consistently. Absorbing component fraction varied systematically with timing within individual eruptions phases.

In addition to identifying long term trends, our analysis provides evidence of downwind particle evolution in individual, MISR-imaged plumes including: particle fallout, physical aggregation and chemical evolution (oxidation and/or particle hydration). The capability to discern dynamics of ongoing volcanic eruptions solely from space-based observations has major implications for global volcano studies. The application of this research is particularly of use in remote regions, where in situ observations are financially or logistically limited, or entirely absent.

Contributors: V. J. B. Flower (613, USRA) and R. A. Kahn (613)

Reference: Flower, V. J. B. and R. A. Kahn, 2018: Karymsky volcano eruptive plume properties based on MISR multiangle imagery, and volcanological implications. *Atmos. Chem. Phys.*, **18**, 3903-3918, https://doi.org/10.5194/acp-2017-868.

2.2.5. Atmospheric gas corrections for aerosol retrievals

Aerosol retrieval algorithms for imagers use reflected light in selected wavelength bands in so-called "window" regions, where gaseous absorption is weak, but still non-negligible. The accuracy of the aerosol retrieval depends on how well the absorption is corrected for. This study shows that when porting the aerosol retrieval algorithm from MODIS to VIIRS, gas absorption differences (for example, see CH_4 absorption in NIR channels), due to the specifics of each sensor, must be characterized in order to avoid biases in aerosol property retrievals. To reduce climate uncertainties, the suggested accuracy of AOD is ±(0.03+10%). This work is also very important for several scientific communities, e.g., the aerosol retrieval community, the community making precise measurements of gaseous absorption characteristics, and the radiative transfer community that models the transmission of light in the atmosphere and its absorption by gases. This work not only clearly lays out an atmospheric correction method employed by remote sensing retrieval algorithms, but also demonstrates the direct influence of improvements made by other communities on the accuracy of an independent product (aerosol optical depth). For example, aerosol radiative effect estimates are highly dependent on the accuracy of this product.

Contributors: F. Patadia (613, MSU), R. C. Levy (613), and S. Mattoo (613, SSAI)

Reference: Patadia, F., R. Levy, and S. Mattoo, 2018: Correcting for trace gas absorption when retrieving aerosol optical depth from satellite observations of reflected shortwave radiation. *Atmos. Meas. Tech.*, **11**, 3205-3219, https://doi.org/10.5194/amt-2018-7.

2.2.6. Long-term satellite data suggest models underestimate future warming and internal variability

When sea surface temperature data are analyzed jointly with MODIS and ISCCP cloud data, a consistent positive low cloud feedback with distinct spatiotemporal patterns and physical meaning emerges. The results demonstrate the important role of low cloud feedback for internal climate variability and global warming. Most current models underestimate this feedback, and thus likely also internal variability and future warming. Our research uses NASA observations to show current state-of-the-art models underestimating critical cloud feedback and implies future warming may be stronger than current consensus estimates. It also suggests that for unearthing cloud feedbacks, it is critical to have long time series of cloud properties from satellite observations.

Contributors: T. Yuan (613, UMBC), L. Oreopoulos (613), S. E. Platnick (610), and K. Meyer (613)

Reference: Yuan, T., L. Oreopoulos, S. E. Platnick, and K. Meyer, 2018: Observations of local positive low cloud feedback patterns and their role in internal variability and climate sensitivity. *Geophys. Res. Lett.*, **45**, 4438-4445, https://doi.org/10.1029/2018GL077904.

2.2.7. Exploring systematic offsets between aerosol products from the two MODIS sensors

In general, the aerosol optical depth (AOD) retrieved from Terra-MODIS (morning) is consistently larger than AOD observed from Aqua-MODIS (afternoon). Applying satellite-like sampling to the global MERRA-2 re-analysis dataset suggests that while there are regions with AM versus PM differences, the overall offset is close to zero. Calibration differences appear to be a likely cause for the MODIS offset, however tested calibration corrections do not entirely remove it. Time series of AOD and Ångström exponent (AE) are important for understanding spatial-temporal variability of aerosol and quantifying global trends for applications of climate and air quality. To make climate data records connecting multiple sensors, we must determine whether differences between two sensors are due to geophysical differences or instrumental differences.

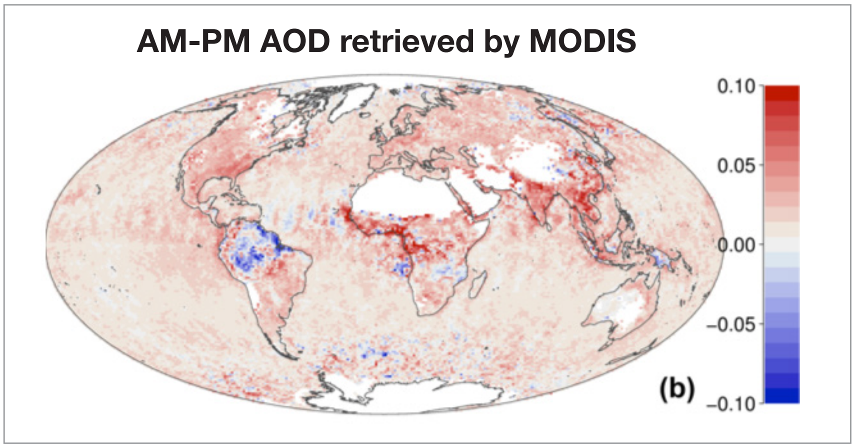


Figure 2.2.7: *0.015 or 13% offset nearly everywhere. Why?*

Contributors: R. Levy (613), S. Mattoo (613, SSAI), V. Sawyer (613, SSAI), Y. Shi (613, USRA), P. Colarco (614), A. Lyapustin (613), Y. Wang (613, UMBC) and L. Remer (613, UMBC)

Reference: Levy, R. C., S. Mattoo, V. R. Sawyer, Y. Shi, P. R. Colarco, A. I. Lyapustin, Y. Wang, and L. A. Remer, 2018: Exploring systematic offsets between aerosol products from the two MODIS sensors. *Atmos. Meas. Tech.*, **11**, 4073-4092, https://doi.org/10.5194/amt-11-4073-2018.

2.2.8. Extending EOS-era aerosol records backward and forward in time with AVHRR and VIIRS

Routine, long-term aerosol monitoring from space is important for many scientific and societal applications, including studies of the Earth's climate, air quality and human health, and hazard (e.g., volcanic eruption, dust storm) monitoring and navigation avoidance. Obtaining a consistent long-term record is crucial to understand how the global burden of aerosols is changing. High-quality routine monitoring of aerosols from space began in the EOS era with the SeaWiFS (launched 1997) and MODIS (launched 2000 and 2002) instruments. The Deep Blue algorithm has been applied to both of these sensors to monitor aerosols. However, SeaWiFS ceased operations in 2010 and the two MODIS sensors are beyond their designed lives.

This work consists of two parts. First, we have demonstrated the applicability of the same algorithm approaches to VIIRS data; the first VIIRS sensor was launched in late 2011, and future VIIRS sensors on the Joint Polar Satellite System (JPSS) platforms will continue the record for several decades. This ensures the future continuity of the Deep Blue aerosol record for both real-time and climate applications. Second, we have demonstrated the potential to extend these time series back in time to potentially 1981 by using the AVHRR sensor series. Near-global aerosol retrievals over land have not been previously achieved using AVHRR measurements. This approximately doubles the potential length of the Deep Blue data record, which will greatly enhance trend studies. This is particularly true for Asian regions, which experienced rapid industrialization in the 1990s; and parts of Europe and North America, where regulations began to decrease aerosol and precursor emissions in the 1990s, both prior to the currently-available data record from EOS-era sensors.

Contributors: M. Sayer (613/616, USRA), N. C. Hsu (613), J. Lee (613, UMD), W. V. Kim (613, UMD)

Reference: Sayer, A. M., N. C. Hsu, J. Lee, N. Carletta, S.-H. Chen, and A. Smirnov, 2017: Evaluation of NASA Deep Blue/SOAR aerosol retrieval algorithms applied to AVHRR measurements. *J. Geophys. Res.: Atmos.*, **122**, 9945-9967, https://doi.org/10.1002/2017JD026934.

2.2.9. A physical approach to optimizing surface PM2.5 modeling outputs using surface and satellite observations

Traditionally, regional-level air quality in populated areas is assessed through chemical transport model (CTM) simulations, loosely constrained by observations from surface monitoring stations which typically provide limited coverage downwind of major pollution sources, or none at all. Using a physical approach, we demonstrate that CTM estimates of fine particulate matter (PM2.5), and its major chemical component species, can be improved in space and time by adding broad regional context information from satellite retrievals of aerosol type. The images below show that the optimized concentration maps are spatially consistent with topography, typifying localized hotspots over known urban areas, and exhibiting realistic dispersion patterns. The optimized air quality estimation accuracy identifies and quantifies specific drivers of adverse, multi-pollutant health effects. Improved satellite retrievals of aerosol type can provide broad regional context and can decrease measurement uncertainties and errors, increasing the accuracy of near-surface air quality characterization. The frequent, spatially extensive and radio metrically consistent instantaneous constraints from satellites are especially useful in areas away from ground monitors and progressively downwind of emission sources. This physical optimization approach uses ground-based monitors where available, combined with aerosol optical depth from both the Multi-angle Imaging SpectroRadiometer (MISR) Research Aerosol retrieval algorithm (RA) and the Moderate Resolution Imaging Spectroradiometer Multi-Angle Implementation of Atmospheric Correction (MAIAC) advanced algorithm, plus MISR qualitative constraints on aerosol size, shape, and light-absorption properties.

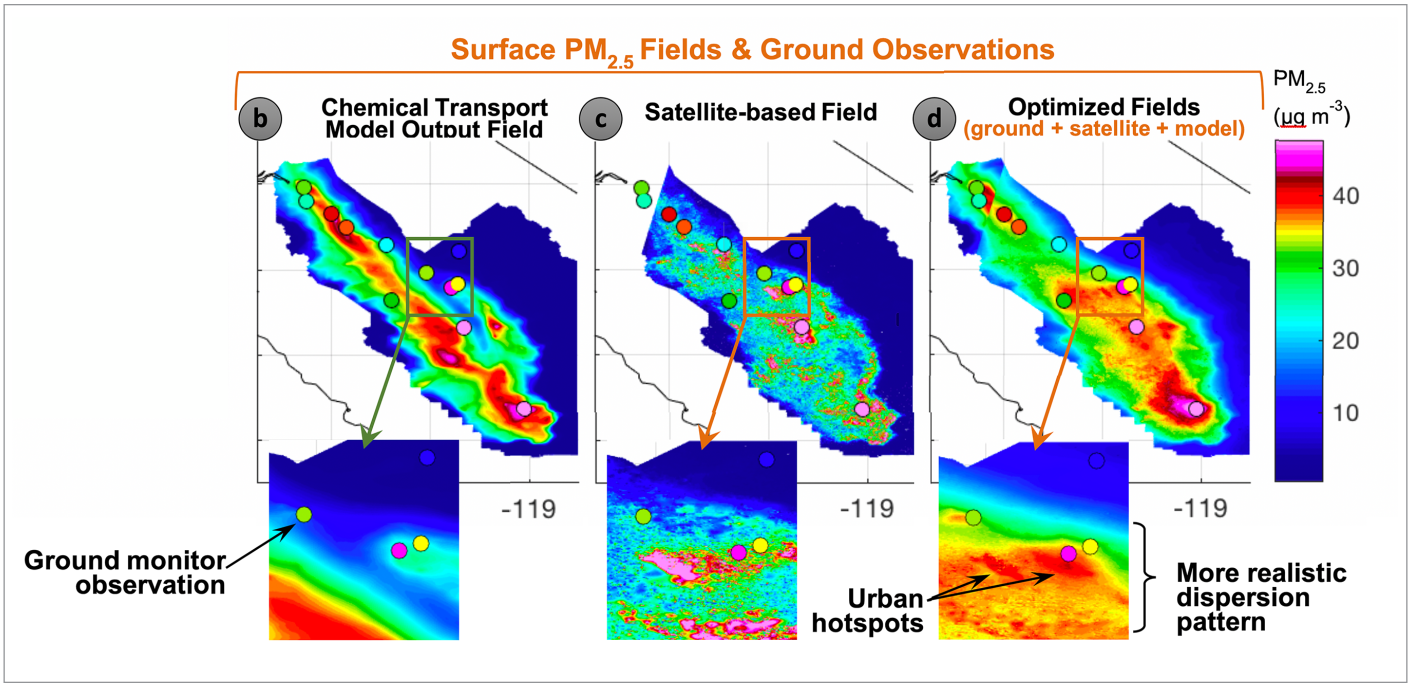


Figure 2.2.9: *Surface PM2.5 fields and ground observations in the San Joaquin Valley.*

Contributors: M. D. Friberg (613, USRA), R. A. Kahn (613), and J. A. Limbacher (613, SSAI)

Reference: Friberg, M. D., R. A. Kahn, J. A. Limbacher, K. W. Appel, and J. A. Mulholland, 2018: Constraining Chemical Transport PM2.5 Modeling Output Using Surface Monitor Measurements and Satellite Retrievals: Application over the San Joaquin Valley. *Atmos. Chem. Phys.*, **18**, 12891-12913, https://doi.org/10.5194/acp-18-12891-2018.

2.2.10. Dropsonde observations unveil the role of mechanical mixing in Antarctic boundary layer

Scientific significance, societal relevance, and relationships to future missions: This study uses unique high-resolution dropsonde profiles of temperature and winds collected over the Antarctic continent during the austral spring season, to provide crucial information on the atmospheric boundary layer structure and conditions of turbulent mixing when the Sun elevation is not at maximum. The erosion of surface-based inversions (SBIs) is caused by wind-driven turbulent mixing that alters the surface and near-surface air temperature, which can, in turn, impact the clear-sky outgoing longwave radiation, surface energy budget, and mass balance. It is found that well-mixed (neutral and convective) boundary layers occur 33% and 18% of the time in west and east Antarctica, respectively. Stable boundary layers without a surface-based inversion (no SBI) occur with a frequency of 14% and 12%, respectively. Knowledge of Antarctic boundary layer structure is crucial for interpreting satellite observations.

The finding emphasizes the need for future field campaigns and continued remote sensing efforts to monitor surface-atmosphere interactions and help predict changes to the Antarctic ice-sheet in an increasingly dynamic planet. This research was supported by the NASA CloudSat/CALIPSO Science Team Recompete program and the NASA ICESat-2 Science Definition Team program.

Contributors: M. Ganeshan (613, USRA) and Y. Yang (613)

Reference: Ganeshan, M. and Y. Yang, 2018: A regional analysis of factors affecting the Antarctic boundary layer during the Concordiasi campaign. *J. Geophys. Res.: Atmos.*, **123**, 10,830-10,841, https://doi.org/10.1029/2018JD028629.

2.2.11. MAIAC (Multi-Angle Implementation of Atmospheric Correction) MODIS C6: A new interdisciplinary suite of atmospheric and surface products

A new MODIS Collection 6 MAIAC product (MCD19) was released in May 2018. The MCD19 suite includes 1km cloud mask, column water vapor, aerosol optical depth (Figure 2.2.11) and type (smoke/dust), smoke plume height, as well as spectral surface reflectance (BRF) at 1 km and 500 m resolution and BRDF model parameters. A subpixel snow fraction and snow grain size are reported for the detected snow. The MAIAC MODIS MCD19 product is an important contribution to the Earth System data record. Due to its advanced cloud and snow detection, MAIAC improves the quality of atmospheric correction, in particular over tropics and at northern latitudes, regions significantly affected by climate change. Since 2014, majority of studies of Amazon tropical forests, which used MODIS data, relied on MAIAC processing. Presently, MAIAC is the only algorithm providing high 1 km resolution reliable aerosol retrievals over land including urban regions. This has drawn an unparalleled interest in the air quality and health studies. Finally, MCD19 data are important for data assimilation and climate models due to high accuracy of MAIAC water vapor, aerosol and land surface BRDF products.

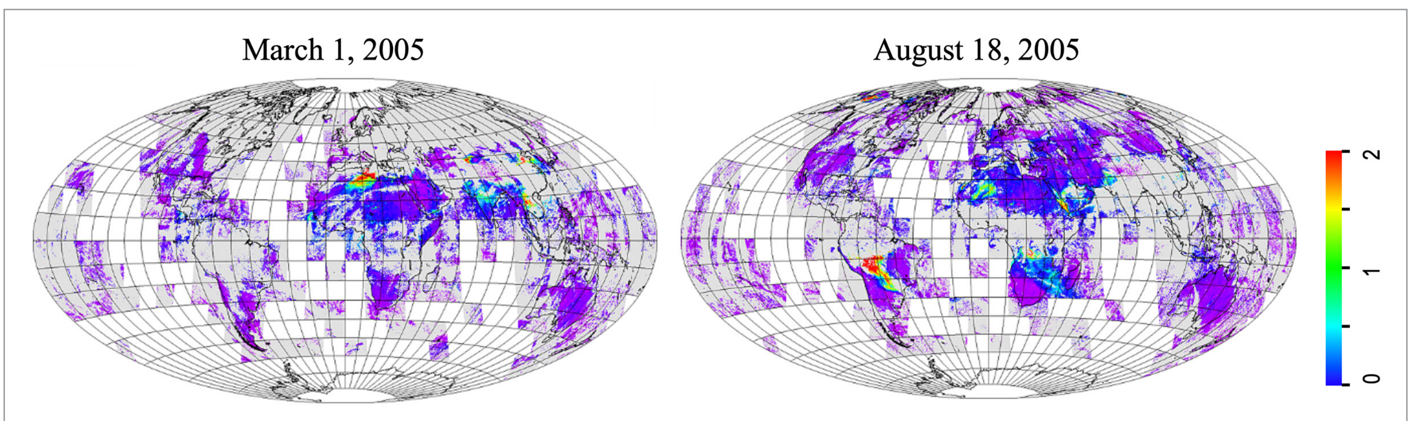


Figure 2.2.11: *Aerosol Optical Depth*

Contributors: A. Lyapustin (613), Y. Wang (613, UMBC), S. Korkin (613, USRA), and D. Huang (613, SSAI)

Reference: Lyapustin, A., Y. Wang, I. Laszlo, R. Kahn, S. Korkin, L. Remer, R. Levy, and J. S. Reid, 2011: Multi-Angle Implementation of Atmospheric Correction (MAIAC): 2. Aerosol Algorithm. *J. Geophys. Res.*, **116**, D03211, https://doi.org/10.1029/2010JD014986.

2.3. Atmospheric Chemistry and Dynamics Laboratory

The Laboratory conducts research including both the gas-phase and aerosol composition of the atmosphere. Both areas of research involve extensive measurements from space to assess the current composition and to validate the parameterized processes that are used in chemical and climate prediction models. This area of chemical research dates back to the first satellite ozone missions and the Division has had a strong satellite instrument, aircraft instrument, and modeling presence in the community. Both the EOS Aura satellite and the Ozone Monitoring Instrument (OMI) U.S. science teams come from this group. The Laboratory also is a leader in the integration and execution of the NPP mission, and is also providing leadership for the former NPOESS, now the newly reorganized JPSS. This group has also developed a state-of-the-are chemistry-climate model, in collaboration with the Global Modeling and Assimilation Office (GMAO). This model has proven to be one of the best performers in a recent international chemistry-climate model evaluation for the stratosphere. Dry deposition of nitrogen dioxide (NO_2) and SO_2 contributes excess nitrogen and sulfur to vegetation, soil, and water. Deposited nitrogen can cause eutrophication, leading to a loss of biodiversity. Deposited nitrogen and sulfur both have the potential to acidify soil and water, and may influence climate by perturbing the carbon uptake of an ecosystem. Measurements of NO_2 and SO_2 columns from OMI in combination with the GEOS-Chem chemical transport model have provided the first global budgets and estimates of spatial patterns of NO_2 and SO_2 dry deposition. These results have potential applications in a range of fields, from atmospheric chemistry to ecology. The upcoming NASA Earth venture mission, Tropospheric Emissions: Monitoring of Pollution (TEMPO), will allow dry deposition to be quantified at very high spatial and temporal resolution.

2.3.1. Chlorine and ozone depletion are declining

Identifying recovery of the Antarctic ozone hole is challenging because year to year changes in the hole are primarily controlled by temperature. Stratospheric chlorine levels are expected to decline because of the Montreal Protocol (MP) and its subsequent amendments. The decline is slow because the atmospheric lifetimes of ozone depleting substances are long. This study is important because it shows the MP is working: it identifies both a decline in chlorine levels inside the ozone hole attributable to the MP and a decline in ozone (O_3) depletion in response to chlorine changes. The value of N_2O and HCl measurements for interpreting O_3 changes supports the need for these measurements in the future as we continue to measure ozone. Co-located MLS N_2O and HCl observations inside the Antarctic ozone hole from 2013-2016 (red) and 2004-2007 (blue) are shown in Figure 2.3.1. The difference between the means of each distribution (solid lines) is highlighted by the arrow. The shift of the distribution toward lower HCl, represents a decline in Antarctic chlorine.

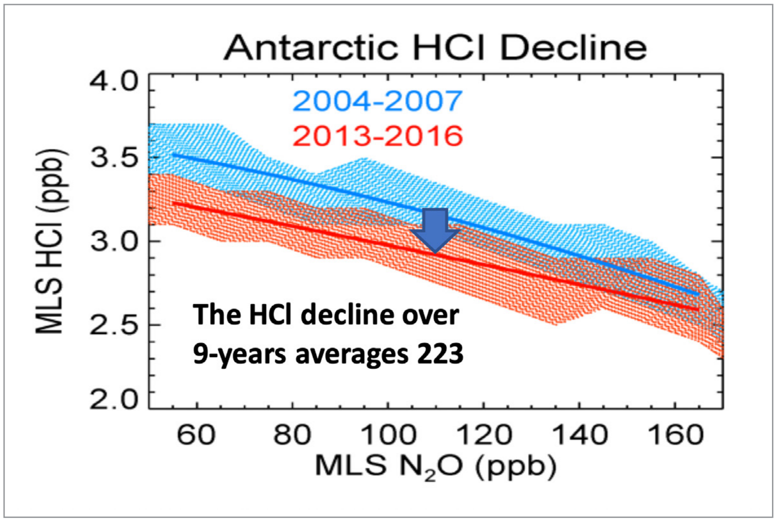


Figure 2.3.1: *Decreases in HCl for constant N_2O values identify changes in stratospheric chlorine loading that are independent of atmospheric dynamical variability.*

Contributors: Susan Strahan (614, USRA) and Anne Douglass (614)

Reference: Strahan, S. E. and A. R. Douglass, 2017: Decline in Antarctic Ozone Depletion and Lower Stratospheric Chlorine Determined From Aura Microwave Limb Sounder Observations. *Geophys. Res. Lett.*, **44**, 382-390, https://doi.org/10.1002/2017GL074830.

2.3.2. Strategic ozonesonde network validates satellite measurements

Satellite-based ozone products and models suitable for exploring complex variability in the tropics are still in development. Given the improvements described in this study, reprocessed SHADOZ ozonesonde data are a new standard reference for evaluating all ozone monitoring satellites, emerging tropospheric products, the assessment of model simulations, and for detecting satellite drift. Figure 2.3.2 shows very high vertical resolution (0.25 km) ozone profile data showcases for the “Wave-One” structure of tropospheric ozone in the tropics. The Wave-One is a permanent feature that models and satellite products aim to reproduce.

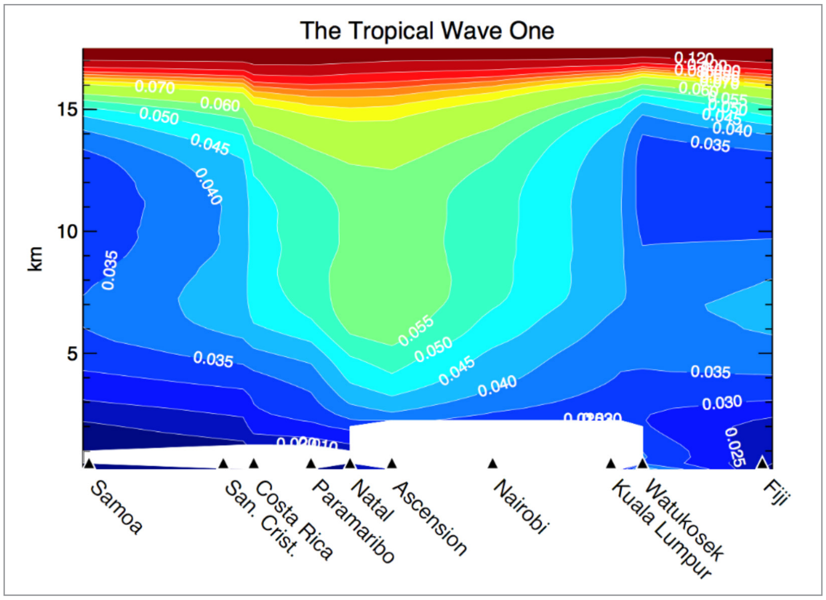


Figure 2.3.2: *Longitudinal cross section of contours of tropospheric ozone mixing ratios (units of ppm), computed from 0.25 km averages of 1998-2016 reprocessed data, for the 10 tropical stations, labeled by station on the x-axis.*

Contributors: A. M. Thompson (610), and J. C. Witte (614, SSAI)

Reference: Thompson, A. M., J. C. Witte, C. Sterling, A. Jordan, B. J. Johnson, S. J. Oltmans, and K. Thiongo, 2017: First reprocessing of Southern Hemisphere Additional Ozonesondes (SHADOZ) ozone profiles (1998–2016): 2. Comparisons with satellites and ground-based instruments. *J. Geophys. Res.: Atmos.*, **122**, 13,000-13,025, https://doi.org/10.1002/2017JD027406.

2.3.3. The Ozone Monitoring Instrument: Overview of thirteen years in space

This overview paper highlights the many ways that Aura OMI data have advanced atmospheric composition research and benefited society. OMI was novel in that it was the first UV-visible Earth remote-sensing instrument to employ a two-dimensional CCD detector. OMI revolutionized the study of trace gas pollutants from space, allowing for accurate emissions to be mapped globally. Until the recent launch of its descendant, the TROPOspheric Monitoring Instrument (TROPOMI) on the European Space Agency (ESA) Sentinel 5 precursor satellite, OMI had the highest spatial resolution of any instrument of its kind. Many satellite instruments now use a similar design including the Ozone Mapping Profiler Suite (OMPS) nadir mapper on the NASA/NOAA Suomi National Polar Partnership (NPP) satellite and JPSS series. The NASA Earth Ventures Instrument 1 (EVI-1) Tropospheric Emissions: Monitoring of Pollution (TEMPO), which will be launched into geostationary orbit, will also employ a similar detector, sweeping across North America hourly. This paper documents the many scientific areas where OMI has made significant contributions. The trace-gas and radiation products from OMI include criteria pollutants, SO_2, NO_2, and O_3, as well as formaldehyde, an O_3 precursor and UV-B radiation at the surface.

Contributors: P. Levelt (KNMI), J. Joiner (614), J. Tamminen (FMI), P. Veefkind (KNMI), P. K. Bhartia (614) and many others

Reference: Levelt, P., J. Joiner, J. Tamminen, P. Veefkind, P. K. Bhartia, D. Stein Zweers, B. N. Duncan, D. G. Streets, H. Eskes, R. van der A, C. McLinden, V. Fioletov, S. Carn, J. de Laat, M. DeLand, S. Marchenko, R. McPeters, J. Ziemke, D. Fu, X. Liu, K. Pickering, A. Apituley, G. Gonzáles Abad, A. Arola, F. Boersma, C Chan Miller, K. Chance, M. de Graaf, J. Hakkarainen, S. Hassinen, I. Ialongo, Q. Kleipool, N. Krotkov, C. Li, L. Lamsal, P. Newman, C. Nowlan, R. Suileiman, L. G. Tilstra, O. Torres, H. Wang, and K. Wargan, 2018: The Ozone Monitoring Instrument: Overview of thirteen years in space. *Atmos. Chem. Phys.*, **18**, 5699-5745, https://doi.org/10.5194/acp-18-5699-2018.

2.3.4. Crop production, residue fires, and air quality over northern India: an intriguing link

Post-monsoon rice crop production in northwestern India has increased by 0.18 million tons/year (2002-2016). A-Train satellite measurements show a consistent increase in NDVI (~0.007/year), residue fires (~500/year), and UV aerosol index/optical depth (~0.03/year). The traditional practice of crop residue burning post-harvest over northwestern India causes hazardous levels air pollution over the populous northern India. In addition to its climatic impacts, extreme levels of particulate matter and trace gases emitted from crop fires during post-monsoon poses a serious threat to the human health of millions living in the region. While the increasing amounts of crop production ensure nation's food security, the lack of an effective crop residue management system has led farmers resorting to burning the waste, which has played a major role in deteriorating regional air quality during post-monsoon. Willingness and partnership between the government and the agricultural sector is crucial for the adoption and enforcement of the viable alternatives to burning. Owing to its long-term record, NASA's A-Train satellites have helped in tracking the temporal evolution of fires and resulting aerosol amounts over the region making possible to quantify the trends and spatial patterns. Currently in-orbit VIIRS instrument on board NASA-NOAA joint satellite mission Suomi-NPP will continue the record of fires and aerosol detection at higher spatial resolution.

Contributors: H. Jethva (614, USRA), O. Torres (614)

Reference: Jethva, H., D. Chand, O. Torres, P. Gupta, A. Lyapustin, and F. Patadia, 2018: Agricultural Burning and Air Quality over Northern India: A Synergistic Analysis using NASA's A-train Satellite Data and Ground Measurements. *Aerosol Air Qual. Res.*, **18**, 1756-1773, https://doi.org/10.4209/aaqr.2017.12.0583.

2.3.5. First SO_2 retrievals from JPSS-1/NOAA-20 OMPS reveal greater details of volcanic plume

SO_2 from anthropogenic (e.g., coal burning) and volcanic sources has important impacts on air quality and climate. NASA has been providing global observations of SO_2 from Aura/OMI and SNPP/OMPS since their launches in 2004 and 2011, respectively. The preliminary SO_2 results here demonstrate that the new NOAA-20 (N20)/OMPS instrument is also capable of producing high-quality SO_2 data, enabling the continuation and extension of the space-based SO_2 data records. In addition, the high spatial resolution offered by N20/OMPS will significantly improve the detection limit for relatively weak SO_2 signals, allowing emissions from even smaller SO_2 sources to be quantified than currently possible with OMI or SNPP/OMPS. N20/OMPS will also provide more accurate estimates of SO_2 injection from small and modest volcanic eruptions, and help to better understand their climate impact. This preliminary test with N20/OMPS further demonstrates that the PCA-based trace gas retrieval algorithm can be quickly implemented with new satellite instruments such as NASA TEMPO and Korean Geostationary Environment Monitoring Spectrometer (GEMS), and the follow-up JPSS/OMPS instruments. The PCA-based OMI and OMPS SO_2 data are also being used to evaluate the SO_2 retrievals from the recently launched ESA's Sentinel-5 Precursor/TROPOspheric Monitoring Instrument (S5P/TROPOMI).

