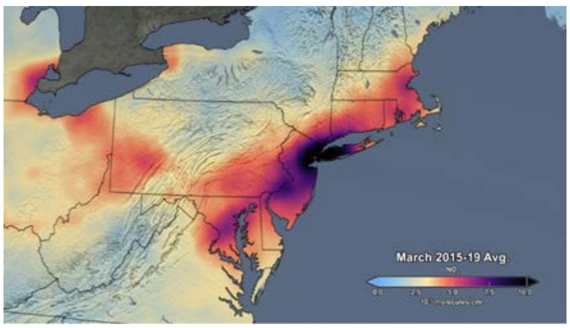
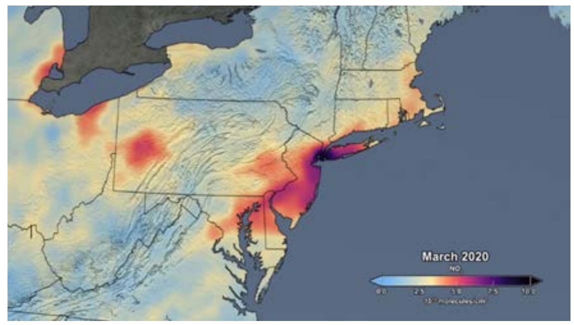
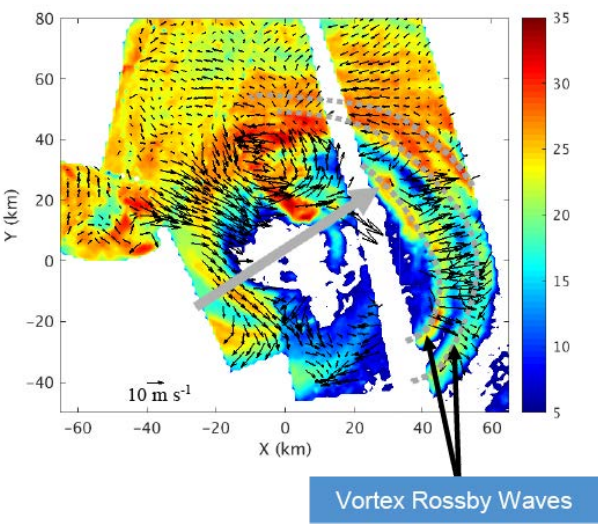
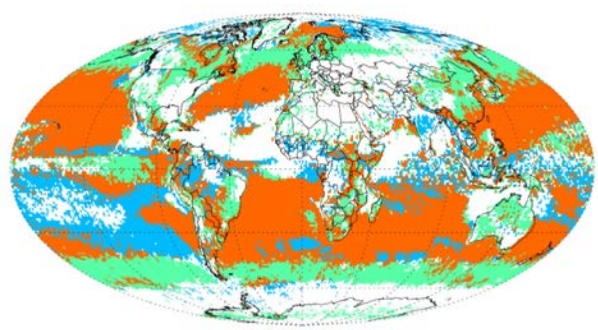
National Aeronautics and Space Administration

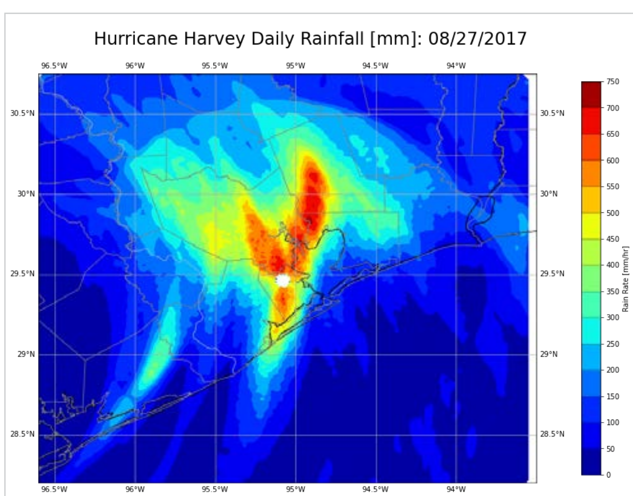
Atmospheric Research
2020 Technical Highlights











NASA/TM-20220019015

On the Cover

Top: In March 2020, the Northeast US saw significant reductions in air pollution over its major metropolitan areas. These recent improvements in air quality have come at a high cost, as communities grapple with widespread lockdowns and shelter-in-place orders as a result of the spread of COVID-19. One air pollutant, nitrogen dioxide (NO_2), is primarily emitted from burning fossil fuels (diesel, gasoline, coal). If processed and interpreted carefully, NO_2 levels observed from space serve as an effective proxy for NO_2 levels at Earth's surface. The images show satellite data of NO_2 from the Aura Ozone Monitoring Instrument (OMI) over the Northeast US in March. The left image shows the mean of the period from 2015 through 2019, while the right image on the right shows the mean for 2020. Variations in weather from year to year cause variations in the monthly means for individual years. March 2020 shows the lowest values as compared to any of the monthly values for March during the OMI data record, which spans 2005 to present.

Middle Left: Most mature hurricanes develop an outer, secondary eyewall that causes significant changes in overall storm intensity. Operational forecasts of these changes are fraught with errors and the science is not fully understood. Analysis of ground-based and airborne (NASA HIWRAP) radar data in Hurricane Matthew (2016) highlights the importance of "vortex Rossby waves" (VRWs) in the storm intensity/structure change. A new mathematical framework was developed that enables the first observational quantification of VRWs in the secondary eyewall formation process. This figure shows the structure of spiral bands breaking off the main eyewall of the storm in the down-shear-right quadrant [see gray arrow] and moving cyclonically in azimuth and outward in radius.

Middle Right: A 12-year (December 2002 to November 2014) global satellite-based cloud (MODIS) and radiation (CERES) dataset was used to examine whether properties and radiative effects of liquid phase clouds differ under distinct aerosol loadings (from either satellite –MODIS – or reanalysis – MERRA) in ways that are consistent with cloud brightening by aerosol. Consistency (areas of red, blue, green in map) is defined as sensitivities to increased aerosol loadings that are: negative for cloud droplet effective radius, positive for cloud optical depth, and positive for shortwave cloud radiative effect.

- *Red:* Consistency for both MERRA and MODIS AOD
- *Blue:* Consistency for MODIS only
- *Green:* Consistency for MERRA only
- *White:* Inconsistency or cannot be determined

Bottom: Radar-estimated daily rainfall totals from Hurricane Harvey for August 27, 2017. Harvey deluged southeast Texas over the period August 25-29, 2017, with total rainfall exceeding 1100 mm. This image shows the one day totals that exceeded 700 mm.

Wolff D. B., A. Petersen, A. Tokay, D. A. Marks and J. L. Pippitt, 2019: Assessing Dual-Polarization Radar Estimates for Extreme Rainfall During Hurricane Harvey. *J. Atmos. Tech.*, **36**, 2501-2520. https://doi.org/10.1175/JTECH-D-19-0081.1.

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NASA STI Program ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role. The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

Technical Publication. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

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

Contractor Report. Scientific and technical findings by NASA-sponsored contractors and grantees.

Conference Publication. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

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

Technical Translation: English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing help desk and personal search support, and enabling data exchange services. For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov.
- E-mail your question via the Internet to help@sti.nasa.gov.
- Fax your question to the NASA STI Help Desk at 443-757-5803
- Phone the NASA STI Help Desk at 443-757-5802.

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

Dear Reader,

Welcome to the 2020 Atmospheres Highlights report. Here we summarize research and scientific communication/outreach accomplishments from the portion of atmospheric science activities at NASA's Goddard Space Flight Center (GSFC) that comprises the Earth Science Division's Atmospheres organization. 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 (Code 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, the 277 personnel in Code 610AT consist of 53 civil servants and 224 cooperative agreement associates, postdoctoral fellows and contractors.

In Memoriam: Dr. Franco Einaudi, the former Chief of the Laboratory for Atmospheres and former Director of Earth Sciences at Goddard, passed away on December 10, 2020. His leadership and contributions were numerous and are still felt here in the Earth Science Division today; please see "In Memoriam", following this message, for an overview of Franco's contributions and legacy.

While the report provides a comprehensive summary of 610AT 2020 activities, below are a few highlights.

Satellite missions: The DSCOVR/EPIC satellite completed its fifth year in orbit in February 2020. Though much of the previous year was spent under safe hold conditions due to a spacecraft pointing issue, operations continued on March 2, 2020 providing images of the Earth from NASA's Earth Polychromatic Imaging Camera (EPIC) instrument at the same rate as before operations were interrupted. The NASA DSCOVER Deputy Project Scientist and numerous science team personnel reside in 610AT.

610AT scientists have long been active in the flagship Earth Observing System (EOS) missions (Terra, Aqua, Aura), serving as project scientists, algorithm product developers, and data users. Terra and Aqua's 21-year and 19-year ongoing missions, respectively, and resulting long-term data records were crucial in 2020 to help understand changes in atmospheric particulates (dust and haze) in the U.S. and globally as a result of modified industrial and transportation activities during COVID-19 pandemic mitigation efforts. Similarly, data from the OMI instrument on Aura (launched in 2004) showed the impact of the pandemic on sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) and, by proxy, the impact on the world's economies. OMI's long-term records crucially put the impact of the pandemic into historical perspective, including natural weather-related variations in NO_2.

SORCE (Solar Radiation and Climate Experiment), also part of NASA's EOS program, ended its 17-year journey on February 25, 2020, successfully extending the continuity of space-era solar irradiance measurements to 40 years as well as beginning a new era of spectral irradiance capabilities. Continuation of the data record is currently being obtained with NASA TSIS-1 observations on the International Space Station (ISS). The Project Scientist for SORCE and TSIS-1 is in 610AT.

The GPM-CO (Core Observatory) mission completed its three-year prime mission lifetime in 2017. The mission was first approved for continued operations via the NASA Headquarters Earth Science 2017 Senior Review process and was continued this past year once again following the 2020 Senior Review.

The 2017 National Academies NASA Earth Science Decadal Survey advocated for advanced capabilities to observe aerosols, clouds, convection and precipitation (ACCP) variables beyond that achievable through GPM, the EOS flagship missions, and active A-Train sensors. 610AT have been working across 610, and with other NASA centers and the university community, to study architectures for future satellite and suborbital science and applications.

Suborbital deployments: Many of our scientists were involved in major NASA suborbital (ground-based and aircraft) field campaigns during 2020. These include:

Gerald Heymsfield (612), John Yorks (612) and other science team members are leading the IMPACTS (Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms) field campaigns. The first campaign was conducted during January-February 2020. Goddard provided the HIWRAP, CRS, EXRAD, CPL, and CoSMIR instruments for flights using the ER-2 and P3 aircraft. Science analysis is in progress to examine how the microphysical characteristics and likely growth mechanisms of snow particles vary across showbands. This is the first major study of U.S. East Coast snowstorms in over 30 years. While the 2020-21 winter campaign was cancelled due to pandemic issues, we are all hopeful that the campaigns can resume in the coming winter.

In 2020, the SHADOZ website passed the 9000 mark of v 6.0 SHADOZ ozone and radiosonde profiles pairs: https://tropo.gsfc.nasa.gov/shadoz.

The Satellite Coastal & Oceanic Atmospheric Pollution Experiment (SCOAPE) project, began in 2017, had the goal to scope out the feasibility of using NASA resources to monitor air pollution over areas of oil and natural gas extraction activities in the Gulf of Mexico. The project was completed in fall 2020 and its findings are documented in two final reports by Bryan Duncan and Anne Thompson.

Thomas Hanisco became the new manager of the ground-based Pandora network replacing Robert Swap who accepted a new position in Code 610 (See Transitions below).

Kudos: As in previous years, 610AT scientists garnered professional honors and other recognition during 2020.

Joanne Joiner won the 2020 William Nordberg Memorial Award, the highest Earth Science honor at Goddard. Joanna's was honored for her exceptional scientific contributions and leadership in the remote sensing of trace gases and photosynthesis.

Ralph Kahn was elected as an AGU Fellow. Ralph has dedicated most of his scientific career to studying aerosols and their major influences on air quality, aviation safety, cloud properties, and global climate. His work as MISR Aerosol Scientist has resulted in more than 15 years of global high quality aerosol observations.

The International Ozone Monitoring Instrument (OMI) team, a large portion of which is in Code 614, was selected by the Council of the American Meteorological Society (AMS) for a Special Award this year for international collaboration to produce novel satellite observations.

The Earth Observatory website experienced its busiest year in its 21-year history, serving on average over 900,000 visitors per month during 2020.

Civil servant personnel: Ian Adams (612), Bryan Duncan (614), Haris Riris (614) and John Moisan (610W) have been named Assistant Lab Chiefs. In these positions they will work with the lab/office chiefs in the planning and overall management of research, operations, and other activities carried out in the laboratories.

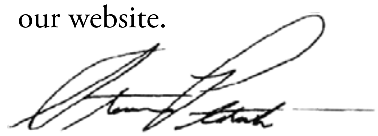
A warm welcome to our new civil servant hires Drs. Edward Nowottnick (joined Code 612 in June), Antonia Gambacorta (joined Code 613 in July), and Glenn Wolff (joined Code 614 in October). Dr. Nowottnick received a PhD from the University of Maryland in 2011; he began his career at Goddard as post-doc fellow and later as an USRA research scientist. Nowottnick will help lead analysis and algorithm development for 612's current and future airborne/spaceborne lidar systems. Dr. Gambacorta received a Ph.D. in Atmospheric Physics from the University of Maryland, Baltimore County in 2008. Her expertise is in atmospheric temperature and moisture sounding, and is currently working on studies for the utilization of hyperspectral IR and microwave data.

Dr. Wolfe holds a Ph.D. in Chemistry from University of Washington, (2010). He's been at NASA GSFC since 2012 will continue to support measurements of trace gases (formaldehyde, ozone, NO_2, and greenhouse gases) on multiple airborne platforms.

Bruce Gentry (612) retired after a Goddard career that began in 1978. Gentry conducted research in high resolution infrared spectrometry and atmospheric remote sensing and participated in the development of several major spectroscopic instruments. In the 1990s, he co-led the original development of Doppler lidar winds measurements based on the edge technique to measure vertical profiles of winds, through the troposphere and lower stratosphere. Bruce became recognized as an international leader in Doppler wind lidar technology and research. This wind profiling capability is now accepted as applicable to global vertical wind measurements through the troposphere from Earth orbit.

Robert Swap (614) accepted the role of Associate Division Director for Mission Planning in February 2020. In this role, Bob works with scientists and stakeholders to promote and enhance GSFC capabilities. His responsibilities include helping formulate new mission concepts, guiding missions already in implementation, developing strategic partnerships (internally, inter-Center, and internationally), working with our Center new business process, and nurturing close relationships with HQ managers.

This report is being published in two media: a printed version and an electronic version on our Atmospheric Science Research Portal site, science.gsfc.nasa.gov/earth/reports. 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

December 2021

IN MEMORIAM

Dr. Franco Einaudi

Dr. Franco Einaudi passed away from complications of pneumonia on December 10, 2020. He was an enthusiastic and highly respected member of the Goddard scientific community for 23 years. He joined Goddard in 1987 and began a career involving planning, organizing, and evaluating a broad program of scientific research, both theoretical and experimental, in the study of Earth science. He served as Head of the Severe Storms Branch, now called the Mesoscale Atmospheric Processes Laboratory (1988-1990), Chief of the Laboratory for Atmospheres (1990-2000), and his last ten years as Director of the Earth Sciences Division. In 1991 as Goddard was designated as the Lead Center for Earth Science in NASA, the Laboratory for Atmospheres, under Dr. Einaudi, became an important arm of Earth Science leadership. He was also instrumental in setting up cooperative agreements within the Earth Sciences Division to better entrain, and provide alternate career paths for, non-civil servant PhD researchers, including the Earth System Science Interdisciplinary Center (ESSIC) at the University of Maryland, College Park, and the Joint Center for Earth Systems Technology (JCET) at the University of Maryland, Baltimore County (UMBC). Dr. Einaudi was recognized nationally and internationally by his peers for his work on gravity waves, gravity waves/ turbulence interaction, propagation of gravity waves in a moist atmosphere, and the role of gravity waves in initiating and interacting with storms.

Following his retirement in 2010, Einaudi spent the next five years as an official NASA ambassador visiting high schools and colleges with high percentages of minority students encouraging them to pursue careers in Earth sciences. In recognition of this work, and as a former American Meteorological Society, president in 2006, the AMS presented him with the Thomas E. Anderson Award in 2014 "for consistent, career-long personal efforts to increase diversity, and for leading institutional changes that will continue to create opportunities for women and under-represented minorities." Dr. Einaudi was also a fellow of the American Meteorological Society, a fellow of the Royal Meteorological Society, a fellow of the American Association for the Advancement of Science and a longtime member of the American Geophysical Union.