Contributors: C. Li (614, UMD), C. Seftor (614, SSAI), G. Jaross (614), and N. Krotkov (614)

Reference: Li, C., N. A. Krotkov, S. Carn, Y. Zhang, R. J. D. Spurr, and J. Joiner, 2017: New-generation NASA Aura Ozone Monitoring Instrument (OMI) volcanic SO_2 dataset: algorithm description, initial results, and continuation with the Suomi-NPP Ozone Mapping and Profiler Suite (OMPS). *Atmos. Meas. Tech.*, **10**, 445-458, https://doi.org/10.5194/amt-10-445-2017.

2.3.6. First observations of volcanic eruption clouds from the L1 Earth-Sun Lagrange point by DSCOVR/EPIC

Satellite measurements of SO_2 and ash emissions by volcanic eruptions are crucial for assessment of volcanic impacts on climate and mitigation of hazards to aviation. Until recently, the majority of such observations were made using satellites in 'low-Earth' (or polar) orbit at altitudes of ~700-800 km, which only provide one measurement per day at low- to mid-latitudes. This means that many volcanic eruptions are first detected from space several hours or up to a day later, precluding studies of dynamic processes in young volcanic clouds (such as emission and oxidation of other sulfur gas species, e.g., hydrogen sulfide, H_2S), which could alter their composition and potential impact.

Our paper reports the first measurements of volcanic SO_2 emissions from an entirely new perspective: the Earth Polychromatic Imaging Camera (EPIC) aboard the Deep Space Climate Observatory (DSCOVR), located at the first Earth-Sun Lagrange point (L1), 1 million miles from Earth. From L1, EPIC views the sunlit Earth continuously as it rotates and can measure volcanic SO_2 with hourly cadence from sunrise to sunset, as demonstrated in the paper using several recent volcanic eruptions as examples. EPIC measurements allow us to detect volcanic eruptions sooner, and track their emissions for longer, than was previously possible with a single sensor. These high cadence observations provide opportunities for more detailed studies of volcanic cloud chemistry and impacts, and could potentially reduce the societal impacts of volcanic eruptions. The hourly observations of volcanic SO_2 provided by EPIC also offer insight into the capabilities of future geostationary UV sensors scheduled for launch in the next decade such as NASA/TEMPO and the Korean GEMS.

Contributors: S. A. Carn (Michigan Technological University), N. A. Krotkov (614), B. L. Fisher (614, SSAI), C. Li (614, UMD), and A. J. Prata (AIRES Pty Ltd.)

Reference: Carn, S. A., N. A. Krotkov, B. L. Fisher, C. Li, and A. J. Prata, 2018: First observations of volcanic eruption clouds from the L1 Earth-Sun Lagrange point by DSCOVR/EPIC. *Geophys. Res. Lett.*, **45**, 11,456-11,464, https://doi.org/10.1029/2018GL079808.

2.3.7. Estimation of terrestrial Global Gross Primary Production (GPP) with satellite data-driven models and eddy covariance flux data

It is of importance for carbon cycle science, in particular for evaluating terrestrial biochemical models (TBMs) to have estimates of global GPP on weekly to monthly time scales. The carbon cycle in general is of interest for missions where XCO_2 is measured, such as OCO-2 and in the future GEO-Carb. In this study we estimate global GPP using MODIS reflectances and chlorophyll fluorescence from an instrument on European weather satellites. Our Global map (Figure 2.3.7) was generated by training a fairly simple regression model to predict GPP using MODIS (MCD43 NBAR) angle adjusted reflectances and solar-induced fluorescence from the Global Ozone Monitoring Experiment-2 (GOME-2) on EUMETSAT MetOp 2. The training was "calibrated" using eddy covariance flux measurements from the FLUXNET 2015 data set. FLUXNET is a global network of more than eight hundred active and historic flux eddy covariance tower measurement sites across the world to measure the exchanges of carbon dioxide, water vapor, and energy between the biosphere and atmosphere.

We account for the fact that photosynthesis is more efficient (per unit incoming light) in cloudy conditions. Our GPP estimates out-performed other popular satellite-based estimates such as FLUXCOM, MODIS GPP (MOD17), and the Vegetation Photosynthesis Model (VPM) as compared with independent FLUXNET data. (FLUXCOM refers to the merging of energy flux measurements from FLUXNET with remote sensing and meteorological data to estimate net radiation, latent and sensible heat and their uncertainties resulting in a database comprised of 147 global gridded products.) Our GPP estimates are higher than previous estimates, particularly in the cloudy tropics and agree well with the single FLUXNET Tier 1 EC tropical flux tower as well as with process models. We have made our global 15 year data set available on the Aura Validation Data Center at https://avdc.gsfc.nasa.gov.

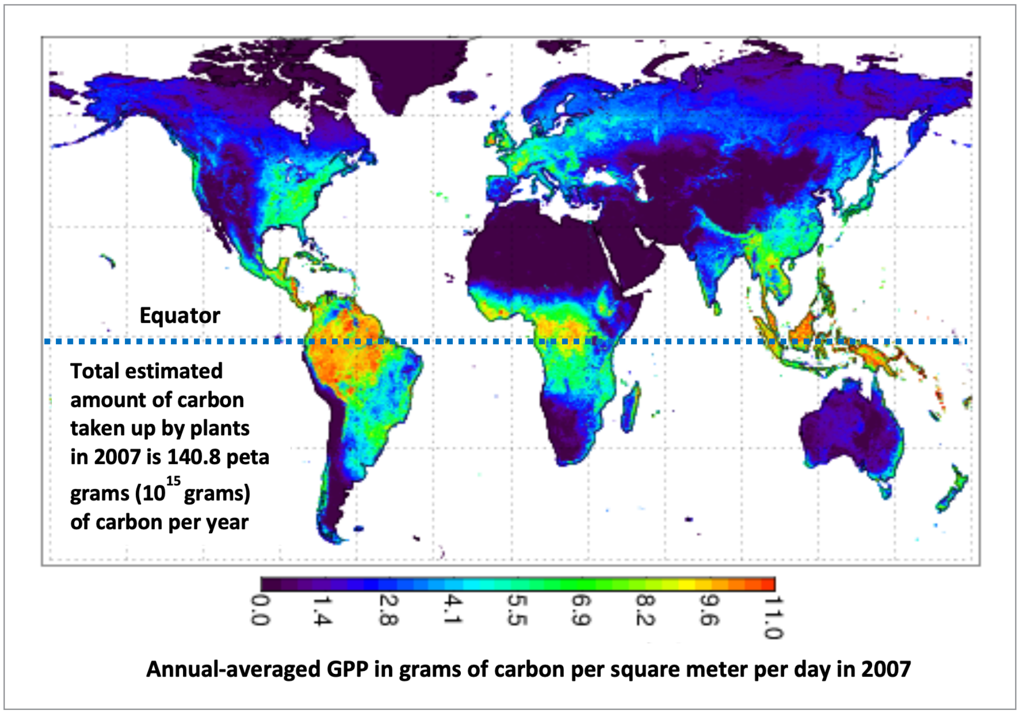


Figure 2.3.7: *Map of averaged GPP estimated with remote sensing data for the year 2007.*

Contributors: J. Joiner (614), Y. Yoshida (614, SSAI), Y. Zhang (Columbia Univ.), G. Duveiller (European Commission), M. Jung (Max Planck Institute), A. (613), Yujie Wang (613, UMBC), C. Tucker (610)

Reference: Joiner, J., Y. Yoshida, Y. Zhang, G. Duveiller, M. Jung, A. Lyapustin, Y. Wang, and C. Tucker, 2018: Estimation of Terrestrial Global Gross Primary Production (GPP) with Satellite Data-Driven Models and Eddy Covariance Flux Data. *Remote Sens.*, **10**, 1346, https://doi.org/10.1175/10.3390/rs10091346.

2.4. Wallops Field Support Office

The Wallops Field Support Office (Code 610.W) supports the Earth science research activities of Code 600 scientists at the Wallops Flight Facility. The Office also conceives, builds, tests, and operates research sensors and instruments at both Wallops and remote sites. Scientists in the Office use radars, aircraft, balloons, in situ and laboratory instruments, autonomous surface vehicles, and satellite platforms to participate in the full complement of Earth science research activities. These activities include measurements, retrievals, data analysis, model simulations, and calibration/ validation. Office personnel collaborate with other scientists and engineers across Goddard and other NASA centers as well as universities, and other government agencies, locally, nationally and internationally. The Office has provided instrumentation and scientific research expertise to several NASA missions and field efforts in 2018.

2.4.1. Blizzard of 2018

The GPM/WFF Precipitation Research Facility sampled the Blizzard of 2018 (January 4) with numerous instruments, including the NASA Polarimetric S-band Radar (NPOL), disdrometers, micro-rain profilers, and snow gauges. A near-nadir GPM overpass during the height of the storm (0544 UTC) sampled snowfall over land and complex mixed-phase precipitation over the ocean.

Contributor: D. B. Wolff (610W)

2.4.2. Using NASA's Precipitation Imaging Package (PIP) to Determine Snow Water Content

The Precipitation Imaging Processor (PIP) designed at NASA Wallops Flight Facility was deployed in support of the International Collaborative Experiment-Pyeongchang Olympics and Paralympics (ICE-POP) during the 2018 Winter Olympics. The experiment took place in February 9-25 and March 8-18, respectively. The NASA team generated forecasts for research associated with improving GPM satellite estimates of snowfall in the mountains and also improving the physics in the models that are used to predict mountain snow, which in turn may be useful for combining with satellites to provide the best snowfall data product. The PIP uses a high-speed video camera to measure the particle size distribution of precipitating particles. Liquid particles have densities of 1 g cm^{-3} and fall predictably along theoretical relations with drop size (mass). Snowflakes and mixed-phase particles, however, have widely varying densities. The relative fall-speed (i.e., the ratio of the snowflake fall-speed to the terminal velocity of a similar sized raindrop) is used to estimate the effective density (eDensity), which is then used to compute the total precipitation by the rain/mixed/snow components of the precipitation event. NASA is interested in developing better measurements of mountain snowfall from space, which involves obtaining a better understanding of

Figure 2.4.2: *NASA's Precipitation Imaging Processor (PIP) in support of the 2018 Winter Olympics in Pyeongchang, South Korea. The PIP is a Wallops-built instrument that uses high resolution video to capture falling snow.*

the physics of snow that produce the signals we see with satellite remote sensors. In a sense we are trying to ensure a triangle of consistency between ground observations, satellite measurements and model-predicted snowfall amount. Snowfall is a important contributor to the hydrological cycle and in many areas is the most abundant source of potable water available. Knowledge of the snow water equivalent in snowfall then is key to improved hydrological modeling and societal impact planning.

Contributor: D. B. Wolff (610W)

Reference: Liang L., R. Meneghini, A. Tokay, and L. F. Bliven, 2016: Retrieval of Snow Properties for Ku-Band Ka-Band Dual-Frequency Radar. *J. Appl. Meteorol. Clim.*, **55**, 1845-1858, https://doi.org/10.1175/JAMC-D-15-0355.1.

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 and deputy project scientists and investigators 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. Spaceflight missions are central to NASA's ability to carry out its science programs. A comprehensive set of observations from existing and planned missions are required and the impact of atmospheric sciences on NASA missions is profound.

3.1.1. Future Mission Studies

Spaceflight missions are central to NASA's ability to carry out its science programs. A comprehensive set of observations from existing and planned missions are required. Code 610AT scientists serve as project and deputy project scientists and investigators for the following missions.

3.1.1.1. ASCENDS

The Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission, recommended by the National Research Council (NRC)'s *2007 Earth Science Decadal Survey*, is considered the technological next step in measuring CO_2 from space following deployment of passive instruments such as the Japanese Greenhouse gases Observing Satellite (GOSAT, 2009) and the NASA Orbiting Carbon Observatory re-flight (OCO-2, 2014). Using an active laser measurement technique, ASCENDS will extend CO_2 remote-sensing capability to include uninterrupted coverage of high-latitude regions and nighttime observations with sensitivity in the lower atmosphere. The data from this mission will enable investigations of the climate-sensitive Southern Ocean and permafrost regions, produce insight into the diurnal cycle and plant respiration processes, and provide useful new constraints for global carbon cycle models. The Atmospheric Chemistry and Dynamics Laboratory has supported ASCENDS through technology development, analysis of airborne simulator data, instrument definition studies, and carbon cycle modeling and analysis. Lab members are engaged in CO_2 instrument development and participate on technology projects in collaboration with the Laser Remote-sensing Laboratory, which targets instrument and mission development for ASCENDS. The Laboratory plays a key role in radiative transfer modeling, retrieval algorithm development, instrument field deployment, and data analysis to develop a laser spectrometric instrument for ASCENDS. Based on experience and knowledge of carbon cycle science, they actively help to keep the technology development on track to best achieve the science objectives. They have also supported the flight project by performing observing system simulations to establish science measurement requirements and to evaluate the impact of various mission technology options.

Because of ASCENDS type satellite mission has not been explicitly recommended in the new *Decadal Survey*, the designated study for geostationary satellite is not continued in Fiscal Year 2019 (FY19).

For further information, please contact S. Randolph Kawa (stephan.r.kawa@nasa.gov).

3.1.1.2. GEO-CAPE

FY18 concludes the Geostationary Coastal and Air Pollution Events (GEO-CAPE) study that has been conducted for 10 years. GEO-CAPE is one of the missions recommended by the first NRC's *Decadal Survey*, with the goal of measuring atmospheric pollution (aerosols and trace gases) and coastal water from a geostationary platform. Scientists in Codes 613 and 614 have been involved in GEO-CAPE atmospheric studies for several years, including defining science objectives, measurement requirements, retrieval accuracy, retrieval sensitivity, etc. In FY18, Goddard scientists involved in GEO-CAPE's Aerosol Working Group have focused on the following tasks: (1) using ABI data (Himawari, GOES-R) for independent algorithm validation, (2) assessing the opportunity and uncertainty of simultaneous retrieval of spectral aerosol absorption and effective aerosol height with existing ground-based and satellite data (UV-NIR), (3) assessing the air quality application values of geostationary satellite AOD measurements with the examination of the existing temporal co-variability of AOD and PM2.5 data over the U.S., and (4) testing aerosol retrieval algorithm with the GEOS-5 Nature Run (in collaboration with the global OSSE team members). The outcome of FY18 study and an overall summary of the 10-year study from the GEO-CAPE aerosol working group was reported at the GEO-CAPE and the Committee on Earth Observation Satellites (CEOS) workshops in spring 2018.

Because a GEO-CAPE-type satellite mission has not been explicitly recommended in the new *Decadal Survey*, the designated study for geostationary satellite is not continued in FY19.

For further information, please contact Mian Chin (mian.chin@nasa.gov).

3.1.1.3 TROPICS

The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission was selected as part of the Earth Venture Instruments-3 solicitation. TROPICS is led by William Blackwell of MIT/ Lincoln Laboratory. Scott Braun (612) is the Goddard project scientist. At Goddard, TROPICS funds cover the project scientist, data assimilation work in the Global Modeling and Assimilation Office (GMAO), and research on moisture impacts on the precipitation structure and the intensity of storms. TROPICS will provide rapid-refresh (~50-minute median refresh rate) microwave measurements over the tropics to observe the thermodynamic environment and precipitation structure of tropical cyclones over much of their lifecycle. TROPICS comprises six CubeSats in two or three ~550-km altitude, 30°-inclination orbital planes for at least one year. TROPICS successfully completed its Key Decision Point-C review in August 2018 and is now an officially confirmed NASA mission. Launch date and number of orbital planes still to be confirmed by NASA Headquarters.

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

Name	Mission
Randy Kawa	ASCENDS
Mian Chin	GEO-CAPE
Scott Braun	TROPICS

Table 3.1.1.2: *Mission Study Scientists*

3.1.2 Active Missions

3.1.2.1 DSCOVR

Deep Space Climate Observatory (DSCOVR) is a NOAA Earth observation and space weather satellite launched by SpaceX on February 11, 2015, from Cape Canaveral. The mission is a partnership between NOAA, NASA, and the U.S. Air Force. NOAA operates the DSCOVR mission, to provide advanced warning of approaching solar storms with the potential to cripple electrical grids, communications, GPS navigation, air travel, satellite operations, and human spaceflight. DSCOVR is positioned at the Sun-Earth first Lagrangian point (L1), about 1,500,000 km from Earth, with the primary goal of monitoring variable solar wind condition and providing early warning of approaching coronal mass ejections. The satellite orbits the L1 point in a six-month Lissajous orbit, with a spacecraft-Earth-Sun angle varying from 4 to 12 degrees. While the primary science objectives of DSCOVR are to make unique space weather measurements, the secondary goal of DSCOVR is to provide unique Earth atmosphere and surface measurements.

There are two NASA Earth science instruments onboard the DSCOVR satellite: the Earth Polychromatic Imaging Camera (EPIC) (see https://epic.gsfc.nasa.gov/about/epic) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR) (see https://epic.gsfc.nasa.gov/about/nistar). EPIC provides spatially resolved radiances from the sunlit face of the Earth on a 2048×2048 pixel CCD in 10 narrowband channels between UV (317 nm), and near-IR (780 nm) with a nadir sampling field of view of approximately 8 km at the center of the image with an effective resolution of 10×10 km^2 for the 443 nm channel and 18×18 km^2 for the other nine filter channels.

The time cadence of these spectral band images is provided on a best effort basis given existing ground system and network capabilities and is no faster than one set of 10 spectral-band images approximately every hour (from mid-April to mid-October) or every two hours (during rest of the year). The DSCOVR project provides raw instrument data, EPIC Level-1 images in CCD counts/second (C/s) that are geolocated on a common grid, and corrected for both dark-current and stray-light. Calibration conversions from C/s to reflectance are given based on the most recent in-flight calibration data. True-color (RGB) images are generated daily and are available at https://epic.gsfc.nasa.gov. As an example, Fig. 3.1.2.1a provides two images: the famous Apollo 17 "blue marble" image and the EPIC image taken on the same day 44 years apart.

NISTAR measures the absolute "irradiance" as a single pixel integrated over the entire sunlit face of the Earth in four broadband channels: (i) visible to far IR (0.2 to 100 ±µm); (ii) solar (0.2 to 4 µm); (iii) near-IR (0.7 to 4 µm); and (iv) photodiode (0.3 to 1 µm) used for validation and co-alignment of NISTAR and EPIC.

The Level-1 EPIC and NISTAR products are publicly available from the NASA's Langley Research Center in Hampton, Virginia, Atmospheric Science Data Center (ASDC). The Earth science instruments onboard DSCOVR provide sunrise to sunset observations (Level-2 product) of global ozone levels (https://epic.gsfc.nasa.gov/science/products/o3), amount and distribution of aerosols (https://epic.gsfc.nasa.gov/science/products/uv), dust and volcanic sulfur dioxide (SO_2) and ash (https://epic.gsfc.nasa.gov/science/products/so2), cloud height over land and ocean (https://epic.gsfc.nasa.gov/science/products/cloud), spectral surface reflectance (https://epic.gsfc.nasa.gov/science/products/vis) and vegetation properties (https://epic.gsfc.nasa.gov/science/products/vegetable); the instruments will monitor effects that indicate changes in climate including Earth radiation budget.

The first release of Level 2 data products has been started in late 2017 and completed in June 2018. The EPIC Level-2 products are also available from ASDC. Examples of such products (ozone, aerosols and atmospherically corrected surface reflectance, clouds, aerosol single scattering albedo and volcanic sulfur dioxide) are shown at https://epic.gsfc.nasa.gov/science/products and in Figures 3.1.2.1b, c, d, and e.

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

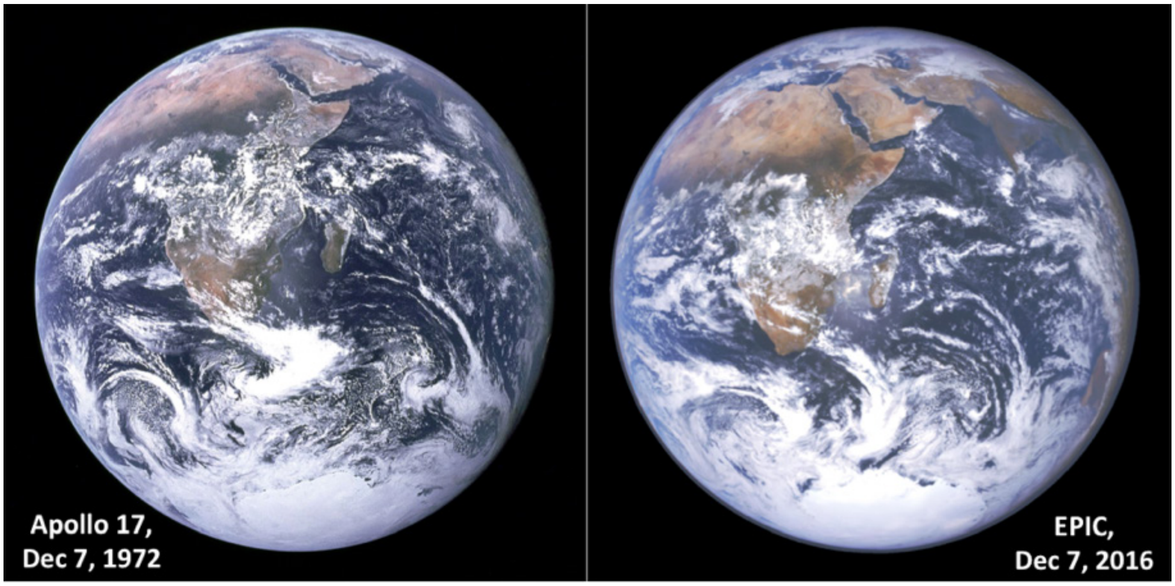


Figure 3.1.2.1a: *Apollo 17 ("blue marble") and DSCOVR EPIC images acquired on December 7, 1972 and 2016, 44 years apart.*

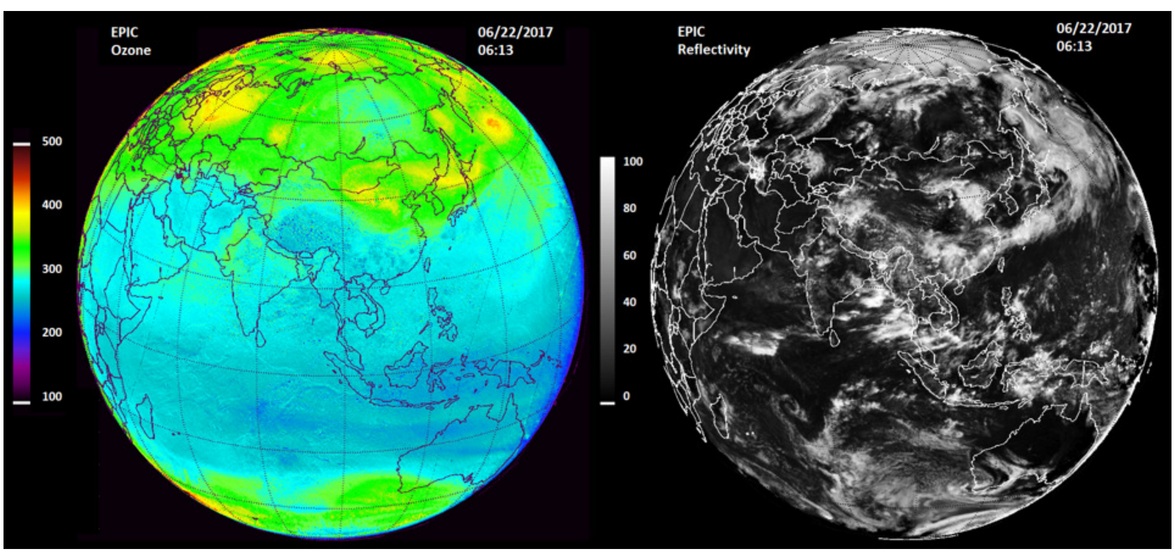


Figure 3.1.2.1b: *Ozone (left in DU: 100 to 500 DU) and reflectivity (Lambert equivalent reflectivity, LER, right in percent: 0 to 100) for June 22, 2017 at 06:13 GMT. These are the basic input data needed to compute UV radiation reaching the ground.*

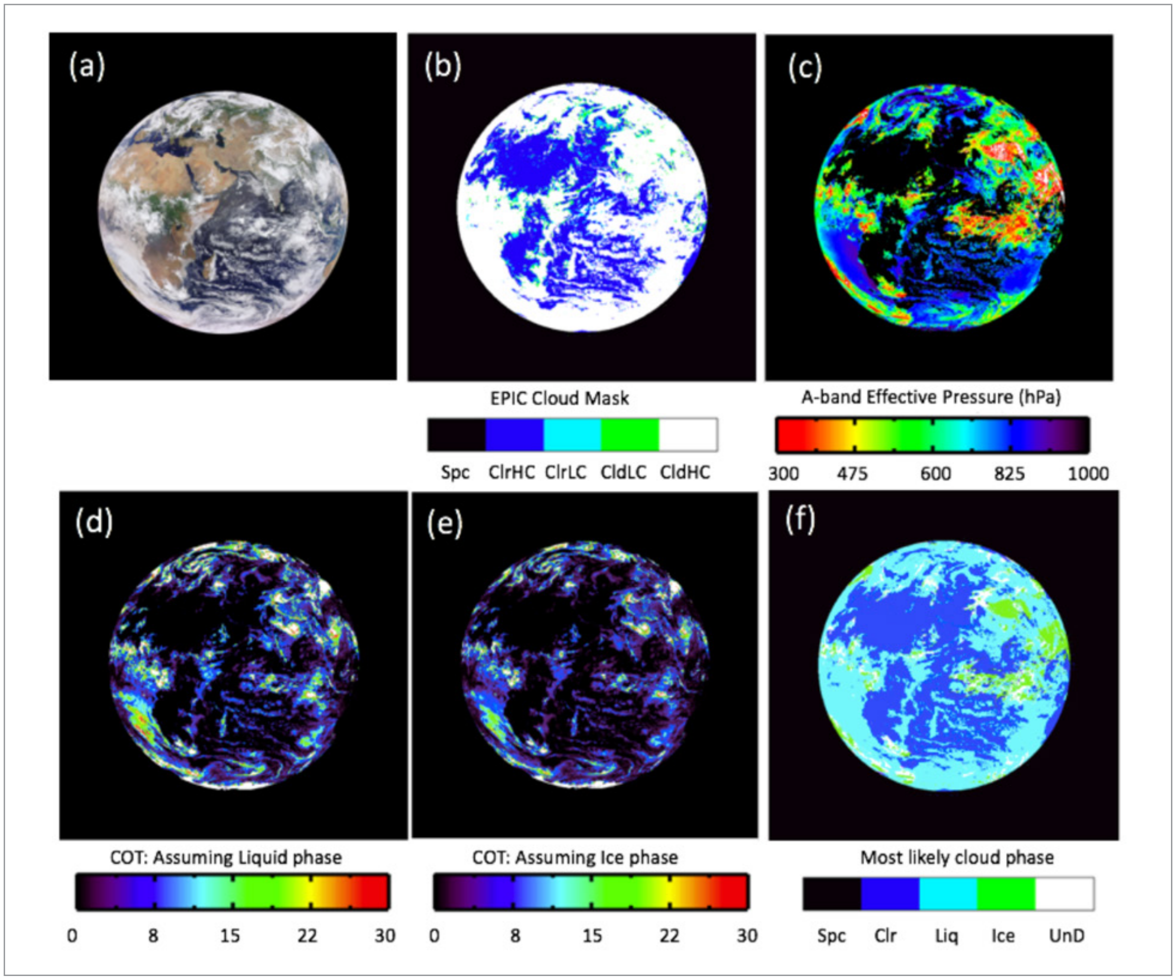


Figure 3.1.2.1c: *Sample EPIC L2 cloud products for the observations at 08 UTC on Aug. 18, 2016: (a) EPIC RGB image; (b) EPIC cloud mask. Spc: space pixels, ClrHC: high confidence clear, ClrLC: low confidence clear, CldLC: low confidence cloudy, and CldHC: high confidence cloudy; (c) oxygen A-band cloud effective pressure; (d) cloud optical thickness assuming liquid phase; (e) cloud optical thickness assuming ice phase; (f) most likely cloud phase. Other L2 cloud products not shown include oxygen B-band cloud effective pressure, and A- and B-band cloud effective height.*