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1. INTRODUCTION

A broad and vigorous program of atmospheric research is carried out in the Earth Sciences Division as shown in Figure 1.1. The atmospheres organization (Code AT) is shown in relation to other organizations performing research in atmospheric sciences; scientific interactions within the organizations are carried out across many areas. Research within the atmospheres organization (610AT) 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 laboratories and office that comprise the organization improve our understanding of the dynamics and physical properties of precipitation, clouds, and aerosols; atmospheric

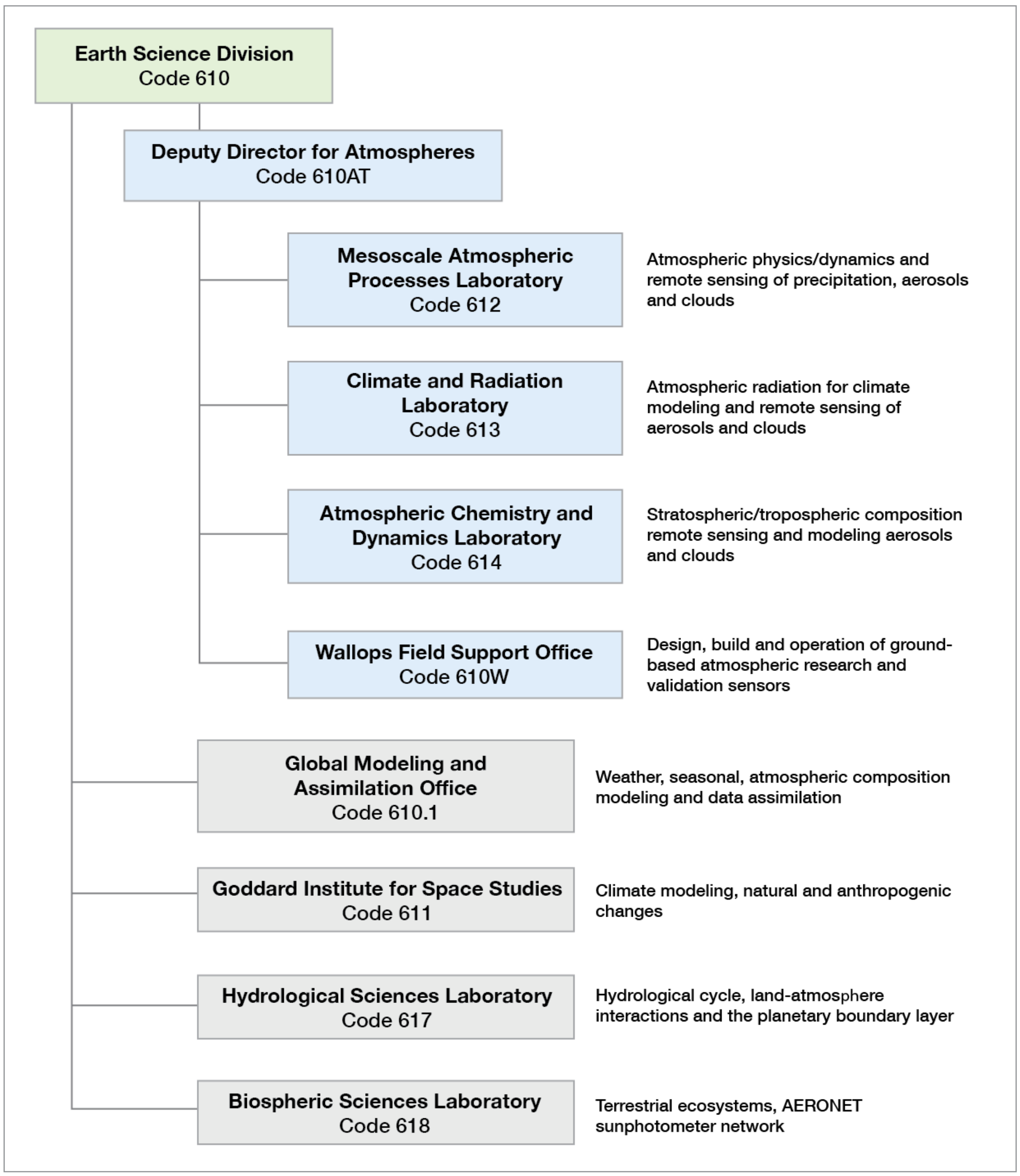

Figure 1.1: *Relationship of 610AT organization to other 610 laboratories and offices performing atmospheric research, and their primary activities.*

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 Earth's climate. The overall scope of the research in the organization covers end-to-end activities, starting with the identification of scientific problems; leading to observational requirements for remote sensing instruments/platforms, technology and retrieval algorithm development along with related model development; followed by satellite and suborbital observations; and eventually, data processing, analyses of measurements, and dissemination to the scientific community and the public. The offices and laboratories of the total Earth Sciences Division can be seen at https://science.gsfc.nasa.gov/earth/orgchart. Instrument scientists in the organization 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 1.2 shows the 20-year record of peer-reviewed publications and proposals among the various laboratories. 610AT strives to maintain the organization's productivity by promoting

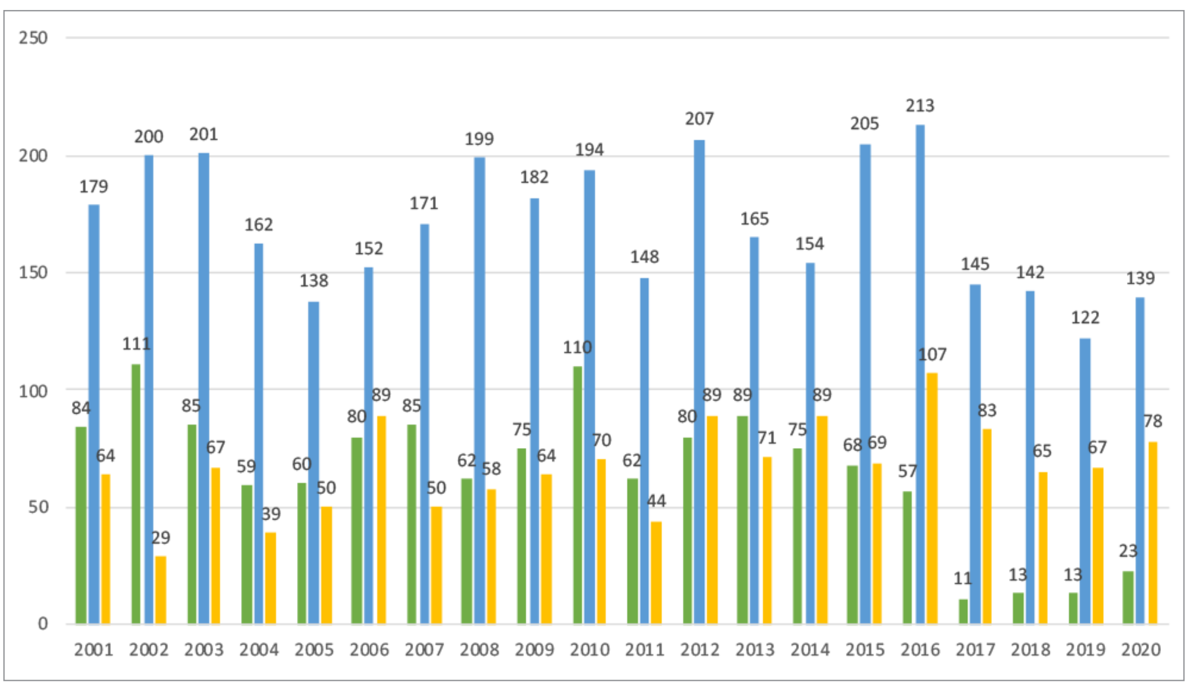

Figure 1.2: *Number of proposals and refereed publications by atmospheric sciences members over the years. The blue bars are the total number of publications and the green bars the number of publications where a laboratory member is first author. Proposals submitted are shown in orange.*

quality while emphasizing coordination and integration among atmospheric disciplines. Being in a NASA center, it is important to achieve an appropriate balance between our scientists' involvement in large collaborative projects and missions vs. active research. Such a balance across the workforce is essential for members of 610AT to develop scientific credentials that are needed to complement mission development and leadership. Interdisciplinary research is carried out in collaboration with other laboratories and research groups within the Earth Sciences Division, across the Sciences and Exploration Directorate, and with partners in universities and other government agencies. Members of the laboratories interact with the general public to support a wide range of interests in the atmospheric sciences. Among other activities, the laboratories raise the public's awareness of atmospheric science by presenting public lectures and demonstrations, by making scientific data available to wide audiences, by teaching, and by mentoring students and teachers. 610AT has made substantial efforts to attract and recruit new scientists through cooperative agreements that often include academic partners (associate scientist), contracts, and the NASA Postdoctoral Program (NPP). We strongly promote societal application of our science products, often making use of partnerships with federal and state agencies that have operational responsibilities. 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 2020. The composition of the organization is shown in Figure 1.3 for each organization code. This report is published in a printed version with an electronic version on our atmospheres website https://science.gsfc.nasa.gov/earth/reports.

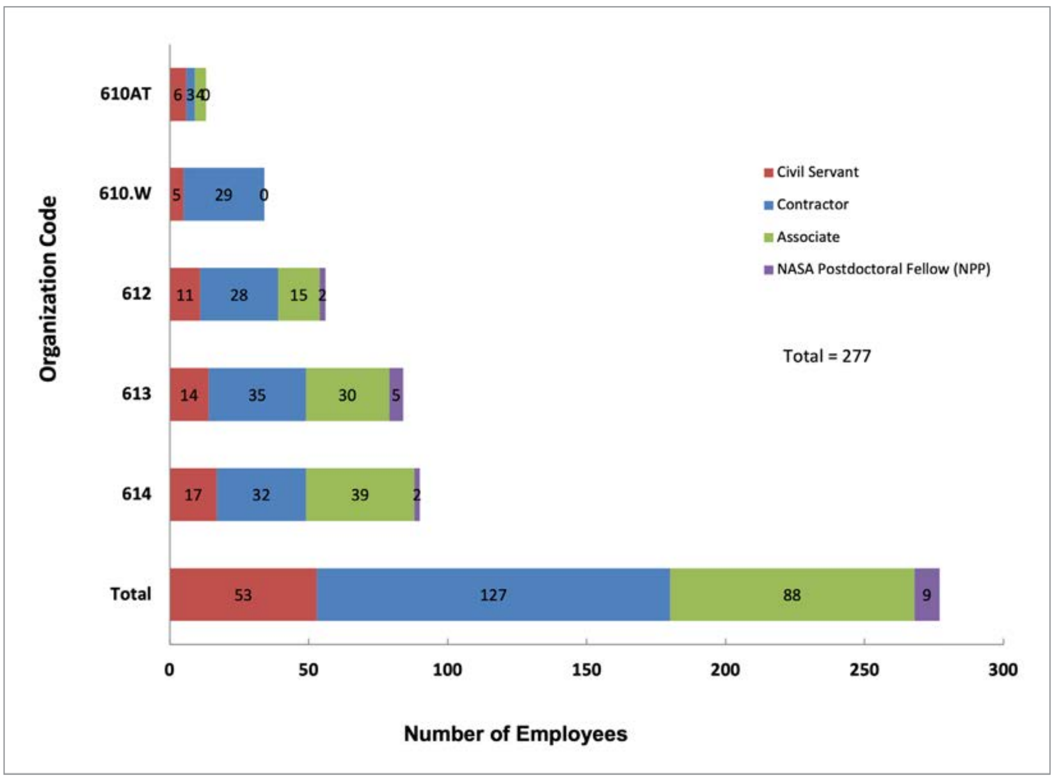

Figure 1.3: *Breakdown of the organizational employee mix.*

2. SCIENCE HIGHLIGHTS

Atmospheric research at Goddard has a long history (more than 50 years) in Earth science studying the atmospheres of both the Earth and the planets. The early days of the TIROS and Nimbus satellites (1960s-1970s) emphasized ozone monitoring, Earth radiation, and weather forecasting. Planetary atmosphere research with the Explorer, Pioneer Venus Orbiter and Galileo missions was carried out until around 2000. In the recent years, EOS missions have provided an abundance of data and information to advance knowledge and understanding of atmospheric and climate processes. Basic and crosscutting research are being carried out through observations, modeling and analysis. Observation data are 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 (http://www.nap.edu/catalog/11820.html. ESAS (Earth Science and Applications from Space) 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 2020. The individual contributor(s) are named at the end of each summary. Additional highlights and other information may be found at the website: atmospheres.gsfc.nasa.gov.

2.1. Mesosale 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 are below.

2.1.1. Lifecycle of a Madden Julian Oscillation (MJO) event simulated with cloud-resolving models and well validated with multiple radars

The MJO shows the most prominent sub-seasonal variations in the tropical atmosphere, but is the least understood. Studying MJO initiation and propagation mechanisms could provide large societal benefit by improving the accuracy of sub-seasonal weather forecast. The high-resolution cloud-resolving model validated in this study can explicitly resolve the full spectra of precipitation features, from individual convection to mesoscale convective complex associated with MJO at its mature stage. These precipitation features are closely related to atmospheric diabatic heating and moisture budgets, which are key processes in MJO's lifecycles. NASA's first space-borne precipitation radar (TRMM PR) data are used to contribute to the U.S. component of an international field program to collect in situ observations to advance the understanding and prediction of MJO. Validations of precipitation structures associated with MJO provide the foundation for further model sensitivity studies. The unique approach of this study is that it combines the ground-based radar observations with TRMM satellite, taking advantages of their unique sampling strategy.

Contributors: Xiaowen Li (NASA/GSFC, Code 612, MSU); Wei-Kuo Tao (NASA/GSFC, Code 612); and Toshihisa Matsui (NASA/GSFC, Code 612, UMD).

Reference: Xiaowen Li, M. A. Janiga, S. Wang, W.-K. Tao, A. Rowe, W. Xu, C. Liu, T. Matsui and C. Zhang, 2018: Evolution of precipitation structure during the November DYNAMO MJO event: Cloud-resolving model inter-comparison and cross validation using radar observations. *J. Geophys. Res.*, **123**, https://doi.org/10.1002/2017JD027775.

2.1.2. POLARRIS: A POLArimetric Radar Retrieval and Instrument Simulator Facilitates Analysis of Observations and Models for the Next Generation Cloud and Precipitation Observing System

Understanding of deep convective clouds is important for weather, climate, and society in terms of intense rainfall, water resource, agriculture, severe weather damages to name a few. Cloud-resolving models (CRMs) have been and will continue to be important tools to understand these process. Consequently, the establishment of robust frameworks to evaluate their dynamical and microphysical outputs is critical, and the widespread emergence of ground-based polarimetric radars has provided the such opportunity. Towards the goal of more comprehensive model evaluation, data assimilation, and polarimetric radar retrieval development, a systematic framework for a polarimetric simulator is required, including a fast and accurate forward model as well as a rigorous inverse component for linking polarimetric observables with retrieved geophysical parameters. To this end, a synthetic polarimetric radar simulator and retrieval package, POLArimetric Radar Retrieval and Instrument Simulator (POLARRIS), has been developed for evaluating CRMs. POLARRIS is a state-of-art polarimetric radar retrieval and instrumental simulator package. POLARRIS allows more comprehensive analysis of cloud, convection, and precipitation processes, better harnessing ground-based polarimetric radars and cloud-resolving models (CRM). For example, detailed hydrometeor distributions can be revealed through polarimetric radar retrievals and compared to simulated polarimetric radar signals through hydrometeor identification (HID) Stacked Frequency of Altitude Diagrams (SFADs). POLARRIS can be applied to a wide range of CRMs and polarimetric radars, such as NASA's S-band dual-POLarimetric radar (N-POL) and the Dual-frequency Dual-polarized Doppler Radar (D3R) at the Wallops Flight Facility (WFF).

Contributor: Toshi Matsui (NASA/GSFC, Code 612, NAD).

Reference: Matsui, T., B. Dolan, S. A. Rutledge, W.-K. Tao, T. Iguchi, J. Barnum, and S. E. Lang, 2019: POLARRIS: A POLArimetric Radar Retrieval and Instrument Simulator. *J. Geophys. Res.: Atmos.*, **124**, https://doi.org/10.1029/2018JD028317.

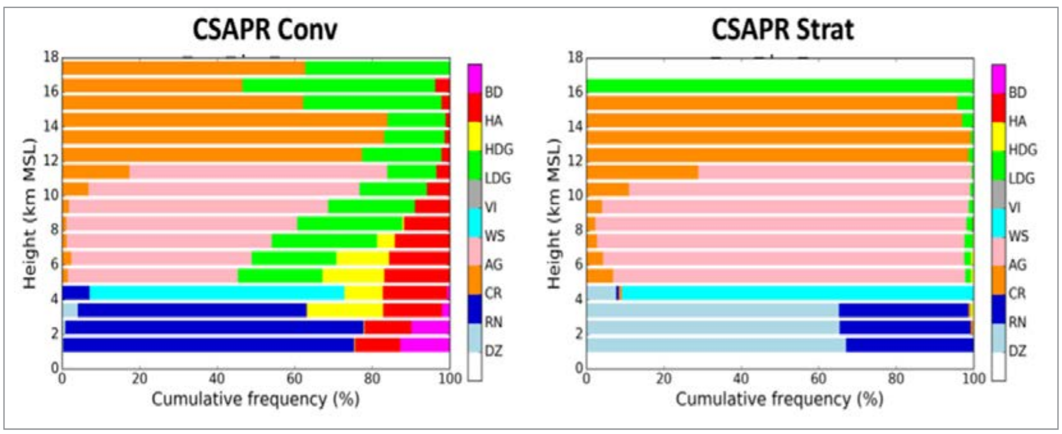

Figure 2.1.2: *The stacked frequency by altitude diagrams (SFADs) of the hydrometeor identification (HID) can summarize the relative frequency of each identified hydrometeor type at each height in the convective (left) and stratiform (right) portions of deep convective systems. HID algorithms retrieve bulk hydrometeor classes for given ranges of polarimetric radar observables from the U.S. Department of Energy (DOE) C-band scanning precipitation radar (CSAPR).*

2.1.3. Estimation of the Wind Vector Over Ocean in the Presence of Rain Using a Dual-frequency Airborne Scatterometer

Accurate estimates of near-surface ocean vector winds are critical to understanding air-sea interactions that help drive the global circulation of the oceans and atmosphere. One of the disadvantages of traditional scatterometer measurements, which use radar backscattering from the surface to infer wind speed and direction, is the influence of precipitation. This introduces errors into the near-surface wind estimates through a modification of the scattered radar signal. This study proposes and analyzes a method that mitigates this source of error, exploiting the differential attenuation at two radar bands that have a consistent response to surface roughness. The Ku (14 GHz) and Ka (35 GHz) radar bands, have a relatively constant differential response to wind speed and direction, but undergo substantial differential attenuation when rain is present.

The different and separable responses to wind and rain allow for estimation of surface winds in raining conditions. Such advances to near-surface ocean wind estimates will expand knowledge about global circulation and improve the ability to sense winds in extreme conditions such as tropical cyclones. Additionally, the knowledge gained from this study will impact current and future NASA missions, such as the Global Precipitation Measurement (GPM) mission as well as measurement concepts listed in the *2017 Decadal Survey* including the Designated Clouds, Convection, and Precipitation (currently under study) or Explorer-class Ocean Surface Winds and Currents.

Contributors: Robert Meneghini (NASA/GSFC, Code 612); Liang Liao (NASA/GSFC, Code 612, MSU); and Gerald M. Heymsfield (NASA/GSFC, Code 612).

Reference: Li, L., and co-authors, 2016: The NASA High-Altitude Imaging Wind and Rain Airborne Profiler. *IEEE Trans. Geosci. Remote Sens.*, **54**, 298-310, https://doi.org/10.1109/TGRS.2015.2456501.

2.1.4. Development and Evaluation of the Raindrop Size Distribution Parameters Provides Vital Ground-truth for the NASA Global Precipitation Measurement Mission

One of the Level-1 Science Requirements specified by the National Aeronautics and Space Administration (NASA) Global Precipitation Measurement (GPM) program states that measurements from the GPM Core Observatory shall estimate the mass weighted mean drop diameter (D_{mass}) of precipitation particle size distribution to within ± 0.5 mm. This study focuses exclusively on the development of parametric relationships for D_{mass} and normalized intercept parameter based on disdrometer-calculated radar observables Z_{DR} and Z_H. These relationships are used in the radar-based validation network software architecture. The study presents the methodology and evaluation used by the GPM ground-validation team to develop D_{mass} (Z_{DR}) and NW(Z_H, D_{mass}) relationships. The methodology relies on the use of polarimetric radar-based retrievals developed from disdrometer datasets collected at six mid-latitude sites and one tropical site. More emphasis was given to the retrieval of D_{mass} because its accuracy is tied to the level-1 requirements of the GPM mission. The sensitivity of the D_{mass} (Z_{DR}) relationships to climate regime and disdrometer type was also presented. A follow-up study of comparison of disdrometer calculated and radar estimate D_{mass} will provide further evidence on the uncertainty of the D_{mass} as a ground-based reference. Accurate estimates of precipitation provide vital information for hazard prediction and identification and resource management, and this calibration and validation reference for GPM ensures high quality products. Beyond GPM, this study is relevant to the Aerosols, Clouds, Convection, and Precipitation (ACCP) Decadal Survey Designated Observable, which is currently under study.

Contributors: Ali Tokay (NASA/GSFC, Code 612, JCET/UMBC); Leo Pio D'Adderio (CNR, Italy); David B. Wolff (NASA/GSFC, Code 610W); and Walter A. Petersen (MSFC).

Reference: Tokay, A., L. P. D'Adderio, D. B. Wolff, and W. A. Petersen, 2020: Development and Evaluation of the Raindrop Size Distribution Parameters for the NASA Global Precipitation Measurement Mission Ground Validation Program. *J. Atmos. Oceanic Technol.*, **37**, 115-128, https://doi.org/10.1175/JTECH-D-18-0071.1.