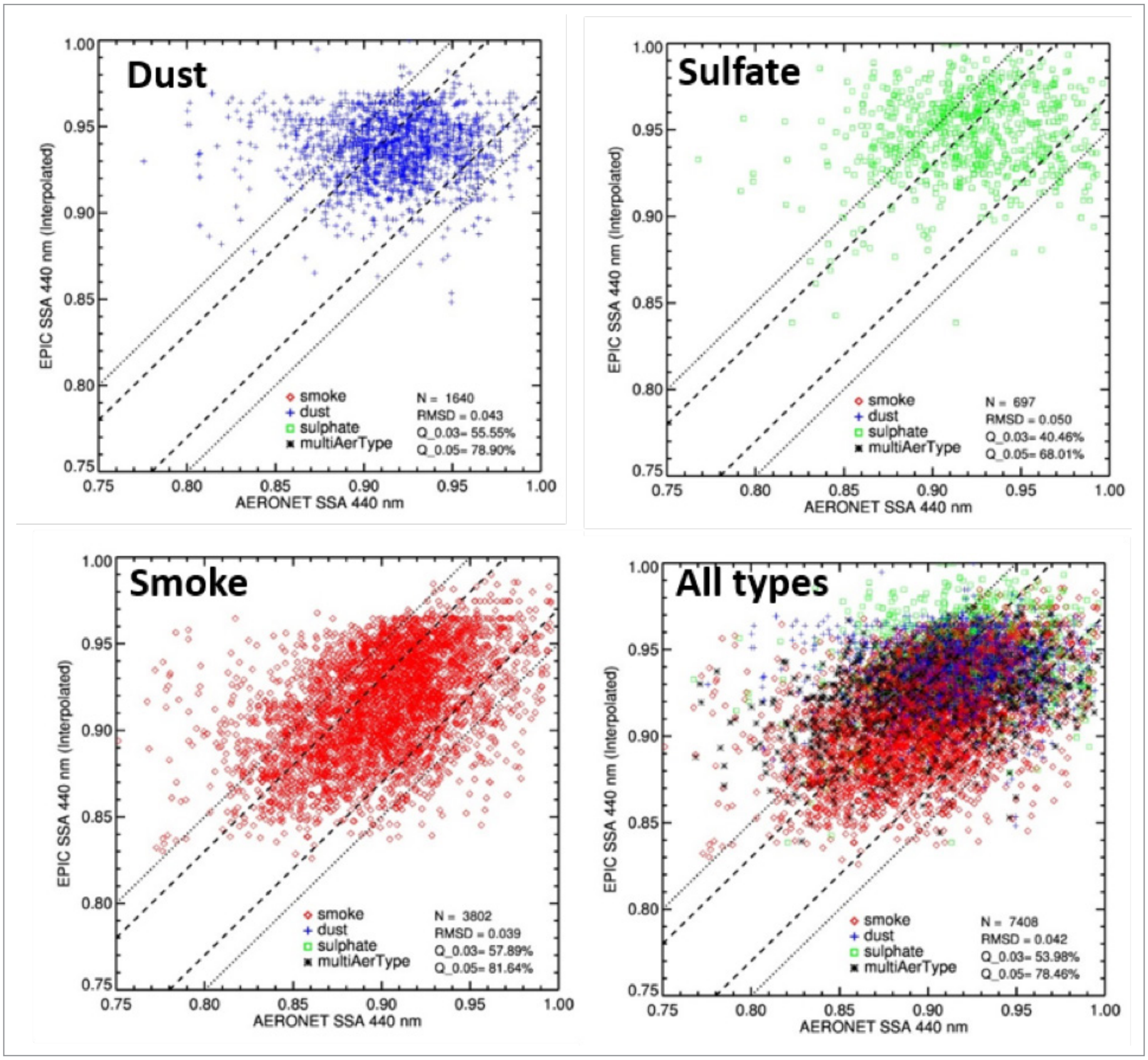


Figure 3.1.2.1d: *Results of the evaluation of EPIC retrieved single scattering (SSA) albedo for different aerosol types using AERONET observations at 380 sites. EPIC retrieved SSA has been converted to 440 nm for comparison to AERONET measured values. Dashed (dotted) lines indicate agreement within 0.03 (0.05). AERONET SSA retrieval uncertainty is 0.03. Statistics indicate number of matchups (N), root mean square error difference (rmsd), and percent of points agreement within 0.03 and 0.05 (Q_0.03 and Q_0.05). Overall, 54% of compared pairs agree within 0.03, whereas 78% agree within 0.05.*

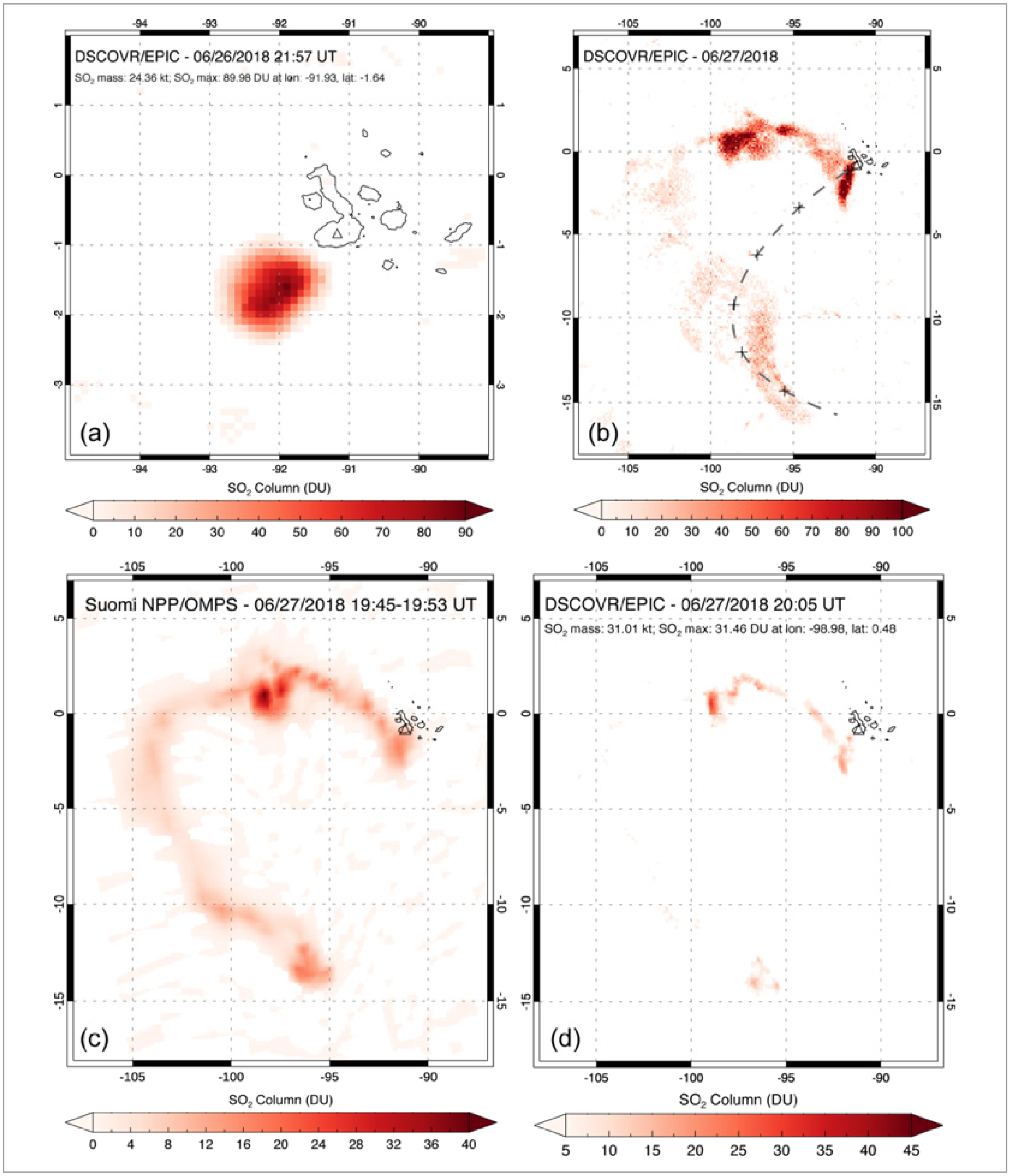


Figure 3.1.2.1e: *(a) EPIC detection of strong SO_2 emissions from Sierra Negra (Galápagos Islands; triangle) at 21:57 UT on June 26, 2018; (b) Cumulative SO_2 column amounts measured in the Sierra Negra volcanic plume by EPIC in 8 exposures on June 27, 2018 (14:38-22:16 UT). Dashed line shows a 36-hour HYSPLIT model trajectory for an eruption to 11 km altitude beginning at 19:00 UT on June 26, with crosses every 6 hours. (c) SNPP/OMPS map of SO_2 emissions from Sierra Negra at 19:50 UT on June 27; (d) EPIC SO_2 map at 20:05 UT on June 27.*

3.1.2.2. Terra

Launched on December 18, 1999, as NASA's Earth Observing System (EOS) flagship observatory, Terra carries a suite of five complementary instruments: (1) Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER), contributed by the Japanese Ministry of Economy, Trade, and Industry with an American science team leader at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, 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) Clouds and the Earth's Radiant Energy System (CERES, Langley) 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) Multi-angle Imaging SpectroRadiometer (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) Moderate Resolution Imaging Spectroradiometer (MODIS, Goddard) 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) Measurement Of Pollution In The Troposphere (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 19 years, the Terra mission has been providing the worldwide scientific community with an unprecedented 83 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 the U.S. Forest Service (ASTER, MODIS, MISR); and carbon management and global crop assessment by USDA and USDA-FAS (MODIS, CERES). On October 6, 2018, Terra completed its 100,000th orbit around Earth. Data from Terra, in combination with Aura, were analyzed to show that clean air programs have continued to improve fine particle pollution while declines in carbon monoxide emissions are slowing down and efforts to reduce nitrogen oxide emissions have not been as successful as expected. Terra's long lifetime, view from above, and its unique combination of sensors provided the spatial assessment for these results that would not be available if those programs used only ground-based measurements. Likewise, Terra's unique views allowed tracking of fire intensity, smoke plume heights, and spatial extent of wildfire activity and pollution during the 2018 Western U.S. fire season, evaluation of the impact of Hawaii's Kilauea eruption, and better understanding of the tracks and impacts Hurricanes Florence and Michael.

For further information, please contact Si-Chee Tsay (si-chee.tsay-1@nasa.gov).

3.1.2.3. Aqua

Aqua is one of NASA's flagship missions for Earth Science operating in the A-Train constellation. It launched on May 4, 2002, and is still going strong in extended operations with four of its instruments (AIRS, AMSU, CERES, and MODIS) continuing to collect valuable data at an approximate rate of 88 Gbytes/day. The 2017 Earth Science Senior Review endorsed the Aqua mission for continued operations through 2020, and preliminarily, through 2023.

Aqua's observations pertain to the atmosphere, oceans, land, and cryosphere and span almost all fields of Earth science, from trace gases, aerosols and clouds in the atmosphere, to chlorophyll in the oceans, to fires on land, to the global ice cover, and numerous other geophysical variables. Thousands of scientists from around the world use Aqua data to address NASA's six interdisciplinary Earth science focus areas: atmospheric composition, weather, carbon cycle and ecosystems, water and energy cycle, climate variability and change, and Earth surface and interior. In 2018, specifically, Aqua data have been used, among others, to: (1) obtain the vertical structure of temperature and humidity within the eyes of hurricanes; (2) monitor changes in global burned area which was shown to have declined by ~25% over the past 18 years; (3) reveal the relationship between ocean biological productivity and the El Niño and Southern Oscillation (ENSO); (4) pinpoint the vulnerability of current and future communities to the detrimental effects of heat waves and extreme heat in urban areas; (5) show that the global distribution of aerosol particles produced by human activities, natural dust storms, and fires is relatively stable; (6) support operationally the United States Drought Monitor (USDM) with surface temperature and humidity observations.

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

3.1.2.4. Aura

On July 15, 2004, the Aura spacecraft was launched with four instruments to study the composition of Earth's atmosphere. Two of the instruments, the Ozone Monitoring Instrument (OMI) and the Microwave Limb Sounder (MLS), continue to make measurements of aerosols, clouds, and ozone (O_3) and constituents related to O_3 in the stratosphere and troposphere. With these measurements the science team has addressed questions concerning the Antarctic ozone hole and the stratosphere's protective O_3 layer, and tropospheric composition and air pollution.

OMI data continue to be used to monitor global air pollution trends, determine the efficacy of mitigation control strategies, and estimate emissions in 2018. For instance, a new global anthropogenic emission inventory of sulfur dioxide (SO_2), a pollutant that contributes to atmospheric haze, was developed from OMI-derived SO_2 and bottom-up emissions estimates. Emissions from over 400 SO_2 sources (e.g., thermal power plants, smelters) were quantified, which account for about 50% of reported anthropogenic SO_2 emissions. Spatio-temporal maps of OMI data of both SO_2 and nitrogen dioxide (NO_2), a pollutant that is emitted from cars and power plants, were highlighted in the 2017 and 2018 EPA *Air Trends Reports*, respectively. Interestingly, OMI data show that U.S. surface NO_2 levels decreased significantly less than projected by the EPA, which a study attributed to a number of possible causes, including a slower than expected decrease in on-road diesel emissions. Additionally, OMI data are being increasingly used to estimate human exposure to UV radiation and air pollutants, including NO_2 and formaldehyde (HCHO). Efforts are ongoing to compare OMI data to data from other recently launched instruments—e.g., Ozone Monitoring Profiler Suite (OMPS), Tropospheric Monitoring Instrument (TROPOMI)—in order to assure a consistent long-term record.

MLS continues to provide uniquely valuable daily near-global profile observations of a range of species in the middle atmosphere. Specifically, these include stratospheric ozone and species related to its variability and trends in response to the long-term decline in ozone depleting substances and increase in greenhouse gases. Since launch, MLS observations have been central to many studies feeding into the four-yearly WMO ozone assessments. The MLS ozone record has been one of the key datasets used to show statistically significant signs of recovery in upper stratospheric ozone. In the lower stratosphere, diagnosis of recovery is complicated by the large degree of interannual variability in atmospheric dynamics. Indeed, a recent paper indicated a continuing decline in lower stratospheric ozone from 1998-2016 (with MLS being the main source of post-2004 observations). However, a follow-up study indicated that subsequent MLS observations in 2017 show a notable ozone increase, changing the interpretation of the ozone behavior from one of a downward trend to one of larger variability. Similarly, MLS data have also been used to quantify the evolution of the Antarctic ozone hole, with studies showing behavior consistent with ozone recovery. Together, these studies and others demonstrate the magnitude of atmospheric variability and of its impacts, and thus underscore the need to continue spaceborne observations of not only stratospheric ozone, but also of chlorine-containing species and long-lived trace gases that, between them, can disentangle chemical and dynamical influences on the long-term evolution of ozone. MLS also provides unique daily global measurements of stratospheric water vapor that continue to be central to many studies seeking to better characterize the processes controlling stratospheric humidity, which has a strong climate impact.

More information on Aura science highlights can be found at https://aura.gsfc.nasa.gov or contact Aura's Project Scientist, Bryan Duncan (bryan.n.duncan@nasa.gov).

3.1.2.5. 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 (www.goes-r.gov). The GOES series of satellites carry sensors that continuously monitor the Earth's atmosphere for developing planetary weather events, the magnetosphere for space weather events, and the Sun for energetic outbursts. The flight project scientist at Goddard assures the scientific integrity of the GOES sensors throughout the mission definition, design, development, testing, and post-launch data-analysis phases of each decade-long satellite series.

Two of the four satellites in the GOES-R series have been launched: GOES-R was launched in November 2016 to become GOES-16, and GOES-S was launched in March 2018 to become GOES-17. Both satellites went through post-launch testing in orbit at 89.5°W before moving to operational positions. GOES-16 was moved to 75.2°W in December 2017, where it became operational as NOAA's GOES-East satellite. GOES-17 drifted the GOES-West position, 137.2°W, in October 2018 and is scheduled to be declared operational as GOES-West in early 2019. Combined, the Advanced Baseline Imagers (ABI) on GOES-16 and -17 provide persistent imagery from New Zealand to Western Africa in 16 visible to thermal infrared spectral channels at spatial resolutions of 0.5 to 2 km.

During the commissioning of GOES-17, the GOES-R team encountered an issue with the ABI cooling system. The cooling system is an integral part of the ABI and is not operating at its designed capacity.

The reduced cooling capacity primarily affects thermal infrared detectors (channels 8-16) which quickly saturate at elevated operated operating temperature. Teams of experts from NOAA, NASA, the ABI vendor, and industry worked to diagnose the issues with the cooling system, plan for fixes on subsequent ABI flight models, and performance optimization of GOES-17 ABI, while operating at warmer-than-designed detector temperatures. The optimization team was able to regain >96% imaging capability by adjusting operational sensor parameters and modifying ground system processing algorithms.

The future GOES satellites, T and U, are currently scheduled for launch in 2020 and 2024. The ABI was removed from the GOES-T spacecraft in fall 2018 to undergo redesign of its cooling system based on studies conducted after the GOES-17 anomaly.

For further information, please contact Robert Levy (robert.c.levy@nasa.gov).

3.1.2.6. GPM

The Global Precipitation Measurement (GPM) mission is an international satellite mission that provides next-generation observations of rain and snow worldwide. NASA and the Japan Aerospace Exploration Agency (JAXA) launched the GPM Core Observatory (GPM-CO) satellite on February 27, 2014. The GPM-CO data are used to unify merged 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 is advancing our understanding of the water and energy cycles, and is extending the use of precipitation data to directly benefit society. The GPM-CO completed its three-year prime mission lifetime in 2017 and is currently in extended operations. GPM has conducted a series of field campaigns with international and domestic partners, the most recent being the Korean Meteorological Administration (KMA)-led International Collaborative Experiment-PyeongChang Olympics Paralympics (ICE-POP) field campaign, which coincided with the 2018 Winter Olympics. The data collected from GPM field campaign instruments provides crucial information to improve the GPM mission's measurements of light rain and snow, to assess the hydrological impacts of precipitation, to directly validate the satellite data products, as well as to help researchers understand how precipitation changes across land and ocean.

Significant milestones and activities were met in 2018 including:

- GPM's Version 05 radiometer products were reprocessed using the Goddard Profiling (GPROF) algorithm by the Precipitation Processing System (PPS) in February 2018 for all TRMM-era partner satellites.

- GPM's Version 05 GPROF radiometer products were reprocessed by the PPS in April 2018 for the TRMM Microwave Imager.

- A new Colorado River Basin GPROF product began processing by the PPS to advance water supply forecasts in the western U.S.

- TRMM Precipitation Radar (PR) products were reprocessed to V06 of the GPM radar algorithm in July 2018.

- GPM's Version 06 radar and combined radar-radiometer products were reprocessed by the PPS in October 2018 while TRMM combined products began reprocessing in November 2018.

- The GPM team is recalibrating TRMM merged products (known as IMERG) back to the start of TRMM with expected reprocessing to start in March 2019.

- The GPM ground validation team participated in the South Korean ICE-POP field campaign.

- GPM all-sky radiances from the GPM Microwave Imager (GMI) began to be assimilated into the NASA Goddard Earth Observing System (GEOS) global model and assimilation system in July 2018, yielding significant forecasting improvements out to 3 days lead time.

- In October 2018, the science team met in Phoenix, Arizona, to review algorithm development and plan future activities, including the upcoming Integrated Multisatellite Retrievals for GPM (IMERG) reprocessing.

- GPM's vigorous outreach and education efforts continue and 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 Scott Braun (scott.a.braun@nasa.gov) or visit the GPM home page at https://gpm.nasa.gov.

3.1.2.7. 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 FY11 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 2018, 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 JPSS-1 mission launched on November 18, 2017, from Vandenburg Air Force Base in California. The J1 mission is very similar to Suomi NPP, using the same spacecraft and a nearly identical instrument complement. In late November 2017, the J1 Advanced Technology Microwave Sounder (ATMS) instrument sent the first science data back to NOAA, was renamed as NOAA-20, and was declared ready for operational use by the National Weather Service in May 2018. The Polar Follow-on Program was approved, continuing the polar observation program with planned launches of JPSS-3 and JPSS-4 in 2026 and 2031. The JPSS-2, JPSS-3, and JPSS-4 missions will have the same spacecraft and similar instruments to Suomi NPP, the

Visible Infrared Imaging Radiometer Suite (VIIRS), the Cross-track Infrared Sounder (CrIS), ATMS, and OMPS. The CERES successor NASA instrument, the Radiation Budget Instrument (RBI) was canceled due to technical, cost and schedule problems. The JPSS-2 VIIRS instrument has its Pre-Ship Review in March 2018, the first JPSS-2 instrument to be ready for space craft integration.

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

3.1.2.8. SORCE

The Solar Radiation and Climate Experiment (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 overlap¬ping 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 has been launched on the International Space Station (ISS) and is operational since March 2018. SORCE is scheduled to end its mission in 2019.

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

3.1.3.9. Suomi NPP

The Suomi 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 ATMS, CrIS, OMPS, CERES, and 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 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 re-competed 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. Current science team members from Earth science/atmospheres include: Can Li for SO_2 and NO_2; Tamas Varnai for aerosols in partly cloudy regions; Hongbin Yu for radiative effects of mineral dust; N. Christina Hsu, VIIRS aerosol products using the Deep Blue algorithm; Steven Platnick, cloud properties using only the channels available on both MODIS and VIIRS; Richard McPeters, total ozone continuing OMI with OMPS including P. K. Bhartia, OMPS Limb Team Leader; and Alexei Lyapustin, VIIRS aerosol and surface reflectance products using MAIAC.

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

3.1.2.10. Earth-IceCube

NASA's Science Mission Directorate (SMD) has chosen a team at Goddard Space Flight Center to build its first Earth cloud observing CubeSat to demonstrate a compact, commercially-available radiometer technology (www.nasa.gov/cubesat). The IceCube team is led by Dong Wu who serves as the project Principal Investigator, with a Greenbelt team responsible for payload development and a Wallops team for CubeSat and ground system development. The 1.3-kg payload in 1.2 U CubeSat units (1 U=10×10×10 cm^3) will demonstrate and validate a new 883-Gigahertz submillimeter-wave receiver to advance cloud-ice remote sensing and help scientists to better understand the role of ice clouds in the Earth's climate system. Global distribution and microphysical properties of ice clouds remain highly uncertain, which is one of the leading error sources in determining Earth's radiation budget and cloud-precipitation processes. IceCube was launched to the International Space Station (ISS) in April 2017 and subsequently released from ISS in May 2017. It obtained the first light data on June 6, 2017, and completed its nominal tech-demo mission by the end of August 2017. The IceCube 883-Gigahertz cloud radiometer had experienced a large (10°C-35°C) orbital temperature variation and achieved 3K radiometric calibration stability. The CubeSat demonstrated capability to operate the 5.6-W payload continuously on both day and night, as well as spinning operation at a rate as high as 3.3 degrees/second. IceCube acquired 16 months of cloud data at orbital altitudes of 200-400 km before its reentry to the atmosphere on October 3, 2018. On September 29, 2018, four days before its reentry, IceCube was able to capture cloud features from Typhoon Trami at an orbital altitude of ~200 km. The IceCube calibrated radiances produced the first 883-GHz cloud ice map, which shows consistent amplitudes with the cloud ice observed during the same period by MLS at 240 and 640 GHz.

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

3.1.2.11. mini-LHR (2-STP-27VP)

The mini-LHR team of Emily Wilson (614), A.J. DiGregorio (614/SSAI), Guru Ramu (699/Beacon), Paul Cleveland (448/Energy Solutions), and Jennifer Young (540/Genesis) announced that their 3.5U CubeSat instrument has shipped to Lawrence Livermore National Laboratory for integration into the 6U bus. The mini-LHR is a laser heterodyne radiometer that has been transitioned into a CubeSat instrument to observe methane, carbon dioxide and water vapor in the limb from Low Earth Orbit with a launch currently scheduled for July 2019.

For further information, please contact Emily Wilson (emily.l.wilson@nasa.gov).

3.1.2.12. TSIS-1

The main objective of the Total and Spectral solar Irradiance Sensor (TSIS) is to acquire solar irradiance measurements to monitor effects of solar radiation on climate. The TSIS total solar irradiance measurements will extend a multi-decadal uninterrupted record of incoming solar radiation, the dominant energy source driving the Earth's climate and the most precise indicator of solar energy input to Earth's system. New SSI data from TSIS-1 established an accurate reference solar spectrum in 200-2400 nm that helps scientists calibrate sensors on other national and international satellites for global climate and environmental studies. Measuring the incoming solar energy at different wavelength bands provides critical elements for understanding how the energy is absorbed by Earth's atmosphere and surface. TSIS includes two instruments: the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM), integrated into a single payload. The TSIS TIM and SIM instruments are upgraded versions of the two instruments that are flying on the SORCE mission launched in January 2003. The Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder (CU) provided the TIM and SIM instruments, as well as the precision solar pointing of the instruments, and provides mission operations. LASP also developed and built the instruments for SORCE.

TSIS-1 was launched to the ISS on December 15, 2017. It made the first-light measurement of solar irradiance in January 2018 and transitioned to normal operation since March 2018. Both TSIS-1 and SORCE instruments tracked daily TSI variations consistently within 0.004 percent. The TSIS-1 data are publicly available since

September 2018 at Goddard Earth Sciences Data and Information Services Center (GES DISC), or https://disc.gsfc.nasa.gov/datasets?keywords=TSIS&page=1. The nominal mission lifetime is 5 years with potential 2-year extension.

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

3.2. Project Scientists

A number of special career positions exist in NASA to help carry out its research programs and missions which are unique in the science community. These include project scientists, study scientists, and instrument 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 3.2a lists project and deputy scientists for current and planned missions. Table 3.2b lists the instrument scientists and major participants in field campaigns.

Project Scientist	Project
Bryan Duncan	Aura
Steven Platnick	EOS
Scott Braun	GPM
James Gleason	JPSS
James Gleason	SNPP
Dong Wu	SORCE
Dong Wu	TSIS-1
Scott Braun	TROPICS
Dong Wu	Earth-ICECube

Deputy Project Scientist	Project
Joanna Joiner	Aura
Lazaros Oreopoulos	Aqua
Alexander Marshak	DSCOVR
Robert Levy	GOES
George Huffman	GPM
Si-Chee Tsay	Terra
Christina Hsu	SNPP

Table 3.2a: *610AT Project and Deputy Project Scientists*

Validation Scientist	Project
Ralph Kahn	EOS/MISR
Matthew McGill	ISS/JEM-EF/CATS

Instrument Scientist/Manager	System	Recent Campaign
Ellsworth Welton	MPLNET	SEALS-sA, ORACLES
Si-Chee Tsay	XBADGER	Wallops Facility Operations
Si-Chee Tsay/David Wolff	ACHIEVE	Wallops Facility Operations
David Wolff	NPOL, D3R, ICE-POP	Wallops Facility Operations
Gerald Heymsfield	HIWRAP	SHOUT
Thomas McGee	TROPOZ, NDACC	KORUS-AQ
Robert Swap	Pandora	KORUS-AQ, OWLETS
Anne Thompson	SO_3 Sondes/SHADOZ	Ascension Island Sondes
Paul Newman/Thomas Hanisco	ISAF	Atom
Steven Platnick	eMAS	ORACLES
Stephan Kawa		CARAFE

Table 3.2b: *610AT Validation (top) and Instrument (bottom) Scientists*

4. Field Campaigns

Field campaigns are investigator-led observational studies planned in specific areas for a defined time period during which measurements are made from airborne platforms and/or ground sites to study physical and chemical processes in the atmosphere. The resources of NASA, other agencies, and other countries are used to carry out scientific experiments and campaigns. The observation platforms serve as a step in the development of space borne instruments or validation and calibration measurements for existing space systems or collecting information leading to a basic understanding of relations between atmospheric process. In 2018, scientists supported the following activities as scientific investigators, or as mission participants, in the planning and coordination phases.

4.1. ATom

The Atmospheric Tomography Mission (ATom) is studying the impact of human-produced air pollution on greenhouse gases and on chemically reactive gases in the atmosphere. Reductions of atmospheric concentrations of methane (CH_4), tropospheric ozone (O_3) and black carbon (BC) aerosols are effective measures to slow global warming and to improve air quality. Airborne instruments are providing data on how atmospheric chemistry is transformed by various air pollutants and their impact on CH_4 and O_3. Mitigation of these short-lived climate forcers is a major component of current international policy discussions. ATom consisted of four global scale deployments in August 2016 (northern summer), February 2017 (winter), October 2017 (fall) and May 2018 (spring). These deployments were designed to identify seasonal patterns in chemical reactivity and the integrated impact of anthropogenic emissions from the major continents. Each deployment was comprised of ~11 flights in a circuit transecting the Pacific and Atlantic basins from nearly pole-to-pole with flight profiles that sampled air at altitudes from 150 m to 11000 m. The ATom suite of instruments aboard NASA's DC-8 flying laboratory measured more than 300 gases and particles in the air and studies their interactions around the world. In the coming year, the science team will use these observations from around the world to better understand chemical processes in the atmosphere that control the short-lived greenhouse gases—methane and ozone, the latter of which is also a health-damaging air pollutant.

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

4.2. CARAFE

The CARbon Airborne Flux Experiment (CARAFE) is a versatile system for direct measurement of vertical fluxes to/from the Earth surface via the airborne eddy covariance technique (Wolfe et al., 2018). The scientific aim of CARAFE is to quantify greenhouse gas (GHG) sources and sinks over diverse ecosystem states and land-use regions in order to improve top-down and bottom-up source/sink estimation, evaluate biophysical process models, and validate top-level flux products from OCO-2 and other space borne missions. CARAFE flies on the NASA Wallops C-23 Sherpa aircraft. Seventeen flights have been made across a variety of biomes in the U.S. mid-Atlantic region in September 2016 and May 2017, and a great cache of data has been acquired. CARAFE 2017 flights were funded by the NASA Carbon Monitoring System Program. Results from CARAFE in May are compared to corresponding data and models taken in September over many of the same surfaces to examine how the uptake of CO_2 and emissions of CH_4 by vegetation vary with phenology (seasonal cycles with respect to climate conditions) for crops and different forest types. CARAFE also added a N_2O/CO sensor to the payload for 2017. Opportunities for further deployment of CARAFE are being explored. Data are available at www-air.larc.nasa.gov/index.html.

CARAFE Investigators: PI S. R. Kawa (614) and co-Is P. A. Newman (610), G. Wolfe (614/UMD), T. Hanisco (614), G. Diskin, K. L. Thornhill, J. Barrick (LaRC), G. Hurtt (UMD), G. Bland (610.W), and S. Pusede (UVA).

For further information, please contact S. Randolph Kawa (stephan.r.kawa@nasa.gov).

Reference: Wolfe, G. M., S. R. Kawa, T. F. Hanisco, R. A. Hannun, P. A. Newman, A. Swanson, S. Bailey, J. Barrick, K. L. Thornhill, G. Diskin, J. DiGangi, J. B. Nowak, C. Sorenson, G. Bland, J. K. Yungel, C. A. Swenson, 2018: The NASA Carbon Airborne Flux Experiment (CARAFE): Instrumentation and Methodology. *Atmos. Meas. Tech.*, **11**, 1757-1776, https://doi.org/10.5194/amt-11-1757-2018.

4.3. ICE-POP

NASA's GPM ground validation program partnered with the Korean Meteorological Administration (KMA) during the execution of the International Collaborative Experiment for the Pyeongchang Olympics and Paralympics (ICE-POP) 2018 field campaign. NASA provided ground-based instruments for forecast and research studies before, during, and after the 2018 Winter Olympic Games (February 9-25, 2018), held in Pyeongchang, South Korea. Preparations for ICE-POP 2018 began in November 2016, when a Letter of Agreement (LOA) was concluded between NASA and KMA.