2.1.5. Recent Advances in the Goddard CSH Algorithm for GPM Expand Capabilities to Address Extratropical Precipitation

The Goddard convective–stratiform heating (CSH) algorithm has been used to retrieve latent heating (LH) associated with clouds and cloud systems in support of the Tropical Rainfall Measuring Mission and Global Precipitation Measurement (GPM) mission. The CSH algorithm requires the use of a cloud-resolving model to simulate LH profiles to build lookup tables (LUTs). However, the LUTs in the previous CSH algorithm were not suitable for retrieving LH profiles at high latitudes or winter conditions that are needed for GPM. The NASA Unified-Weather Research and Forecasting (Nu-WRF) Model is used to simulate three eastern continental U.S. (CONUS) synoptic winter and three western coastal/offshore events. The relationship between LH structures (or profiles) and other precipitation properties (radar reflectivity, freezing-level height, echo-top height, maximum dBZ height, vertical dBZ gradient, and surface precipitation rate) is examined, and a new classification system is adopted with varying ranges for each of these precipitation properties to create LUTs representing high latitude/winter conditions. The performance of the new LUTs is examined using a self-consistency check by comparing LH profiles retrieved from the LUTs using model-simulated precipitation properties with those originally simulated by the model as the truth.

Contributors: Wei-Kuo Tao (NASA/GSFC, Code 612); Takamichi Iguchi (NASA/GSFC, Code 612, UMD); and Stephen Lang (NASA/GSFC, Code 612, SSAI).

References: Tao, W., T. Iguchi, and S. Lang, 2019: Expanding the Goddard CSH Algorithm for GPM: New Extratropical Retrievals. *J. Appl. Meteorol. Climatol.*, **58**, 921-946, https://doi.org/10.1175/JAMC-D-18-0215.1.

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. Climate*, **31**, 5997-6026, https://doi.org/10.1175/JCLI-D-17-0224.1.

2.1.6. Combined Lidar-polarimeter Observations Enable Novel Classification of Cirrus Cloud Ice Crystal Habits

For the first time, lidar (Cloud Physics Lidar-CPL) and polarimeter (Research Scanning Polarimeter-RSP) data from the SEAC4RS campaign is combined to cluster ice crystals into seven distinct habits. The results of this classification were compared to in-situ Cloud Particle Imager (CPI) data and frequencies for irregulars, spheroids, columns and rosettes agreed within 5%, while less agreement was found for plates (~16%). This study shows the potential for retrievals of ice crystal properties from future space-based mission such as Aerosols, Clouds, Convections and Precipitation (A-CCP). Cirrus consistently cover almost half the Earth and can either warm or cool the atmosphere depending on their microphysical and optical properties. Due to uncertainties in cirrus microphysical properties, radiative forcing calculations generally assume more simplified crystal habits than those shown in this study. These assumptions lead to inaccuracies of cloud radiative forcing estimates. Retrievals from combined backscatter lidar and a multi-channel/multi-angle polarimeter flown on board the same platform, as demonstrated here, serves as a direct response to priorities set forth by NASA's Decadal Strategy for Earth Observation from Space (2018). This study suggests that a detailed ice crystal habit retrieval could be applied to combined space-based lidar and polarimeter observations, like those obtained in the upcoming A-CCP spaceborne mission to study cloud and aerosol properties.

Contributors: Natalie Midzak (Univ. of North Dakota); John Yorks (NASA/GSFC, Code 612); and others.

Reference: Midzak, N., J. E. Yorks, J. Zhang, B. van Diedenhoven, S. Woods, and M. McGill, 2020: A classification cirrus ice crystal habits using combined CPL and RSP data during the SEAC4RS campaign. *J. Atmos. Oceanic Technol.* (in review).

2.1.7. Radar Observations Discover Impact of Waves on Hurricane Secondary Eyewall Formation

Most mature hurricanes develop an outer, secondary eyewall that causes significant changes in overall storm intensity. Operational forecasts of these changes are fraught with errors and the science is not fully understood. Analysis of ground-based and airborne (NASA HIWRAP) radar data in Hurricane Matthew (2016) highlights the importance of "vortex Rossby waves" (VRWs) in the storm intensity/structure change. A new mathematical framework was developed that enables the first observational quantification of VRWs in the secondary eyewall formation process. The results of this work indicate that the convectively-coupled VRWs are leading to a direct spin-up of the outer-core tangential wind field and the development of a secondary eyewall. This is in contrast to studies that have described VRWs as playing an indirect role in the secondary eyewall formation by expanding the outer envelope of vorticity, which assists in the axisymmetrization of convective-scale vorticity anomalies. It was also determined with the airborne radar and satellite data that convective bursts formed in the inner-core of Matthew through the dynamic interaction between a VRW spiral band and a mesovortex circulation. This work has high societal impact since secondary eyewall formation and evolution are common features of hurricanes that can cause significant changes in storm intensity.

Contributors: Stephen Guimond (NASA/GSFC, Code 612, UMBC); P. Reasor (NOAA/HRD); G. Heymsfield (NASA/GSFC, Code 612); and M. McLinden (NASA/GSFC).

References: Guimond, S. R., P. D. Reasor, G. M. Heymsfield, and M. McLinden, 2020: The dynamics of vortex Rossby waves and secondary eyewall development in Hurricane Matthew, 2016: New insights from radar measurements. *J. Atmos. Sci.*, **77**, 2349-2374, doi: 10.1175/JAS-D-19-0284.1.

Guimond, S. R. L. Tian, G. M. Heymsfield, and S. J. Frasier, 2014: Wind retrieval algorithms for the IWRAP and HIWRAP airborne Doppler radars with applications to hurricanes. *J. Atmos. Oceanic Technol.*, **31**, 1189-1215, doi: 10.1175/JTECH-D-13-00140.1.

2.1.8. International Study Highlights Gaps to Address with Future Spaceborne Cloud and Precipitation Radars

Existing and planned spaceborne radar missions provide vital cloud and precipitation information over data-sparse oceans and remote land areas. The international community is currently debating how the next generation of spaceborne radars shall enhance current capabilities and address remaining gaps. Current knowledge of clouds and precipitation has highly benefitted from past (TRMM) and present spaceborne based radar missions (GPM, CloudSat, and RainCube) but important gaps still remain for a thorough understanding of the water cycle and its evolution in a warming climate. Spaceborne radars are a critical part of the cloud and precipitation remote sensing observing system; however, apart from the long-waited EarthCARE radar, the next generation of cloud and precipitation radar systems is still under consideration. NASA Decadal Survey activities for the combined designated ACCP observables have provided significant technology development needed for the next generation of spaceborne radars. The NASA activities have brought together the international radar community to identify key scientific questions, to define associated science requirements, to enable technical and cost-effective solutions to address them, and to seeking support by coordinating funding at the national and international level.

Contributors: G. Heymsfield (NASA/GSFC, Code 612); M. Grecu (NASA/GSFC, Code 612, MSU); L. Li (NASA/GSFC, Code 550); R. Roy, S. Tanelli, M. Lebsock (JPL); R. Dhillon, D. Watters, K. Mroz, U. Leicester, A. Battaglia (Polytechnic U. Turin); P. Kollias, (SUNY Stony Brook); K. Lamer (Brookhaven Lab); and K. Furukawa (JAXA).

Reference: Battaglia, A., Kollias, P., Dhillon, R., Roy, R., Tanelli, S., Lamer, K., M. Grecu, M. Lebsock, D. Watters, K. Mroz, G. Heymsfield, L. Li, and K. Furukawa, 2020: Spaceborne cloud and precipitation radars: Status, challenges, and ways forward. *Rev. Geophys.*, **58**, e2019RG000686. https://doi.org/10.1029/2019RG000686.

2.1.9. Five Years of GPM Observations Reveal Land Surface Response to Precipitation (September)

Using a 1-Dimensional VARiational retrieval (1DVAR) retrieval algorithm, we examined five years of GPM data for sensitivity to accumulated rain and snow. Our analysis revealed significant correlation to accumulated rain at the lower frequencies in many regions and significant correlation to snowpack at the higher frequencies, showing the potential use of passive/active microwave. Although the original purpose of this work was to develop databases to improve the characterization and classification of surface properties in the GPM Level-2 precipitation algorithms, many additional applications are enabled by this dataset. For example, these relationships are already being used by coauthor, Yalei You, to develop multi-satellite precipitation retrieval based on the change in emissivity. This method has the advantage of capturing short-lived or rapidly developing precipitation events that may be missed in between overpasses of microwave sensors. In addition, Community Radiative Transfer Model (CRTM) developers have inquired about the use of the GPM Microwave Imager (GMI) emissivity atlas in order to evaluate its utility in Numerical Weather Prediction (NWP) data assimilation systems. Finally, the sensitivity of the Ka-band backscatter may prove to be complementary to passive microwave and Synthetic Aperture Radar (SAR) methods for observing a wide spectrum of snowpacks in a future Snow Water Equivalent (SWE) mission.

Contributors: S. Joseph Munchak (NASA/GSFC, Code 612); Sarah Ringerud (NASA/GSFC, Code 612, UMD); Ludovic Brucker (NASA/GSFC/USRA, Code 615); Yalei You (UMD/ESSIC); Iris de Gelis (CLS, Brest, France); and Catherine Prigent (LERME, Paris, France).

Reference: S. J. Munchak, S. Ringerud, L. Brucker, Y. You, I. de Gelis and C. Prigent, 2020: An Active–Passive Microwave Land Surface Database From GPM. *IEEE Trans. Geosci. Remote Sens.*, **58(9)**, 6224-6242, doi: 10.1109/TGRS.2020.2975477.

2.1.10. High Resolution, Altitude-corrected Monthly Satellite Precipitation Product Improves Estimates in Mountain Regions

The High-Resolution Altitude-Corrected Precipitation (HRAC-Precip) dataset spatially downscales, and then applies altitude-dependent bias corrections to NASA's Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA). Correcting these biases is particularly important for water management, because the snowpack that accumulates in high mountain regions around the world (the Sierra Nevada Mountains in California and the Rocky Mountains in Colorado for the continental U.S.) is critical for summer water supplies. Improving the bias of satellite precipitation estimates has an important impact on hydrological modeling; HRAC-Precip provides improvements in mountainous regions, where flash flooding is very sensitive to high-intensity precipitation events. As well, the water that is stored in high-altitude snowfields during the winter provides a critical water resource for downstream regions, and the TMPA biases in wintertime high-altitude regions are rather large. HRAC-Precip is considered a proof of concept for possible application to additional and future datasets. In particular, the successor to the TMPA, which has now ended, is the integrated Multi-satellitE Retrievals for the Global Precipitation Measurement (GPM) mission (IMERG). IMERG is also known to have biases in regions with complex terrain and snowy/icy surfaces. IMERG employs zonal-average adjustments to the Global Precipitation Climatology Project (GPCP) to address these deficiencies, but the HRAC-Precip concept points to one approach that will provide a finer-scale adjustment that will render IMERG more useful in these problematic situations.

Contributors: George J. Huffman (NASA/GSFC, Code 612); Hossein Hashemi (Lund U., Sweden); Jessica Fayne (UCLA); and Venkat Lakshmi (U.Va.).

Reference: Hashemi, H., J. Fayne, V. Lakshmi, G. J. Huffman, 2020: Very High Resolution, Altitude-Corrected, TMPA-Based Monthly Satellite Precipitation Product over the CONUS. *Sci. Data*, **7**, article 74, doi: 10.1038/s41597-020-0411-0.

2.1.11. Innovative New Approach to Horizontal Wind Retrievals from NASA High-altitude Airborne Radars Will Advance Understanding of Storm Dynamics

Velocity-azimuth display (VAD) retrievals of horizontal wind profiles from airborne radars typically only use data from the edge of the circle traced out by a single scan of the radar. The large footprint and small number of data points makes this approach prone to contamination by error-inducing weather features (e.g., thunderstorm updrafts). Our improved method combines multiple scans to produce a much greater data density over a similarly-sized footprint. The greater data density reduces the influence of each individual data point, making the technique much more robust to error sources, as demonstrated in our error analysis.

This work improves the ability to observe horizontal winds in the vicinity of deep convection and other environments that are typically considered challenging for VAD wind retrievals. The retrievals provide horizontal wind vectors and deformation fields at high vertical resolution and enable improvements in the analysis of the dynamics of precipitation features. Our improved technique has strong applications for wind retrievals in large convectively active weather systems such as hurricanes and winter storms. The improved VAD technique described here is being actively used to retrieve horizontal winds from the radar data collected by the NASA ER-2 during the ongoing NASA Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS). Plans are underway to attempt to perform these retrievals in real-time to support mission operations during both the upcoming second-and third-year IMPACTS deployments as well as the deployments for future field campaigns.

Contributors: Charles N. Helms (NASA/GSFC, Code 612, USRA/NPP); Matthew L. W. McLinden (NASA/GSFC, Code 555); Gerald M. Heymsfield (NASA/GSFC, Code 612); and Stephen R. Guimond (NASA/GSFC, Code 612, UMBC/JCET).

Reference: Helms, C. N., M. L. W. McLinden, G. M. Heymsfield, and S. R. Guimond, 2020: Reducing errors in velocity-azimuth display (VAD) wind and deformation retrievals from airborne Doppler radars in convective environments. *J. Atmos. Oceanic Technol.*, **37(12)**, 2251-2266 doi: 10.1175/JTECH-D-20-0034.1. NTR #18544-1.

2.1.12. Compact Graphical Representation of Spatial Time Series Data Sets Reveals Subtle Changes in Tropical Ocean Rainfall

Long-term global precipitation datasets are a key tool for understanding the global water cycle and facilitating a wide range of water-related applications, including flood and landslide analysis, water resource management, agricultural forecasting, microinsurance, and transportation. Many of these applications are sensitive to whether the precipitation occurs in a few heavy events or many lighter events, so it is important to understand fluctuations over time in the histogram. Before the Histogram Anomaly Time Series (HATS), these fluctuations were uncovered with a somewhat hunt-and-peck computation of histograms for various periods of time. With HATS, the entire record of histogram fluctuations is readily observed. HATS can be used to display histograms accumulated over whatever region the researcher wishes, and the native time resolution of the maps is likewise at the researcher's discretion. Finally, the current work applies a light polynomial filter to reduce distracting noise, but a heavier, lighter, or no filter can be applied.

Essentially every global precipitation dataset is constructed from a heterogenous collection of input data (both surface- and satellite-based). One of the key steps in these algorithms is to minimize the jumps that occur when the different data sources contribute to the analysis. As such, the resulting precipitation time series contains both natural and artificial variations. HATS permits researchers to visually identify breakpoints in the histogram time series, which can then be analyzed in more depth to determine whether they are real or artificial. The display is sufficiently easy to create that the focus can be on finding times/regions of consistent behavior that can then be used for computing statistics of interest.

This initial work has been done with precipitation data, but it is equally applicable to histograms of other data fields, such as temperature, water vapor, or aerosol content. The main change would be to shift the color bar from logarithmic to linear for fields with a more equitable distribution of small and large values.

Contributors: G.J. Huffman (NASA/GSFC, Code 612); G. Potter (NASA/GSFC, 606.2, USRA); D.T. Bolvin (NASA/GSFC, Code 612, SSAI); M.G. Bosilovich (NASA/GSFC, Code 610.1); J. Hertz (NASA/GSFC, Code 606.2, InuTeq); and Laura E. Carriere (NASA/GSFC, Code 606.2).

Reference: Potter, G., G. J. Huffman, D. T. Bolvin, M. G. Bosilovich, J. Hertz, L. E. Carriere, 2020: Histogram Anomaly Time Series: A Compact Graphical Representation of Spatial Time Series Data Sets. *Bull. Amer. Meteor. Soc.*, **101(12)**, E2133-E2137, doi:10.1175/BAMS-D-20-0130.

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 may be found in the list of refereed articles in Appendix II and in the material 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 ISCCP data analysis. Leadership and participation in science and validation field campaigns provide key measurements as well as publications and presentations. Laboratory scientists serve in key leadership positions on international programs, panels, and committees, serve as project scientists on NASA missions and PI's on research studies and experiments, and make strides in many areas of science leadership, education, and outreach. Some of the laboratory research highlights for the year are described below. These cover the areas aerosol-cloud-precipitation interactions, aerosol effects on climate, reflected solar radiation, land-atmosphere feedback, polar region variations, and hydrological cycle changes. The laboratory also carries out an active program in mission concept developments, instrument concepts and systems development, and Global Climate Models (GCMs). The projects link on the Climate and Radiation Laboratory 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 2019 are summarized are below.

2.2.1. MERRA-2 Represents Skilfully the Thermodynamic Structure of the Antarctic Boundary Layer

Reanalyses data such as MERRA-2, when used in conjunction with satellite observations from CALIPSO and ICESat-2, can be extremely beneficial for estimating the as yet unknown radiative impacts of Antarctic atmospheric events (e.g., blowing snow). This study evaluates MERRA-2 boundary layer thermodynamic structure over the Antarctic continent by comparing against high-resolution dropsonde observations collected during the austral spring season Concordiasi campaign (September-December 2010). Overall, MERRA-2 exhibits a good representation of surface-based inversions (SBIs), while it underpredicts mixed layers (MLs) and no SBIs especially over elevated regions of the East Antarctic plateau. Advances in data assimilation and improvements in turbulence parameterization under very stable conditions, may further improve the representation of the polar atmosphere and boundary layer thermodynamic structure in the model.

Contributors: Manisha Ganeshan (NASA/GSFC, Code 613, USRA) and Yuekui Yang (NASA/GSFC, Code 613).

Reference: Ganeshan, M., and Y. Yang, 2019: Evaluation of the Antarctic boundary layer thermodynamic structure in MERRA2 using dropsonde observations from the Concordiasi campaign. *Earth Space Sci.*, **6**, 2397-2409. https://doi.org/10.1029/2019EA000890.

2.2.2. Understanding Volcanic Plume Evolution from Space

As they are transported downwind, the particles in volcanic plumes are affected by processes such as deposition, aggregation and new particle formation. Analyzing changes in aerosol optical depth (AOD) and Retrieved Effective Particle Size (REPS) from Multi-angle Imaging SpectroRadiometer (MISR) observations allows us to infer the characteristics of plume dispersion. We find that MISR-derived dispersion regimes correlate with meteorological conditions (e.g., wind shear, atmospheric stability), underscoring the influence of environmental factors on plume dispersion.

Volcanic emissions represent a major source of atmospheric aerosols that can have regional to global impacts. The extent to which volcanic aerosols disperse depends on the size and composition of the eruption. However, atmospheric dynamics can mitigate, or exacerbate, the impact of volcanic particles. Assessing particle dispersion with these remote sensing techniques can improve our understanding, and ability to predict, the hazards posed by volcanic eruptions.

A comprehensive evaluation of volcanic eruptions in Kamchatka (Russia) identified that plumes with size-independent particle loss occurred in the least stable atmospheric conditions, suggesting that turbulent atmospheric conditions force particles out of suspension, irrespective of size. However, when plumes are lofted into a more stable layer, gravitational settling dominates, and preferentially removes larger particles. Understanding the meteorological characteristics driving plume dispersion can help refine atmospheric dispersion models, which are used to track the geographic extent and regional or global impact of volcanic emissions, for use in air quality and other disaster-response applications.