An initial suite of GPM ground validation equipment arrived at the Daegwallyeong Weather Station, South Korea, in early May 2017. Two Precipitation Imaging Package (PIP) instruments and two Micro Rain Radars (MRR) were shipped in July 2017. The NASA Dual-polarization, Dual-Frequency, Doppler Radar (D3R) was shipped from NASA Wallops Flight Facility in September 2017. In October an internet-accessible GPM overpass prediction site (https://gpm-gv.gsfc.nasa.gov/Tier1) was set up for the domain of the campaign. GPM rain gauges, MRRs, and PIPs are operated at numerous locations in the domain. Goddard and Colorado State University successfully deployed the D3R on the roof of the Daegwallyeong Weather Station in South Korea in October.

KMA generously funded the transportation and installation of the D3R and also funded NASA and Contractor staff for operations during the campaign.

The ICE-POP field campaign was a huge success. The D3R provided high-quality, multi-frequency observations of winter precipitation (rain, mixed phase, and snow) in complex terrain, and the resultant data will significantly aid the GPM GV program for years to come. Additionally, NASA disdromers provided important observations of drop size distributions, the PIP was able to quite accurately provide in-situ estimates of snow water equivalent critical for snow measurements and hydrology.

For further information, please contact David B. Wolff (david.b.wolff@nasa.gov).

4.4. MPLNET

The Micro Pulse Lidar Network (MPLNET) project added eight new sites in 2018, some older ones were discontinued, and at this time, there are a total of 25 sites in the network. Three new sites were added in Thailand through a partnership with the National Astronomical Research Institute of Thailand (NARIT) at Doi Inathon, Songkhla Regional Observatory, and Princess Sirindhorn AstroPark. Another new Thailand site was added at Silpakorn University with long-term partners there who previously operated a site at Om Koi. Two new sites were established in Taiwan through our longstanding partnership with National Central University and the Taiwanese EPA at Kaohsiung and Xitun. A new site was also begun on King George Island (off Antarctica) with new partners at the Universidad de Santiago de Chile. A short-term site was established at Bidur, Nepal in support of the NASA High Mountain Asia field campaign in conjunction with the SMART-COMMIT-ACHIEVE group at Goddard. An older site from a 2012 field campaign was re-established at Kuching, Malaysia with long-term partners at National University of Singapore, Universiti Kebangsaan Malaysia, and the Malaysian Meteorology Department. Kuching will now be a permanent site in MPLNET. Finally, the lidar at one of our older sites at Santa Cruz de Tenerife was replaced with a new polarized lidar in 2018, and the entire network now has polarized lidars.

For further information, please contact Ellsworth Welton (ellsworth.j.welton@nasa.gov).

4.5. NDACC

The Stratospheric Ozone Lidar is currently deployed at the Deutscher Wetterdienst (DWD) observatory, at Hohenpeissenberg in southern Germany, for the purpose of participating in a Network for the Detection of Atmospheric Composition Change (NDACC) ozone profiling validation campaign. These campaigns are a regular part of the NDACC Validation Protocol, for instrumentation at different sites around the globe. Participating in this deployment (October 2018 and February 2019) from 614 are Thomas McGee (614), PI of the group, John Sullivan (614), and additional staff from SSAI. These campaigns are scheduled to end in early 2019. The equipment will then be shipped onward to New Zealand. A campaign is planned there in April or May 2019. The AT trailer is undergoing a significant upgrade to the radar used to control the transmission of laser light into navigable airspace, which is expected to be completed in early 2019.

For further information, please contact Thomas McGee (thomas.j.mcgee@nasa.gov).

4.6. Ozone Water-Land Environmental Transition Study-2 (OWLETS-2)

The monitoring of ozone (O_3) in the troposphere is of pronounced interest due to its known toxicity and health hazard as a photo chemically generated pollutant. One of the major difficulties for the air quality modeling, forecasting, and satellite communities is the validation of O_3 levels in sharp transition regions, as well as near-surface vertical gradients. Significant land-water gradients in coastal regions can occur due to differences in emissions, surface deposition, boundary layer height, and cloud coverage. Therefore, vertical, horizontal, and temporal (4-D) measurements are needed to describe complex scenes to improve forecast models and air quality satellite retrievals.

The OWLETS-2 field campaign (J. Sullivan, 614, principal investigator) was conducted in summer 2018 in the Baltimore, Maryland region to better characterize O_3 across the coastal boundary. This began as a NASA 2017 Science Innovation Fund (SIF) Award and was further supported by the GeoTASO project, the Student Airborne Research Program-East (SARP-E), the Pandora project, the Tropospheric Ozone Lidar Network (TOLNet), and NASA Headquarters. Additional support was provided by the Maryland Department of the Environment; University of Maryland, Baltimore County (UMBC); University of Maryland, College Park; and Howard University. OWLETS utilized a unique combination of two TOLNet lidars, UAV/mobile units equipped with O_3 and surface sensors, ozonesondes, and surface sensors to characterize the water-land differences in O_3.

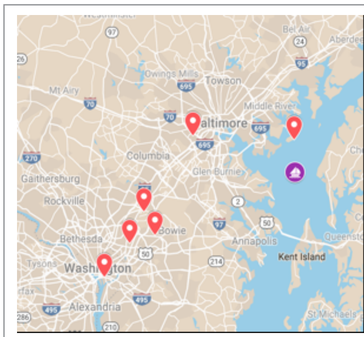
NASA Goddard (Code 614/618) ground based networks (e.g., TOLNet, Pandora, AERONET) were used to provide a framework for future collaborative investigations and provide a novel validation platform. The 614 lidar was deployed to UMBC to provide profiles of ozone from the boundary layer into the free troposphere. Pandora and AERONET instruments were also deployed to sample column amounts of trace gases and aerosols. The Langley Code E304 TOLNet Lidar, as well as Pandora and AERONET, were deployed to the Hart Miller Island, two to three miles offshore from Baltimore's Inner Harbor. The UMD Cessna and GeoTASO (PI and support from 614) flights provided additional chemical information regarding vertical and horizontal gradients between the land-water interfaces. Ship-borne measurements of additional trace gases were provided by research vessels (support from 614/NASA Headquarters/TCP and Howard University), which further supported Pandora instruments and provided shipborne measurements of additional trace gases and aerosols. This combination of observations has provided a unique characterization of O_3 and other pollutants to help provide feedback to air quality forecast models as well as future satellite remote sensing systems such as NASA's TEMPO mission.

Participating in the OWLETS campaign from the 614 lidar group are: John Sullivan, Laurence Twigg, Thomas Mcgee, Grant Sumnicht, and Natasha Dacic, from Pandora: Robert Swap, Joe Robinson, Nader Abuhassan, Alex Kotsakis, Lena Shalaby, from the GeoTASO group: Matt Kowaleski, Scott Janz, from the R/V cruise: Maria Tzortziu, from the ozonesonde team: Ryan Stauffer, Anne Thompson, and additional support from: Reem Hannun, Jason St Clair, and Glenn Wolfe. Participation from NASA LaRC was also extensive, with support from Timothy Berkoff, Travis Knepp, Jay Al-Saadi, Laura Judd, Margaret Pippin and many student interns.

For further information, please contact John Sullivan (john.t.sullivan@nasa.gov).

4.7. Pandora

During the summer of 2018, the NASA Pandora Project supported two NASA field campaigns with 11 instruments, seven of which became long-term fixed observation sites. During the June and July months, the OWLETS 2 campaign took place in the northern Chesapeake Bay region between Washington, D.C. and Baltimore, Maryland. In similar fashion to the OWLETS 1 campaign from 2017, OWLETS 2 was an attempt to better characterize air quality in complex coastal regions and around urban centers. A layout of the measurement sites, including Pandora locations, is included in Figure 4.7a.



Sites:

Hart Miller Island: Pan 26 and 30
University of Maryland Baltimore County: Pan 19
Howard University Beltsville: Pan 18
SERC (research vessel): Pan 24

NASA GSFC: Pan 2 and 32 (reference)
NOAA ARL (College Park): Pan 21
NASA HQ: Pan 33 (not operational)

Figure 4.7a: *Layout of the measurement sites, including Pandora locations*

Additionally, to investigate the evolving nature of ozone formation and transport in the NYC region and downwind, the Northeast States for Coordinated Air Use Management (NESCAUM) association launched the Long Island Sound Tropospheric Ozone Study (LISTOS). In addition to Pandora and other ground-based instrumentation, LISTOS datasets included satellite, aircraft, balloon (ozonesondes), and marine-based data collection and analysis methods, all of which probed the New York City pollution plume and its evolution over and around Long Island Sound. A highlight of preliminary LISTOS data analysis from Pandora and the recently launched TROPOMI instrument onboard the Sentinel-5 Precursor satellite is shown in Figure 4.7b and is the work of NASA Pandora Project collaborators at the Environmental Protection Agency.

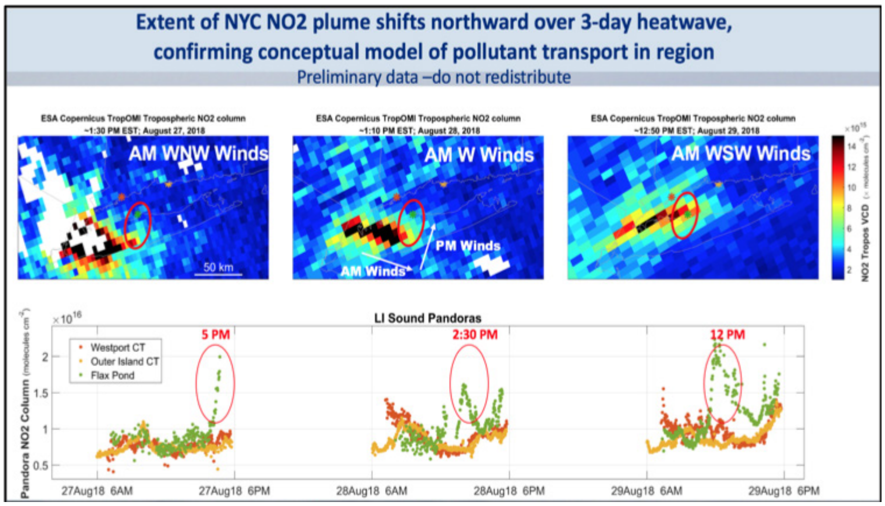


Figure 4.7b: *Combined TROPOMI (top panels) and Pandora (bottom panels) view of Long Island Sound nitrogen dioxide pollution plume evolution during the LISTOS campaign. Plots: Lukas Valin, EPA.*

In addition to campaign involvement, the NASA Pandora Project was heavily featured at the 2018 American Geophyisical Union (AGU) and 2019 American Meteorological Society (AMS) conferences, as well as throughout the broader scientific community. At AGU (AMS), over 25 (5) abstracts mentioned or used Pandora data. Additionally, over 15 peer-reviewed manuscripts that utilized Pandora data were published in calendar year 2018.

For further information, please contact Robert Swap (robert.j.swap@nasa.gov).

4.8. SHADOZ

SHADOZ launches are ongoing at 13 stations (see Figure 4.8a). There are more than 7500 sets of archived SHADOZ ozone and radiosonde profiles at the website https://tropo.gsfc.nasa.gov/shadoz.

Major activities for SHADOZ in 2018 were: (1) continued work on the first major reprocessing of the 20-year SHADOZ data record; (2) on-going participation in ozonesonde quality assurance activities (workshops) and important conferences; (3)

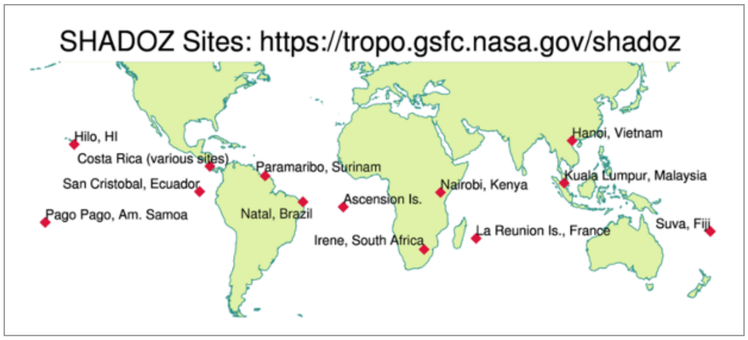


Figure 4.8a: *Map of operating SHADOZ stations in 2018.*

visits to SHADOZ stations by Principal Investigator Anne Thompson (610) and Co-Investigator Rennie Selkirk; (4) dual ozonesonde launches to test SHADOZ techniques in a June-July campaign, SHALLOTS (SHADOZ OWLETS Parallel Ozonesonde Test Study) in Maryland and Virginia.

Reprocessing of the 1998-2017 SHADOZ data for 13 stations by Goddard and NOAA partners is now complete and four publications (three in the Journal of Geophysical Research from Goddard, one NOAA) in 2017 and 2018 have documented this important activity. The new version 6.0 SHADOZ data include an overall uncertainty in the ozone value for the first time. Preliminary results from the JOSIE-SHADOZ (2017) lab intercomparison experiment, published online in the Bulletin of the American Meteorological Society https://journals.ametsoc.org/doi/full/10.1175/BAMS-D-17-0311.1, showed that biases for certain instruments that were characterized in JOSIE-2000, are largely unchanged. Station practices as tested in JOSIE-SHADOZ were found to be within ~5% in precision and in accuracy when compared to the JOSIE reference, both in total ozone and throughout the stratospheric and tropospheric profile.

Meetings, conferences and an important follow-on workshop where the 614 core SHADOZ group (Anne Thompson, Jacquie Witte, Ryan Stauffer) presented on the reprocessed data and ozonesonde quality assurance included the NOAA GMAC in Boulder (May 2018), SPARC General Assembly (Japan, October 2018), the World Meteorological Organization (WMO, Sept. 2018, see Figure 4.8b) and AGU (Washington, D.C.). SHADOZ data continue to be widely used for analysis of stratospheric and tropospheric ozone trends; they are being rapidly ingested into the European CAMS (Copernicus Atmospheric Monitoring Service).

The 2018 SHADOZ station visits this year made by Principal Investigator Thompson were to Hilo, Hawaii, in April, and to Hanoi, Vietnam in October (Figure 4.8c). The NOAA Mauna Loa Observatory hosts ozone instrumentation at 3.2 km altitude and the SHADOZ launches are made the National Weather Service facility at the Hilo Airport (sea level). The figure displays the results of a dual launch in Hilo as a follow-on

Figure 4.8b: *Ozone experts meeting at the World Meteorological Organization, Geneva, September 2018. Credit: G. Braathen, WMO.*

to the JOSIE-SHADOZ campaign. The same radiosonde was used but the potassium iodide sensing solutions in two electrochemical concentration cell (ECC) ozonesondes differed in concentration. Differences in ozone readings between the two instruments varied slightly throughout the profile but the total ozone columns agreed to within 2%. The methods tested in Hilo represent practices at nine SHADOZ stations.

Figure 4.8c: *The ozone operations team in Hanoi, Vietnam, part of the Hydrological and Meteorological Services of Vietnam, Aerological and Meteorological Observatory. Credit: A. Thompson, Goddard.*

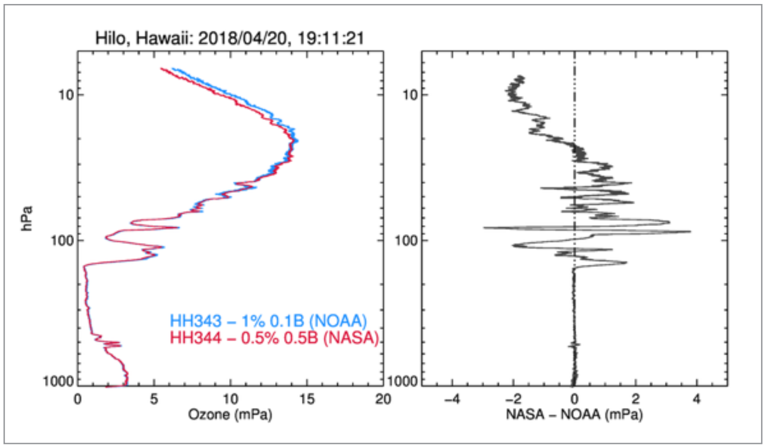


Figure 4.8d: *Data from a dual NASA-NOAA ozonesonde launch in Hilo, Hawaii, April 20 2018, using different sensing solution types. Sondes were prepared by A. Thompson (Goddard) and B. Johnson (NOAA). The NASA profile gives a higher ozone reading in the upper troposphere and lower stratosphere, to ~70 hPa in the right panel. Above that level to balloon burst, the NOAA profile is higher. However, the total integrated ozone columns are both within 2% of one another and with satellite overpasses from OMPS. Credit: J. Witte (614, SSAI).*

For further information please, contact Anne Thompson (anne.m.thompson@nasa.gov).

4.9. Seven South East Asian Studies Field Deployment

Southeast Asia (SEA), an extensive agrarian region, has witnessed vibrant economic growth and rapid urbanization in recent decades. During boreal spring in SEA, biomass-burning aerosols from natural forest fires and slash-and-burn agricultural practices strongly modulates the regional atmospheric composition over northern SEA. Questing for a deeper understanding of the way aerosols affect Southeast Asian weather, climate, and the environment, a grassroot Seven South East Asian Studies (7-SEAS) project integrates an international effort involving Indonesia, Malaysia, Philippines, Singapore, Taiwan, Thailand, Vietnam, and the U.S. (NASA Goddard and Navy/ONR) in forming a highly interdisciplinary science team. Research topics include seven focus areas from which the program derives its name: (1) clouds and precipitation, (2) radiative transfer, (3) anthropogenic and biomass-burning emissions and evolution, (4) natural background atmospheric chemistry, (5) tropical-subtropical meteorology, (6) regional now casting, forecasting, and interannual/climate outlooks, and (7) satellite and model calibration/validation.

7-SEAS project started in May 2007 and immediately launched a warm-up exercise (Virtual Biomass Burning Experiment, at https://www.nrlmry.navy.mil/aerosol/7seas), using all data collected in August 2007 over entire SEA. Subsequently, two pilot Intensive Observation Periods (IOPs), one focused mainly on studies over the maritime continent and the other in the northern regions of the 7-SEAS domain, were successfully conducted. Two 7-SEAS special issues were published collectively for these activities (https://doi.org/10.1016/j.atmosres.2012.06.005 and https://doi.org/10.1016/j.atmosenv.2013.04.066) in 2013. To further facilitate an improved understanding of the regional air quality as influenced by aerosol-cloud effects in climatologically important cloud regimes, 7-SEAS/BASELInE (Biomass-burning Aerosols & Stratocumulus Environment: Lifecycles & Interactions Experiment) was conducted in spring 2013-2015 over northern SEA (https://doi.org/10.4209/aaqr.2016.08.0350, which represents the third volume of the 7-SEAS special issue in 2016). Consequently, the recent Decadal Survey (2017) targeted Earth's planetary boundary layer (PBL) as a high priority and crosscutting science measurement for incubation studies of future satellite observations. Thus, the follow-on 7-SEAS/BASELInE (spring 2018-2020) are designed to take these challenges. Remote sensing and in-situ observations from suborbital—e.g., Unmanned Aircraft System (UAS)—and ground-based platforms, though spatially limited, can supply information on evolving properties of aerosols and light rainfall at low levels and near the Earth's surface, thereby filling satellite observational gaps and providing additional constraints on model microphysics. Additional units of UAS are planned to participate the spring IOPs in 2019-2020 over northern 7-SEAS. These measurements are crucial not only for studying aerosol impact on air quality and human health, but also for evaluating and improving microphysical process representation in models to better understand aerosol-cloud interactions and the relationships between in-cloud and surface precipitation characteristics.

For further information, please contact Si-Chee Tsay (si-chee.tsay-1@nasa.gov).

4.10. Rajo-Megha Field Deployment

The objectives of the Radiation, Aerosol Joint Observation-Modeling Exploration over Glaciers in Himalayan Asia (RAJO-MEGHA), Sanskrit for Dust-Cloud project are to exploit the latest developments of satellite, ground-based networks and modeling capabilities in addressing the overarching scientific question: What are the spatiotemporal properties of light-absorbing aerosols in the atmosphere-surface column and their relative roles in causing accelerated seasonal snowmelt in the High Mountain Asia (HMA)? Comprehensive regional-to-global simulation/assimilation models, advancing in lockstep with the advent of satellite observations and complementary surface network measurements, are playing an ever-increasing role in better understanding the changes of Earth environment. However, the complex characteristics of HMA, such as its rugged terrain, atmospheric inhomogeneity, snow susceptibility, and ground-truth accessibility, introduce difficulties for the aforementioned research tools to retrieve/assess radiative effects on snow/ice melting with a high degree of fidelity.

RAJO-MEGHA project started in the fall of 2017 and is scheduled to last until the onset of Asian summer monsoon in late May 2020. The Goddard team participated jointly in the International Centre for Integrated Mountain Development (ICIMOD)'s fall/spring expedition to the Yala glacier regions, yearly. Since October 2017, a suite of solar-powered AERONET Sun/sky spectro-radiometer and SMARTLabs solar/terrestrial radiometers have been in operational at two high elevation sites of Kyanjin (3.9 km a.s.l.) and ICIMOD Black Carbon station (4.9 km a.s.l.), the latter similar to the recently discontinued EvK2-Pyramid observatory (5.05 km a.s.l. near Mt. Everest basecamp at 27.95°N, 86.81°E). Starting in the fall of 2018, a Lagrange-like setting of radiance/irradiance/backscatter-intensity measurements (AERONET/SMARTLabs/MPLNET) are conducted along airmass inflows from the Indo-Gangetic Plains to High Himalaya-Nepal to evaluate the evolution of aerosol/trace-gas properties. Furthermore, multiple AERONET Sun-sky spectroradiometers will be deployed in setting like the Distributed Regional Aerosol Gridded Observation Networks (DRAGON) centered around the foothill supersite (Bidur, Nepal) in the spring season of 2020 to characterize aerosol optical depth and single-scattering albedo, among other parameters, in a 2D domain for satellite retrievals and model simulations comparison/validation. Thus, large-scale satellite and uniquely distributed ground-based network measurements, synergized with modeling results, establish a critically needed database to advance our understanding of changes in snowmelt processes over HMA due to the presence of light-absorbing aerosols.

For further information, please contact Si-Chee Tsay (si-chee.tsay-1@nasa.gov).

5. Web Development

Global Science & Tech Inc. (GST) manages a task to provide maintenance and development of websites that includes 610AT laboratories, instruments, missions, and projects, and assures that they meet all NASA Goddard IT security requirements and are updated regularly. During 2018, nearly a quarter of all planned development projects (610AT and 610HBG) were allocated to either building new websites or rebuilding legacy websites. Another 24% of planned projects represented Drupal re-designs, some more involved than others. 29% of approved projects involved information architecture changes (revised menu systems, new content types, improved curator tools, reorganized or revamped content, etc.), while the final 23% involved either building or fixing special features.

Drupal is a free and open-source content management framework that provides a back-end framework for at least 2.3% of all websites worldwide—ranging from personal blogs to corporate, political, and government sites.

Figure 5 shows the 2018 activities, and comparisons to previous years, for the combined laboratories. Major activities affecting Code 610AT websites included EPIC, Sun Climate (TSIS), MODIS, and ARSET. Work included information architecture redesigns (EPIC and TSIS); as well as the addition of special features like new calendar controls (MODIS) and a new mobile-friendly calendar of events (ARSET). Ongoing Code 610AT activities include a new image ingest system and web accessible Global Imagery Browse Services (GIBS), an application for MODIS, and/or the ability to coordinate with the MODIS Adaptive Processing System (MODAPS) to build an Application Programming Interface (API) and take over image server operations. Custom Drupal modules are being created for retrieving different categories of image products based on a variety of scientific metrics. A reusable user interface for image display and controls per product type is being designed. Planned projects for AT programs include 11 legacy web applications that will either need to be completely rebuilt in a modern platform (such as Drupal 8), consolidated into newly rebuild web applications (like the planned Earth Science Gateway), or else decommissioned. In the future, eight Code AT websites will need to be completely rebuilt in either Drupal 8 or the upcoming Drupal 9 versions.

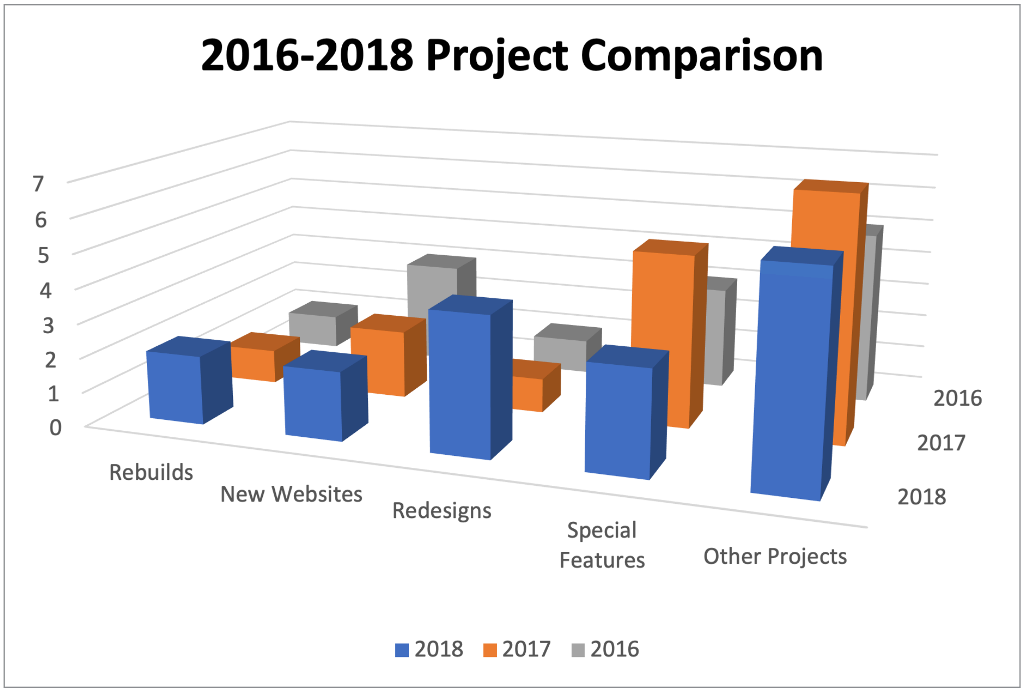


Figure 5: *2018 activities, and comparisons to previous years, for AT and HBG Laboratories.*

6. Introduction

This year many deserving employees were recognized for outstanding accomplishments, leadership, or service. Notable achievements were recognized by Goddard Space Flight Center, 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.

6.1. Agency Honor Awards

Honor Award	Recipient	Citation
Outstanding Leadership Medal	Dennis Chesters (612)	For exceptional and sustained NASA leadership and service for the NOAA GOES satellite series missions.
Exceptional Service Medal	George Huffman (612)	For exceptional service in delivering and maintaining state-of-the-art retrievals of global precipitation estimates for science and society.
Exceptional Scientific Achievement Medal	Lazaros Oreopoulos (613)	For exceptional advancements in interpretation of spaceborne cloud observations and development of novel methodologies for evaluating clouds and radiation in climate models.

6.2. Robert H. Goddard Awards

Atmospheric Research team members received the following individual awards.

Robert H. Goddard Award	Recipient	Citation
Award of Merit	James Gleason (614)	For exceptional and far-reaching career achievements including the role of Project Scientist for critical next generation NASA-NOAA polar orbiting satellite systems.
Science	Alexei Lyapustin (613)	For outstanding work developing and implementing an innovative algorithm that greatly improves cloud detection, aerosol retrievals and atmospheric correction.
Science	Dongliang Wu (613)	For exceptional work towards greatly advancing the sub-millimeter remote sensing of ice clouds.

Robert H. Goddard Award	Recipient	Citation
Science	Gail Jackson (formerly 612)	For outstanding scientific leadership of the Global Precipitation Measurement mission and Earth Science Decadal Survey activities.
Professional/Administrative	Marion August (613, InuTeq, LLC)	For outstanding work setting new standards of excellence in financial analysis, record keeping, and proposal budget support.
Secretarial/Clerical	Cathy Newman (613, SSAI)	For outstanding multiyear administrative support of distinct quality that sets new levels of excellence.

6.3. External awards and recognition

Paul Newman (610) was elected as president-elect for the American Geophysical Union Atmospheric Sciences Section. Election results available at https://elections.agu.org.

Wei-Kuo Tao (612) was elected as a fellow of the Meteorological Society of Republic of China (Taiwan). The citation reads "Excellent scientific research in developing and applying cloud resolving model to improve our understanding of cloud dynamic, microphysical and precipitation processes."

Ali Tokay (612, UMBC) received the American Meteorological Society (AMS) Editor's Award for his contribution to the Journal of Applied Meteorology and Climatology. The citation reads "For frequent and in-depth reviews of manuscripts related to precipitation microphysics and estimation, and remote sensing using radar."

David Wolff (610W) was recognized by the National Space Club Scholars Program (sponsored by NASA in cooperation with the National Space Club and Foundation) for Student Mentoring during the summer 2018 session. His student worked with GPM scientists to improve the Precipitation Imaging Package instrument.

Santiago Gassó (613, UMD) was chosen by students at the Huinca Renancó Middle School in Córdoba, Argentina, as a notable Argentinean scientist in atmospheric sciences and recognized his work on dust transport. Additionally, classrooms in the school are named after accomplished Argentinean scientists and Dr. Gassó's name was chosen for this honor for room number 17.

Ryan Stauffer (614, USRA) received an Early Career Poster Presentation award at the SPARC (Stratosphere-troposphere Processes And their Role in Climate) 2018 General Assembly held in Kyoto, Japan, October 1-5. His poster was titled "Evaluation of MERRA-2-based Ozone Profile Simulations with the Global Ozonesonde Network."

Mian Chin (614) was listed in the Clarivate Analytics list of 2018 Highly Cited Researchers. This list recognizes world-class researchers selected for their exceptional research performance, demonstrated by production of multiple highly cited papers that rank in the top 1% by citations for field and year in *Web of Science*.

6.4. William Nordberg Award

The William Nordberg award for Earth Sciences is given annually to an employee of Goddard 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 Joanne Simpson on November 4, 1994. All current and past atmospheric science recipients of this award are listed below.

Anne Thompson (610) received the William Nordberg Memorial Award for Earth Sciences during the Scientific Colloquium (Building 3) on October 31. The award was presented by Mark Clampin, Director of SED (600). Anne delivered the Nordberg Memorial Lecture entitled "Variability in Ozone Structure: Lessons from Strategic Ozonesonde Networks."

Figure 6.4: *Anne Thompson receiving William Nordberg Award from 600 Director, Mark Clampin, and giving the William Nordberg Memorial Lecture. Credit: T. Mickal (NASA/Goddard)*

Anne's incredibly wide-ranging research and service, nationally and internationally, makes her such a deserving recipient of this award. Although her research focuses on tropospheric chemistry, it has spanned a broad realm of Earth science, including seminar work in air/sea exchange of trace gases, the importance of stratosphere-troposphere exchange for ozone, and the interconnection of atmospheric composition and climate. Anne has spent a large part of her time in the chemistry lab as well as in the field, characterizing the distribution of tropospheric ozone from satellites and ground-based measurements.

Anne Thompson

Anne has been President of the Commission on Atmospheric Chemistry and Global Pollution where she led efforts to coordinate global research. She is co-chair of the steering committee for the Network for the Detection of Atmospheric Composition Change. Anne is a fellow of the AMS, AGU and the American Association for the Advancement of Science (AAAS) and has been elected President of the Atmospheric Sciences Section of the AGU and AMS Councils.

Anne engages people and brings them together to form measurement networks. She has been a driving force in forging the link between ground, suborbital and satellite observations in ozone. Somehow, Anne has also managed to put the training of young scientists in the United States and abroad on the front-burner as well. Her research has resulted in more than 260 referred papers and an H-index of >54. Anne is a leader of people, technology, and science.

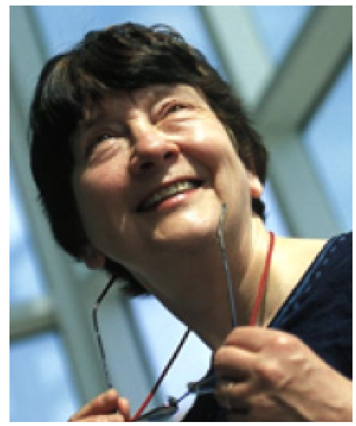
William Nordberg Award Recipients	Year
Joanne Simpson	1994
Mark Schoeberl	1998
William K. M. Lau	1999
Michael D. King	2001
P. K. Bhartia	2003
Robert Adler	2007
Wei-Kuo Tao	2008
Paul Newman	2011
Anne Douglass	2013
Anne Thompson	2018

6.5. American Meteorological Society

6.5.1. 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.





Honorary AMS members: David Atlas, left (The David and Lucille Atlas Remote Sensing Prize); Joanne Simpson, center (The Joanne Simpson Mentorship Award); and Eugenia Kalnay, right.

6.5.2. 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. Scott Braun (612) and George Huffman (612) were named new 2019 Fellows and honored at the AMS Annual Meeting in January 6-10, 2019.


2019 AMS Fellows: Scott Braun, left and George Huffman, right.

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

6.6. American Geophysical Union

6.6.1. Jule Gregory Charney Lecture

Paul Newman (610) was among five distinguished scientists who received accolades from groups representing their disciplines within AGU for Bowie Lectures. AGU inaugurated the Bowie Lecture in 1989 to commemorate the fiftieth presentation of the William Bowie Medal, which is named for AGU's first president and is the highest honor given by the organization. The Atmospheric Sciences Section recognized Paul's presentation at the Jule Gregory Charney Lecture. The award recognizes sustained and unique contributions to enlightening our understanding of the Earth and its atmosphere and oceans, and of the solar system and exoplanets. You can find the announcement at https://eos.org/agu-news/2018-agu-section-awardees-and-named-lecturers.

6.6.2. 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 committee of Fellows." 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 or discovery, (2) paradigm shift, and/or (3) sustained impact." The following current and former Goddard atmospheric scientists have received this distinguished honor.

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

6.6.3. 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 from Goddard, 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

7. Communication

7.1. 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 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.

7.2. University and K-12 Interactions

Brian Campbell (610W, GST) gave a virtual presentation on the GLOBE SMAP Block Pattern Soil Moisture Measurement Protocol to 32 students and 4 educators at the Brazil School in Trinidad on January 5. Students will begin taking soil moisture measurements as part of the larger ENSO Student Research Campaign.

On January 9, Dorian Janney (612, ADNET) organized and presented during the ENSO Phase III "Water in Our Environment" webinar during AGU. This webinar focused on Asia and the Pacific, and emphasized the ways in which NASA EOS data are studying floods and landslides in these areas. Brian Campbell (610W, GST) also participated and presented during this webinar. There were 16 teachers, four scientists, and 37 students who participated in this webinar.

Brian Campbell (610W, GST) gave a virtual demonstration and presentation at the GLOBE workshop for Tobago on January 24. There were 50 students, five educators, and two supervisors from three Tobagan secondary schools. Those schools participating were the Goodwood Secondary School, Mason Hall Secondary School, and Speyside High School. Brian's demonstration and presentation were both on the SMAP satellite mission, how to take measurements using the GLOBE SMAP Block Pattern Soil Moisture Protocol, and how to compare the GLOBE student soil moisture data with the SMAP satellite data on NASA Worldview. Students will start taking these measurements at their schools and become part of the larger GLOBE ENSO Student Research Campaign.

Charles Ichoku (613) was invited to speak to students of the Science, Technology, and Math Preparation Scholarships (STAMPS) Program at the University of North Carolina Greensboro (UNCG) on experiences and prospects of working as NASA scientists or interns, in order to encourage their interest in STEM studies. He interacted with a group of about 20 students and faculty via Google Hangouts, February 5.

Dorian Janney (612, ADNET) and Brian Campbell (610W, GST) held the sixth NASA GLOBE ENSO Student Research Campaign Monthly Science & Research Webinar for Phase III: Water in Our Environment on February 8. The focus of this was landslides, with the spotlight on the recent landslides that occurred in California. Dalia Kirschbaum (617), a NASA scientist who is an expert on landslides, explained how and why we study them from space. Tom Parr, a NASA geologist whose home was impacted by the mudslide, described the reasons for this natural disaster, as well as how it affected his community. During the webinar collaboration time, Dorian talked about some of the GLOBE protocols that can be used to predict these natural disasters and to describe their impact on the environment.

Kristen Weaver (612, SSAI) staffed a GLOBE informational table at the Global Education Resource Fair held in Washington, D.C. on February 16, part of the Teachers for Global Classrooms program.

On February 23, Dorian Janney (612, ADNET) gave a webinar to teachers in Pennsylvania who are a part of the Goddard Office of Education's ongoing continuing professional development certificate program. Her talk focused on the use of GPM and other NASA EOS data to inform efforts in sustainability worldwide.

Brian Campbell (610W, GST) and Dorian Janney (612, ADNET) held the third GLOBE ENSO Phase III Short Observation & Data Analysis (SODA) Webinar. This webinar was held on February 28. "Live from New Jersey," with students from the Medford Memorial Middle School in Medford, New Jersey, presenting their research. The students discussed their GLOBE protocol data collection, data analysis, and research to explore the question, "How do wind speed and wind direction affect the chemistry of rainwater?" Collaboration discussions with participants followed the presentation. Students and teachers from around the world discussed how the data in New Jersey is useful to them, and how they might be able to answer the same type of research question in their locality. Participants from Croatia, Netherlands, Brazil, and the United States (including Puerto Rico) attended the hour-long webinar.

Dorian Janney (612, ADNET) organized the ENSO Student Research Campaign Phase III March Science and Collaboration Webinar entitled, "Connections and Collaboration!" on March 8. During this webinar, they heard from GLOBE students who work with Audra Kay Edwards in Hawkins, Texas, and from two groups of GLOBE students in Nigeria: Oluwafemi Olawale and his students from Jos, central Nigeria, and A. S. Akinwumiju and his students from the south western part of Nigeria. During this webinar, these students gave a birds-eye glimpse of what their school looks like, a few pictures of their local environment, and information on how they have used GLOBE protocols to learn about water in their environment this year. Brian Campbell (610W, GST), lead for the GLOBE ENSO Student Research Campaign, discussed the next ENSO Campaign's Short Observation & Data Analysis (SODA) webinar on March 22. Participating in the webinar were over 120 participants from eight countries.

Dorian Janney (612, ADNET) had the following activities:

- Judged eight student science projects for The GLOBE Program's International Virtual Science Symposium.

- Attended the DEVELOP "Western Europe Health and Air Quality" project handoff at The Wilson Center on March 20. She was featured in their final video.

- Wrote a blog entitled "Landslides - We Need Your Help!" on March 22.

- Participated in the GLOBE North America Regional Meeting at Purdue University on March 27-30. She gave a presentation entitled "How to Encourage and Facilitate Connection and Collaboration between GLOBE Schools."

Brian Campbell (610W, GST) and Dorian Janney (612, ADNET) held the fourth NASA GLOBE ENSO Student Research Campaign's Short Observation & Data Analysis (SODA) webinar on March 22. The presentation highlighted "The Genesis Project: Transitioning from Data to Action," a program that has been working with students and educators since 1999 to take measurements within the New York watershed. Through the water measurements taken, a grant was awarded to fund "The Genesis Project." The data indicated that the water quality in the stream was impaired. The students took water quality information using GLOBE protocols as part of their local ecosystem measurements. The webinar was attended by 24 students and educators from Florida, Michigan, Maryland, Indiana, Pennsylvania, California, Ohio, New Jersey, New York, District of Columbia, and Puerto Rico.

Matthew DeLand (614, SSAI) presented the weekly physics department colloquium at Michigan Tech University on Thursday April 5. His talk was titled "Small Satellite Instruments for Stratospheric Aerosols at NASA Goddard Space Flight Center."

Dorian Janney (612, ADNET) organized and implemented the latest GLOBE ENSO Student Research Campaign's "Connections and Collaborations" webinar, on April 12, with presentations from students in Taiwan, Croatia, Finland, and the United States. Attending this global webinar were over 90 participants from Croatia, Finland, Taiwan, Peru, and the United States, with classrooms joining in from all the participating countries, despite the 12-hour maximum difference in time zones.

Kristen Weaver (612, SSAI) presented about GLOBE Observer to Girl Scout Troop 693 at Ritchie Park Elementary School in Rockville, Maryland on April 12. The students learned how to make cloud observations with GLOBE Observer, completed a hands-on activity about cloud opacity, and learned how NASA studies clouds and the Earth. Attendance was fifteen girls and five adults.

Kristen Weaver (612, SSAI) led an activity as part of a field trip of eighth graders from Gaithersburg Middle School to the Goddard Visitor Center on April 18. The students made cloud observations with GLOBE Observer, measured surface temperature, and learned about how NASA studies clouds and the Earth.

Peter Colarco, John Sullivan, and Omar Torres (all 614) were invited to participate in the UMBC Atmospheric Physics Second Earth Day Symposium at the University of Maryland, Baltimore County, on April 20. Peter Colarco presented a talk titled "Impact of simulated dust particle size on direct radiative forcing in the NASA Goddard Earth Observing System (GEOS) model." John Sullivan presented a talk titled "Overview of the 2017 OWLETS: summary of observations and initial results." Omar Torres presented a talk titled "Satellite-based atmospheric remote sensing using near UV observations." The symposium was organized by the graduate students in the atmospheric physics program.

Dorian Janney (612, ADNET) organized and lead a group of eight outdoor environmental educators and classroom teachers from the Montgomery County Public Schools on a "stream study" on April 22 as a part of an Earth Day event. She modeled the use of several GLOBE Program hydrology protocols and led the group through the site identification process for this location. This group will return to check the quality of this stream once each season, and the members will have access to the stream testing materials so they can check the water quality in streams in their area.

Brian Campbell (610, GST) implemented the latest GLOBE ENSO Student Research Campaign's Phase III Short Observation & Data Analysis (SODA) webinar on April 26. The webinar, entitled "Does Data Drive Question or Do Questions Drive Data? A Curious Question Case of the Chicken and the Egg" live from David Wooster Middle School in Stratford, Connecticut. Eight middle school students presented on their water research surrounding several bodies of water (inlet streams, pipes, ponds, outlet stream, and intermittent pipes) near their school. The data collected were then analyzed and a graphical analysis was presented. Participants from Croatia, Switzerland, Finland, Poland, and the United States (including Puerto Rico) attended the webinar.

Dorian Janney (612, ADNET) organized and lead four sessions for the Department of State's "Take Your Child to Work Day" event on April 26. These sessions focused on showing the children and their parents how to use the GLOBE program hydrology protocols to determine the quality of water in their streams. She also shared information about the GPM mission, describing how it is able to measure global precipitation and how those measurements are used for real-world applications.

Dorian Janney (612, ADNET) organized and implemented the latest GLOBE ENSO Student Research Campaign's "North Meets South" webinar, on May 10, with presentations from students in Suriname, United States, and Argentina. There were also classrooms of students from Argentina, Suriname, Peru, Uruguay, and the United States, present. This webinar and associated research further solidifies the importance of knowing all about water in our environment. At the end of the student presentations, Brian Campbell (610W, GST) discussed the upcoming GLOBE ENSO Campaign's Short Observation & Data Analysis Webinar on May 31, and about the ICESat-2 Tree Height Citizen Science Campaign.

On May 7, Dorian Janney (612, ADNET) ran the family program for the NIH Children's Inn. The focus was using NASA satellites to study the Earth, and she had hands-on activities as well as a slide presentation for the 14 children and 11 adults who were present for the hour-long program.

On May 20-24, George J. Huffman (612) presented four Hyperwall sessions on "Global Precipitation Measurement Mission" to about 20 high school students, 11 high school teachers, and two general audiences, and judged two student presentations/posters. He also substituted as presenter for Michael Freilich (NASA Headquarters) NASA Earth Sciences Division Overview Briefing to the Japan Geoscience Union (JpGU) meeting May 23 in Chiba, Japan.

Brian Campbell (610W, GST) represented NASA, the GLOBE ENSO Student Research Campaign, and the AEROKATS and Rover Education Network (AREN) at the 2018 GLOBE Midwest Student Research Symposium at Wayne State University in Detroit, Michigan on May 18-19. Over 60 students from middle and high schools competed with their GLOBE protocol research through scientific posters. During the symposium, Brian served as a science judge and gave a welcoming address entitled "NASA Earth Science and GLOBE: Bringing a Better Understanding of our Home Planet One Measurement at a Time." Also, Brian gave four, 30-minute workshops entitled, "NASA Earth Science, the GLOBE Program, and Citizen Science." This workshop served as an informal forum for the students to learn about how NASA can look at GLOBE data, what the NASA satellites see, and just about anything NASA related was discussed.

Brian Campbell (610W, GST) implemented the latest NASA GLOBE Program's ENSO Student Research Campaign Phase III: Water in our Environment's "Short Observation & Data Analysis (SODA)" webinar on May 31. During this webinar, students from the Mahopac High School in Mahopac, New York presented their environmental water research project entitled, "Can Students Affect Water Quality."

Brian Campbell (610W, GST) gave a tour of Wallops to a group of eight retired educators on June 6. This tour consisted of learning all about NASA Earth science at Wallops, Range Control, and Airborne Campaigns. The visit will transform into some of the educators doing citizen science with the GLOBE Program in the near future. Some of the visitors are currently docents in Washington, D.C. and Maryland.

Geoffrey Bland (610W) and Kay Rufty (615, GST) supported the NASA CANS sponsored AEROKATS and ROVER Educational Network project team meeting held at Montana State University (MSU) in conjunction with the GLOBE Student Regional Symposium. Members of the team participated in the GLOBE student poster session as judges, and a demonstration of AEROKATS instrumented kite flying was conducted for GLOBE students, educators and parents. An additional demonstration/workshop was conducted with Montana Space Grant Consortium's Balloon Outreach, Research, Exploration, and Landscape Imaging System (BOREALIS) project students and faculty, successfully engaging participants in hands-on light training.

Kristen Weaver (612, SSAI) presented to 36 pre-service teachers and nine faculty mentors in the MUREP Educator Institute at NASA Goddard on June 12, about how NASA and the GPM mission study weather, climate, and hurricanes, and shared a number of hands-on classroom activities.

Brian Campbell (610W, GST) gave an online presentation to students in Ghana on June 26. Twenty-two students and three teachers in Sunyani, Ghana attended the virtual discussion on NASA Earth Science and the GLOBE Program. Students will be taking GLOBE protocol measurements to better understand their local environment.

The Goddard In-Situ Observations Lab participated in the NASA Student Airborne Research Program (SARP). This program is an eight-week competitive internship for rising senior undergraduates designed for full immersion in NASA airborne sciences. Scientists Glenn Wolfe (614, UMBC) and Jason St. Clair (614, UMBC) interacted with students and provided measurement support on the NASA DC-8 with two new instruments, the Compact Airborne Formaldehyde Experiment (CAFE) and the Compact Airborne NO2 Experiment (CANOE). Flights targeted the rich variety of pollution sources in lower California and took place June 25-27.

On July 5, Dorian Janney (612, ADNET) ran four workshops at the NYCALC (Native Youth Community Adaptation and Leadership Congress) at the National Conservation and Training Center in Shepherdstown, West Virginia. She showed them how to use the GLOBE Observer app, and they made observations for both the Clouds and the Mosquito Habitat Mapper. There was a total of 72 high school students and five adults who participated in these workshops.

Dorian Janney (612, ADNET) was invited to interact with middle school students on July 20, who were participating in the "STEMming from the Earth" summer camp at Wooten High School in Potomac, MD. There were 24 students who were mostly from underserved populations learning how to protect Earth's freshwater resources.

Dorian Janney (612, ADNET) presented information on July 27 about the GPM Disease Initiative and the GLOBE Observer Mosquito Habitat Mapper for the SSA/MA webinar, which focused on Citizen Science efforts taking place this year.

Precipitation is more than just a component of the water cycle. It's a spectrum ranging from drizzle on a relaxed Sunday afternoon to severe storms that lead to mass flooding. But beyond devastating after-effects, what features categorize precipitation as "extreme?" This is the question Texas A&M University-Corpus Christi doctoral student Kevin

Nelson sought to answer during the eight weeks he spent at Goddard conducting proprietary research on the development of new algorithms used to identify extreme precipitation events, as well as examine their spatiotemporal and physical characteristics.

Thanks to his existing work on both extreme weather like tropical cyclones and gentle marine stratocumulus boundary layers, as well as his programming skills, Nelson was one of 18 distinguished individuals chosen to work with leading NASA scientists during the summer 2018 internship titled, "Advanced Computing in Earth Science: Development of an Extreme Precipitation Monitoring System at NASA" at Goddard. "The definition of extreme precipitation is very different from deserts, plains to rainforests," said Nelson, who studies coastal and marine system science with a focus on meteorology. "We need to analyze what makes each precipitation event special to help us understand why and when extreme weather trends happen, and how they're related to each other and to their physical characteristics."

At Goddard, Nelson increased his programming ability, practiced what he learned in past classes, and worked with satellite data sets he's never used before under the mentorship of research scientist, Dr. Yaping Zhou, an active science team member of the new NASA Precipitation Measurement Mission. "Life at NASA isn't just rockets and engineering," said Nelson. "There's a huge focus on the sciences as well. It's an amazing experience, but behind the scenes, a good portion of time is spent sitting at a desk – where I worked full-time, coding, debugging algorithms, and making figures. But overall, it's a great chance to learn from innovators working on the coolest and newest science." During the occasional moments he wasn't in front of a computer screen, Nelson enjoyed visiting national monuments and going to Washington, D.C., attending NASA outreach events like the Goddard Science Jamboree, and meeting the creators of satellites he uses for his research. According to Nelson, his advisor Dr.

Kevin Nelson (Photo: © 2018 SmugMug, Inc.)

Feiqin Xie, associate professor of atmospheric science, is the reason he applied for the NASA internship. "I am very glad Kevin was awarded the highly competitive NASA internship to study the extreme precipitation events that are also immensely important to our coastal community," said Xie. "The experience to help NASA solve a state-of-the-art science question will surely make a mark on Kevin's career and inspire him moving forward."

On August 30, Holli Kohl (610, SSAI) and Kristen Weaver (612, SSAI) presented about the forthcoming Land Cover tool in the GLOBE Observer app to the monthly meeting of the Federal Community of Practice for Crowdsourcing and Citizen Science.

Geoffrey Bland (610W) and Ted Miles (NASA-retired) have successfully obtained a patent for their remotely operated water craft that has been used for a broad host of educational outreach activities on August 28. The platforms make use of COTS technology for controlling the craft including radio remote control, power management, and sensor integration. The platform has been used as a teaching tool in schools, including the UMD Eastern Shore, where it has been used in engineering and environmental monitoring efforts. The novelty in this platform is that it is low cost, capable of traveling through very shallow water, and can be used as a teaching tool for STEM efforts. U.S. Patent 10,059,418 B1, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180005310.pdf.

On September 10, Dorian Janney (612, ADNET) presented on the upcoming GLOBE Program "Mission Mosquito" for which she is a co-lead during the NESEC monthly online meeting. She shared information on the rationale behind this new campaign as well as some of the goals they hope to achieve through this three-year effort.

On October 6, Kristen Weaver (612, SSAI) presented to 15 middle school students as part of the Prince George's County, Maryland 4-H Science Adventures program, sharing information about GLOBE Observer and the connections to NASA Earth science, and helping them collect data on clouds and surface temperature.

On October 18, Anne Douglass (614, Emeritus) was a guest on Facebook Live for the Smithsonian Air and Space Museum program STEM in 30. The program is aimed at middle schoolers and each segment is 30 minutes. This question and answer episode on the layers of the atmosphere followed a presentation on the 25 mile (40 km) world record sky dive by Alan Eustace. The episode is available on Facebook at https://www.facebook.com/STEMin30/videos/1910835475649188/ or you can visit airandspace.si.edu/connect/stem-30.

On November 8, Dorian Janney (612, ADNET) presented to the entire fourth grade at Cedar Grove Elementary School in Clarksburg, Maryland as a part of the Maryland STEM Festival activities. She shared information on the Global Precipitation Measurement mission's science, technology, and real-world applications. There were 114 students and four teachers who attended this assembly.

On November 8, Brian Campbell (610W, GST) participated in the 2018 Worcester County Maryland STEMFest Event at the Furnace Town Living Heritage Center in Snow Hill, Maryland. During the event, Brian implemented hands-on activities related to the NASA ICESat-2 Mission and the Holo GLOBE Program, a virtual reality program that allows participants to view NASA Earth Science data in 3D. There were eight groups of students, totaling 114 students, and ten educators that participated in the event.

On November 9, Dorian Janney (612, ADNET) organized and presented during the second GLOBE Mission Mosquito webinar. She shared information on how and why NASA EOS data are used to predict, monitor, and respond to mosquito-transmitted disease and described how GLOBE teachers could have their students collect similar ground-based environmental data relevant to this campaign. This webinar can be viewed at https://www.youtube.com/watch?v=sBqt9PxFSIA.

On November 19, Dorian Janney (612, ADNET) ran a table at the Parkland Magnet Middle School for Aerospace Technology in Rockville, Maryland to share the science and technology behind the GPM mission with the ~150 middle school and 100 parents who attended this evening event.

On November 28, Jie Gong (613, USRA) visited Cold Spring Elementary School in Potomac, Maryland (see photo below) and shared her knowledge about environment pollutants and climate change with 58 fourth grade students and teachers. This activity is in-line with their science curriculum on environmental studies where Dr. Gong discussed NASA's role on observing, monitoring, and predicting the air pollutants and major ground sources, as well as the impacts and causes of the climate change.

7.3. 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 among the various laboratories.

7.3.1. Atmospheric Sciences Distinguished Lecture Series

Date	Speaker	Title
April 5	William Lau, Goddard, Code 610 Emeritus, UMD	Origin, Maintenance and Variability of the Asian Tropopause Aerosol Layer (ATAL): The Roles of Monsoon Dynamics
April 19	Stephan Fueglistaler, Princeton University	CO_2 radiative forcing and the tropical hot spot controversy
June 21	William Brune, Pennsylvania State University	What atmospheric chemists could learn from Donald Rumsfeld
August 16	Mark Bourassa, Florida State University	Scatterometer Winds for Tropical Cyclone Cyclogenesis Applications, and Thoughts About Future Winds Missions
September 20	Jennifer Kay, University of Colorado at Boulder	Clouds in a Changing Arctic
October 12	Larry Di Girolamo, University of Illinois at Urbana-Champaign	Perspectives on Terra data fusion for improved Earth science products and knowledge
October 29	Kerry H. Cook, University of Texas at Austin	Understanding Observed and Projected Climate Change over Africa
November 15	Susan C. van den Heever, Department of Atmospheric Science, Colorado State University	The Ups and Downs of Updrafts and Downdrafts
December 19	Bojan R. Bojkov	Overview of EUMETSAT Remote Sensing Products and Science Activities

Atmospheric Sciences Distinguished Lecture Series (Luke Oman, Coordinator).

7.3.2. Climate and Radiation

Date	Speaker	Title
January 12	Kwang-Yul Kim, Seoul National University	Mechanisms of Arctic Amplification and Sea Ice Loss: Relative Importance of Vertical Processes versus Horizontal Processes
January 17	Alek Petty, Goddard, Code 615, UMD	Precipitation, snow accumulation and sea ice thickness over the Arctic Ocean
January 24	Prof. Ning Zeng, Department of Atmospheric and Oceanic Science, UMD	Making SENSE of our environment: monitoring urban air pollution, weather and greenhouse gases with a smart sensor network
February 7	Bradley M. Hegyi, Langley, USRA	The impact of atmospheric moisture intrusions on fall and winter Arctic sea ice growth: a case study of the 2016-17 sea ice growth season

Date	Speaker	Title
February 21	Isaac Moradi, Goddard, Code 610.1, UMBC	Tropospheric Humidity: A Known Unknown
March 7	Yaping Zhou, Goddard, Code 613, MSU	Extreme Precipitation: Theory, Trends and Monitoring
March 28	Mariel Friberg, Goddard, Code 613, Georgia Institute of Technology Constraining	Air Quality Modeling With Combined Surface Station and Satellite Measurements
April 4	Yingxi R. Shi, Goddard, Code 613, USRA	Characterizing smoke emitted from extreme biomass burning events over Indonesia in 2015 using satellites observations from the A-Train
April 17	Itai Kloog, Department of Geography & Environmental Development, Ben-Gurion University of the Negev and Allan Just, Department of Environmental Medicine and Public Health, Icahn School of Medicine at Mount Sinai	Using MODIS for predicting ground-level PM2.5 for public health applications: lessons learned from models in the US, Mexico, Israel, and Europe
April 18	Kristina Pistone, Bay Area Environmental Research Institute, NASA's Ames Research Center, Silicon Valley, California	Results from ORACLES-2016: observed biomass burning aerosol properties over the southeast Atlantic Ocean and the relationship to meteorology
May 3	Xu Liu, Langley	Fast Radiative Transfer Model and Retrieval Algorithm for Current and Future Hyperspectral Satellite Remote Sensors
May 15	Jasper F. Kok, Department of Atmospheric and Oceanic Sciences, University of California-Los Angeles	Does the dust direct radiative effect cool or warm the planet?
June 13	James A. Limbacher, Goddard, Code 613, SSAI	The MISR Research Aerosol Retrieval Algorithm: Maximizing information content from multi-angle remote-sensing
June 20	Xiaomei Lu, Langley, SSAI	Development of innovative uses of CALIPSO data
June 20	Yi Wang, Ph.D. student, The University of Iowa	MODIS Retrieval of Aerosol Optical Depth over Turbid Coastal Water
September 7	Hye-Yeong Chun, Department of Atmospheric Sciences, Yonsei University	Small-Scale Convective Gravity Waves: Contributions to the Large-Scale Circulations in the Middle Atmosphere
September 19	Prof. Zhibo Zhang, Physics Department/UMBC	Subgrid Variations of the Cloud Water and Droplet Number Concentration Over Tropical Ocean: Satellite Observations and Implications for Warm Rain Simulation in Climate Models

Date	Speaker	Title
September 25	Jussi Leinone, Jet Propulsion Laboratory	From Snowflake Models to Space-Based Radar Retrievals of Atmospheric Ice
October 10	Tamas Várnai, Goddard, Code 613, UMBC	Characterizing ice clouds using EPIC observations of sun glint
October 24	Jia Yue, Goddard, Code 613, UMD	Weather/Climate Versus Space Weather/Space Climate
November 7	Alexei Lyapustin, Goddard, Code 613	Multi-angle Implementation of Atmospheric Correction (MAIAC) Algorithm
November 28	Pengwang Zhai, Goddard, Code 613, UMBC	A Glamorous Marriage between Spectrometer and Polarimeter: A Theoretical Exploration on NASA's PACE Science
December 17	Hironobu Iwabuchi, Graduate School of Science, Tohoku University	Deep-learning cloud retrieval based on three-dimensional radiative transfer
December 19	Lauren M. Zamora, Goddard, Code 613, UMD	Satellite-based insights into how combustion aerosols change average Arctic cloud properties

Seminar Series Coordinators: January- June 2018 Hongbin Yu and Lauren M. Zamora (UMD) and June-December 2018, Yuekui Yang (613) and Jae N. Lee (UMBC)

7.3.3. 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?

Date	Speaker	Title
January 24	Harvey Moseley, Goddard, Code 660	HIRMES Probing the Inner Secrets of Protoplanetary Systems—and that's not all!
March 28	Elizabeth M. Middleton, Goddard, Code 618	Four Satellites and a Cornfield
April 18	Gavin A. Schmidt, NASA GISS	Contingencies, Communications and Climate
May 23	Dennis Andrucy, NASA Headquarters	Speak Your Mind, but Ride a Fast Horse; From GS-1 to SES. How in the world did that happen?
June 28	Christopher J. Scolese, Director, Goddard	Fins to Computers
September 26	Gerald R. North, Texas A&M University	The Rise of Climate Science, a Memoir by Gerald R. North

Date	Speaker	Title
November 13	Robert W. Corell, Global Environment and Technology Foundation	Science Goes Global
November 28	Christa Peters-Lidard, Goddard, Code 610	My Childhood Dream Came True—What's Next?

Manic Talks point of contact: Charles Gatebe, GESTAR-USRA, Climate and Radiation Laboratory.