Contributors: Verity Flower (NASA/GSFC, Code 613, USRA) and R. Kahn (NASA/GSFC, Code 613).

Reference: Flower, V. J., and R. A. Kahn, 2020: Interpreting the volcanological processes of Kamchatka, based on multi-sensor satellite observations. *Remote Sens. Environ.*, **237**, 111585. DOI:10.1016/j.rse.2019.111585.

2.2.3. Searching for Signals of Aerosol-cloud Interactions with Large-scale Datasets

A satellite-based 12-year global dataset was employed to examine whether cloud properties and cloud radiative effects differ under distinct aerosol loadings (AODs) in ways that are consistent with the classic aerosol-cloud interaction paradigms. Detecting climate-relevant aerosol-cloud interactions from space is a very challenging endeavor particularly when only "snapshot" observations are available for large parts of the planet (i.e., from polar orbiting satellites) and when confounding meteorological influences are also present. Our study has attempted, quite successfully, the detection of aerosol-cloud interaction signals under such imperfect observations and limitations by counteracting with: (1) Large data volume and focus on only the most prevalent aerosol-cloud interactions; (2) Classifying clouds into regimes thereby constraining to some extent meteorological variability; (3) Using both a satellite and a re-analysis aerosol dataset. Ideally, a more diverse information content should be exploited, sacrificing perhaps universal spatiotemporal coverage. Such information content should possibly comprise information on the type and vertical location of aerosol, microphysical cloud properties such as profiles of droplet number concentrations, the short-term temporal evolution of cloud and aerosol fields, and the state of the atmosphere. We should strive for such measurements in future missions most notably that (those) targeting the Aerosol, Cloud, Convection and Precipitation (A-CCP) observables recommended by the *2017 Decadal Survey*.

Contributors: Lazaros Oreopoulos (NASA/GSFC, Code 613); Nayeong Cho (NASA/GSFC, Code 613, JCET/UMBC); and Dongmin Lee (NASA/GSFC, Code 613, MSU).

References: Albrecht, B. A., 1989: Aerosols, Cloud Microphysics, and Fractional Cloudiness. *Sci.*, **245(4923)**, 1227-1230.

Oreopoulos, L., N. Cho, and D. Lee, 2020: A global survey of apparent aerosol-cloud interaction signals. *J. Geophys. Rese.: Atmos.*, **125**, e2019JD031287. https://doi.org/10.1029/2019JD031287.

Twomey, S., 1977: Influence of pollution on shortwave albedo of clouds. *J. Atmos. Sci.*, **34(7)**, 1149-1152.

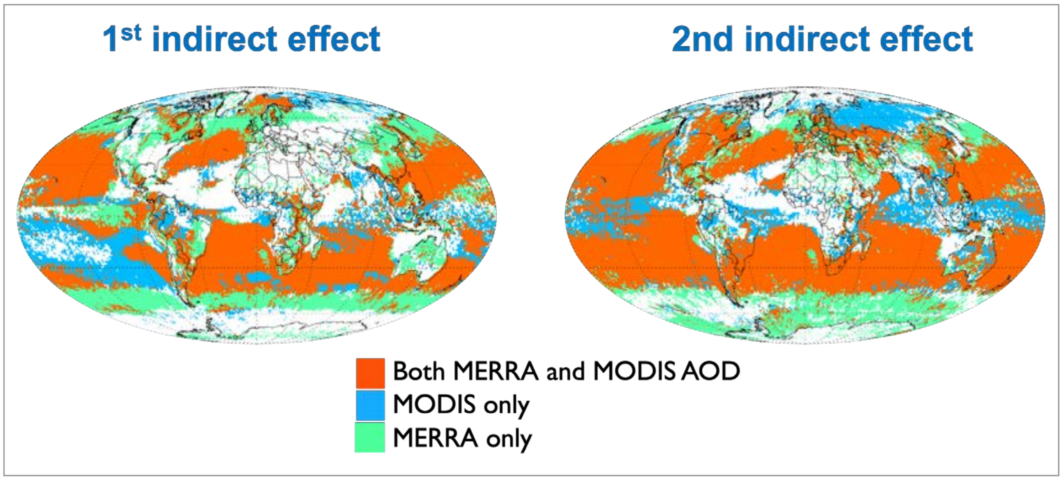

Figure 2.2.3: *A satellite-based 12-year global dataset was employed to examine whether cloud properties and cloud radiative effects differ under distinct aerosol loadings (AODs) in ways that are consistent with the classic aerosol-cloud interaction paradigms. The maps above are evidence of aerosol effects on MODIS-inferred liquid cloud regimes showing where first and second indirect effects may be occurring for clouds identified by MODIS as belonging to liquid regimes. Different colors are used for grid cells where the criteria are met solely for MODIS and MERRA-2 AODs and for grid cells where agreement between the two AOD datasets exists.*

2.2.4. MODIS Observing Distinct Trends of Combustion Aerosol

A novel analysis of Aqua MODIS observations (2003-2017) shows distinct trends of combustion aerosol (e.g., industrial/urban pollution, biomass burning) in the four major continental outflow regions: declining in Europe and North America, increasing in South Asia, and declining after 2008 in East Asia. The observed trends are consistent with how pollution emissions have changed in different regions because of economic growth and implementation of environmental policies. "The method we developed to distinguish combustion aerosol from dust from MODIS retrievals allows us to examine aerosol trends pertinent to man-made and natural sources separately. The MODIS observations complemented by CAM5 source-tagging simulations further trace the change to individual sources. Future satellite missions, such as the A-CCP mission recommended by the *2017 Decadal Survey*, should develop more advanced satellite sensors with enhanced capabilities of deciphering aerosol properties to better distinguish combustion aerosol from dust. An integration of such new observations with MODIS data could allow to monitor any meaningful trends in episodic emissions of biomass burning smoke and dust."

Contributors: Hongbin Yu (NASA/GSFC, Code 613); Yang Yang and Hailong Wang (DOE PNNL); Qian Tan (BAERI); Mian Chin (NASA/GSFC, Code 614); Robert Levy (NASA/GSFC, Code 613); Lorraine Remer (NASA/GSFC, Code 613, JCET/UMBC); Steven Smith (DOE PNNL); and Tianle Yuan and Yingxi Shi (NASA/GSFC, Code 613, JCET/UMBC).

Reference: Yu, H., Y. Yang, H. Wang, Q. Tan, M. Chin, R. Levy, L.A. Remer, S. Smith, T. Yuan, Y. Shi., 2020: Interannual variability and trends of combustion aerosol and dust in major continental outflows revealed by MODIS retrievals and CMA5 simulations during 2003-2017. *Atmos. Chem. Phys.*, **20**, 139-161.

2.2.5. Learning About Biomass-burning Aerosol Absorption Properties from Ground-based Measurements in Thailand

The SMART-s (Spectral Measurements for Atmospheric Radiative Transfer-spectroradiometer) was used to obtain new information on atmospheric aerosols and trace gases from the measurements made at near source regions of biomass-burning in Fang, Thailand. The strong spectral absorption variability in the UV region indicated large amounts of carbonaceous aerosols. This combined with the capability of SMART-s to also retrieve trace gases (e.g., O_3, NO_2, H_2O) provides key information for monitoring atmospheric composition and for future satellite-based aerosol/trace gas retrievals that can be used for comparison/validation. The SMART retrieval algorithm (Jeong et al., 2020) aims to obtain optimum information on atmospheric aerosols and trace gases using a minimization technique. The algorithm output ranges from basic quantities such as total column amounts to high-order inversion products of trace gases and aerosols such as spectral refractive index and size distribution of aerosols. The simultaneous retrievals of trace gases and aerosols can provide useful information on atmospheric chemistry, such as aerosol hygroscopicity, and mass proportion of elemental and organic carbon.

Contributors: Ukkyo Jeong (NASA/GSFC, Code 613, UMD/ESSIC); Si-Chee Tsay (NASA/GSFC, Code 613); David M. Giles (NASA/GSFC, Code 618, SSAI); Brent N. Holben (NASA/GSFC, Code 618); Robert J. Swap (NASA/GSFC, Code 610); Nader Abuhassan (NASA/GSFC, Code 614, UMBC/JCET); Jay R. Herman (NASA/GSFC, Code 614, UMBC/JCET); John W. Cooper (NASA/GSFC, Code 618, SSAI); and James J. Butler (NASA/GSFC, Code 618, SSAI).

References: Jeong U., S.-C. Tsay, et al., 2020: The SMART-s trace gas and aerosol inversions: I. Algorithm Theoretical Basis for column property retrievals. *J. Geophys. Res.: Atmos.*, **125**, doi:10.1029/2019JD032088.

Jeong U., S.-C. Tsay, et al., 2018: Langley calibration analysis of solar spectroradiometric measurements: spectral aerosol optical thickness retrievals. *J. Geophys.Res.: Atmos.*, **123**, 4221-4238, doi:10.1002/2017JD028262.

Tsay, S.-C., H. B. Maring, N.-H. Lin, et al., 2016: Satellite-surface perspectives of air quality and aerosol-cloud effects on the environment: An overview of 7-SEAS/ BASELInE. *Aerosol Air Qual. Res.*, **16**, doi:10.1029/aaqr.2016.08.0350.

2.2.6. Cloud Detection Over Snow and Ice Using DSCOVR-EPIC's Oxygen Bands

Satellite cloud detection over snow and ice with passive remote sensing instruments is challenging due to the lack of contrast between clouds and cold/bright surfaces. Detections usually rely on shortwave infrared (IR) channels. With no such channels available, the Earth Polychromatic Imaging Camera (EPIC) instrument onboard the Deep Space Climate Observatory (DSCOVR) relies on two oxygen band ratios to detect clouds over snow and ice. We developed a novel dynamic threshold scheme for the oxygen band ratios and achieved significant improvements over the existing algorithm.

The oxygen band technique developed in this study is relatively insensitive to the surface and atmosphere temperature and provides a solution to polar cloud detection when infrared channels are not available, or struggle to distinguish between cloudy and clear scenes. Cloud detection with oxygen band could be a great addition in future emissions for monitoring cloud change over snow and ice covered polar and high mountain regions.

The image below shows cloud fractions derived from (a) composite GEO/LEO retrievals, (b) original EPIC cloud mask, (c) new EPIC cloud mask over Antarctica in January 2017. Note that the GEO/LEO composites are produced by NASA Langley, and comprises GEO satellites from GOES, MET, Himawari, and LEO satellites from Terra, Aqua, VIIRS, etc. Since the GEO satellites do not cover beyond 60°, the GEO/ LEO measurements in the Antarctic are in reality only from LEO.

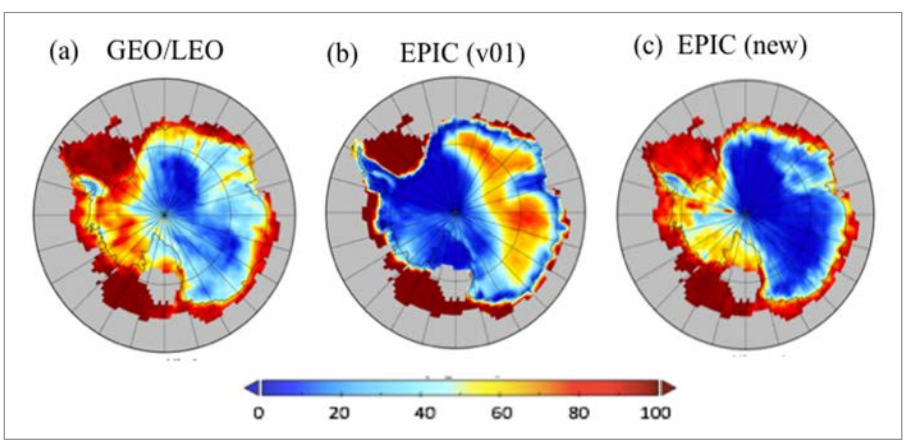

Figure 2.2.6.: *Cloud fractions derived over Antarctica in January 2017.*

Contributors: Yaping Zhou (NASA/GSFC, Code 613, UMBC-JCET); YuekuiYang (NASA/GSFC, Code 613); Meng Gao (NASA/GSFC, Code 616, SSAI); and Peng-Wang Zhai (NASA/GSFC, Code 613, UMBC).

Reference: Zhou, Y., Y. Yang, M. Gao, and P.-W. Zhai. 2020: Cloud detection over snow and ice with oxygen A-and B-band observations from the Earth Polychromatic Imaging Camera (EPIC). *Atmos. Meas, Tech.*, **13(3)**, 1575-1591.
https://doi.org/ 10.5194/amt-13-1575-2020.

2.2.7. Using VIIRS SNPP to Continue MODIS Aerosol as a Climate Data Record

The release of a Dark Target aerosol retrieval product for VIIRS on Suomi-NPP, provides continuity with the nearly 20-year data record from MODIS Aqua. Values of aerosol optical depth (AOD) are highly correlated with MODIS Aqua, but are offset higher. The effects of atmospheric aerosol on the global climate are among the largest remaining sources of uncertainty to the global radiative balance, and suspended particles also have serious implications for public health worldwide. The Global Climate Observing System has set criteria for creating climate data records (CDRs) to understand aerosol as a climate measurement. An aerosol CDR must have global coverage, spatial resolution 10 km or finer, temporal resolution every four hours, accuracy better than ±0.03 or 10%, drift less than 0.01 per decade, and at least 30 years record length. The MODIS Dark Target retrieval approaches all these requirements except for temporal resolution (set by their polar orbit) and length of record (Terra and Aqua both expected to stop measurements by the mid-2020s). Because the VIIRS instrument is similar in design but intended for several future launches as well as the two (SNPP and NOAA-20) already producing data, the VIIRS version of the Dark Target retrieval can be used to extend the record to the required 30 years as long as the differences between it and the existing MODIS product are sufficiently understood.

Contributors: Virginia Sawyer (NASA/GSFC, Code, 613, SSAI); Robert C. Levy (NASA/GSFC, Code 613); Shana Mattoo (NASA/GSFC, Code 613, SSAI); Geoff Cureton (CIMSS/SSEC, UW-Madison); Yingxi Shi (NASA/GSFC, Code 613, JCET/UMBC); and Lorraine Remer (JCET/UMBC).

Reference: Sawyer, V., R. C. Levy, S. Mattoo, G. Cureton, Y. Shi, L. A. Remer, 2020: Continuing the MODIS Dark Target Aerosol Time Series with VIIRS. *Remote Sens.*, **12**, 308, https://doi.org/10.3390/rs12020308.

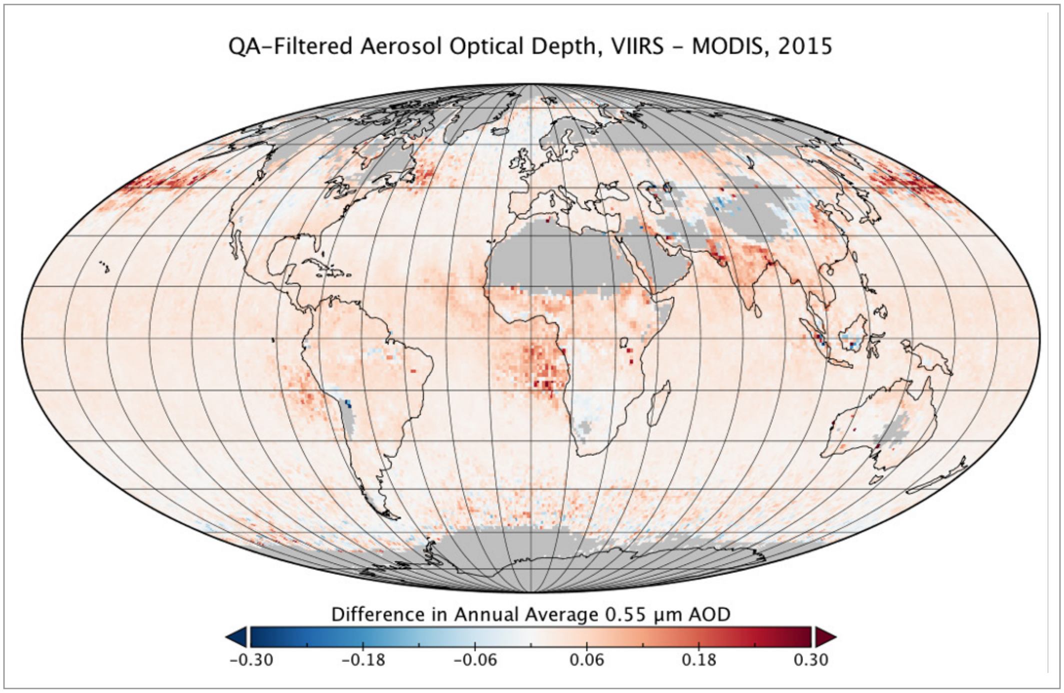

Figure 2.2.7.: *The difference in annual average AOD for each 1°×1°grid cell in 2015, using the same quality flags for land and ocean. The Dark Target retrieval assigns a QA value to each retrieval, with QA=0 for marginal retrievals and QA=3 for good retrievals without any complicating factors. For long-term statistics, we recommend filtering by QA flag: the land analysis here is done with QA=3 only, but because surface reflectance estimates are much more reliable over ocean, the ocean analysis is done with QA=1, 2 and 3.*

2.2.8. Daytime Cloud Fraction Variability Using DSCOVR/EPIC Observations

EPIC's unique position at the Lagrange point, L1, between the Sun and the Earth (1.5 million km from Earth) makes observations of the daytime variability in cloud fraction on the sunlit side of the Earth possible. Over ocean, cloud fraction shows a minimum at noon, increasing early morning and late afternoon. In contrast, there is no discernible daytime pattern over land, with cloud fraction evolution depending strongly on latitude. Regionally, EPIC confirms the known cycles of marine stratocumulus and convection.

Cloud cover is one of the main factors determining the Earth energy balance. However, up-to-date, analyses of its diurnal (daytime) changes at global scales was only available from ISCCP or General Circulation Models, which provided contrasting results in many situations. Currently, direct observations of daytime cloud variability on a global scale are only possible with the EPIC instrument (epic.gsfc.nasa.gov) of the DSCOVR satellite due to its unique location. This work will potentially be useful for assessing cloudiness in current and future GCMs and for a more in-depth understanding of the importance of daytime cloud cover variability in a changing climate. Furthermore, these findings underscore the importance of the L1 vantage point for the Earth sciences research.

Contributors: Alfonso Delgado-Bonal (NASA/GSFC, Code 613, USRA); Alexander Marshak (NASA/GSFC, Code 613); Yuekui Yang and Lazaros Oreopoulos (NASA/GSFC, Code 613).

Reference: Delgado-Bonal, A., A. Marshak, Y. Yang, and L. Oreopoulos, 2020: Daytime variability of cloud fraction from DSCOVR/EPIC observations. *J. Geophys. Research: Atmos.*, **125**, e2019JD031488. https://doi.org/10.1029/2019JD031488.

2.2.9. Deep Blue Aerosol Layer Height from VIIRS and OMPS-NM

An operation-ready Aerosol Single-scattering albedo and Height Estimation (ASHE) algorithm has been implemented in the VIIRS Deep Blue aerosol algorithm suite to provide the height of absorbing aerosols from synergistic use of VIIRS and OMPS, both onboard the S-NPP satellite. With extensive spatial coverage, the dataset can contribute to better understanding of the effects of aerosol layer height on aerosol radiative effects, long-range transport, and surface air quality.