Table 7.3.4. Atmospheric Chemistry and Dynamics

Date	Speaker	Title
January 4	Junhua Liu/Sarah Strode, Goddard, Code 614, USRA	Representativeness of ATom Transects using GEOS-5 and GMI-CTM Simulations
January 18	Susan Strahan, Goddard, Code 614, USRA	Decline in Antarctic ozone depletion and lower stratospheric chlorine determined from Aura Microwave Limb Sounder
January 18	Qing Liang, Goddard, Code 614	Emerging new CFCs emissions: A revelation of CFC bottom-up emissions with GEOSCCM and atmospheric observation
January 25	Diego Loyola, Goddard, Code 614, UMBC	Initial results of TROPOMI/Sentinel-5 Precursor
February 1	Natayla Kramarova, Goddard, Code 614	Progress in creating trend quality ozone profiles from OMPS LP
February 1	Ghassan Taha, Goddard, Code 614, USRA	OMPS LP observations of the Canadian Boreal fired in 2017
February 15	Mark Olsen, Goddard, Code 614, MSU	STE and Tropospheric Ozone in the MERRA-2 GMI Replay: Initial Results
February 15	Jerry Ziemke, Goddard, Code 614, MSU	Measurements and model simulations of decadal changes/trends in tropospheric ozone
February 22	Anne Thompson and Ryan Stauffer, Goddard, Code 614 and Goddard, Code 614, USRA	JOSIE-SHADOZ (2017) Preliminary Results: Sondes Soaring Higher Characterizing UT/LS Ozone from Global Ozonesonde Profiles Using a Clustering Technique and Meteorological Reanalysis
March 1	Glen Wolfe, Goddard, Code 614, UMBC	Formaldehyde Variability in the Remote Atmosphere: Results from Atom
March 1	Reem Hannun, Goddard, Code 614, UMBC	The NASA Carbon Airborne Flux Experiment (CARAFE): Elucidating Regional Surface Exchange of CO_2 and CH_4
March 22	Alexander Cede, Goddard, Code 614, USRA	Progress and Improvement of the Pandora
March 29	Xiaohua Pan, Goddard, Code 614, UMD	Indonesian fires and drought during 1979-2016: connection with ENSO and IOD, impact on air quality and atmospheric composition

Date	Speaker	Title
May 10	Charles Jackman, Goddard, Code 614, EMERITUS	Galactic Cosmic Ray and Other Forcing on the Atmosphere
May 17	Krzysztof Wargan, Goddard, Code 610.1, SSAI	Multidecadal changes in the UTLS ozone from the MERRA-2 reanalysis and the GMI chemistry model
May 17	Emma Knowland, Goddard, Code 610.1, USRA	Stratospheric Intrusion Catalog: A 10-year compilation of events identified by using an objective feature tracking model with NASA's MERRA-2 Reanalysis
May 31	John Sullivan, Goddard, Code 614	The Ozone Water-Land Environmental Transition Study (OWLETS): Overview, Key Findings, and Looking Towards Summer 2018
June 14	Rennie Selkirk, Goddard, Code 614, USRA	Profiling Volcanic SO_2 with Balloonsondes in Costa Rica and Opportunities for Validation of Satellite Retrievals
June 28	Pete Colarco/Parker Case, NASA Goddard/Student	Stratospheric Aerosol Modeling in 614 and the Impact of the Cerro Hudson Volcanic Eruption on Polar Ozone
July 12	John Burrows, IUP	Sensing and Sensibility: passive remote sensing of key trace constituents from space made in Bremen
July 19	Wonei Choi, GEMS Scientist	Development of an aerosol height retrieval algorithm using the O_4 absorption based on UV hyperspectral measurements
July 19	Jiwon Yang, GEMS Scientis	Development of SO_2 hybrid algorithm using PCA and DOAS based on GEMS measurements
July 26	Sujung Ko, Yonsei University	Status of GEMS instruments and algorithm
August 16	Olga Tweedy, Goddard, Code 614, USRA	The impact of boreal summer ENSO events on tropical lower stratospheric ozone
September 6	Yao Zhang, Columbia University	Combining optical remote sensing and solar induced fluorescence to improve gross primary productivity estimation
September 13	Paul Newman, Goddard, Code 610	The February 2018 Major Stratospheric Sudden Warming
September 20	Mike Heney, Goddard, Code 614, SSAI	PIV card and the ACD Unix Cluster
October 4	Mark Schoeberl, Langley	Stratospheric water, cirrus and the winter tropical saturation layer
Novermber 8	Joanna Joiner, Goddard, Code 614	Estimation of gross primary production (GPP) using a satellite data driven approach with eddy covariance flux
December 6	Sudhanshu Pandey, SRON	Early analysis of TROPOMI XCH_4 for detection and quantification of local CH_4 emissions

7.4. AeroCenter Seminars

Aerosol research is one of the nine cross-cutting themes of the Earth Sciences Division at Goddard. AeroCenter is an interdisciplinary union of researchers at Goddard and other organizations in the Washington, D.C. metropolitan area (including NOAA, University of Maryland, 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 role of aerosol in air quality and human health; and the atmospheric correction of aerosol blurring of satellite imagery of the ground. Our regular activities include strong collaborations among aerosol community, informal weekly AeroCenter Forum (seminars, discussions, posters, and paper reviews), and annual aerosol research update.

Date	Speaker	Title
February 6	Mike Fromm, NRL	Stratospheric Smoke to Rival Sulfate: the pyroCb Plume of 2017
February 20	Hiren Jethva, Goddard, Code 614, USRA	A Global OMACA Product of Optical Depth of Aerosols above Clouds: Results from 12-Year Long OMI Record
March 20	Dave Giles, Goddard, Code 618, SSAI	Automatic Quality Assurance of Sun Photometer Aerosol Optical Depth
April 3	Guoyong Wen, Goddard, Code 613, MSU	Observations and Radiative Transfer Model Calculations of Shortwave Irradiance Reduction during 2017 Solar Eclipse
April 11	Zhibo Zhang, UMBC	Toward an Observation-Based Estimate of Dust Net Radiative Effects in Tropical North Atlantic Through Integrating Satellite Observations and In Situ Measurements of Dust Properties
April 17	Kirk Knobelspiesse, Goddard, Code 616	Remote sensing of aerosols with small satellites in formation flight
May 8	Dongchul Kim, Goddard, Code 614, USRA	Modeling Dust–North America, Asia, and the Northern Pacific Ocean
May 18	Jerome Riedi, ICARE, U. de Lille	Preparatory Studies for the Multi-View, Multi-Channel, Multi-Polarisation Imaging (3MI) Mission: Calibration Challenges and Opportunities for Clouds and Aerosols Remote Sensing
June 19	Andrew Sayer, Goddard, Code 613, USRA	Deep Blue aerosol updates: MODIS C6.1 and VIIRS
October 2	Reed Espinosa, Goddard, Code 613, USRA	Speciated Models of Aerosol Size Distribution, Complex Refractive Index and Spherical Fraction Retrieved from Airborne In Situ Angular Light Scattering and Absorption Measurements

Date	Speaker	Title
October 30	Seoung-Soo Lee, UMD	Effects of aerosol on the spatiotemporal homogeneity of precipitation and associated heavy precipitation in urban areas
November 6	Ali Omar, Langley	The CALIPSO Version 4 Automated Aerosol Classification and Lidar Ratio Selection Algorithm
November 20	Matt Deland, Goddard, Code 614, SSAI	Stratospheric Aerosol Observations With a Cubesat-Scale Instrument
December 4	Lazaros Oreopoulos, Goddard, Code 613	A global-scale search for cloud responses to aerosol variations using a Cloud Regime framework
December 18	Huisheng Bian, Goddard, Code 614, GESTAR	Observationally constrained analysis of aerosols in the marine atmosphere

Seminar series coordinators: David Giles, Jasper Lewis, Ed Nowottnick, and Yingxi Shi.

7.5. Cloud Precipitation Center

The Goddard Cloud-Precipitation Center (CPC), established in 2016, is a cross-laboratory union for cloud-precipitation researchers mainly at Goddard. CPC offers discussions and collaborations across NASA laboratories through interactive seminar series on every other Tuesday at 11am. CPC maintains a member mailing list for seminar announcement, publications, and conference information. Main seminar topics include (1) cloud-precipitation processes and interactions with surface process, aerosols, mesoscale dynamics, and large-scale circulations, (2) remote sensing, radiative transfer, and scattering theory of cloud and precipitation particles, (3) cloud microphysics and convection measurements and parameterizations, and (4) satellite missions and field campaigns associated with cloud and precipitation processes. In the 2018 season, CPC hosted 11 seminars, and the current CPC member list holds 80 members.

Date	Speaker	Title
February 15	Satoh Masaki, AORI, University of Tokyo	Impact of precipitating ice hydrometeors on longwave radiative effect estimated by a global cloud-system resolving model
February 15	Woosub Roh, AORI, University of Tokyo	Evaluations of mixed-phase clouds in NICAM over the Southern Ocean in NICAM using Joint simulator
February 27	Mircea Grecu, Goddard, Code 612, MSU	Non-parametric methodology to estimate precipitating ice from multiple frequency radar reflectivity observations
March 27	Erin Munsell, Goddard, Code 612, NPP-USRA	Next-Generation Geostationary Satellite (GOES-16) Observations of Rapidly-Intensifying Tropical Cyclones: Hurricanes Harvey (2017) and Irma (2017)

Date	Speaker	Title
April 10	Ivy Tan, Goddard, Code 613, NPP-USRA	Mixed-Phase Clouds & Their Role in Climate Change
May 18	Jérôme Riedi, ICARE, Université de Lille	Preparatory Studies for the Multi-View, Multi-Channel, Multi-Polarisation Imaging (3MI) Mission: Calibration Challenges and Opportunities for Clouds and Aerosols Remote Sensing
June 12	John Yorks, Goddard, Code 612	The Relationship Between Thin Cirrus Properties and Dynamic Formation Mechanism
September 25	Mei Han, Goddard, Code 612, MSU	Comparisons of Bin and Bulk Microphysics Schemes in Simulations of Radar and Radiometer Measurements For a Topographic Winter Precipitation Event
September 25	Jussi Leinone, JPL	From Snowflake Models to Space-Based Radar Retrievals of Atmospheric Ice
October 23	Ian Adams, Goddard, Code 612	Active and Passive Three-Dimensional Radiative Transfer Simulations of Clouds and Precipitation
November 13	Chenxi Wang, Goddard, Code 613, ESSIC	Impact of ice cloud heterogeneities on retrievals using passive satellite sensors

Coordinators: Toshi Matsui and Kerry Meyer

7.6. Public Outreach

Science plays and important role in peoples' lives and has a significant (and increasing) impact on humans and the environment. In order to improve links between science and society, Code 610AT scientists donate time to public outreach activities to communicate the importance and benefits of NASA's Earth science research through engagement with local, regional, and national organizations and institutions. Target audiences may include policy makers, resource managers, teachers, students, citizens, and particular professional groups. Outreach activities may include public lectures, field trips for students or adults, community or professional training or education workshops, and service on boards or committees. The following sections summarize many such activities.

7.6.1. Earth Observatory

The Earth Observatory is housed in Code 613 and works with scientists and education and outreach partners from across the agency to publish thousands of images and hundreds of articles about NASA's Earth science and climate change research. Images from the Earth Observatory regularly appear in the mass media, popular science magazines, textbooks, and blogs. The idea of the Earth Observatory was hatched in the late 1990s during an impromptu brainstorming session between the late Yoram

Kaufman, then the Terra mission's project scientist, and David Herring, the Terra mission outreach coordinator. They wanted to create a virtual observatory, where anyone on the internet could see what NASA satellites were seeing and learn what NASA scientists were learning from EOS missions. Over years, the Earth Observatory has come to seem like a fixture of NASA Earth science outreach. As the site has matured, a community of regular readers has grown up alongside it.

In 2018, the Earth Observatory Group continued to routinely research, write, produce imagery, and publish its Image of the Day (IOTD) product for every single day of the year. The IOTD series is the only communications product within the Earth Science Division that is published on a daily basis (including weekends) and is regularly featured not only through NASA flagship social media accounts but also by numerous popular media outlets. Also in 2018, the team developed and deployed a new design for the flagship website https://earthobservatory.nasa.gov. The new design and implementation takes advantage of the latest advancements in responsive website interfaces to better accommodate users who are using mobile devices to access the site, and continues to provide access to the entire back catalog of nearly 15,000 stories and articles.

For additional information please contact Kevin Ward (kevin.a.ward@nasa.gov, (503-246-1608).

7.6.2. Activities

NASA's Applied Remote Sensing Training (ARSET) program held a 5-day training on the "Application of Remote Sensing to Support the Management of Hydrographic Watersheds in Latin America and the Caribbean." The event was held at Iguazu Falls, Brazil, November 29-December 6. There were 45 attendees representing water management agencies from over 10 countries across the Americas. The training was delivered in Spanish and English. In addition, a total of 25 presentations and step-by-step exercises on access and use of NASA resources. At the end of the training, attendees presented 10 group projects on application of the data and skills learned to their region of interest. The training was conducted by Amita Mehta (612, UMBC) and Erika Podest (JPL), with assistance with coordination, editing, and translation from Elizabeth Hook (613, SSAI), Brock Blevins (614, SSAI), David Barbato (614, UMBC), Ana Prados (614, UMBC), and Marines Martins (613, SSAI).

Santiago Gassó (613, MSU) has been appointed to the Scientific Steering Committee (SSC) of the Surface Ocean-Lower Atmosphere Study (SOLAS). The SOLAS project (www.solasint.org) is an international research initiative aiming to understand the key biogeochemical physical interactions and feedbacks between the ocean and atmosphere. The SOLAS program is jointly sponsored by the Scientific Committee on Oceanic Research (SCOR), the international Commission on Atmospheric Chemistry and Global Pollution (iCACGP) and the World Climate Research Programme (WCRP).

SOLAS was originally established as a core project of IGBP (International Geosphere-Biosphere Programme), and became a core project of Future Earth in 2015.

A recent paper and news release on ozone hole recovery detected with Aura MLS measurements: Susan Strahan (614, USRA) was interviewed by *The Star Spot*, a space themed podcast and radio show focusing on all aspects of astronomy and space exploration. Episodes feature interviews with guests of wide-ranging backgrounds: scientists, engineers, educators, artists, politicians, and business people. The topics included in the interview included the importance of the ozone layer to life on Earth, the effect of CFCs on the ozone layer, and the recovery of the ozone layer and ozone hole. The podcast can be found here https://starspotpodcast.com.

Susan Strahan (614, USRA) had her work presented in a video titled "Proof of Ozone Hole Recovery due to Chemicals Ban." The news story reports that we now have a way to measure total inorganic chlorine inside the ozone hole, and we have found it has declined over the Aura period, 2004-2016. In addition, O_3 depletion inside the Antarctic vortex has been quantified using MLS measurements, and it is declining along with the chlorine levels. These observations show that the Montreal Protocol and its amendments are working to help the ozone layer. This story has been picked up by quite a few news organizations, including Newsweek and NBC News. https://www.nasa.gov/feature/goddard/2018/nasa-study-first-direct-proof-of-ozonehole-recovery-due-to-chemicals-ban.

Dorian Janney (612, ADNET) organized and presented during the ENSO Phase III "Water in Our Environment" webinar on January 9. This webinar focused on Asia and the Pacific, and emphasized the ways in which NASA EOS data are studying floods and landslides in these areas. There were several presenters from Thailand who showed how they use various types of technology such as drones, automated weather stations, and GLOBE protocols to study the impact of extreme precipitation on their local environment. Brian Campbell (610W, GST) also participated and presented on the upcoming GLOBE ENSO *Short Observations & Data Analysis (SODA)* webinars and NASA Thailand precipitation satellite imagery. Earths science supported "Cosmic Designs with the National Philharmonic Orchestra" on January 27-28 at the Strathmore Arts Hall in Bethesda, Maryland. There were 4,000 adults and children in attendance over the two days, where they heard about ongoing projects, received NASA materials, and participated in science chats. The following people supported the event: Dorian Janney (612, ADNET), Stephanie Uz (610), Aimee Neeley (616, SSAI), Ivona Cetinic (616, USRA), Javier Concha (616, USRA), and Trena Ferrell (610).

On January 29, Dorian Janney (612, ADNET) presented the Family Program for the NIH Children's Inn in Bethesda, Maryland. She shared information on the GPM (Global Precipitation Measurement) mission, and included several demonstrations and hands-on activities for the 14 children and seven adults who participated that evening.

Brian Campbell (610W, GST) gave a demonstration and presentation entitled, "ICESat-2: How Does NASA Use Lasers in Space?" at the Muhlenberg Community Library in Reading, Pennsylvania on February 5. This program was presented in conjunction with the Explore Earth exhibition. *Explore Earth: Our Changing Planet*, a traveling exhibit for libraries, is part of the STAR Library Education Network (STAR_NET) led by the National Center for Interactive Learning at the Space Science Institute. Exhibit partners include the American Library Association, the Lunar and Planetary Institute, and the Afterschool Alliance.

On February 18, Dorian Janney (612, ADNET) gave a presentation on the GPM mission to the ~150 parents and their children who were attending the Sunday Experiment at the Goddard Visitor Center, entitled "It's All About Weather". She also ran a table throughout the event, sharing the science and applications behind the GPM mission using hands-on activities and demonstrations. This was a joint effort between NASA's GPM mission and the scientific missions of NOAA-20, the first satellite of the JPSS program.

Pawan Gupta (614, USRA), Melanie Follette-Cook (614, MSU), and Bryan Duncan (614) conducted an in person training in Jakarta, Indonesia, "NASA Remote Sensing for Air Quality Applications" as part of the NASA Applied Remote Sensing Training Program (ARSET) from March 20-23. With assistance from Elizabeth Hook (613, SSAI) and Brock Blevins (614, UMBC), this training was coordinated and hosted by BMKG (Badan Meteorologi, Klimatologi, danGeofisika) of Indonesia in partnership with the U.S. Embassy, Jakarta. Over the course of three and a half days, 42 participants representing 15 organizations across 6 countries attended the training. This training covered the access and use of NASA resources for decision-making activities related to air quality. The ARSET program is managed by Ana Prados (614, UMBC).

The U.S. Embassy in Jakarta, Indonesia, organized a two-hour public outreach meeting on the evening of March 23 at the @america cultural center in the Pacific Place Mall, in Jakarta, Indonesia. The embassy invited stakeholders, including government officials, civil society, organizations, academics and other interested parties to learn more about air quality monitoring from space. Pawan Gupta (614, USRA), Bryan Duncan (614), and Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) officials provided presentations on "Checking Air Quality from Space." NASA's presentations provided an overview of space-based air quality measurements, the ARSET program, accessing NASA data and tools, and how U.S. agencies, institutions, and international constituents use satellite air quality data and techniques. Melanie Follette-Cook (614, MSU) provided live demonstration of NASA's Worldview tool before a Q&A session. NASA ARSET team visited Jakarta to conduct a training on satellite remote sensing of air quality at BMKG.

On March 27, Bryan Duncan (614) met with the Director of the Atmospheric Science and Technology Center (PSTA), Mr. Halimurrahman, of Indonesia's National Institute of Aeronautics and Space (LAPAN) in Jakarta to discuss restarting ozonesonde data collection within Indonesia for the NASA SHADOZ network (https://tropo.gsfc.nasa.gov/shadoz). Anne Thompson (610), the SHADOZ PI, joined the meeting by teleconference. Joshua Lustig and Murni Sri of the U.S. State Department were in attendance to facilitate the agreement between NASA and LAPAN. Bryan Duncan (614) met recently with several Indonesian air quality researchers to discuss potential collaborations on evaluating and improving the NASA GMAO experimental global air quality forecast system, work led by Christoph Keller and Emma Knowland (610.1).

On March 23, Bryan Duncan (614) met with Professor Puji Lestari (Institut Teknologi Bandung) and Dwi Atmoko (Indonesian Agency for Meteorological, Climatological and Geophysics) to discuss accessing Indonesia air quality data for forecast evaluation. On March 26, Duncan met with Professor Bambang Saharo (Institut Pertanian Bogor) and Dr. Israr Albar (Ministry of Environment and Forestry) to discuss evaluation of wildfire emissions. Paul A. Newman (610), Qing Liang (614), Michael Kurylo (614, USRA), and Tyeisha Philson (614, SSAI) attended the 2nd draft review of the "Scientific Assessment of Ozone Depletion: 2018" at the NOAA Earth System Research Laboratory in Boulder, Colorado. This 2018 assessment is mandated to be produced every four years under the "Montreal Protocol on Substances that Deplete the Ozone Layer." The assessment covers trends of ozone depleting substances such as chlorofluorocarbons (CFCs) and their substitutes, new science findings on polar and global ozone, the impact of ozone on climate change, and the impact of climate on ozone. This assessment also includes a chapter on hydrofluorocarbons (HFCs). HFCs are substitutes for CFCs mainly in the air conditioning and refrigeration sectors. While HFCs are weak ozone depleting agents, they are powerful greenhouse gases, and are now controlled under the Montreal Protocol. The 2018 assessment was published in December 2018.

On March 28, Bryan Duncan (614) met with the Deputy Governor for Spatial Planning and Environment, Mr. Oswar Muadzin Mungkasa, at the Governor of DKI Jakarta Province Office to discuss a research collaboration between NASA and the city government of Jakarta, Indonesia to explore the use of NASA satellite data for urban problems (e.g., air and water quality, sea-level rise, flooding, etc.). Both parties agreed to move forward with a collaboration, with a first goal to focus on air quality. This collaboration is organized through the auspices of the Goddard Urban Environments internal task group, which is co-led by Ben Poulter (618) and Lesley Ott (610.1).

Dorian Janney (612, ADNET) participated in the "Going Viral" event April 5-7 in Chapel Hill, North Carolina. During this event, experts from the NC Museum of Natural Sciences, UNC Gillings School of Global Public Health, RTI International, and the Smithsonian Institution teamed to sponsor a day-long event designed to help the public understand the risks, newest science, and best ways to predict, prevent, prepare for, and respond to an infectious disease pandemic. The event focuses primarily on flu, but content and experiences are also applicable to other infectious diseases such as SARS, MERS, Zika, and Ebola. Dorian was an invited presenter for the "Going Viral: Impact and Implications of the 1918 Flu Pandemic" and presented a poster on a case study of the use of NASA EOS data to predict malaria in Thailand, which included information about the upcoming GPM-sponsored "Vector-borne and Water-related Disease" initiative and upcoming workshop. In addition, Dorian ran a table with hands-on activities to help visitors understand how NASA EOS missions, such as GPM, collect data which are being used to better understand and respond to vector-borne and water-related disease.

Many 610 colleagues supported NASA's two-day Earth Day event "Celebrate Earth Day with NASA" at Union Station in Washington, D.C., April 19-20: Kristen Weaver (612, SSAI) and Todd Toth (160, ADNET) represented GLOBE. Visiting students and the general public helped create a cloud in a bottle, learned how NASA uses technology to study the clouds, and how they can make their own observations with GLOBE Observer. Dorian Janney (ADNET, 612), assisted by Caroline Juang, ran the GPM table, which featured hands-on activities, demonstrations, and information on the two main instruments onboard the GPM Core Observatory.

Dorian Janney (612, ADNET) organized and presented at the NASA "Vector-borne and Water related Disease" workshop which was held on May 17 at The Wilson Center in Washington, D.C. There were over 75 in person participants, and over 50 remote participants. After the workshop, there was a reception held at the Hay-Adams Hotel in Washington, D.C., with more than 100 participants, including those from the Department of State's "Mission Mosquito" workshop, which had been held in Washington, D.C. on the same date.

Kristen Weaver (612, SSAI) staffed an Earth science table focusing on GPM and GLOBE in the NASA booth area at Escape Velocity, the convention for the Museum of Science Fiction, held at the Gaylord Convention Center in National Harbor, Maryland from May 25-27. She also sat on a panel titled "Earthrise," discussing the famous images from 1968, and how our views of Earth have changed over time.

Dorian Janney (612, ADNET) gave a presentation for the 36 participants who were attending a two-day "Mission Mosquito" workshop at the Department of State in Washington, D.C on May 18. This hour-long presentation showed the participants how NASA EOS data are being used to predict, monitor, and respond to vector-borne and water-related disease as well as how to use the GLOBE Observer Mosquito Habitat Mapper (MHM) app.

Dorian Janney (612, ADNET) was an invited participant and presenter for the joint GLOBE Program and Department of State "GLOBE Zika Education and Prevention" workshop in Lome, Togo. During June 7-8, she was responsible for presenting how NASA EOS data are being used to predict, monitor, and respond to mosquito-borne disease and helped show the participants how to use the GLOBE Observer MHM app. There were over 60 participants who represented 17 countries in Africa at this training.

Dorian Janney (612, ADNET) organized and presented a webinar entitled "Using NASA EOS data to predict, monitor, and respond to vector-borne and water-related disease: Advanced level." Amita Mehta (612, UMBC) showed participants how to access and layer data sets, and Antar Jutla (WVU) and Mike Wimberly (SDSU) shared their research studies to provide case studies of these applications of NASA EOS data.

The following 613 Laboratory members participated in the 2018 AeroCenter Annual Update held at the Goddard Visitor Center, July 9.

Speakers included:

- Falguni Patadia (613, MSU): MODIS Dark Targeto
- Andrew Sayer (613, USRA): Deep Blue Aerosol Group
- Alexei Lyapustin (613): MAIAC and DSCOVR/EPIC
- Ralph Kahn (613): MISR
- Hongbin Yu (613): Dust in the Earth System

Posters included:

- Mariel Friberg (613, USRA): "Constraining chemical transport PM2.5 and its speciated component modeling outputs using surface monitor measurements and satellite retrievals"
- Lauren Zamora (613, UMD): "A satellite-based estimate of aerosol-cloud microphysical effects over the Arctic Ocean"
- Reed Espinosa (613, USRA): "The role of absorption in retrievals of aerosol optical and microphysical properties from measurements of absolute and polarized phase function"
- Hongbin Yu (613): (1) "Using satellite observations to estimate dust deposition into the tropical Atlantic Ocean" and (2) "Interannual variability of African dust with seasonal distinction in recent decades from a multi-satellite analysis"
- Yingxi Shi (613, USRA): "Understanding airborne fertilization of oceanic ecosystems: A case study"
- Tianle Yuan (613, UMBC): "Future decline of African dust: Insights from the Holocene"
- James Limbacher (613, SSAI): "A MISR pixel-level aerosol retrieval algorithm for turbid, shallow, and eutrophic waters"
- Verity Flower (613, USRA): "Interpreting volcanological processes using spaceborne remote sensing imagery"

The NASA Applied Remote Sensing Training (ARSET) program offers satellite remote sensing training that builds the skills to integrate NASA Earth Science data into an agency's decision-making activities. Trainings are offered in many areas of remote sensing, including air quality, climate, disaster relief, health, land, and water resources. These trainings, offered both online and in person, have a worldwide reach of over 13,000 participants and more than 3,600 organizations. Managed by Ana Prados (614, UMBC), the ARSET program team consists of training coordinator, Brock Blevins (614, UMBC), technical writer and editor, Elizabeth Hook (613, SSAI), program evaluator, Annelise Carleton-Hug, and project support, Marines Martins (613, SSAI). There are many specialty leads and instructors including Melanie Follette-Cook (614, MSU), Pawan Gupta (614, USRA), Amber Jean McCullum (ARC-SGE), Amita Mehta (612, UMBC), Erika Podest (JPL-329G), and Cynthia Schmidt (ARC-SGE). To learn more about ARSET and their upcoming trainings, or to suggest a training, visit https://arset.gsfc.nasa.gov.

Brian Campbell (610W, GST) attended the GLOBE Learning Expedition (GLE) in Killarney, Ireland, July 1-6. During this time, Brian gave two presentations: "Taking Data to the Next Level: Water in Our Environment and the H2yOu Project" and "Three Phase of the GLOBE ENSO Student Research Campaign." Brian also gave a workshop entitled, "Height Matters: School-based Measurements and Citizen Science with the ICESat-2 Mission." The GLE was attended by over 450 participants from 43 countries and was a huge success.

Paul A. Newman (610), Qing Liang (614), Michael Kurylo (614), and Tyeisha Philson (614, SSAI) attended the WMO/United Nations Environment Programme Scientific Assessment of Ozone Depletion: 2018 in Les Diablerets, Switzerland July 16-20. This assessment is mandated to be produced every four years under the "Montreal Protocol on Substances that Deplete the Ozone Layer." The meeting was attended by the (World Meteorological Organization) WMO and (United Nations Environment Programme) UNEP Representatives, co-chairs of the Scientific Assessment Panel, Chapter authors, Chapter review editors, and selected reviewers. This assessment is a follow-up to the Chapter Discussion and Finalization Meeting in March 2018 (Boulder, Colorado). In Switzerland, the chapter authors presented chapter level presentation updates, identified significant issues raised at the Boulder meeting, and reviewed chapter summary bullets and figures to determine what should or should not be included in the "draft" executive summary. Discussion topics included updates on ODSs and other gases of interest to the Montreal Protocol, hydrofluorocarbons (HFCs) which are powerful greenhouse gases, global, polar, and stratospheric ozone changes (past, present, and future), and preliminary discussions were also conducted on the ancillary document 20 Questions and Answers About the Ozone Layer: 2018 Update. The finalized Executive Summary was published in December 2018.

Dorian Janney (612, ADNET) worked alongside Trena Ferrell (610) on July 20 supporting planetary science with their Space Night at the Bowie Baysox stadium in Bowie, Maryland. They provided Earth science materials and talked to the public about the GPM mission and the GLOBE Observer program. There were over 5,460 people of all ages in attendance.

Santiago Gassó (613, MSU) was interviewed on July 18 by BBCmundo.com (the BBC website for Spanish speakers) about dust and its impacts. The article (in Spanish) entitled "From the Sahara to the Amazons: four fascinating impacts of desert dust traveling thousands of kilometers to reach Latin America" can be found at https://www.bbc.com/mundo/noticias-45019573.

Paul A. Newman (610) attended the 40th Open Ended Working Group of the Montreal Protocol of Substances that Deplete the Ozone Layer in Vienna, Austria, July 9-13, 2018. As part of the Montreal Protocol's Scientific Assessment Panel, Paul and his colleagues presented some results on a recent NOAA paper by Dr. Steve Montzka that showed that emissions of CFC-11 were increasing in spite of the fact that production of this gas is fully banned by the Montreal Protocol.

Nickolay Krotkov (614) participated in CEOS working group on Cities on Volcanoes 10 meetings September 4-7 in Naples, Italy. He gave presentation on "Satellite volcanic plume monitoring with TOMS, OMI, and operational OMPS instruments."