Since the interactions between aerosols, radiation, clouds, and precipitation, which have myriad implications for Earth's climate system, take place in 3-D space, information on the vertical structure of aerosols (in addition to their horizontal distribution) is essential for better quantification of the radiative effects of aerosols. Thus, retrievals of the height information from satellite sensors have been of great interest. CALIOP and MISR missions have successfully served the scientific community on this matter. However, with swath widths of 70 m for CALIOP and 360 km for MISR, spatial coverages of those instruments are somewhat limited. The new data product from synergistic use of VIIRS and OMPS can thus complement the existing datasets. This synergy can continue with the current JPSS mission (continued VIIRS and OMPS instruments) and planned PACE mission (OCI instrument equipped with required spectral bands in a single sensor).

Contributors: Jaehwa Lee (NASA/GSFC, Code 613, UMD/ESSIC); N. Christina Hsu (NASA/GSFC, Code 613); and others.

References: Lee, J., N. C. Hsu, A. M. Sayer, C. J. Seftor, and W. V. Kim (in press), Aerosol layer height with enhanced spectral coverage achieved by synergy between VIIRS and OMPS-NM measurements. *IEEE Geosci. Remote Sens. Lett.*, https://doi.org/10.1109/LGRS.2020.2992099.

Lee, J., N. C. Hsu, C. Bettenhausen, A. M. Sayer, C. J. Seftor, and M.-J. Jeong, 2015: Retrieving the height of smoke and dust aerosols by synergistic use of VIIRS, OMPS, and CALIOP observations. *J. Geophys. Research: Atmos.*, **120**, 8372-8388, https://doi.org/10.1002/2015JD023567.

Jeong, M.-J., and N. C. Hsu, 2008: Retrievals of aerosol single-scattering albedo and effective aerosol layer height for biomass-burning smoke: Synergy derived from 'A-Train' sensors. *Geophys. Res. Lett.*, **35**, L24801, https://doi.org/10.1029/2008GL036279.

2.2.10. The Dark Target Algorithm for Observing the Global Aerosol System: Past, Present and Future

We have taken a step back (30 years) to review the experience of the Dark Target aerosol algorithm and its contribution to science and applications. The impact is demonstrated by the hundreds of scientific papers that have used the product for climate, air quality, model development and other applications, as well as the papers that borrowed facets of the algorithm for developing new algorithms. The DT product was the first to be used by operational air quality forecasters, and the first to be used in a global assimilation system. We have learned many "lessons" while struggling to develop, implement, validate, and maintain consistency of the DT algorithm on 20+ years of MODIS data, as well as adapting the algorithm to new sensors. Our 30+ year long list of triumphs and failures could help guide algorithm development for future missions. The 30-year effort has been instrumental in characterizing the global aerosol system, contributing to new science and new applications. The figure below shows AOD at 0.55 μm, retrieved using the latest DT aerosol algorithm on multiple sensors/platforms. Along the perimeter, globes represent AOD retrieved from: Advanced Baseline Imager (ABI) on NOAA's GOES-East and GOES-West, Advanced Himawari Imager (AHI) on Japan's Himawari-8, MODIS on NASA's Terra and Aqua, and the Visible Infrared Imaging Suite (VIIRS) on Suomi-NPP. The center globe is a (0.1° x 0.1° gridded) aggregate for 23:15 UTC ± 15 minutes on 03 December 2018. Applying the common DT algorithm to multiple sensors moves closer to our goal of creating a uniform global aerosol dataset.

Contributors: Lorraine A. Remer (JCET and Physics, UMBC); Robert C. Levy (NASA/GSFC, Code 613); Shana Mattoo (NASA/GSFC, Code 613, SSAI); and many members of the Dark Target aerosol retrieval team (past and present).

Reference: Remer, L. A.; R. C. Levy, S. Mattoo, D. Tanré, P. Gupta, Y. Shi, V. Sawyer, L. A. Munchak, Y. Zhou, M. Kim, C. Ichoku, F. Patadia, R.-R. Li, S. Gassó, R. G. Kleidman, B. N. Holben, 2020: The Dark Target Algorithm for Observing the Global Aerosol System: Past, Present, and Future. *Remote Sens.*, **12(18)**, 2900.
https://doi.org/10.3390/rs12182900.

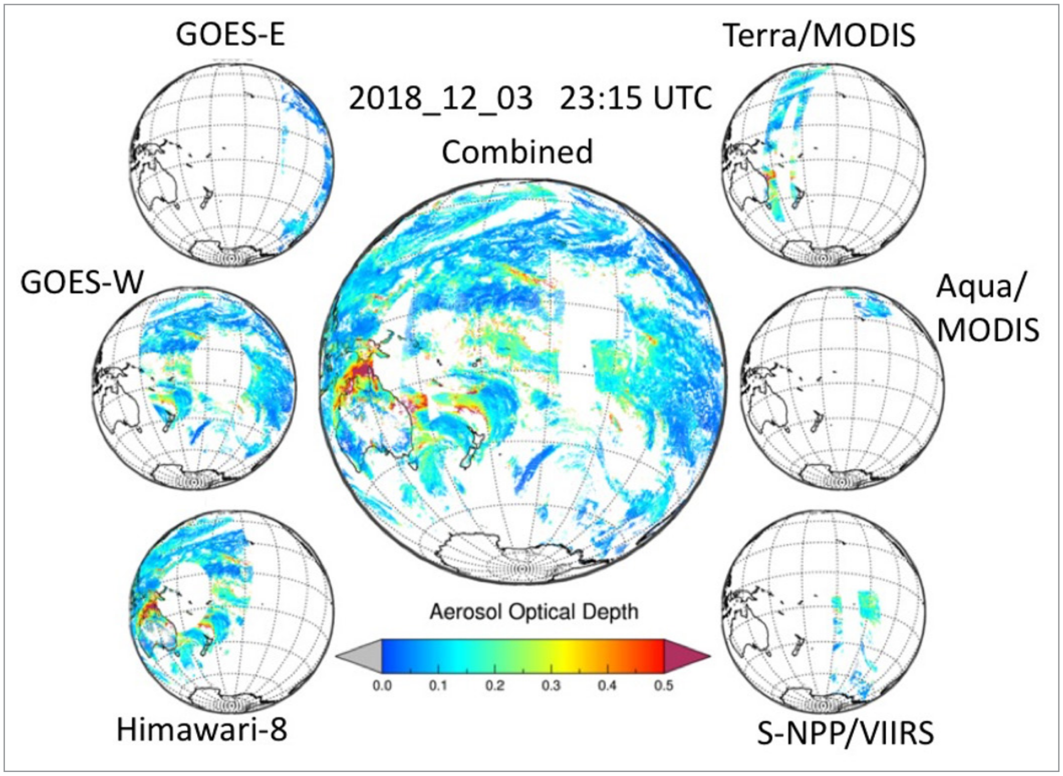

Figure 2.2.10: *During the 1990s, the Dark Target aerosol algorithm was developed for MODIS, today it is applied to a constellation of satellite sensors.*

2.2.11. Detecting Cloud Morphology in NASA MODIS Data with Deep Learning

A deep learning model was developed that combines domain expertise and machine learning to detect marine boundary layer cloud mesoscale morphology with high accuracy and efficiency as part of NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) program. The model's performance enables the study of cloud morphology at unprecedented scales.

Cloud morphology goes beyond individual pixels and two-point statistics and can be defined in terms of a few systematically occurring cloud patterns. Critical physical processes under pin cloud morphologies and understanding them is a key to reducing uncertainties in a range of important open questions related to low cloud feedback, low cloud modeling and aerosol-cloud interactions that future Decadal Survey missions will pursue. Being able to efficiently and accurately detect cloud morphology provides a solid framework for further study and analysis.

Contributors: Tianle Yuan (NASA/GSFC, Code 613, UMBC/JCET); Hua Song (NASA/GSFC, Code 613, SSAI); Robert Wood, Johannes Mohrmann, Kerry Meyer, Lazaros Oreopoulos (NASA/GSFC, Code 613); Steven Platnick (NASA/GSFC, Code 610).

Reference: Yuan, T., H. Song, R. Wood, J. Mohrmann, K. Meyer, L. Oreopoulos and S. Platnick, 2020: Applying Deep Learning to NASA MODIS Data to Create a Community Record of Marine Low Cloud Mesoscale Morphology. *Atmos. Meas. Tech.*, **13**, 6989-6997. https://doi.org/10.5194/amt-2020-61.

2.2.12. Aerosols Increase Deep Convective Cloud (DCC) Prevalence, But Saharan Dust May Dampen This Effect

After accounting for meteorological co-variability, aerosols (especially marine-generated aerosols associated with dimethyl sulfide, DMS) are associated with substantially increased North Atlantic deep convective cloud (DCC) prevalence. However, dust may dampen marine aerosol effects by scrubbing the atmosphere of ocean-emitted cloud active particle precursors.

DCCs strongly influence tropical and sub-tropical climate, precipitation, and atmospheric chemistry; aerosol impacts on DCC prevalence are critical for modeling these effects. Our observation-based, advanced statistical method accounts for strong meteorological co-variability, and quantifies the aerosol impacts over large spatial and temporal scales without requiring knowledge of the underlying microphysics or cloud-active aerosol concentrations, which are highly uncertain. Our approach, demonstrated in a region where corroborating measurements are relatively abundant, can be applied in future studies to better understand and quantify aerosol-cloud interactions in other regions and with other cloud types, thus contributing to a major focus area of the Decadal Survey.

Contributors: L. Zamora (NASA/GSFC, Code 613, ESSIC/UMD); R. Kahn (NASA/GSFC, Code 613).

Reference: Zamora, L. M., and R. A. Kahn, 2020: Saharan Dust Aerosols Change Deep Convective Cloud Prevalence, Possibly by Inhibiting Marine New Particle Formation. *J. Climate*, **33(21)**, 9467-9480. doi: 10.1175/jcli-d-20-0083.1.

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 OMI instrument U.S. science team come from this group. The laboratory also is a leader in the integration and execution of the NPP mission, and is also providing leadership for the former NPOESS, now the newly reorganized Joint Polar Satellite System (JPSS). This group has also developed a state-of-the-art chemistry-climate model in collaboration with the Goddard Modeling and Analysis Office (GMAO). This model has proved to be one of the best performers in a recent international chemistry-climate model evaluation for the stratosphere. Highlights of laboratory research activities carried out during the year are summarized. Dry deposition of NO_2 and SO_2 contributes excess nitrogen and sulfur to vegetation, soil, and water. Deposited nitrogen can cause eutrophication, leading to a loss of biodiversity. Deposited nitrogen and sulfur both have the potential to acidify soil and water, and may influence climate by perturbing the carbon uptake of an ecosystem. Measurements of NO_2 and SO_2 columns from the Ozone Monitoring Instrument (OMI) in combination with the GEOS-Chem chemical transport model have provided the first global budgets and estimates of spatial patterns of NO_2 and SO_2 dry deposition. These results have potential applications in a range of fields, from atmospheric chemistry to ecology. The upcoming NASA Earth venture mission TEMPO (Tropospheric Emissions: Monitoring of Pollution) will allow dry deposition to be quantified at very high spatial and temporal resolution.

2.3.1. Ceramic Industry is a Large Source of SO_2 Pollution in India

Observations from the Ozone Monitoring Instrument (OMI), onboard the NASA's Earth Observing System (EOS) Aura satellite, reveal a large SO_2 pollution "hotspot" over Morbi, Gujarat, India, attributed to the ceramic industries in the area. Morbi ceramic SO_2 emissions are ~5 times higher in 2017 compared to 2005. India's ceramic industry is an important source of anthropogenic SO_2 emissions that are not accounted for in common emissions inventories but can be estimated from satellite OMI SO_2 data. OMI observed a five-fold increase in India's ceramic industry SO_2 emissions from 2005 (~25 kt) to 2017 (~125 kt) over the Morbi region. These new OMI emissions estimates can be used to monitor the impact of policy regulations to close Morbi-based ceramic units that are running on coal gasifiers. These new satellite-derived estimates can be used to help make more informed decisions on impacts of SO_2 emissions from the ceramic industries, as well as from oil refineries and power plants, on environment and human health. For example, these new satellite estimates can be used to monitor the impact of policy regulations such as those recently (March 9, 2019) issued by Gujarat Pollution Control Board (GPCB) to close Morbi based ceramic units that are running on coal gasifiers following the National Green Tribunal order.

Contributors: S. K. Kharol (Environment and Climate Change Canada, U. Toronto); V. Fioletov, C. A. McLinden, M. W. Shephard, and C.E. Sioris (Environment and Climate Change Canada); C. Li (NASA/GSFC, Code 614, UMD); and N. A. Krotkov (NASA/GSFC, Code 614).

Reference: Kharol, S. K., V. Fioletov, C. A. McLinden, M. W. Shephard, C. E. Sioris, C. Li, and N. A. Krotkov, 2020: Ceramic industry at Morbi as a large source of SO_2 emissions in India. *Atmos. Environ.*, **223**, 117243.
https://doi.org/10.1016/j.atmosenv.2019.117243.

2.3.2. New Sensor for Stratospheric Aerosol Measurements–MASTAR

Aerosol climate effects arise from both tropospheric and stratospheric aerosols. While previous assessments of aerosol-climate effects have focused on the impact of anthropogenic aerosols in the troposphere (e.g., IPCC [2013]), the stratospheric component of aerosol profiles is also important. This component can have multiple sources (e.g., smaller volcanic eruptions, anthropogenic pollution, large wildfires), and leads to a global cooling that offsets some of the warming expected from increases in greenhouse gases. Including stratospheric aerosol effects in climate models is thus a priority for the Earth science community to improve climate model accuracy. Vertically resolved measurements of aerosol extinction with extensive spatial sampling are needed to supply the appropriate initial distribution of aerosol loading, composition, and size distribution for model calculations. The current OMPS Limb Profiler instrument has limited sensitivity to aerosols in the Southern Hemisphere because of its viewing geometry. A new Multi-Angle Stratospheric Aerosol Radiometer (MASTAR) instrument makes measurements in both forward and backward directions along the orbit track to provide a consistent sensitivity to aerosol abundance at all latitudes. Simultaneous cross-track measurements will supply valuable additional information about inhomogeneous events such as volcano eruption plumes. These measurements could also support near-real time requirements such as routing of air traffic to avoid the hazards posed by such plumes. The simplified optical design enables a 3U-Cubesat form factor. A NASA high-altitude balloon test flight is scheduled for the Fall 2020.

Contributors: Matthew DeLand (NASA/GSFC, Code 614, SSAI); Matthew Kowalewski (NASA/GSFC, Code 614, USRA); and Peter Colarco (NASA/GSFC, Code 614).

References: Kowalewski, M. G., M. T. DeLand, P. R. Colarco, L. Ramos-Izquierdo, W. Mamakos, and A. J. DiGregorio, 2020: Evolution of the Multi-Angle Stratospheric Radiometer. Presented at the American Meteorological Society 100th Annual Meeting, Boston, MA, 13-17 January 2020.

DeLand, M., P. Colarco, M. Kowalewski, L. Ramos-Izquierdo, and N. Gorkavyi, 2019: MASTAR: Limb scattering measurements of stratospheric aerosols. Presented at the 10th Atmospheric Limb Workshop, Greifswald, Germany, 4-7 June 2019.

Acknowledgements: Nick Gorkavyi (SSAI/Code 614) created the initial concept for this instrument. Luis Ramos-Izquierdo (Code 551) has led the optical design of MASTAR, and William Mamakos (Design Interface) has led the mechanical design and fabrication of MASTAR.

Figure 2.3.2: A new Multi-Angle Stratospheric Aerosol Radiometer (MASTAR) instrument makes measurements in both forward and backward directions along the orbit track to provide a consistent sensitivity to aerosol abundance at all latitudes. Simultaneous cross-track measurements will supply valuable additional information about inhomogeneous events such as volcano eruption plumes. A NASA high-altitude balloon test flight is scheduled for the Fall 2020.

2.3.3. Reductions in Nitrogen Dioxide Air Pollution Presumably Associated with Reductions in Fossil Fuel Use

Over the past several weeks, the Northeast U.S. has seen significant reductions in air pollution over its major metropolitan areas. These recent improvements in air quality have come at a high cost, as communities grapple with widespread lockdowns and shelter-in-place orders as a result of the spread of COVID-19. One air pollutant, nitrogen dioxide (NO_2), is primarily emitted from burning fossil fuels (diesel, gasoline, coal). If processed and interpreted carefully, NO_2 levels observed from space serve as an effective proxy for NO_2 levels at Earth's surface.

Satellite data of NO_2 from the Aura Ozone Monitoring Instrument (OMI) over the Northeast U.S. in March was collected to show the mean of the period from 2015 through 2019, and the mean for 2020. The images show satellite data of NO_2 from the Aura Ozone Monitoring Instrument (OMI) over the Northeast U.S. in March. The top image shows the mean of the period from 2015 through 2019, while the bottom image on the right shows the mean for 2020.

Though variations in weather from year to year cause variations in the monthly means for individual years, March 2020 shows the lowest values as compared to any of the monthly values for March during the OMI data record, which spans 2005 to present.

In fact, the data indicate that the NO_2 levels in March 2020 are about 30% lower on average across the region of the I-95 corridor from Washington, DC to Boston than when compared to the mean of 2015 to 2019. The images are free and publicly-available and may be downloaded.

The OMI NO_2 data will enable new scientific and applied research for air quality, climate studies, economics, and health professionals assessments.

Contributors: Joanna Joiner (NASA/GSFC, Code 614); Bryan Duncan (NASA/GSFC, Code 614); and GSFC Aura Ozone Monitoring Instrument (OMI) Team.

Website: https://airquality.gsfc.nasa.gov

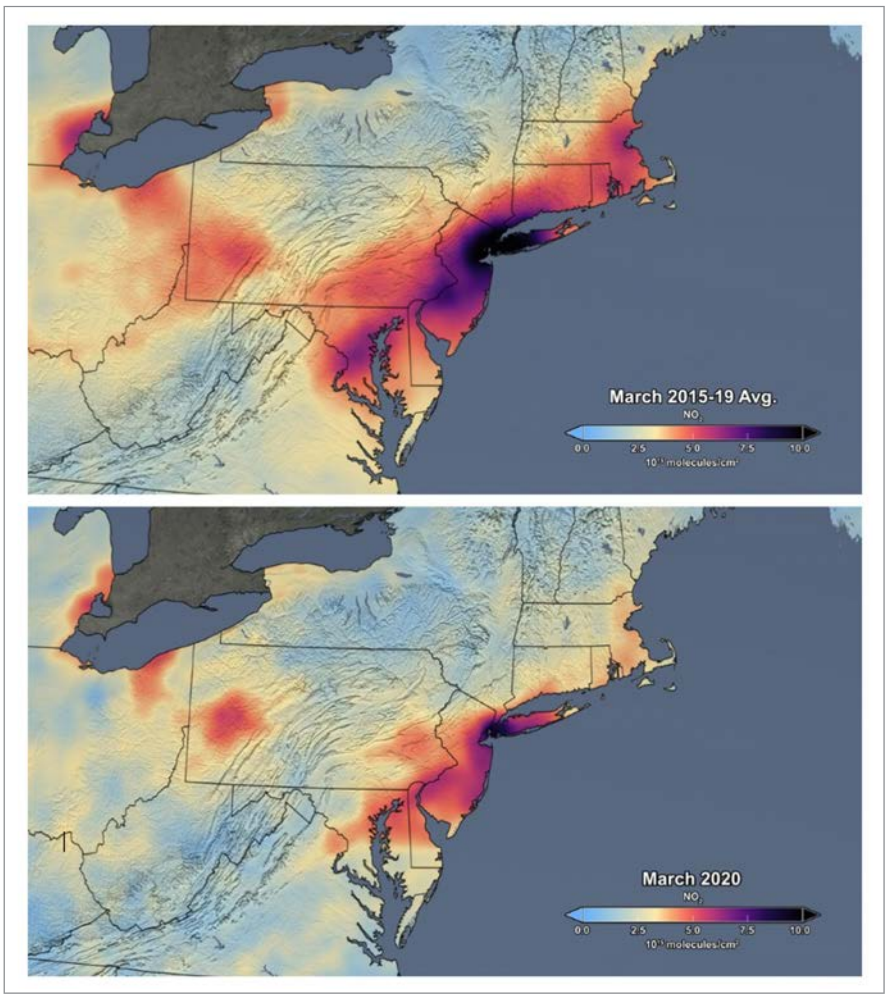

Figure 2.3.3: *Satellite data of NO_2 from the Aura Ozone Monitoring Instrument (OMI) over the Northeast U.S. in March was collected to show the mean of the period from 2015 through 2019, and the mean for 2020.*

2.3.4. Aura Ozone Monitoring Instrument (OMI) Reductions in Sulfur Dioxide & Nitrogen Dioxide Air Pollution over South Asia Associated with Efforts to Control the Spread of COVID-19

On March 24, 2020, Prime Minister Modi ordered a nationwide stay-at-home order for India's 1.3 billion citizens in an attempt to slow the spread of COVID-19.

The highest SO_2 levels are over eastern India and primarily associated with electricity generation; the coal burned has sulfur impurities. Independent estimates indicate that electricity generation for India was down about 10% and 25% in March and April 2020, respectively, as compared to March and April 2019. One exception is in southern India which could be related to increased thermal power generation that came online before the stay-at-home order. However, there was not a similar increase in NO_2, so possibly coal with higher sulfur content was used in 2020 relative to 2019 without a significant increase in coal consumed.

The OMI NO_2 and SO_2 data will enable scientific and applied research. The following are two examples:

- *Air Quality:* While air pollution is decreasing around the world due to lockdown orders, the U.S. government has relaxed pollution emission restrictions on some industrial sectors (e.g., power plants). Therefore, the changes in air pollution associated with the pandemic will serve as a natural experiment in how the atmosphere responds to changes in pollutant emissions from various sources.

- *Climate:* Several recent studies by the proposers have shown that NO_2 emissions inferred from satellite data serve as an effective proxy for co-emitted CO_2 emissions from cities and power plants. Therefore, researchers may be able to assess the impact of the pandemic on climate gas emissions.

Contributors: Can Li (NASA/GSFC, Code 614, UMD); Lok Lamsal (NASA/GSFC, Code 614, USRA); Yasuko Yoshida (NASA/GSFC, Code 614, SSAI); Joanna Joiner (NASA/GSFC, Code 614); Bryan Duncan (NASA/GSFC, Code 614); and GSFC Aura OMI Team.

Website: https://airquality.gsfc.nasa.gov. The images are free and publicly-available and may be downloaded.

2.3.5. Abrupt Decline in Tropospheric Nitrogen Dioxide over China After the Outbreak of COVID-19

Tropospheric nitrogen dioxide (NO_2) indicates economic activities, as NO_2 is primarily emitted from fossil fuel consumption. We evaluated the reduction in satellite measurements of NO_2 tropospheric vertical column densities (TVCD) before and after the Lunar New Year (LNY). The observed reduction in 2020 is ~20% lower than the typical holiday-related reduction. We related to this reduction to two of the

Chinese government's actions: the announcement of the first report in each province and the date of a province's lockdown. Both actions are associated with nearly the same magnitude of reductions.

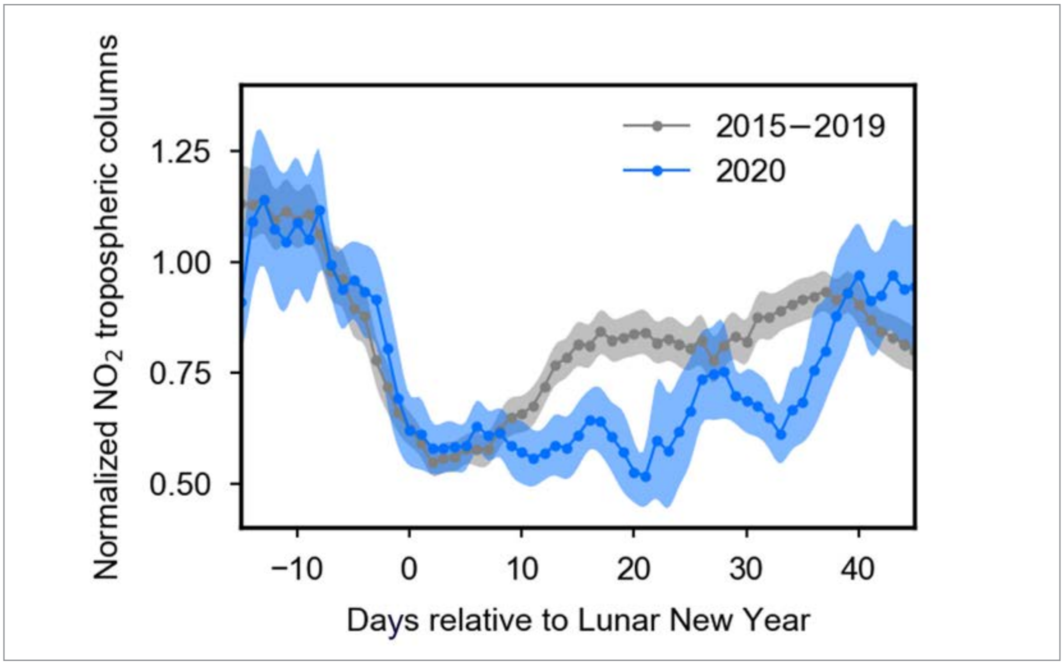

Figure 2.3.5: *Days relative to 1 lunar New Year*

We used two instruments (OMI and TROPOMI) to investigate the reductions in NO_2TVCDs over China after the outbreak of COVID-19. We used the Goddard Earth Observing System coupled to the NASA Global Modeling Initiative (GEOS-GMI) model simulations with constant emissions to rule out the possibility that the large NO_2TVCD decreases observed in 2020 are driven by changes in the meteorological conditions. We next explored how COVID-19 policy interventions are associated with reductions in NO_2TVCD. Our results suggest that the announcement of the first case was followed by a reduction in NO_2, with a further reduction following the actual lockdown. Examining this unusual period has provided a scenario of a society that has substantially lowered fossil fuel usage including mobility associated with these fuels.

Contributors: Fei Liu (NASA/GSFC, Code 614, USRA); Sarah A. Strode (NASA/GSFC, Code 614, USRA); Yasuko Yoshida (NASA/GSFC, Code 614, SSAI); Sungyeon Choi (NASA/GSFC, Code 614, SSAI); Lok N. Lamsal (NASA/GSFC, Code 614, USRA); Can Li (NASA/GSFC, Code 614, UMD); Nickolay A. Krotkov (NASA/GSFC, Code 614); Joanna Joiner (NASA/GSFC, Code 614); and others.

Reference: Liu, F., A. Page, S. A. Strode, Y. Yoshida, S. Choi, B. Zheng, L. N. Lamsal, C. Li, N. A. Krotkov, H. Eskes, R. van der A, P. Veefkind, P. F. Levelt, O. P. Hauser, J. Joiner, 2020: Abrupt decline in tropospheric nitrogen dioxide over China after the outbreak of COVID-19. *Sci. Adv.*, **6(28)**, eabc2992.
https://doi.org/10.1126/sciadv.abc2992.

2.3.6. New Generation Aura OMI NO_2 Standard Product

The new NASA NO_2 algorithm provides the first global satellite trace-gas retrieval with OMI-MODIS synergy accounting for surface reflectance anisotropy in cloud and NO_2 retrievals. It also provides improved spectral fitting procedures for NO_2 and oxygen dimer (for cloud) retrievals, retrievals based on high resolution field of view specific input information, and improved treatment over snow/ice surfaces.

The new product incorporates the most salient improvements and enhances the NO_2 data quality in several ways. The retrieval algorithm is based on a conceptually new, geometry-dependent surface Lambertian equivalent reflectivity (GLER) data that are available on an OMI pixel basis. The GLER product is calculated using the VLIDORT model, which uses as input high resolution bidirectional reflectance distribution function (BRDF) information from Aqua MODIS instruments over land and the wind-dependent Cox-Munk wave-facet slope distribution over water, the latter with contribution from the water-leaving radiance. The GLER combined with consistently retrieved oxygen dimer (O_2-O_2) absorption-based cloud fractions and pressures provide high-quality data inputs to the new NO_2 retrieval scheme.

The algorithms developed for OMI are being implemented for other similar past and currently operating satellite spectrometers, and serve as foundation for future instruments, including geostationary instruments, such as TEMPO. The algorithms currently applied for NO_2 retrievals can be applied to improve retrievals of other species such as formaldehyde, sulfur dioxide, and ozone.

Contributors: Lok Lamsal (NASA/GSFC, Code 614, USRA); Nickolay Krotkov (NASA/GSFC, Code 614); Alexander Vasilkov, Sergey Marchenko, Wenhan Qin, Eun-Su Yang, Zachary Fasnacht, Joanna Joiner (NASA/GSFC, Code 614); Sungyeon Choi, David Haffner, William H. Swartz, Bradford Fisher, and Eric Bucsela.

Reference: Lamsal, L. N., N. A. Krotkov, A. Vasilkov, S. Marchenko, W. Qin, E.-S Yang, Z. Fasnacht, J. Joiner, S. Choi, D. Haffner, W. H. Swartz, B. Fisher, J. Bucsela, 2020: OMI/Aura Nitrogen Dioxide Standard Product with Improved Surface and Cloud Treatments. *Atmos. Meas. Tech.*, submitted.

2.3.7. Satellite-based Reflectances Capture Large Fraction of Variability in Global Gross Primary Production (GPP) at Weekly Time Scales

Gross primary production (GPP), the amount of carbon dioxide (CO_2) that is assimilated by plants through photosynthesis, is one of the most variable and uncertain components of the global carbon cycle. Dynamic global vegetation models, driven by observed environmental changes, are used for global carbon budget assessments. Bench marking these models globally with data-driven GPP estimates is critical for understanding the land sink. A general conclusion of our work is that data quality and processing techniques play a substantial role and can affect interpretation of the satellite data and its effectiveness for estimating GPP.

Our results will be applicable to the upcoming NASA Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) mission and the geostationary Earth Ventures Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission as well as decadal survey Surface Biology and Geology (SBG) mission. In addition, our MODIS product may be continued (before launch of these new instruments) with the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument flying on NOAA operational satellites.

Contributors: Joanna Joiner (NASA/GSFC, Code 614) and Yasuko Yoshida (NASA/GSFC, Code 614, SSAI).

Reference: Joiner, J., and Y. Yasuko, 2020: Satellite-based reflectances capture large fraction of variability in global gross primary production (GPP) at weekly time scales. *Agric. For. Meteorol.*, **291** (108092), 10.1016/j.agrformet.2020.108092.

2.3.8. GEOS GMI-based Climatology of Diurnal Variability in Stratospheric Ozone to Reduce Uncertainty in Multi-Satellite Data Records

Observational studies of stratospheric ozone often involve data from multiple instruments measuring at different times of day. Ozone diurnal variability is largest in the mesosphere. The smaller stratospheric signal was often ignored because a full characterization of the diurnal cycle was not available. The primary goal of this work was to further our analysis of long-term trends in stratospheric ozone and our understanding of the chemical composition of the stratosphere. The climatology produced in this study can be used to support any number of instrument validation studies, modeling efforts, and long-term constituent analyses. The Clean Air Act Amendments of 1977, Public Law 95 95, mandates that NASA and other key agencies submit biennial reports to Congress and EPA on the state of our knowledge of the upper atmosphere, particularly the stratosphere.

Contributors: Stacey Frith (NASA/GSFC, Code 614, SSAI); P. K. Bhartia (NASA/GSFC, Code 610); Luke Oman (NASA/GFSC, Code 614); Natalya Kramarova (NASA/GFSC, Code 614); Richard McPeters (NASA/GFSC, Code 614); and Gordon Labow (NASA/GSFC, Code 614, SSAI).

Reference: Frith, S. M., P. K. Bhartia, L. D. Oman, N. A. Kramarova, R. D. McPeters, and G. J. Labow, 2020: Model-based climatology of diurnal variability in stratospheric ozone as a data analysis tool. *Atmos. Meas. Tech.*, **13**, 2733-2749, https://doi.org/10.5194/amt-13-2733-2020.

2.3.9. Unprecedented 2020 U.S. West Coast Wildfire Season: A View from DSCOVR-EPIC Using Near UV Observations

Unprecedented amounts of carbonaceous aerosols were produced by multiple fires over the U.S. West Coast in September 2020. Continental scale smoke plumes from these wildfires were observed from EPIC's unique vantage point [Marshak et al., 2018] multiple times a day, for about five weeks since the onset of the fires in early September. Observations were made by the Earth Polychromatic Imaging Camera (EPIC) onboard the Deep Space Climate Observatory at the Lagrangian (L1) point about one million miles away between the Earth and the Sun. The intensity of the 2020 Pacific Northwest wildfire season has no precedent in this century. It is only comparable to hemispheric scale megafires over thirty years ago such as the 1987 Yellowstone Park fires and the 1988 Great China Fire [Torres et al., 2011]. Although the 2020 U.S. West Coast wildfire season was significantly more intense than in recent years, it is consistent with an increasing trend in fire frequency and intensity in this region observed over the last few years. In addition to casualties and economic losses as well as deterioration of air quality in the vicinity of the fires, smoke plumes associated with fires in the Pacific Northwest have been found to reach the lower stratosphere [Torres et al., 2020] where the residence time of carbonaceous aerosol particles is significantly longer, likely resulting in climate effects. The figure below shows the spatial extent of multiple smoke plumes from fires in the U.S. West Coast on September 14 (20:44 UTC) in terms of the qualitative UV Aerosol Index (UVAI) calculated from measured 340 nm and 388 nm radiances. The figure shows the spread of the plumes that covered, at least partially, almost the entire contiguous United States, except for Florida. The plumes also reached northern Mexico, southern Canada and the Pacific Ocean. Double-digit UVAI values are associated with aerosol optical depth larger than about 4.0 for aerosol layers higher than 3 km above the surface.

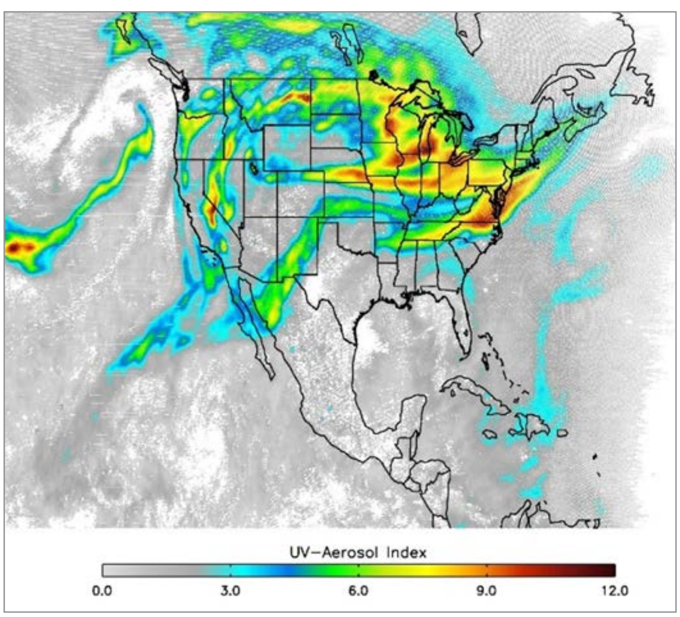

Figure 2.3.9: *Spatial extent of smoke plume on September 14, 2020 in terms of UV Aerosol Index.*

Contributors: Omar Torres (NASA/GSFC, Code 614) and Changwoo Ahn (NASA/GSFC, Code 614, SSAI).

References: Marshak, A., J. Herman, S .Adam, B. Karin, S.Carn, A. Cede, I. Geogdzhayev, D. Huang, L. Huang, Y. Knyazikhin, M. Kowalewski, N. Krotkov, A. Lyapustin, R. McPeters, K.G. Meyer, O. Torres,and Y. Yang, 2018: Earth Observations from DSCOVR EPIC Instrument. *Bull. Amer. Meteor. Soc.*, **99**, 1829-1850, doi:10.1175/BAMS-D-17-0223.1.

Torres, O., P. K. Bhartia, G. Taha, H. Jethva, S. Das, P Colarco et al., 2020: Stratospheric injection of massive smoke plume from Canadian boreal fires in 2017 as seen by DSCOVR-EPIC, CALIOP, and OMPS-LP observations. *J. Geophys. Res.: Atmos.*, **125**, e2020JD032579, https://doi.org/10.1029/2020JD032579.

Torres, O., and L. Remer, 2011: History of passive remote sensing of aerosol from space. *Aerosol Remote Sensing*, J. Lenoble, L. Remer and D. Tanré, Eds, Springer Heidelberg, New York, Dordrecht London. doi:10.1007/978-3-642-17725-5.

2.3.10. NDACC Stratospheric Transport Trends from 1994-2018 Show Hemispheric Asymmetry

The Age of Air (AoA), a measure of the average time air spends in the stratosphere, has been getting younger in the Southern Hemisphere relative to the Northern Hemisphere at a rate of 1 month/decade since 1994. The shorter satellite data records from the Aura MLS (Microwave Limb Sounder) are consistent with the NDACC findings. NDACC is the ground-based Network for the Detection of Atmospheric Composition Change.

Chemistry climate models predict that the stratospheric AoA will decrease this century due to increasing greenhouse gases, but the expected rate of change is small. It will be hard to detect because observed year-to-year variations in transport and composition are large. This analysis uses 24-yr records of long-lived stratospheric trace gases to tease out the small signal of transport change. The results were surprising, because the observed hemispheric asymmetry was opposite of what the models predicted. The models were also surprising because they revealed previously unrecognized large amplitude variability with a 5-7 year period. We show evidence that this variability is caused by interactions between the annual cycle of the circulation and the Quasi-biennial Oscillation in tropical wind regimes. The results from the analysis of this 24-yr long data record stand in opposition to the model predictions. We do not yet understand why.

Contributors: Susan Strahan (NASA/GSFC, Code 614); Dan Smale (NIWA); Anne Douglass and Luke Oman (NASA/GSFC, Code 614); and NDACC PIs from around the world, NASA/GSFC, USRA, et al.

Reference: Strahan, S. E., D. Smale, A. R. Douglass, T. Blumenstock, J. W. Hannigan, F. Hase, et al., 2020: Observed hemispheric asymmetry in stratospheric transport trends from 1994 to 2018. *Geophys. Res Lett.*, **47**, e2020GL088567, https://doi.org/10.1029/2020GL088567.