An invitation was received, in August, from Lisa Muzzuca (450.3) for Charles (Chuck) Cote (610, SSAI) and Bill Redisch (Retired) to visit the Search and Rescue (SAR) Control Center in building 25. Lisa is researching the early history of the program. In the 1970's Bill, Bernie Trudell (Deceased) and Chuck carried out the research and coordination between agencies and countries that resulted in NASA's formal involvement and leadership role with a new start in 1978. Internationally, this effort ultimately became a four nation SARSAT program in 1979, with United States, Russia, France, and Canada partnerships. The first Search and Rescue payload was launched aboard COSPAS-1 in 1982 followed by SARSAT launches aboard the TIROS satellites. Bernie became the first SAR program manager. Today, 43 countries participate in the program where 43,000 rescues have been achieved worldwide since inception. The system now operates with three operational satellite systems in low Earth, medium Earth, and geosynchronous orbits. Emergency transmissions at 406 MHz are detected and located near instantaneously and sent to rescue operations. Emergency transmitters are purchased commercially. Lisa is the current SAR manager and is also carrying out research to improve the system performance and location accuracy by an order of magnitude via a new beacon waveform. This international satellite aided rescue program began here at GSFC and was another wonderful NASA first.

On September 22, Brian Campbell (610W, GST) attended and presented at the NASA 60th Anniversary Celebration. Brian started off the celebration by giving a 15-minute lecture entitled, "Height Matters with the NASA ICESat-2 Mission" to a full auditorium at the Wallops's Visitors Center. Brian also set up and staffed an interactive ICESat-2 table where participants used a variety of clinometers to measure the heights of several trees surrounding the Visitors Center. The event drew in over 1000 people in over three hours. On September 5-19, the Applied Remote Sensing Training Program (ARSET) provided 6 hours of instruction in an advanced level webinar: "Monitoring Water Quality Using Satellite Image Processing." Presenters Amita Mehta (612, UMBC) and Africa Flores (NASA's Marshall Space Flight Center in Huntsville, Alabama) focused on applications of optical data from a number of satellite sensors, including MODIS, VIIRS, Landsat-8 OLI, Sentinel-2 MSI, and Sentinel-3 OLCI. The training also focused on using SeaDAS software developed by the Ocean Biology Processing Group (OBPG) for ocean color water quality data analysis and image processing. One session focused on monitoring and analyzing MODIS- and VIIRS-derived chlorophyll-a concentration and sea surface temperatures as indicators for harmful algal blooms. Another session looked at Landsat-8 OLI image processing and algorithm development for chlorophyll-a retrievals. The webinar was attended by 747 participants from 78 countries. Brock Blevins (614, UMBC), Elizabeth Hook (613, UMBC), Selwyn Hudson-Odoi (614, UMBC), Ana Prados (614, UMBC), and Daniel Knowles (616, SSAI) also contributed to this effort.

NASA Headquarters requested an updated storm-total visualization for Hurricane Florence, and posted this on the main @NASA social media accounts to help promote the NASA Earth Science Disasters Program. The @NASA tweet garnered 484 retweets and 1,876 "likes" as of September 24.

The NASA Applied Remote Sensing Training (ARSET) program conducted a four-session webinar series entitled, "High Temporal Resolution Air Quality Observations from Space." This training was attended by 544 participants representing ~400 organizations from 73 countries. This course was organized and instructed by Pawan Gupta (Marshall) and supported by Brock Blevins (614, SSAI), Elizabeth Hook (613, SSAI), and Selwyn Hudson Odoi (614, UMBC), and Melanie Follette-Cook (614, MSU). This webinar series covered high temporal resolution geostationary satellite observations for air quality applications. Attendees learned about new and upcoming geostationary missions covering the Americas, Asia, and Africa (GOES, HIMAWARI, GOCI, GEMS, INSAT), as well as current data availability and access. The ARSET program is managed by Ana Prados (614, UMBC).

Trena Ferrell (610) and Kristen Weaver (612) supported International Observe the Moon Night on October 20 at the Goddard Visitor Center. They talked about the GLOBE Observer App and had a demo activity. Over 400 people attended the event.

On October 17, Dorian Janney (612, ADNET) organized and presented during the GLOBE Mission Mosquito K-12 Webinar #1. This webinar was the kick-off event for the campaign, and there were 39 participants who attended in real-time from states all across the country, as well as from at least 4 different countries. The archived webinar can be viewed at https://www.youtube.com/watch?v=U6xiMzt2t-A&feature=youtu.be.

The GPM outreach team debuted a new visualization style for IMERG, developed by Owen Kelley (610.2, GMU) and Matt Lammers (610.2, SGT). It shows an animation of IMERG storm-total accumulations side by side with a rolling three-hour accumulation. GPM web developer Jacob Reed (617, Telophase) edited the raw visualizations of Hurricane Florence and Typhoon Mangkhut to add captions and credits and published them to the @NASARain social media accounts.

On November 1, Dorian Janney (612, ADNET) presented to two educators and 21 fourth grade students at Summit Hall Elementary School in Gaithersburg, Maryland, to share information about the Global Precipitation Measurement mission's science, technology, and real-world applications as a part of the Maryland STEMFEST events for this year.

On November 1, Dorian Janney (612, ADNET) worked with four middle school students in Michigan via Zoom to assist them with their GLOBE Science Fair project which focuses on using the GLOBE "Mosquito Habitat Mapper" along with other GLOBE protocols and the Land Cover GLOBE Observer tool.

On November 4, Dorian Janney (612, ADNET) presented to the eight middle school students and 16 parents who are working with the First LEGO League ELECTRONS team in Boyds, Maryland to share information about the Global Precipitation Measurement mission's science, technology, and real-world applications as a part of the Maryland STEMFEST events for this year.

Over 100 early career researchers associated with the GSFC Science and Exploration Directorate presented their work at the Early Career Scientist Forum on November 1. The 58 talks and 44 posters covered current research in Earth sciences, astrophysics, heliophysics, and solar system exploration. The organizing committee included Erwan Mazarico (698), Lauren Andrews (610.1), Manuela Girotto (610.1, USRA), Stephen Munchak (612), Manisha Ganeshan (613), Edward Nowottnick (614), Gregory Mosby (665), Knicole Colón (667), James Leake (671), Erin Dawkins (675), and Giada Arney (693).

Participants from the Earth Sciences Division included the following:

- Code 612 – Mesoscale Atmospheric Processes Lab: John Yorks; Lisa Milani; Patrick Selmer; Sarah Ringerud; Scott Ozog; and Joe Munchak.
- Code 613 – Climate and Radiation Lab: Elizabeth Hook; Gala Wind; Manisha Ganeshan; Mariel Friberg; Yingzxi Shi
- Code 614 – Atmospheric Chemistry and Dynamics Lab: Alexander Kotsakis; Joe Robinson; John Sullivan; Joseph Robinson; Julie Nicely; Natasha Dacic; Olga Tweedy; Ryan Stauffer; and Xiaohua Pan

8. Atmospheric Sciences in the News

The following pages contain news articles and press releases that describe some of the laboratory's activities during 2018.

First Direct Proof of Ozone Hole Recovery Due to Chemicals Ban

Date: January 4, 2018

Source: NASA/Goddard Space Flight Center

Summary: For the first time, scientists have shown through direct satellite observations of the ozone hole that levels of ozone-destroying chlorine are declining, resulting in less ozone depletion.

A view of Earth's atmosphere from space. Credit: NASA

For the first time, scientists have shown through direct satellite observations of the ozone hole that levels of ozone-destroying chlorine are declining, resulting in less ozone depletion.

Measurements show that the decline in chlorine, resulting from an international ban on chlorine-containing human made chemicals called chlorofluorocarbons (CFCs), has resulted in about 20 percent less ozone depletion during the Antarctic winter than there was in 2005—the first year that measurements of chlorine and ozone during the Antarctic winter were made by NASA's Aura satellite.

"We see very clearly that chlorine from CFCs is going down in the ozone hole, and that less ozone depletion is occurring because of it," said lead author Susan Strahan, an atmospheric scientist from NASA's Goddard Space Flight Center in Greenbelt, Maryland.

CFCs are long-lived chemical compounds that eventually rise into the stratosphere, where they are broken apart by the Sun's ultraviolet radiation, releasing chlorine atoms that go on to destroy ozone molecules. Stratospheric ozone protects life on the planet by absorbing potentially harmful ultraviolet radiation that can cause skin cancer and cataracts, suppress immune systems and damage plant life.

Two years after the discovery of the Antarctic ozone hole in 1985, nations of the world signed the Montreal Protocol on Substances that Deplete the Ozone Layer, which regulated ozone-depleting compounds. Later amendments to the Montreal Protocol completely phased out production of CFCs.

Past studies have used statistical analyses of changes in the ozone hole's size to argue that ozone depletion is decreasing. This study is the first to use measurements of the chemical composition inside the ozone hole to confirm that not only is ozone depletion decreasing, but that the decrease is caused by the decline in CFCs.

The study was published Jan. 4 in the journal *Geophysical Research Letters*.

The Antarctic ozone hole forms during September in the Southern Hemisphere's winter as the returning sun's rays catalyze ozone destruction cycles involving chlorine and bromine that come primarily from CFCs. To determine how ozone and other chemicals have changed year to year, scientists used data from the Microwave Limb Sounder (MLS) aboard the Aura satellite, which has been making measurements continuously around the globe since mid-2004. While many satellite instruments require sunlight to measure atmospheric trace gases, MLS measures microwave emissions and, as a result, can measure trace gases over Antarctica during the key time of year: the dark southern winter, when the stratospheric weather is quiet and temperatures are low and stable.

The change in ozone levels above Antarctica from the beginning to the end of southern winter—early July to mid-September—was computed daily from MLS measurements every year from 2005 to 2016. "During this period, Antarctic temperatures are always very low, so the rate of ozone destruction depends mostly on how much chlorine there is," Strahan said. "This is when we want to measure ozone loss."

They found that ozone loss is decreasing, but they needed to know whether a decrease in CFCs was responsible. When ozone destruction is ongoing, chlorine is found in many molecular forms, most of which are not measured. But after chlorine has destroyed nearly all the available ozone, it reacts instead with methane to form hydrochloric acid, a gas measured by MLS. "By around mid-October, all the chlorine compounds are conveniently converted into one gas, so by measuring hydrochloric acid we have a good measurement of the total chlorine," Strahan said.

Nitrous oxide is a long-lived gas that behaves just like CFCs in much of the stratosphere. The CFCs are declining at the surface but nitrous oxide is not. If CFCs in the stratosphere are decreasing, then over time, less chlorine should be measured for a given value of nitrous oxide. By comparing MLS measurements of hydrochloric acid and nitrous oxide each year, they determined that the total chlorine levels were declining on average by about 0.8 percent annually.

The 20 percent decrease in ozone depletion during the winter months from 2005 to 2016 as determined from MLS ozone measurements was expected. "This is very close to what our model predicts we should see for this amount of chlorine decline," Strahan said. "This gives us confidence that the decrease in ozone depletion through mid-September shown by MLS data is due to declining levels of chlorine coming from CFCs. But we're not yet seeing a clear decrease in the size of the ozone hole because that's controlled mainly by temperature after mid-September, which varies a lot from year to year."

Looking forward, the Antarctic ozone hole should continue to recover gradually as CFCs leave the atmosphere, but complete recovery will take decades. "CFCs have lifetimes from 50 to 100 years, so they linger in the atmosphere for a very long time," said Anne Douglass, a fellow atmospheric scientist at Goddard and the study's co-author. "As far as the ozone hole being gone, we're looking at 2060 or 2080. And even then there might still be a small hole."

Story Source: Materials provided by NASA/Goddard Space Flight Center. Original written by Samson Reiny. Note: Content may be edited for style and length.

Reference: Strahan, S.E, A.R. Douglass: Decline in Antarctic Ozone Depletion and Lower Stratospheric Chlorine Determined From Aura Microwave Limb Sounder Observations, 2018. *Geophys. Res. Lett.*, **45**, 382-390, https://doi.org/10.1002/2017GL074830.

The Hole in the Ozone Layer Is at Its Smallest in Nearly Three Decades

By Stephanie Pappas, *Live Science*

Although phasing out the chemicals that caused the ozone hole has led to gradual improvement, natural variability in the climate has also played a role.

Higher temperatures over Antarctica this year shrank the hole in the ozone layer to the smallest it's been since 1988.

The ozone hole is a depletion of ozone gas (O_3) in the stratosphere above Antarctica. The three-oxygen molecule is toxic at ground level, but high in the atmosphere, it deflects dangerous ultraviolet rays from reaching Earth's surface.

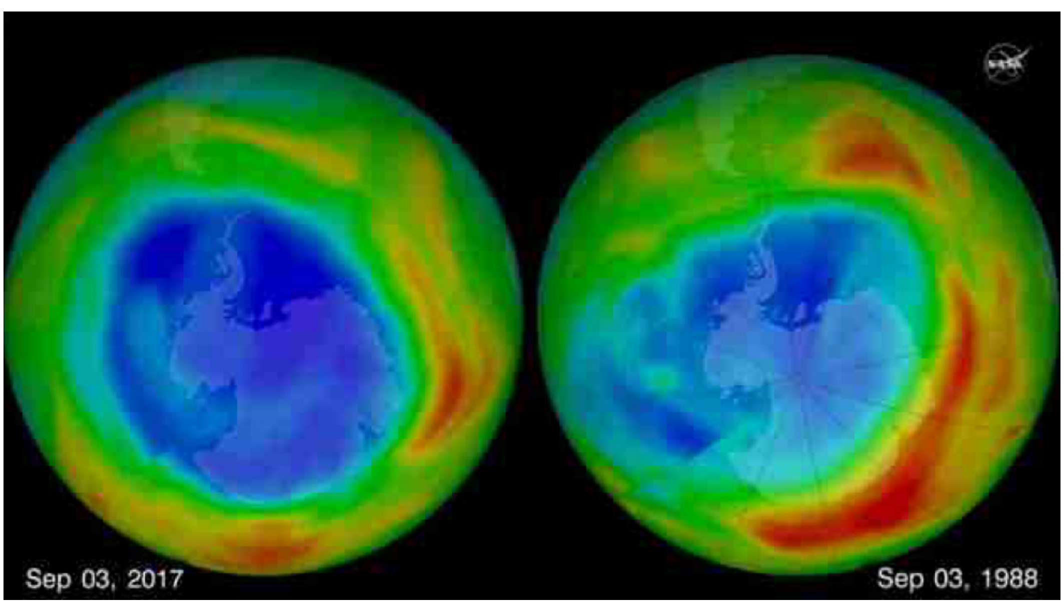
In 1985, scientists first detected the hole in the ozone layer and realized it was being caused by man-made chlorine and bromine, often found in chlorofluorocarbons (CFCs), compounds used as refrigerants. In 1987, the Montreal Protocol initiated the phase-out of these chemicals. As they gradually leave the atmosphere, the ozone hole will heal, and scientists expect it to return to 1980s size by 2070.

Natural variability affects this healing year-to-year, however.

"The Antarctic ozone hole was exceptionally weak this year," Paul Newman, chief scientist for Earth Sciences at NASA's Goddard Space Flight Center in Greenbelt, Maryland, said in a statement. "This is what we would expect to see given the weather conditions in the Antarctic stratosphere." [Infographic: Earth's Atmosphere Top to Bottom at https://www.livescience.com/29572-earth-atmosphere-layers-atmospheric-pressure-infographic.html]

Weather and ozone

In the upper atmosphere, CFCs break apart, freeing chlorine to react with ozone molecules, a reaction that creates oxygen and chlorine monoxide. Similar reactions occur with bromine. Polar stratospheric clouds, which form in frigid temperatures, speed up this process by providing surfaces for the reactions to occur on. That's why the ozone hole worsens in the Southern Hemisphere winter.



The hole in Earth's protective ozone layer that forms over Antarctica each September was the smallest seen since 1988, according to NASA and NOAA. Credit: NASA's Goddard Space Flight Center/Kathryn Mersmann

Higher temperatures in the stratosphere, on the other hand, allow ozone to remain more stable in the atmosphere, meaning they keep the ozone hole smaller on a year-to-year basis. This year on Sept. 11, NASA measured the maximum extent of the hole at 7.6 million square miles (19.6 million square kilometers), 2.5 times the size of the United States.

That was smaller than in 2016, when the maximum extent was 8.9 million square miles (22.2 million square km), also a below-average size. According to NASA, the average maximum extent of the ozone hole since 1991 has hovered at about 10 million square miles (25.8 million square km).

Historic high

However, scientists said that two years of lower-than-usual ozone hole extent isn't a sign that the ozone layer is healing faster than expected. Instead, it's a side effect of the Antarctic vortex—a low-pressure system that rotates clockwise above the southernmost continent—undergoing a few years of instability and warmth, which prevented the proliferation of polar stratospheric clouds.

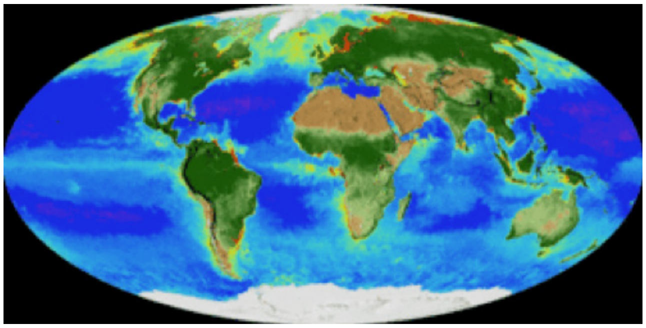
Using an instrument called a Dobson spectrophotometer, NASA researchers monitor the concentration of ozone over Antarctica on a regular basis. On Sept. 25, the concentration of ozone reached a minimum of 136 Dobson Units, which is the highest minimum since 1988. However, that concentration is still low compared with the 1960s, before man-made compounds created the ozone hole. In that decade, ozone concentrations over Antarctica were between 250 and 350 Dobson Units.

Story Source: https://www.livescience.com/60858-smallest-ozone-hole-over-antarctica.html

A Scientist's Final Paper Looks Toward Earth's Future Climate

A NASA scientist's final scientific paper, published posthumously this month, reveals new insights into one of the most complex challenges of Earth's climate: understanding and predicting future atmospheric levels of greenhouse gases and the role of the ocean and land in determining those levels.

From space, satellites can see Earth breathe. A new NASA visualization shows 20 years of continuous observations of plant life on land and at the ocean's surface, from September 1997 to September. 2017. On land, vegetation appears on a scale from brown (low vegetation) to dark green (lots of vegetation); at the ocean surface, phytoplankton are indicated on a scale from purple (low) to yellow (high). This visualization was created with data from satellites including SeaWiFS, and instruments including the NASA/NOAA Visible Infrared Imaging Radiometer Suite and the Moderate Resolution Imaging Spectroradiometer.



Credit: NASA

A paper published in the Proceedings of the National Academy of Sciences was led by Piers J. Sellers, former director of the Earth Sciences Division at NASA's Goddard Space Flight Center, who died in December 2016. Sellers was an Earth scientist at NASA Goddard and later an astronaut who flew on three space shuttle missions.

The paper includes a significant overarching message: The current international fleet of satellites is making real improvements in accurately measuring greenhouse gases from space, but in the future a more sophisticated system of observations will be necessary to understand and predict Earth's changing climate at the level of accuracy needed by society.

Sellers wrote the paper along with colleagues at NASA's Jet Propulsion Laboratory and the University of Oklahoma. Work on the paper began in 2015, and Sellers continued working with his collaborators up until about six weeks before he died. They carried on the research and writing of the paper until its publication.

The paper focuses on the topic that was at the center of Sellers' research career: Earth's biosphere and its interactions with the planet's climate. In the 1980s he helped pioneer computer modeling of Earth's vegetation. In the new paper, Sellers and co-authors investigated "carbon cycle–climate feedbacks"—the potential response of natural systems to climate change caused by human emissions—and laid out a vision for how to best measure this response on a global scale from space.

The exchange of carbon between the land, ocean and air plays a huge role in determining the amount of greenhouse gases in the atmosphere, which will largely determine Earth's future climate. But, there are complex interactions at play. While human-caused emissions of greenhouses gases are building up in the atmosphere, land ecosystems and the ocean still offset about 50 percent of all those emissions. As the climate warms scientists are unsure whether forests and the ocean will continue to absorb roughly half of the emissions—acting as a carbon sink—or if this offset becomes lower, or if the sinks become carbon sources.

Paper co-author David Schimel, a scientist at JPL and a longtime scientific collaborator of Sellers', said the paper captured how he, Sellers and the other co-authors saw this scientific problem as one of the critical research targets for NASA Earth science.

“We all saw understanding the future of carbon cycle feedbacks as one of the grand challenges of climate change science,” Schimel said.

Scientists’ understanding of how Earth’s living systems interact with rising atmospheric levels of greenhouse gases has changed tremendously in recent decades, said co-author Berrien Moore III, of the University of Oklahoma. Moore has been a scientific collaborator with Sellers and Schimel since the 1980s. He said that back then, scientists thought the ocean absorbed about half of annual carbon emissions, while plants on land played a minimal role. Scientists now understand the ocean and land together absorb about half of all emissions, with the terrestrial system’s role being affected greatly by large-scale weather patterns such as El Niño and La Niña. Moore is also the principal investigator of a NASA mission called GeoCarb, scheduled to launch in 2022, that will monitor greenhouse gases over much of the Western Hemisphere from a geostationary orbit.

NASA launched the Orbiting Carbon Observatory-2 (OCO-2) in 2014, and with the advancement of measurement and computer modeling techniques, scientists are gaining a better understanding of how carbon moves through the land, ocean and atmosphere. This new paper builds on previous research and focuses on a curious chain of events in 2015. While human emissions of carbon dioxide leveled off for the first time in decades during that year, the growth rate in atmospheric concentrations of carbon dioxide actually spiked at the same time.

This was further evidence of what scientists had been piecing together for years – that a complex combination of factors, including weather, drought, fires and more, contributes to greenhouse gas levels in the atmosphere.

In a 2016 interview, Piers Sellers talked about his enthusiasm and appreciation for working at NASA’s Goddard Space Flight Center.

However, with the new combination of OCO-2 observations and space-based measurements of plant fluorescence (essentially a measure of photosynthesis), researchers have begun producing more accurate estimates of where carbon was absorbed and released around the planet during 2015, when an intense El Niño was in effect, compared to other years.

The paper follows a report from a 2015 workshop on the carbon cycle led by Sellers, Schimel, and Moore. Schimel and Moore both pointed out that every one of the more than 40 participants in the workshop contributed to a final scientific report from the meeting – a rare occurrence. They attributed this, in part, to the inspirational role Sellers played in spurring thought and action.

“When you have someone like Piers in the room, there’s a magnetic effect,” Moore said. “Piers had his shoulder to the wheel, so everyone had to have their shoulders to the wheel.”

Schimel and Moore said the workshop paper lays out a vision for what's needed in a future space-based observing system to measure, understand, and predict carbon cycle feedbacks: active and passive instruments, and satellites both in low-Earth and geostationary orbits around the world. In the coming years, NASA and space agencies in Europe, Japan, and China, will all launch new greenhouse-gas monitoring missions.

"Piers thought it's absolutely essential to get it right," said Schimel, "and essential to more or less get it right the first time."

The authors dedicated the paper's publication to Sellers, and in their dedication referenced a Winston Churchill quote often cited by the British-born scientist. They wrote: "P.J.S. approached the challenge of carbon science in the spirt of a favorite Churchill quote, 'Difficulties mastered are opportunities won,' and he aimed to resolve the carbon–climate problem by rising to the difficulties and seizing the opportunities."

For more: https://www.pnas.org/content/early/2018/07/05/1716613115.

Tiny Satellite's First Global Map of Ice Clouds

By: Patrick Lynch, NASA's Goddard Space Flight Center, Greenbelt, Md.

Editor: Sara Blumberg

Date: May 15, 2018

Source: NASA/Goddard Space Flight Center

Summary: Looking at Earth from the International Space Station, astronauts see big, white clouds spreading across the planet. They cannot distinguish a gray rain cloud from a puffy white cloud. While satellites can see through many clouds and estimate the liquid precipitation they hold, they can't see the smaller ice particles that create enormous rain clouds.

Looking at Earth from the International Space Station, astronauts see big, white clouds spreading across the planet. They cannot distinguish a gray rain cloud from a puffy white cloud. While satellites can see through many clouds and estimate the liquid precipitation they hold, they can't see the smaller ice particles that create enormous rain clouds.

An experimental small satellite has filled this void and captured the first global picture of the small frozen particles inside clouds, normally called ice clouds.

Deployed from the space station in May 2017, IceCube is testing instruments for their ability to make space-based measurements of the small, frozen crystals that make up ice clouds. "Heavy downpours originate from ice clouds," said Dong Wu, IceCube principal investigator at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Ice clouds start as tiny particles high in the atmosphere. Absorbing moisture, the ice crystals grow and become heavier, causing them to fall to lower altitudes. Eventually, the particles get so heavy, they fall and melt to form rain drops. The ice crystals may also just stay in the air.

Like other clouds, ice clouds affect Earth's energy budget by either reflecting or absorbing the Sun's energy and by affecting the emission of heat from Earth into space. Thus, ice clouds are key variables in weather and climate models.

This is a three-month average of ice clouds. The brightest peak areas represent the largest concentration of ice clouds. They are also the spots with heavy precipitation beneath. They reach up to the top of the troposphere from deep convection, which is normally strongest in the tropics.

Measuring atmospheric ice on a global scale remains highly uncertain because satellites have been unable to detect the amount of small ice particles inside the clouds, as these particles are too opaque for infrared and visible sensors to penetrate. To overcome that limitation, IceCube was outfitted with a submillimeter radiometer that bridges the missing sensitivity between infrared and microwave wavelengths.

Despite weighing only 10 pounds and being about size of a loaf of bread, IceCube is a bona fide spacecraft, complete with three-axis attitude control, deployable solar arrays and a deployable UHF communications antenna. The CubeSat spins around its axis, like a plate spinning on a pole. It points at Earth to take a measurement then looks at the cold space to calibrate.

Originally a 30-day technology-demonstration mission, IceCube is still fully operational in low-Earth orbit almost a year later, measuring ice clouds and providing data that's "good enough to do some real science," Wu said.

"The hard part about developing the CubeSat is making the commercial parts durable in space," said Tom Johnson, Goddard's Small Satellite manager stationed at NASA's Wallops Flight Facility in Virginia. "We bought commercial components for IceCube and spent a lot of time testing the components making sure each part worked."

Over the past year, engineers tested the satellite's limits while on orbit. They wanted to see if the instrument's batteries stored enough power to run 24 hours. IceCube charges its batteries when the Sun shines on its solar arrays. During the test, safeguards prevented the satellite from losing all its power and ending the mission; however, the test was successful. The batteries operated the IceCube all night and recharged during the day. This change made the CubeSat more valuable for science data collection.

While the IceCube team planned for the mission to operate for 30 days in space, "It does not cost very much to keep it going," Johnson said, "so we extended the mission due to the outstanding science that IceCube is performing. We download data eight to 10 times a week. Even if we miss a week, the CubeSat can hold a couple of weeks of data."

Johnson says he is not surprised by how long IceCube has lasted. "It will last about a year, when it will reenter Earth's atmosphere and burn up in."

The IceCube team built the spacecraft using funding from NASA's Earth Science Technology Office's (ESTO) In-Space Validation of Earth Science Technologies (InVEST) program and NASA's Science Mission Directorate CubeSat Initiative.

Small satellites, including CubeSats, are playing an increasingly larger role in exploration, technology demonstration, scientific research and educational investigations at NASA. They have been used in planetary space exploration, fundamental Earth and space science, and developing precursor science instruments like cutting-edge laser communications, satellite-to-satellite communications and autonomous movement capabilities.

Story Source: https://www.nasa.gov/feature/goddard/2018/tiny-satellites-first-global-map-of-ice-cloudss.

NASA Calculated Heavy Rainfall Leading to California Mudslides

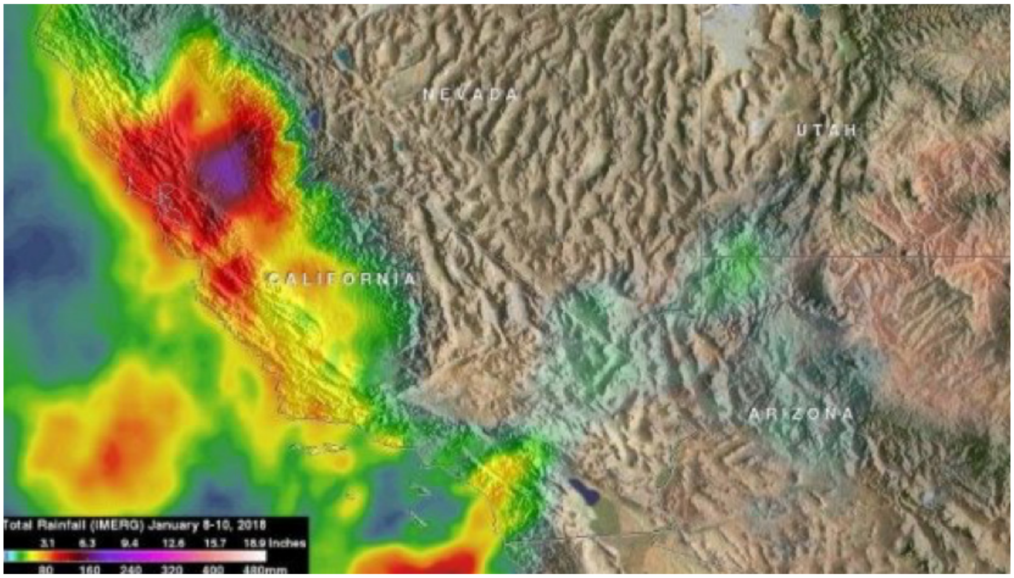
Date: January 11, 2018

Source: NASA/Goddard Space Flight Center

Summary: Winter rains falling on recently burned ground triggered deadly mudslides in Santa Barbara County, California on Jan. 9. NASA calculated the amount of rain fall between Jan. 8 and 10, 2018 and calculated the potential for landslides.

Winter rains falling on recently burned ground triggered deadly mudslides in Santa Barbara County, California on January 9. NASA calculated the amount of rain fall between January 8 and 10, 2018 and calculated the potential for landslides.

At NASA's Goddard Space Flight Center in Greenbelt, Maryland, a landslide potential map was generated by the global Landslide Hazard Assessment for Situational Awareness (LHASA) model, a model that combines precipitation data from the Global Precipitation Measurement or GPM mission satellite with a global landslide susceptibility map. LHASA gives a broad overview of landslide hazard in nearly real time, but site-specific information should be obtained prior to emergency operations or building projects.