2.3.11. Inconsistencies in Sulfur Dioxide Emissions from the Canadian Oil Sands and Potential Implications

Emissions of sulfur dioxide (SO_2) reported to the Canadian inventory fell by a factor of two due to the introduction of additional emission control measures (flue gas scrubbing). However, the average SO_2 as seen by the Ozone Monitoring Instrument (OMI) on-board the NASA Aura satellite did not show any indication of the decline between these two periods. The reason for the discrepancy remains unknown. OMI-derived SO_2 emissions compared to those reported to the Canadian inventory agree with each other until 2013. Beginning in 2014, reported emissions are seen to decrease from the additional scrubbing of SO_2, but that has not been confirmed by OMI.

This study represents an important study whereby existing Aura OMI satellite observations can be used to verify reported emissions, and identify potential issues with current reporting procedures. If SO_2 emissions have not decreased as expected, the area of critical load exceedances of aquatic ecosystems downwind would increase by an estimated 150,000 km^2.

The next generation of instruments will enable more accurate emissions and improved detection limits. This includes the geostationary constellation of satellites: NASA's TEMPO (Tropospheric Emissions: monitoring of pollution) over North America, http://tempo.si.edu, over Europe (ESA's and Copernicus Sentinel 4 UVN) and East Asia the recently launched (Geostationary Environment Monitoring Spectrometer (GEMS) on board the GeoKOMPSAT satellite.

Contributors: C. McLinden (ECCC); Nick Krotkov (NASA/GSFC, Code 614); Can Li (NASA/GSFC, 614) and 11 others.

Reference: McLinden, C. A., C. L. F. Adams, V. Fioletov, D. Griffin, P. A. Makar, X. Zhao, A. Kovachik, N. Dickson, C. Brown, N. Krotkov, C. Li, N. Theys, P. Hedelt, and D. G. Loyola, 2020: Inconsistencies in sulphur dioxide emissions from the Canadian oil sands and potential implications. *Environ. Res. Lett.*, http://iopscience.iop.org/article/10.1088/1748-9326/abcbbb.

2.4. Wallops Field Support Office

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

2.4.1. Radar Retrievals of Extreme Rainfall During Hurricane Harvey

Hurricane rainfall is very difficult to retrieve using conventional radar estimates due to the unique collection of a large number of small and medium drop sizes, and the near saturated vertical profile of water and ice within the storm. Hurricane Harvey made landfall west of Houston, Texas, on August 25, 2017, and stalled over south central Texas for several days. Parts of the Houston area received more than 1 m of rainfall over a five-day period.

NASA Global Precipitation Measurement (GPM) assessed several common radar retrieval methods using WSR-88D radar data and Harris County Flood Warning System rain gauges during Hurricane Harvey. An attenuation-based method was developed and compared to three conventional retrievals that rely on measured radar variables as input. The attenuation-based retrieval provided very low biases of about 5%, while the other methods resulted in underestimation of the areal rainfall by about 50%, and suffered from significant blockage of the radar beam. The ability to accurately estimate rain areal rainfall during Hurricanes is extremely important for flood warnings and rescue. Conventional methods that utilize only the measured radar data are not effective in hurricanes due to the rather unusual combination of a large number of small and medium drops. This finding is extremely valuable for future now-casting of hurricane rainfall events and flood warning/prediction, which can save lives

Contributor: David B. Wolff (NASA/GSFC, Code 610.W, Wallops Flight Facility)

References: Wolff, D., B. et al., 2019: Assessing Dual-Polarization Radar Estimates of Extreme Rainfall during Hurricane Harvey. *J. Atmos. Oceanic Technol.*, **36**, 2501-2520.

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Bringi, V. N., et al., 2004: Evaluation of a New Polarimetrically Based ZR Relation. *J. Atmos. Oceanic Technol.*, **21**, 612-623.

Ryzhkov, A., et al., 2014: Potential Utilization of Specific Attenuation for Rainfall Estimation, Mitigation of Partial Beam Blockage, and Radar Networking. *J. Atmos. Oceanic Technol.*, **31**, 599-619.

Wang Y., and V. Chandrasekar, 2009: Algorithm for Estimation of the Specific Differential Phase. *J. Atmos. Oceanic Technol.*, **26**, 2565-2578.

3. Major Activities

3.1. Missions

3.1.1. Future Mission Studies

3.1.1.1. 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. TROPICS is expected to launch a pathfinder satellite (the qualification unit, launched via rideshare opportunity) in June 2021 and the full constellation of six satellites in early-to-mid 2022 pending selection of a launch provider. In the time prior to launch, activities are focused on development and evaluation of the rainfall retrieval algorithm and temperature and humidity products using simulated orbital data based on a high-resolution hurricane nature run. Post launch, TROPICS funds will 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.

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

3.1.2. Active Missions

3.1.2.1. Terra

Terra's 21-year ongoing mission, with a healthy suite of instrument and spacecraft systems, morning orbit, careful stewardship of spacecraft resources (fuel, batteries, data storage), and maintenance of instrument calibrations throughout mission life, continues to provide a unique, cost-efficient, and long-term climate and environmental record not available from any other satellite platform. The Terra team continued to improve the spatial sampling, quality, accessibility, and ease of use of Terra's data products in response to feedback from the scientific community. As an example, the Terra/Aster team has delivered over 90 million high-resolution topographic data sets from its global archive, highlighting both the accessibility and demand for this recently updated product. The data quality from the platform's sensors was critical to the success of demonstrating the validity of products from newer satellite and airborne sensors as well as providing supporting data to multiple field campaigns. Terra's land and atmosphere products are used by multiple federal and international agencies for volcanic ash monitoring, weather forecasting, forest fire monitoring, carbon management, and global crop assessment. The mission's long-term record was crucial in 2020 to help understand changes in atmospheric particulates (dust and haze) concentrations and other air pollutants in the US and globally as a result of pandemic mitigation efforts. Evaluations of how well state-of-the-art global climate models are representing observed changes rely on Terra measurements of sea-surface temperature and sea-ice boundary conditions. Terra's five instruments continue to play a key role in understanding fire location and intensity, burn areas and revegetation, and injection and transport of aerosols and carbon monoxide in the atmosphere, especially important for the unprecedented 2020 wildfires in Australia and the U.S. Terra is currently in extended operations. The 2020 Earth Science Senior Review endorsed the Terra mission for continued operations through 2023.

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

3.1.2.2. 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 2020 Earth Science Senior Review endorsed the Aqua mission for continued operations through at least 2023. The Senior Review Science Panel gave Aqua the highest possible scores for Science Merit, Relevance, and Data Quality. Furthermore, Aqua was only one of two missions (the other being Terra) to receive a utility score of "Very High" from the National Interests sub-panel.

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. Over the course of the mission, over 19,000 peer-reviewed publications have been published incorporating Aqua data, and the number of citations to these publications has exceeded 498,000. In 2019 alone, over 7,000 terabytes of Aqua data were distributed to users and over 2,000 peer-reviewed articles were published incorporating Aqua data and advancing the scientific understanding of the Earth system. Recent scientific achievements made possible with Aqua data include a 15-year global record of AIRS surface temperature data that matches well with major global surface temperature in situ data, the creation of a multi-year record with MODIS data revealing a consistent and slowly moderated concentration of chlorophyll a in low latitudes, and the estimation with CERES data of the vast amount of carbon dioxide emissions that are equivalent to the additional solar radiative heating in the event of a complete disappearance of Arctic sea ice during the sunlit portion of the year.

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

3.1.2.3. Aura

On July 15, 2004, the Aura spacecraft was launched. The suite of Aura measurements continues to provide comprehensive information essential to understanding how Earth's ozone layer, air quality, and radiation balance respond to changes in atmospheric composition caused by both human activities and natural phenomena, a key NASA Earth science objective. Data from the Microwave Limb Sounder (MLS) and Ozone Monitoring Instrument (OMI), the two remaining instruments of Aura's original four, include profiles and columns of stratospheric ozone and trace gases important to its evolution, columns of tropospheric trace gases central to air quality, and climate-relevant measurements, including cloud properties, water vapor, aerosols, and ozone.

Data from MLS and OMI, the workhorses of the Aura Mission since launch, complement those from other sensors in the Program of Record, including from instruments in the A-Train satellite constellation, and contribute to fulfilling two observing system priorities in the *2017 Decadal Survey* for Earth Science and Applications from Space: "Ozone and Trace Gases: Vertical profiles of ozone and trace gases (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution" and "Radiance Inter-calibration". Since the loss of the European Space Agency Envisat, most MLS measurements are unique and critical for answering fundamental questions about the causes of long-term changes in stratospheric composition. The unprecedented stability and characterization of the OMI radiometric calibration makes it a "gold standard" that can be used for evaluating other spaceborne ultraviolet (UV)/Visible sensors. In addition, this has enabled OMI's unanticipated use in the solar community for tracking solar spectral irradiance (SSI) variability from UV through visible wavelengths.

In boreal spring 2020, MLS data proved instrumental in monitoring the evolution of record loss of stratospheric ozone over the Arctic. In fact, the atmosphere dynamics and chemistry over the Arctic behaved more like those found over the Antarctic, the location of the "ozone hole" that began forming each austral spring in the 1980s because of man-made chlorofluorocarbons (CFCs). Scientific analyses of MLS data are ongoing to determine the cause(s) of this record loss over the Arctic. MLS data also featured prominently in scientific analyses of the impact of pollution on the upper troposphere and lower stratosphere of numerous record-setting wildfires around the world, especially in Australia and the western U.S., in late 2019 and 2020.

In 2020, OMI data of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) were instrumental in assessing the impact of the COVID-19 pandemic on air pollution and, by proxy, the world's economies. NO_2 is emitted when fossil fuels are burned so changes in its concentration serve as a proxy for changes in the use of fossil fuels, which drive the world's economies. OMI's long-term records crucially put the impact of the pandemic into historical perspective, including natural variations in NO_2 associated with weather. Several COVID-19 websites feature the OMI data: NASA Air Quality Observations from Space (https://airquality.gsfc.nasa.gov) and the NASA COVID-19 Dashboard (https://earthdata.nasa.gov/covid19/).

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).

3.1.2.4. DISCOVR

The Deep Space Climate Observatory (DSCOVR) is located near the Earth's L1 point where it monitors the solar wind and observes the Earth with two sensors: NISTAR (https://epic.gsfc.nasa.gov/about/nistar) and EPIC (https://epic.gsfc.nasa.gov). Earth sensors measure radiative fluxes of the entire sunlit Earth and key spectral characteristics at 10-15 km resolution. In 2019, DSCOVR gyros have deteriorated significantly over the years and NOAA has placed the spacecraft into Safe Hold on June 28, 2019. This temporarily terminated EPIC and NISTAR data generation. The DSCOVR mission returned to full operational service on March 2, 2020, after a nine month hiatus due to the deterioration of its gyros. The spacecraft—now relying only on its star tracker for attitude determination—is able to return Earth images at the same rate as before the event. DSCOVR has ample fuel and power generation capabilities to continue operating for at least through 2030—and probably longer. The ESD Senior Review panel agreed with this assessment and recommended continuing the mission for the next three years. The DSCOVR NISTAR and EPIC Science Team Meeting was held virtually October 6-8, 2020. The presentations are available at https://avdc.gsfc.nasa.gov/pub/DSCOVR/Science_Team_Meetings/Science_Team_Meeting_Oct_2020/. The meeting provided an opportunity to learn the status of EPIC and NISTAR, the status of recently released improved L2 data products, and the science results being achieved from the L1 point. The next STM will be held in the fall of 2021 (hopefully, in person).

For further information, please contact Alexander Marshak (alexander.marshak-1@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). Each GOES satellite carries 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 throughout the mission definition, design, development, testing, and post-launch data-analysis phases of each decade-long satellite series. Since February 2019, Robert Levy (613) is the Deputy to Flight Project Scientist, Joel McCorkel (618).

The current series is known as GOES-R, which includes four satellites (R, S, T and U). GOES-R was launched in November 2016 to become GOES-16, with GOES-S 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 and became NOAA's GOES-East in December 2017. GOES-17 was moved to 137.2°W and was declared operational as GOES-West in February 2019. The Earth-facing sensors on each satellite are the Advanced Baseline Imagers (ABI) and the Geostationary Lightning Mappers (GLM). The ABI provides persistent imagery in 16 visible to thermal infrared spectral channels at spatial resolutions of 0.5 to 2 km. The two ABIs provide consistent imagery from New Zealand to Western Africa every 10 minutes, over the Continental U.S. every 5 minutes, and mesoscale scans every 30 seconds. The GLM detects all forms of lightning during both day and night, characterizing the frequency, location and extent of lightning discharges to identify intensifying thunderstorms and tropical cyclone development. GOES-T is scheduled for launch in December 2021, and GOES-U in 2024.

Although the ABI on GOES-16 performed nominally at launch, the ABI on GOES-17 developed issues with its cooling system. Essentially, at particular times of the year and at particular time of day, the cooling system cannot sufficiently counteract heating by the Sun. This results in elevated temperatures which lead to noise and saturation in the thermal infrared detectors (channels 8-16), impacting the ability to accurately retrieve some essential meteorological parameters. In 2019, teams of experts from NOAA, NASA, the ABI vendor, and industry worked to diagnose and mitigate the problem, regaining >96% of the imaging capability by adjusting operational sensor parameters and modifying the ground system processing algorithms. During 2020, there was continued efforts for mitigation and improvement, such as fine tuning the algorithm for "predictive calibration" and a switch to "Flex Mode" during the period of most severe impact, and the team claims nearly 98% imaging capability. With the cooling problem on GOES-17 mostly mitigated by early March 2020, NOAA decommissioned GOES-15 (previous generation) as a backup GOES-West.

In addition to the major issue of the cooling system on GOES-17, 2020 has seen mitigation for smaller issues related to calibration (on both satellites) and image striping (on GOES-17). GLMs on both satellites are generally working nominally, however there are investigations into the small discrepancies between GLM-16 and GLM-17 for collocated scenes. Operational products (NOAA) from both GOES-16 and 17 are going through review, from beta to provisional to full validation. A "delta" evaluation for the products impacted by GOES-17 cooling was added.

Despite the COVID pandemic, the GOES-R project made progress on the future GOES satellites (T and U), including environmental testing GOES-T. GOES-T is scheduled for launch in December 2021 and began "mission rehearsal" in December 2020. In 2018, the ABI on GOES-T underwent redesign of its cooling system based on studies conducted after the GOES-17 anomaly. After being rebuilt, it is performing nominally. Hardware issues for the GLM on GOES-T have been resolved. GOES-U is scheduled to launch in 2024 and progress is being made accordingly.

The GOES program has been planning the observing system beyond the GOES-R series (i.e., 2030-2050), currently known as GEO-XO (Geostationary and Extended Orbits). The GEO-XO user requirements working group has made recommendations for a constellation approach including advanced sensors in GEO, new sensors in elliptical orbit (polar observing), and integration with commercial and international partners.

Finally, the GOES-R flight scientists (McCorkel and Levy) have helped further Code 610 science efforts. 2019 included a new ROSES proposal call focused on geostationary science, for which many 610 proposals were submitted and some were selected. They have participated in conferences and meetings, and advocate for NASA's development of advanced research and techniques using data from the GOES-R series and similar observations from international platforms.

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

3.1.2.6. SORCE

SORCE (Solar Radiation and Climate Experiment) ended its 17-year journey on February 25, 2020, to successfully extend the continuity of space-era solar irradiance measurements to 40 years. As part of its Phase-F activities, the project completed the final update on SORCE ATBDs (Algorithm Theoretical Basis Documents).

3.1.2.7. Suomi NPP

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

In 2019, Suomi NPP continued to meet its two primary goals: (1) providing satellite observations to NOAA for NOAA products and services, primarily weather forecasts, and (2) providing satellite observations to continue the Earth science data products created using data from the NASA Earth Observing System (EOS) satellites. A number of primary S-NPP products have now demonstrated their capabilities to provide critical continuity and near-real-time data, extending the EOS observation long time series, in monitoring changes in land, ocean and atmosphere as well as Earth's radiation budget. In 2019, researchers using VIIRS ocean color data unveil the most comprehensive view of the distribution of a zooplankton species to date, and alter our understanding of the behavior of this key zooplankton species, which will provide important resources to the fishery industry. OMPS total ozone data indicate that the 2019 ozone hole was the smallest on record since its discovery in 1982, thanks to the unusual warmer temperatures during the 2019 Antarctic spring. OMPS Limb Profiler data have further revealed details of the development of the Antarctic ozone hole in 3D. By adding the VIIRS observations, the NASA land products has now built a 50+ years long time series, about land surface vegetation resources and monitoring with implications on carbon storage, biodiversity, coastal zone impacts, and progress in cropland monitoring, which can provide early and local insights on crop yield and is critical for farmers, government agencies, and the financial markets. In addition, VIIRS data were used extensively to provide timely information during the disaster events such as the Alaska and California wildfires 2019. Suomi-NPP nighttime Black Marble products also help conduct damage assessments of power outage impacts in the Carolinas from Hurricane Dorian.

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

3.1.2.8. JPSS-1 (NOAA 20)

The Joint Polar Satellite System (JPSS) is the Nation's next generation polar-orbiting operational environmental satellite system. JPSS is a collaborative program between NOAA and its acquisition agent, NASA. JPSS was established in the President's FY 2011 budget request (February 2010) as the civilian successor to the restructured National Polar-orbiting Operational Environmental Satellite System (NPOESS). As the backbone of the global observing system, JPSS polar satellites circle the Earth from pole-to-pole and cross the equator about 14 times a day 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 2020, 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. In 2020, NASA Suomi NPP team has continued production and free and open distribution of data products. By adding these datasets to the EOS records, scientists are now able to build multi-satellite, multidecadal (>30 years) time series not only with high accuracy and long-term stability suitable for studies of Earth systems science, but also with additional enhancements. For example, Ozone Mapping and Profiler Suite (OMPS) total ozone data reveal the formation of a large and deep Antarctic ozone hole in 2020 (12th-largest in 40 years of satellite records), as a result of persistent cold temperatures and strong circumpolar winds in the Antarctic lower stratosphere in August-October 2020. Aided by the enhanced 3D ozone distribution mapping capability provided by OMPS Limb Profiler (LP), it is further found that the lower stratospheric ozone concentration between about 13 and 22 km dropped to extremely low levels in October 2020. Because of the Montreal Protocol and its amendments, the levels of ozone depleting substances had declined by about 16% since its peak in 2000, preventing the 2020 hole from being as large as it would have been under the same weather conditions 20 years ago.

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, instruments including the Advanced Technology Microwave Sounder (ATMS), the Cross-track Infrared Sounder (CrIS), the Ozone Mapping and Profiler Suite (OMPS), the Cloud and Earth Radiant Energy System (CERES), and the Visible Infrared Imaging Radiometer Suite (VIIRS). On May 30, 2019, NOAA declares the NOAA-20 instruments and spacecraft fully operational. All the instruments are in routine operational use by NOAA and NASA. 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 NOAA-20, VIIRS, CrIS, ATMS, and OMPS. In 2020, the JPSS-2 VIIRS and OMPS instruments were integrated on the JPSS-2 spacecraft and the ATMS and CrIS instruments will be integrated in early 2021. JPSS-2 environmental testing including thermal vacuum testing will be done in mid-2021.