NASA's IMERG analysis of Jan. 8 through 10, 2018 revealed that the heaviest rainfall occurred over the Sacramento Valley where over 8 inches (203 mm) were indicated. A rainfall total of 5 inches (127 mm) was reported in Ventura County. Credit: NASA/JAXA/Hal Pierce

At least 17 residents of southern California have been killed by the deadly mudslides. A storm moving in from the Pacific Ocean dropped heavy rain over soil that was laid bare by last month's wild fires. Heavy rainfall loosened surface sediments in Santa Barbara County early Tuesday, Jan. 9 caused deadly mudslides. According to the California Department of Transportation parts of US 101, a major highway connecting northern and southern California has been closed because of mud and debris.

NASA's GPM or Global Precipitation Measurement mission satellite provides information on precipitation from its orbit in space. GPM is a joint mission between NASA and the Japan Aerospace Exploration Agency or JAXA. GPM also utilizes a constellation of other satellites to provide a global analysis of precipitation that are used in rainfall calculations.

At NASA Goddard, a rainfall analysis was constructed using NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) data. Precipitation data acquired from satellites in the GPM Constellation during the period from January 8 to 10, 2018 were used in creating a rainfall accumulation map. The analysis showed the heavy rainfall that occurred over California during the past three days.

The IMERG analysis revealed that the heaviest rainfall occurred over the Sacramento Valley where over 8 inches (203 mm) were indicated. Southern California had heavy rainfall but the effects of the drenching rain was magnified by the bare soil left by last month's wildfires. A rainfall total of 5 inches (127 mm) was reported in Ventura County.

For information from Santa Barbara County, visit: https://www.countyofsb.org

For information about the road closures, visit the California Department of Transportation: http://www.dot.ca.gov

Story Source: Original article written by Hal Pierce (Code 612) / Rob Gutro (Code 130); https://www.nasa.gov/feature/goddard/2018/nasa-calculated-heavy-rainfall-leading-to-california-mudslides

Ozone Hole Modest Despite Optimum Conditions for Ozone Depletion

Date: November 2, 2018

Source: NASA/Goddard Space Flight Center

Summary: The ozone hole that forms in the upper atmosphere over Antarctica each September was slightly above average size in 2018, scientists reported today.

This time-lapse photo from Sept. 10, 2018, shows the flight path of an ozonesonde as it rises into the atmosphere over the South Pole from the Amundsen-Scott South Pole Station. Scientists release these balloon-borne sensors to measure the thickness of the protective ozone layer high up in the atmosphere. Credit: Robert Schwarz/ University of Minnesota.

The ozone hole that forms in the upper atmosphere over Antarctica each September was slightly above average size in 2018, NOAA and NASA scientists reported today.

Colder-than-average temperatures in the Antarctic stratosphere created ideal conditions for destroying ozone this year, but declining levels of ozone-depleting chemicals prevented the hole from as being as large as it would have been 20 years ago.

"Chlorine levels in the Antarctic stratosphere have fallen about 11 percent from the peak year in 2000," said Paul A. Newman, chief scientist for Earth Sciences at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "This year's colder temperatures would have given us a much larger ozone hole if chlorine was still at levels we saw back in the year 2000."

According to NASA, the annual ozone hole reached an average area coverage of 8.83 million square miles (22.9 square kilometers) in 2018, almost three times the size of the contiguous United States. It ranks 13th largest out of 40 years of NASA satellite observations. Nations of the world began phasing out the use of ozone-depleting substances in 1987 under an international treaty known as the Montreal Protocol.

The 2018 ozone hole was strongly influenced by a stable and cold Antarctic vortex —the stratospheric low pressure system that flows clockwise in the atmosphere above Antarctica. These colder conditions—among the coldest since 1979—helped support formation of more polar stratospheric clouds, whose cloud particles activate ozone-destroying forms of chlorine and bromine compounds.

In 2016 and 2017, warmer temperatures in September limited the formation of polar stratospheric clouds and slowed the ozone hole's growth. In 2017, the ozone hole reached a size of 7.6 million square miles (19.7 square kilometers) before starting to recover. In 2016, the hole grew to 8 million square miles (20.7 square kilometers).

However, the current ozone hole area is still large compared to the 1980s, when the depletion of the ozone layer above Antarctica was first detected. Atmospheric levels of human-made ozone-depleting substances increased up to the year 2000. Since then, they have slowly declined but remain high enough to produce significant ozone loss.

NOAA scientists said colder temperatures in 2018 allowed for near-complete elimination of ozone in a deep, 3.1-mile (5-kilometer) layer over the South Pole. This layer is where the active chemical depletion of ozone occurs on polar stratospheric clouds. The amount of ozone over the South Pole reached a minimum of 104 Dobson units on Oct. 12—making it the 12th lowest year out of 33 years of NOAA ozonesonde measurements at the South Pole, according to NOAA scientist Bryan Johnson.

"Even with this year's optimum conditions, ozone loss was less severe in the upper altitude layers, which is what we would expect given the declining chlorine concentrations we're seeing in the stratosphere," Johnson said.

A Dobson unit is the standard measurement for the total amount of ozone in the atmosphere above a point on Earth's surface, and it represents the number of ozone molecules required to create a layer of pure ozone 0.01 millimeters thick at a temperature of 32 degrees Fahrenheit (0 degrees Celsius) at an atmospheric pressure equivalent to Earth's surface. A value of 104 Dobson units would be a layer that is 1.04 millimeters thick at the surface, less than the thickness of a dime.

Prior to the emergence of the Antarctic ozone hole in the 1970s, the average amount of ozone above the South Pole in September and October ranged from 250 to 350 Dobson units.

What is ozone and why does it matter?
Ozone comprises three oxygen atoms and is highly reactive with other chemicals. In the stratosphere, roughly 7 to 25 miles (about 11 to 40 kilometers) above Earth's surface, a layer of ozone acts like sunscreen, shielding the planet from ultraviolet radiation that can cause skin cancer and cataracts, suppress immune systems and damage plants. Ozone can also be created by photochemical reactions between the Sun and pollution from vehicle emissions and other sources, forming harmful smog in the lower atmosphere.

NASA and NOAA use three complementary instrumental methods to monitor the growth and breakup of the ozone hole each year. Satellite instruments like the Ozone Monitoring Instrument on NASA's Aura satellite and the Ozone Mapping Profiler Suite on the NASA-NOAA Suomi National Polar-orbiting Partnership satellite measure ozone across large areas from space. The Aura satellite's Microwave Limb Sounder also measures certain chlorine-containing gases, providing estimates of total chlorine levels.

The total amount of ozone in the atmosphere is exceedingly small. All of the ozone in a column of the atmosphere extending from the ground to space would be 300 Dobson units, approximately the thickness of two pennies stacked one on top of the other.

NOAA scientists monitor the thickness of the ozone layer and its vertical distribution above the South Pole by regularly releasing weather balloons carrying ozone-measuring "sondes" up to 21 miles (~34 kilometers) in altitude, and with a ground-based instrument called a Dobson spectrophotometer.

Story Source: https://www.nasa.gov/feature/goddard/2018/ozone-hole-modest-despite-optimum-conditions-for-ozone-depletion

NASA Surveys Hurricane Damage to Puerto Rico's Forests

Date: July 11, 2018

Source: NASA/Goddard Space Flight Center

Summary: On Sept. 20, 2017, Hurricane Maria barreled across Puerto Rico with winds of up to 155 miles per hour and battering rain that flooded towns, knocked out communications networks and destroyed the power grid. In the rugged central mountains and the lush northeast, Maria unleashed its fury as fierce winds completely defoliated the tropical forests and broke and uprooted trees. Heavy rainfall triggered thousands of landslides that mowed over swaths of steep mountainsides.

On April 25, 2018, the G-LiHT team captured this aerial image of El Yunque National Forest. Credit: NASA.

On September 20, 2017, Hurricane Maria barreled across Puerto Rico with winds of up to 155 miles per hour and battering rain that flooded towns, knocked out communications networks and destroyed the power grid. In the rugged central mountains and the lush northeast, Maria unleashed its fury as fierce winds completely defoliated the tropical forests and broke and uprooted trees. Heavy rainfall triggered thousands of landslides that mowed over swaths of steep mountainsides.

In April, a team of NASA scientists traveled to Puerto Rico with airborne instrumentation to survey damages from Hurricane Maria to the island's forests.

"From the air, the scope of the hurricane's damages was startling," said NASA Earth scientist Bruce Cook, who led the campaign. "The dense, interlocking canopies that blanketed the island before the storm were reduced to a tangle of downed trees and isolated survivors, stripped of their branches."

NASA's Earth-observing satellites monitor the world's forests to detect seasonal changes in vegetation cover or abrupt forest losses from deforestation, but at spatial and time scales that are too coarse to see changes. To get a more detailed look, NASA flew an airborne instrument called Goddard's Lidar, Hyperspectral and Thermal Imager, or

G-LiHT. From the belly of a small aircraft flying one thousand feet above the trees, G-LiHT collected multiple measurements of forests across the island, including high-resolution photographs, surface temperatures and the heights and structure of the vegetation.

The U.S. Forest Service, the U.S. Fish and Wildlife Service, the Federal Emergency Management Agency and NASA provided funding for the airborne campaign.

The team flew many of the same tracks with G-LiHT as it had in the spring of 2017, months before Hurricane Maria made landfall, as part of a study of how tropical forests regrow on abandoned agricultural land. The before-and-after comparison shows forests across the island still reeling from the hurricane's impact.

Using lidar, a ranging system that fires 600,000 laser pulses per second, the team measured changes in the height and structure of the Puerto Rican forests. The damage is palpable. Forests near the city of Arecibo on the northern side of the island grow on limestone hills with little soil to stabilize trees. As a result, the hurricane snapped or uprooted 60 percent of the trees there. In the northeast, on the slopes of El Yunque National Forest, the hurricane trimmed the forests, reducing their average height by one-third.

Data from G-LiHT is not only being used to capture the condition of the island's forests; it is an important research tool for scientists who are tracking how the forests are changing as they recover from such a major event.

"[Hurricane] Maria pressed the reset button on many of the different processes that develop forests over time," said Doug Morton, an Earth scientist at NASA's Goddard Spaceflight Center and G-LiHT co-investigator. "Now we're watching a lot of those processes in fast-forward speeds as large areas of the island are recovering, with surviving trees and new seedlings basking in full sunlight."

Among the areas that the team flew over extensively was El Yunque National Forest, which Hurricane Maria struck at full force. The U.S. Forest Service manages El Yunque, a tropical rainforest, as well as its designated research plots, which were established in the late 1930s. University and government scientists perform all manner of research, including measuring individual trees to track their growth, counting flowers and seeds to monitor reproduction, and analyzing soil samples to track the nutrients needed for plant growth.

One important assessment of a tree's health is its crown, which comprises the overall shape of a treetop, with its branches, stems and leaves. Hurricane winds can heavily damage tree crowns and drastically reduce the number of leaves for creating energy through photosynthesis.

"Just seven months after the storm, surviving trees are flushing new leaves and regrowing branches in order to regain their ability to harvest sunlight through photosynthesis," Morton said, while also noting that the survival of damaged trees in the years ahead is an open question.

While it's difficult to assess tree crowns in detail from the ground, from the air G-LiHT's lidar instrument can derive the shape and structure of all of the trees in its flight path. The airborne campaign over Puerto Rico was extensive enough to provide information on the structure and composition of the overall forest canopy, opening up a range of research possibilities.

"Severe storms like Maria will favor some species and destroy others," said Maria Uriarte, an ecologist at Columbia University who has studied El Yunque National Forest for 15 years and is working with the NASA team to validate flight data with ground observations. "Plot level studies tell us how this plays out in a small area but the damage at any particular place depends on proximity to the storm's track, topography, soils and the characteristics of each forest patch. This makes it hard to generalize to other forests in the island."

But with G-LiHT data scientists can study the storm impacts over a much larger area, Uriarte continued. "What's really exciting is that we can ask a completely different set of questions," she said. "Why does one area have more damage than others? What species are being affected the most across the island?"

Understanding the state of the forest canopy also has far-reaching implications for the rest of the ecosystem, as tree cover is critical to the survival of many species. For example, birds such as the native Iguaca parrot use the canopy to hide from predator hawks. The canopy also creates a cooler, humid environment that is conducive to the growth of tree seedlings and lizards and frogs that inhabit the forest floor. Streams that are cooled by the dense shade also make them habitable for a wide diversity of other organisms.

Yet by that same token, other plants and animals that were once at a disadvantage are now benefiting from changes brought about by the loss of canopy.

"Some lizards live in the canopy, where they thrive in drier, more sunlit conditions," said herpetologist Neftali Ríos-López, an associate professor at the University of Puerto Rico-Humacao Campus. "Because of the hurricane those drier conditions that were once exclusive to the canopy are now extended down to the forest floor. As a result, those animals are better adapted to those conditions and have started displacing and substituting animals that are adapted to the once cooler conditions."

"Who are the winners and losers in this new environment? That's an important question in all of this," said NASA's Doug Morton. During the airborne campaign, he spent several days in the research plots of El Yunque taking three-dimensional images of the forest floor to complement the data from G-LiHT. He said it's clear that the palms, which weathered the hurricane winds better than other broad-leafed trees, are among the current beneficiaries of the now sun-drenched forest. And that's not a bad thing.

"Palm trees are going to form a major component of the canopy of this forest for the next decade or more, and in some ways they'll help to facilitate the recovery of the rest of this forest," Morton said. "Palms provide a little bit of shade and protection for the flora and fauna that are recolonizing the area. That's encouraging."

The implications of this research extend beyond the forest ecosystem, both in time and space, said Grizelle Gonzalez, a research ecologist with the U.S. Forest Service and project lead for the research plots in El Yunque. As an example, she pointed out that the hurricane caused the mountain streams to flood and fill with sediment that ultimately flowed into the ocean. Sediment can negatively impact the quality of the drinking water as well as the coral communities that fisheries depend on for both subsistence and commerce.

"It's beautiful to see that so many federal agencies came together to collaborate on this important work because forests play a key role in everything from biodiversity and the economy to public health," Gonzalez said.

G-LiHT data also has global implications. In July, the team heads to Alaska to continue surveying the vast forestland in the state's interior to better understand the impacts of accelerated Arctic warming on boreal forests, which, in turn, play a key role in cooling Earth's climate by sequestering carbon from the atmosphere. "G-LiHT allows us to collect research data at the scale of individual trees across broad landscapes," Morton said. "Forests from Alaska to Puerto Rico are constantly changing in response to climate warming and disturbances such as fire and hurricanes."

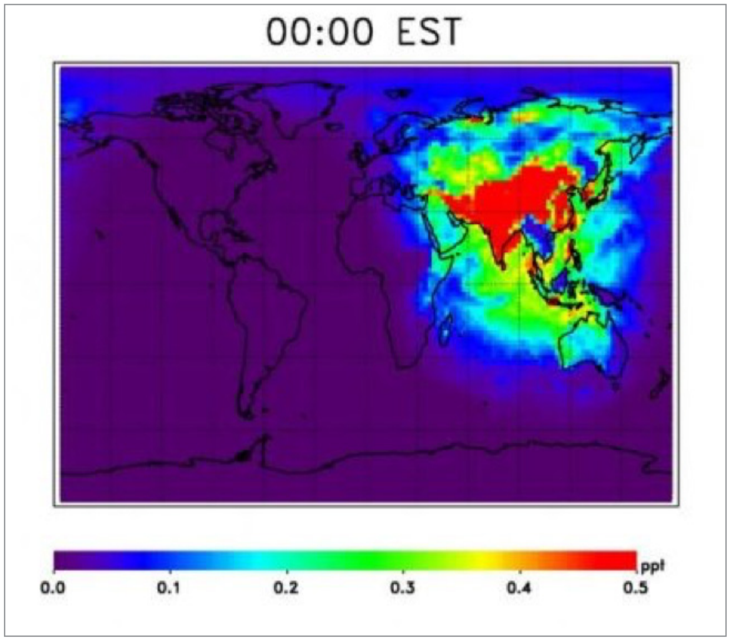
Story Source: https://www.nasa.gov/feature/goddard/2018/nasa-studies-storm-damage-to-puerto-rico-forests

Greenhouse Gas 'Detergent' Recycles Itself in Atmosphere

Date: November 30, 2018

Source: NASA/Goddard Space Flight Center

Summary: A simple molecule in the atmosphere that acts as a 'detergent' to break down methane and other greenhouse gases has been found to recycle itself to maintain a steady global presence in the face of rising emissions, according to new research. Understanding its role in the atmosphere is critical for determining the lifetime of methane, a powerful contributor to climate change.



Model output of OH primary production over a 24-hour period in July tracks with sunlight across the globe. Higher levels of OH over populated land are likely from OH recycling in the presence of NO and NO_2, which are common pollutants from cars and industry. Credit: NASA / Julie Nicely

A simple molecule in the atmosphere that acts as a "detergent" to break down methane and other greenhouse gases has been found to recycle itself to maintain a steady global presence in the face of rising emissions, according to new NASA research. Understanding its role in the atmosphere is critical for determining the lifetime of methane, a powerful contributor to climate change.

The hydroxyl (OH) radical, a molecule made up of one hydrogen atom, one oxygen atom with a free (or unpaired) electron is one of the most reactive gases in the atmosphere and regularly breaks down other gases, effectively ending their lifetimes. In this way OH is the main check on the concentration of methane, a potent greenhouse gas that is second only to carbon dioxide in contributing to increasing global temperatures.

With the rise of methane emissions into the atmosphere, scientists historically thought that might cause the amount of hydroxyl radicals to be used up on the global scale and, as a result, extend methane's lifetime, currently estimated to be nine years. However, in addition to looking globally at primary sources of OH and the amount of methane and other gases it breaks down, this new research takes into account secondary OH sources, recycling that happens after OH breaks down methane and reforms in the presence of other gases, which has been observed on regional scales before.

"OH concentrations are pretty stable over time," said atmospheric chemist and lead author Julie Nicely at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

"When OH reacts with methane it doesn't necessarily go away in the presence of other gases, especially nitrogen oxides (NO and NO_2). The break down products of its reaction with methane react with NO or NO_2 to reform OH. So OH can recycle back into the atmosphere."

Nitrogen oxides are one set of several gases that contribute to recycling OH back into the atmosphere, according to Nicely's research, published in the *J. Geophys. Res: Atmos.,*. She and her colleagues used a computer model informed by satellite observations of various gases from 1980 to 2015 to simulate the possible sources for OH in the atmosphere. These include reactions with the aforementioned nitrogen oxides, water vapor and ozone. They also tested an unusual potential source of new OH: the enlargement of the tropical regions on Earth.

OH in the atmosphere also forms when ultraviolet sunlight reaches the lower atmosphere and reacts with water vapor (H_2O) and ozone (O_3) to form two OH molecules. Over the tropics, water vapor and ultraviolet sunlight are plentiful. The tropics, which span the region of Earth to either side of the equator, have shown some evidence of widening farther north and south of their current range, possibly due to rising temperatures affecting air circulation patterns. This means that the tropical region primed for creating OH will potentially increase over time, leading to a higher amount of OH in the atmosphere. This tropical widening process is slow, however, expanding only 0.5 to 1 degree in latitude every 10 years. But the small effect may still be important, according to Nicely.

She and her team found that, individually, the tropical widening effect and OH recycling through reactions with other gases each comprise a relatively small source of OH, but together they essentially replace the OH used up in the breaking down of methane.

"The absence of a trend in global OH is surprising," said atmospheric chemist Tom Hanisco at Goddard who was not involved in the research. "Most models predict a 'feedback effect' between OH and methane. In the reaction of OH with methane, OH is also removed. The increase in NO_2 and other sources of OH, such as ozone, cancel out this expected effect." But since this study looks at the past thirty-five years, it's not guaranteed that as the atmosphere continues to evolve with global climate change that OH levels will continue to recycle in the same way into the future, he said.

Ultimately, Nicely views the results as a way to fine-tune and update the assumptions that are made by researchers and climate modelers who describe and predict how OH and methane interact throughout the atmosphere. "This could add clarification on the question of will methane concentrations continue rising in the future? Or will they level off, or perhaps even decrease? This is a major question regarding future climate that we really don't know the answer to," she said.

Story Source: Materials provided by NASA/Goddard Space Flight Center. Note: Content may be edited for style and length.

Reference: Nicely, J.M., T.P. Canty, M. Manyin, L.D. Oman, R.J. Salawitch, S.D. Steenrod, S.E. Strahan, S.A. Strode, 2018: Changes in Global Tropospheric OH Expected as a Result of Climate Change Over the Last Several Decades. *J. Geophys. Res.: Atmos.*, **123**, 10,774-10,795, https://doi.org/10.1029/2018JD028388.

ACRONYMS AND ABBREVIATIONS

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

A

AAAS American Association for the Advancement of Science
ABI Advanced Baseline Imager
ACATS Airborne Cloud-Aerosol Transport System
ACE Aerosol, Chemistry, and Ecosystems
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
ARSET Applied Remote Sensing Training
ASCENDS Active Sensing of CO2 Emissions over Nights, Days, and Seasons
ASIF Air Sea Interaction Facility
ASR Atmospheric System Research
ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer
AT Atmospheres
ATB Attenuated Total Backscatter
ATM Airborne Topographic Mapper
ATMS Advanced Technology Microwave Sounder
AVHRR Advanced Very High Resolution Radiometer

B

BC Black Carbon
BESS Beaufort and East Siberian Sea
BEST Beginning Engineering Science and Technology
BMKG Indonesian Agency for Meteorology, Climatology and Geophysics
BOREALIS Balloon Outreach, Research, Exploration and Landscape Imaging System
BRDF Bidirectional Reflectance-Distribution Functions

C

CAFE Compact Airborne Formaldehyde Experiment
CALIOP Cloud-Aerosol LIdar with Orthogonal Polarization
CALIPSO Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMS Copernicus Atmospheric Monitoring Service
CANOE Compact Airborne NO2 Experiment
CANs Cooperative Agreement Notices
CAR Cloud Absorption Radiometer
CARAFE CARbon Airborne Flux Experiment

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
CCP	Clouds, Convection, and Precipitation
CEOS	Committee on Earth Observation Satellites
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
COSPCFMIP	Observation Simulator Package
COTS	Commercial Off-The-Shelf
CPC	Cloud-Precipitation Center
CPL	Cloud Physics Lidar
CPR	Cloud Profiling Radar
CR	Cloud regimes
CrIS	Cross-track Infrared Sounder
CRM	Cloud-resolving Models
CRS	Cloud Radar System
CTM	Chemical Transport Model
CVS	Cloud Vertical Structure

D

D3R	Dual-polarization, Dual-Frequency, Doppler Radar
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
DRAGON	Distributed Regional Aerosol Gridded Observation Networks
DSCOVR	Deep Space Climate Observatory
DT	Dark-target
DYNAMO	Dynamics of the Madden-Julian Oscillation

E

EC	Environment Canada
ECO-3D	Exploring the Third Dimension of Forest Carbon
ECS	Equilibrium Climate Sensitivity
EDOPER-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
ESAS	Earth Science and Applications from Space
ESS	Earth and Space Sciences
ESSIC	Earth System Science Interdisciplinary Center
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites

F

FMI	Finnish Meteorological Institute
FV	Finite Volume

G

G-IV	Gulfstream IV
GCE	Goddard Cumulus Ensemble
GCM	Global Climate Model
GCPEXGPM	Cold Season Precipitation Experiment
GEMS	Geostationary Environmental Monitoring Sensor
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
GIBS Global Imagery Browse Services
GLE GLOBE Learning Expedition
GLOBE Global Learning and Observations to Benefit the Environment
GLOPAC Global Hawk Pacific Missions
GMAC Grants Management Advisory Council
GMAO Global Modeling and Assimilation Office
GMIG PM Microwave Imager
GMI Global Modeling Initiative
GOES Geostationary Operational Environmental Satellites
GOES-R Geostationary Operational Environmental Satellite – R Series
GOSAT Greenhouse gases Observing Satellite
GPCEXGPM 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
GST Global Science & Tech Inc.
GUV Global Ultraviolet
GV Ground Validation

H

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
HFC Hydrofluorocarbons
HMA High Mountain Asia
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

I

I3RC Intercomparison of 3D Radiation Codes
IAMAS International Association of Meteorology and Atmospheric Sciences
IASI Infrared Atmospheric Sounding Interferometer
iCACG Pinternational Commission on Atmospheric Chemistry and Global Pollution
ICAP International Cooperative for Aerosol Prediction
ICCARS Investigating Climate Change and Remote Sensing
ICE-POP International Collaborative Experiment for the Pyeongchang Olympics and Paralympics
ICESat Ice, Cloud, and land Elevation Satellite
ICIMOD International Centre for Integrated Mountain Development
IGAC International Global Atmospheric Chemistry
IGBP International Geosphere-Biosphere Programme
IGP Indo–Gangetic Plain
IIP Instrument Incubator Program
IMERG Integrated Multisatellite Retrievals for GPM
INPE National Institute for Space Research (Brazil)
IOTD Image of the Day
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
IWRAP Imaging Wind and Rain Airborne Profiler

J

JAXA Japanese Aerospace Exploration Agency
JCET Joint Center for Earth Systems Technology
JOSIE Jülich Ozone Sonde Intercomparison

	Experiment
JPL	Jet Propulsion Laboratory in Pasadena, California
JPSS	Joint Polar Satellite System
JSC	NASA's Johnson Space Center in Houston, Texas
JWST	James Webb Space Telescope

K

KMA	Korean Meteorological Administration

L

LAPAN	Indonesia's National Institute of Aeronautics and Space
LaRC	Langley Research Center in Hampton, Virginia
LASP	Laboratory for Atmospheric and Space Physics
LDCM	Landsat Data Continuity Mission
LDSD	Low Density Sonic Decelerator program
LEO	Low Earth Orbit
LIS	Lightning Imaging Sensor
LIS	Land Information System
LISTOS	Long Island Sound Tropospheric Ozone Study
LOA	Letter of Agreement
LPVEx	Light Precipitation Validation Experiment
LRRP	Laser Risk Reduction Program
LW	Long Wave

M

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
MHM	Mosquito Habitat Mapper
MISR	Multi-angle Imaging Spectroradiometer
MJO	Madden-Julian Oscillation
MLS	Microwave Limb Sounder
MMF	Multi-scale Modeling Framework
MMF-LIS	Multi-scale Modeling Framework Land Information System
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
MRMS	Multi-Radar/Multi-Sensor
MSU	Montana State University
MSU	Morgan State University
MUREP	Minority University Research and Education Project

N

NAS	National Academy of Sciences
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
NDACC	Network for the Detection of Atmospheric Composition Change
NDVI	Normalized Difference Vegetation Index
NEO	NASA Earth Observations
NESEC	Northeast States Emergency Consortium
NEXRAD	Next Generation Radar
NFOV	Narrow Field-of-View
NIH	National Institutes of Health
NIR	Near-infrared
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
NU-WRF	NASA Unified Weather Research and Forecast
NYCALC	Native Youth Community Adaptation and

	Leadership Congress

O

OASIS	Ocean Ambient Sound Instrument System
OBPG	Ocean Biology Processing Group
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
ONR	Office of Naval Research
ORS	Operationally Responsive Space
OSC	Orbital Sciences Corporation
OWLETS	Ozone Water Land Environmental Transition Study

P

PACE	Pre-Aerosols, Clouds, and Ecology
PAO	Public Affairs Office
PARSIVEL	PARticle Size VELocity
PBL	Planetary Boundary Layer
PCA	Principal Component Analysis
PD	Polarization Difference
PDF	Probability Distribution Function
PECAN	Plains Elevated Convection at Night
PI	Principal Investigator
PIP	Precipitation Imaging Package
PIP	Precipitation Imaging Processor
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

R

RADEX	Radar Definition Experiment
RAJO-MEGHA	Radiation, Aerosol Joint Observation-Modeling Exploration over Glaciers in Himalayan Asia
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

S-HIS	Scanning High-Resolution Interferometer Sounder
SA	System Administrator
SAF	Satellite Application Facility
SAIC	Science Applications International Corporation
SAL	Saharan Air Layer
SAR	Search and Rescue
SARP	Student Airborne Research Program
SBI	Surface-Based Inversions
SC	Solar Cycle
SCOR	Scientific Committee on Oceanic Research
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
SHOUT	Sensing Hazards with Operational Unmanned Technology
SIM	Spectral Irradiance Monitor
SIMPL	Swath Imaging Multi-polarization Photon-counting Lidar
SLALOM	Snow retrievaL ALgorithm fOr gMi
SMAP	Soil Moisture Active Passive
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMD	Science Mission Directorate
SNPP	Suomi National Polar-orbiting Partnership
SODA	Short Observation & Data Analysis
SOLAS	Surface Ocean - Lower Atmosphere Study
SONGNEX	Shale Oil and Natural Gas Nexus
SORCE	Solar Radiation and Climate Experiment
SpaceX	Space Exploration Technologies Corp.

SPARC	Stratosphere-troposphere Processes And their Role in Climate
SPARRO	Self-Piloted Aircraft Rescuing Remotely Over Wilderness
SPE	Solar Proton Event
SSA	Single Scattering Albedo
SSAI	Science Systems and Applications, Inc.
SSC	Scientific Steering Committee
SSI	Solar Spectral Irradiance
SST	Sea Surface Temperature
STAMPS	Science, Technology, and Math Preparation Scholarships
STAR_NET	STAR Library Education Network
STEM	Science, Technology, Engineering, and Mathematics
SWG	Science Working Group
SWOT	Surface Water Ocean Topography

T

TBM	Terrestrial Biochemical Model
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
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
TROPOMI	Troposhere Ozone Monitoring Instrument
TSI	Total Solar Irradiance
TSIS	Total Spectral Solar Irradiance Sensor
TWiLiTE	Tropospheric Wind Lidar Technology Experiment

U

UARS	Upper Atmosphere Research Satellite
UAS	Unmanned Aircraft Systems
UAVs	Unmanned Aerial Vehicles
UMBC	University of Maryland, Baltimore County
UMD	University of Maryland, College Park
UMSA	Universidad Mayor San Andres
UNCG	University of North Carolina - Greensboro
UND	University of North Dakota
UNEP	United Nations Environment Programme
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

V

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
VPM	Vegetation Photosynthesis Model

W

WAVES	Water Vapor Validation Experiments Satellite and sondes
WCRP	World Climate Research Programme
WFF	Wallops Flight Facility
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting

APPENDIX 1: REFEREED ARTICLES

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