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

3.1.3.9. 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. Data collected from past GPM field campaign instruments and from routine ground validation sites and national radar network products provides crucial information to improve GPM algorithms and validate precipitation estimates. Goddard GPM research efforts are focused on improvements to algorithms for measurement of light rain and snow and orographic precipitation, assessment of the hydrological impacts of precipitation, and improvements to merged multi-satellite precipitation estimates. Significant milestones and activities were met in 2020 including:

- Preparation and submittal of the 2020 Senior Review proposal for extended operations. Completion of the Senior Review led to HQ approval for continued operations for the next 3-6 years.

- Final preparation by algorithm teams for reprocessing of GPM products to Version 08 in 2021.

- A workshop on ground validation activities to identify key areas of research for utilizing validation data for the improvement of retrieval algorithms.

- Evaluation of Global Modeling and Assimilation Office rainfall analyses. The GMAO now routinely assimilates all-sky passive microwave observations from the GPM microwave imager and several other GPM constellation satellites, which is expected to improve model analyses of precipitation. GPM and the GMAO is evaluating these products to see if they eventually reach the quality of the multi-satellite estimates, and at such time the model analyses could become an important rainfall product for use by the research community.

- In October 2020, the science team met virtually due to COVID-19 to review recent science advancements, assess progress of GPM working groups, and review algorithm development and plans for the 2021 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.

3.1.2.10. mini-LHR

On December 5, 2019, the SpaceX Commercial Resupply Service (CRS) 19 launched from Cape Canaveral carrying the NASA/GSFC & LLNL (Lawrence Livermore

National Laboratory) CubeSat MiniCarb to the ISS. On January 31, 2020, MiniCARB was deployed through the Cygnus hatchway into a low-Earth orbit. Mini-Carb is a passive, occultation-viewing laser heterodyne radiometer designed to observe CH4, CO_2 and H_2O.

GSFC team: Emily Wilson (NASA/GSFC, Code 610), AJ DiGregorio (NASA/GSFC, Code 614, SSAI), Guru Ramu (NASA/GSFC, Code 699, Beacon), Jennifer Young (NASA/GSFC, Code 540, Genesis), Paul Cleveland (NASA/GSFC, Code 448, Energy Solutions), Melissa Floyd (NASA/GSFC, Code 699).

LLNL team: Bill Bruner, Vincent Riot, Lance Simms, Darryll Carter.

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

3.2. Project Scientists

Project Scientist	Project
Bryan Duncan	Aura
Steven Platnick	EOS
Scott Braun	GPM
James Gleason	JPSS
James Gleason	SNPP
Dong Wu	TSIS-1
Scott Braun	TROPICS
Robert Levy	GOES

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

Table 3.2.1: *610AT Project and Deputy Project Scientists*

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

Instrument Scientist/Manager/PI	Project/System	Recent Campaign
Ellsworth Welton	MPLNET	FIREX- McCall, Idaho.
Si-Chee Tsay	XBADGER	7 SEAS and RAJO MEGHA
Si-Chee Tsay/David Wolff	ACHIEVE	Wallops Facility Operations
David Wolff	NPOL, D3R, ICE-POP	Wallops Facility Operations
Gerald Heymsfield	HIWRAP	IMPACTS Planning
Thomas McGee	TROPOZ	NDACC and TROLIX 19
Robert Swap	Pandora	SCOAPE, ESA TROLIX 19 and ESA S5P Satellite Validation (PI A. Richter) TROLIX 19
Anne Thompson	SO3 Sondes/SHADOZ	Launches were ongoing at 13 stations
Paul Newman/Thomas Hanisco	ISAF	Atom
Steven Platnick	eMAS	FIREX AQ

Table 3.2.2: *610AT Validation (top) and Instrument (bottom) Scientists*

4. Field Campaigns

4.1. MPLNET

The Micro Pulse Lidar Network (MPLNET) project added several sites in Canada forming a subnet called MPLCAN. This new collaboration created four additional MPLNET sites in Eastern Canada in Toronto, London, Sherbrooke, and Halifax, and one in the Arctic circle in Eureka, NU. Toronto, London, and Sherbrooke sites are active, and Halifax and Eureka will be operational later this year. There are four more sites in planning phase: Houston, TX; Amazon, Brazil; Erlin, Taiwan; and NASA Ames.

Reprocessing of all MPLNET data in our new Version 3 (V3) system continued through the year, with delays due to COVID pushing the release of the new data set to 2021. The V3 effort included polarizing all lidars in the network to provide more information on particle shape, as well as more accurate ability to detect tenuous cloud and aerosol layers. In addition, an automated instrument diagnostic and alert system was created to track instrument health, data availability, and calibrations and provide automated email alerts when necessary. A multi-threaded processing system was created with detailed logging and online access that is capable of growing as the network does. New methods of calibrating the lidars were established. These combined efforts allow for easier management of the network and more up-to-date calibration histories. The V3 development also included the creation of new data products and enhancements to existing ones, notably the addition of cloud phase and thin cloud optical depths to the cloud product. Also, improved calibrations for the aerosol product along with addition of lunar AOD derived night time lidar profiles and aerosol depolarization ratios. Lastly, a new PBL product with continuous mixed layer height and estimates of the mixed layer AOD vs the total column AOD is included in V3.

New web service capabilities were add to the MPLNET website. Data download and dynamic plotting APIs were created to facilitate easier access to our data and ability to link our plots with external websites. MPLNET site metadata can now be download as CSV or KML files with various search and filter options available. Work is ongoing to harmonize our metadata with the WMO Integrated Global Observing System (WIGOS) metadata standard, and MPLNET sites are included in the WMO Observing Systems Capability Analysis and Review Tool (OSCAR) for large scale programmatic planning. For further information, please contact Ellsworth Welton (ellsworth.j.welton@nasa.gov).

4.2. SHADOZ

SHADOZ (Southern Hemisphere Additional Ozonesondes) launches are ongoing at 12 stations (see Figure 4.2.1) with re-activation of the San Cristóbal and Watukosek, Java, stations expected in 2021. Two important accomplishments were the September

2020 signing of a 5-year Interagency Agreement with the USAF to support weekly launches at Ascension and the November 2020 signing of a 5-year Agreement between NASA Headquarters and LAPAN, the Indonesian Space Agency, to resume Watukosek launches after a 7-year gap (Figure 4.2.1). In 2020, the SHADOZ website passed the 9000 mark of v6.0 SHADOZ ozone and radiosonde profiles pairs: https://tropo.gsfc.nasa.gov/shadoz. Users may download files with specified total ozone uncertainty. SHADOZ data have been used in two 2020 satellite product evaluation publications (Hubert et al., 2020; Wang et al., 2020). Due partly to COVID-19, SHADOZ data collection was ~20% lower than 2019 but all stations who reported in the past year have resumed operations. Figure 4.2.2 shows the Natal, Brazil, station overseen by GSFC (610 and 610W) at the resumption of sonde and Dobson measurements. PI A. Thompson visited the University of Costa Rica station at San Pedro 6-9 February where ISS/SAGE III collaborators tested two aerosol sondes in a dual launch.

SHADOZ analyses were presented at three conferences: AMS 100th Annual Meeting, Boston, 13 January; virtual NOAA GMAC, 17 July; virtual ISS/SAGE III Science Team Meeting, 20 October. Our principal scientific activities all focused on quality assurance efforts with SHADOZ partners from NOAA and NCAR as well as NDACC Swiss and Dutch Co-Is. The primary outcome is a new report on the Assessments of Standard Operating Procedures for OzoneSondes (ASOPOS) that will be published next year by WMO/Global Atmospheric Watch in collaboration with NDACC and the Intl. Ozone Commission; SHADOZ PI A. Thompson is a co-editor of the Report. The 11-member ASOPOS authors team met virtually three times and one time each with sonde manufacturers and reviewers. The new ASOPOS "Best Practices" report for global ozonesonde stations has dedicated chapters on uncertainties, metadata collection and sonde preparation, and data processing steps, including the need to reference final ozone profile data to a world standard UV instrument. The ASOPOS report references our post-2013 "drop-off" paper (Stauffer et al., 2020) that won a GSFC 610AT Group Award in 2020. The drop-off phenomenon, that affects 25-30% of sonde stations worldwide, refers to a sudden loss of 3-8% in the total column ozone amount when the sonde is referenced to the OMI or OMPS satellite or to co-located Dobson or Brewer spectrometers. R. Stauffer was elected Sonde Working Group Co-Chair at the Network for the Detection of Atmospheric Composition Change (ndacc.org) at its November 4-6 virtual Steering Committee Meeting. A. Thompson is serving as co-chair of NDACC.

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

References: Hubert, K.-P. Heue, J-C. Lambert, T. Verhoelst, M. Allaart, S. Compernolle, P. D. Cullis, A. Dehn, C. Félix, B. J. Johnson, A. Keppens, D. E. Kollonige, C. Lerot, D. Loyola, M. Mohamad, F. R. daSilva, A. Piters, H. Selkirk, A. M. Thompson, J. P. Veefkind, H. Vömel, J. C. Witte, and C. Zehner, 2020: TROPOMI tropospheric ozone column data: Geophysical assessment and comparison to ozonesondes, GOME-2B and OMI. *Atmos. Meas. Tech.*, amt-2020-123, in press.

Stauffer, R. M., A. M. Thompson, D. E. Kollonige, J. C. Witte, D. W. Tarasick, J. M. Davies, H. Vömel, G. A. Morris, R. Van Malderen, B. J. Johnson, R. R. Querel, H. B. Selkirk, R. Stübi, and H. G. J. Smit, 2020: A post-2013 drop-off in total ozone at third of global ozonesonde stations: ECC Instrument Artifacts? *Geophys. Res. Lett.*, **41**, e2019GL086791.doi: 10.1029/2019GL086791.

Wang, H. J. R., R. Damadeo, D. Flittner, N. Kramarova, G. Taha, S. Davis, A. M. Thompson, S. Strahan, Y. Wang, L. Froidevaux, D. Degenstein, A. Bourassa, W. Steinbrecht, K. Walker, R. Querel, T. Leblanc, S. Godin-Beekman, D. Hurst and E. Hall, 2020: Validation of SAGE III/ISS solar occultation ozone products with correlative satellite and ground based measurements. *J. Geophys. Res.*, **125**, e2020JD032430. doi: 10.1002/2020JD032430.

Figure 4.2.1: *Map of operating SHADOZ stations.*

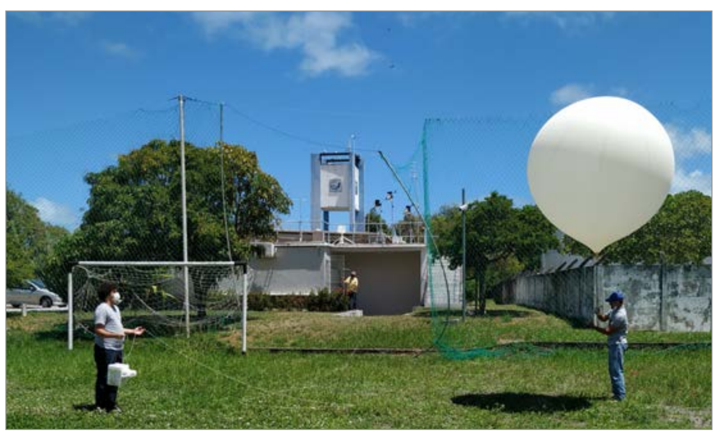

Figure 4.2.2 (left): *Mr. Christianus Dewanto of the Indonesian Space Agency (LAPAN) signing NASA Agreement for SHADOZ, Nov. 2020. Credit: LAPAN.* ***Figure 4.2.3 (right):*** *Resumption of ozonesonde launches in October 2020 by operators in Natal (Rio Negro, Brazil) following COVID-19 operations shutdown.*

4.3. eMAS/Oracles/FIREX-AQ

Following a reanalysis of the eMAS calibration for FIREX-AQ, the calibration of the eMAS solar bands for FIREX-AQ data was adjusted due to an issue found with solar irradiance data used. A revised Level-1B dataset was then generated. Also, two papers related to eMAS FIREX-AQ data were submitted for publication. One paper used eMAS imagery of the Williams Flats fire in support of showing the ability of the ER-2 based NAST-I instrument to remotely measure fire related carbon monoxide emissions and emission evolution. The other paper compared solar reflective band data for three ER-2 based instruments: eMAS, AirMSPI, and AVIRIS-C collected over a vicarious calibration site during FIREX-AQ. Results showed agreement of three instruments within the required 5% uncertainty across the visible bands, but on the order of 10% across the shortwave infrared bands, with the uncertainty mostly attributed to differences in the input solar spectral irradiance models, and surface reflectance datasets used.

For further information please contact: Thomas G. Arnold (tom.arnold@nasa.gov).

4.4. 7-SEAS

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. Many PBL profiles of thermodynamic parameters (e.g., T, P, RH, wind) and aerosol microphysics/optical properties (e.g., mass, number concentration, scattering and absorption) have been acquired in spring 2019 in the vicinity of Chiang Mai, Thailand, near the source regions of biomass-burning activities. Due to the COVID-19 pandemic, additional units of UAS from international participants (e.g., Taiwan, Thailand and Vietnam), planned to participate the spring IOPs in 2020 over northern 7-SEAS, were postponed. 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).

4.5. RAJO MEGHA

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 were planned, but postponed due to the COVID-19 pandemic, to deploy 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).

4.6. Pandora

The NASA Pandora Project supports the development, calibration and operation of a ground-based spectrometer instrument called the Pandora. The instrument measures the abundance of trace gases (O_3, NO_2, HCHO, and SO_2) in the Earth's atmosphere using differential absorption spectroscopy and a sun/sky/moon viewing spectrometer. The Pandora instrument is small, robust and inexpensive enough to be operated remotely around the globe.

The NASA Pandora Project is part of a larger collaboration between NASA and the European Space Agency, ESA. Together NASA and ESA operate the Pandonia Global Network (PGN) that provides calibration, operational support and data analysis from the global network of Pandora instruments. In 2020, the PGN supported 55 official instruments and an additional 80+ unofficial instruments.

Team Members: Tom Hanisco (NASA/GSFC, Code 614), Nader Abuhassan (NASA/GSFC, Code 614, JCET), Lena Shalaby (NASA/GSFC, Code 614, JCET), Alex Kotsakis (NASA/GSFC, Code 614, NPP), Fernando dos Santos (ESSIC), Michael Gray (NASA/GSFC, Code 614, SSAI), Stephen Smith (SciGlob), Joe Robinson (NASA/GSFC, Code 614, JCET).

Figure 4.6.1: *Global distribution of the Pandora instruments in the PGN. Data can be accessed at https://www.pandonia-global-network.org.*

Highlights from 2020:

- 2020 is marked by the COVID-19 closure. Lab calibrations at GSFC were allowed on a limited basis. Operations of the network proceeded with minimal impact by working at home and remote locations.

- 35 instruments were added to the PGN during 2020.

- Supported the COVID rapid response study of aircraft emissions at the Baltimore/Washington International Airport. Collaborators in this project are Prof. Jennifer Kaiser at Georgia Tech and Prof. Elena Lind at Virginia Tech.

- Supported the GEMS Map of Air Pollution (GMAP) campaign in Seosan, Korea. NASA provided instruments and technical support. Collaborators include Limseok Chang and Jhoon Kim at the Korean National Institute of Environmental Research (NIER).

- Installed Pan37 at Langley and Pan49 at Wallops.

- In 2020, the standard products for the Pandora instrument are column O_3 and column NO_2. In late 2020, we began implementing new calibrations and retrieval code from our ESA partners. Instruments are being calibrated to determine stray light within the spectrometers and operation is being converted to a sky-scan mode to permit MAX-DOAS retrievals of NO_2 and HCHO profiles. 14 instruments have been converted to measure profiles in 2020. This new profile capability will become standard in 2021.

Figure 4.6.2: *Michael and Steven installed Pan37 at Langley (Left) and Pan49 at Wallops.*

References: Ialongo, I., H. Virta, H. Eskes, J. Hovila and J. Douros: Comparison of TROPOMI/Sentinel-5 Precursor NO_2 observations with ground-based measurements in Helsinki, *Atmos. Meas. Tech.*, **13**, 205-218, https://doi.org/10.5194/amt-13-205-2020, 2020.

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Verhoelst, T., et al., 2020: Ground-based validation of the Copernicus Sentinel-5p TROPOMI NO_2 measurements with the NDACC ZSL-DOAS, MAX-DOAS and Pandonia global networks. *Atmos. Meas. Tech. Discuss.* [preprint], https://doi.org/10.5194/amt-2020-119, in review.

For further information please contact: Thomas Frost Hanisco (thomas.hanisco@nasa.gov).

4.7. SCOAPE

The Satellite Coastal & Oceanic Atmospheric Pollution Experiment (SCOAPE) project had the goal to scope out the feasibility of using NASA resources to monitor air pollution over areas of oil and natural gas extraction activities in the Gulf of Mexico.

The project was funded through a 2017 reimbursable agreement between NASA and the Department of Interior Bureau of Ocean Energy Management (BOEM), which is responsible for monitoring offshore air quality and to assessing the impact of air pollution from offshore sources on onshore air quality. The NASA Applied Sciences Program also provided funds to support civil servant participation in this project. The project was completed in fall 2020 and its findings are documented in two final reports:

- Duncan, B. N., 2020: NASA resources to monitor offshore and coastal air quality. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2020-046. 32 p.

- Thompson, A.M., 2020: Evaluation of NASA's remote-sensing capabilities in coastal environments. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2020-047. 33 p.

For further Information please contact Bryan Duncan (bryan.n.duncan@nasa.gov).

4.8. IMPACTS

Northeastern U.S. snowstorms impact large populations in major urban corridors, and cause major disruptions to transportation, commerce, and public safety. Snowfall within these storms is frequently organized in multi-scale banded structures that are poorly understood and poorly predicted by current numerical forecast models. Despite this, no major study of U.S. East Coast snowstorms has taken place in over 30 years. To address these needs, the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) Earth-Venture Suborbital-3 (EVS-3) field campaign is taking place during the winters of 2020, 2022, and 2023 to sample a range of East Coast snowstorms using airborne remote sensing and in situ instrumentation. The first campaign was conducted during January-February 2020. The ER-2 aircraft flew nine missions at high altitude with a suite of remote sensing instruments including cloud and precipitation radars, lidar, and passive microwave instruments. Goddard provided the HIWRAP, CRS, EXRAD, CPL, and CoSMIR instruments. The P-3 aircraft flew 10 missions within clouds to sample environmental and microphysical quantities using a turbulent air motion measurement system, microphysics probes, and a dropsonde system that sampled vertical profiles of temperature, humidity and winds. Several well-coordinated flights that sampled winter storms were conducted with both aircraft. The storms were further north in New York State and New England than anticipated due to an unusually warm winter, and one of the flights was for a Midwest snow storm. The airborne measurements were supplemented with ground-based measurements from rawinsondes launched from IMPACTS-funded mobile sounding systems and at National Weather Service stations, ground-based radars stationed over Long Island, and the New York State mesonet ground network. Science analysis is in progress with 2020 IMPACTS data sets that examine how the microphysical characteristics and likely growth mechanisms of snow particles vary across snowbands, and understanding the dynamical and thermodynamical mechanisms of snowband formation, organization and evolution.

For further information please contact Gerald Heymsfield (gerald.heymsfield@nasa.gov).

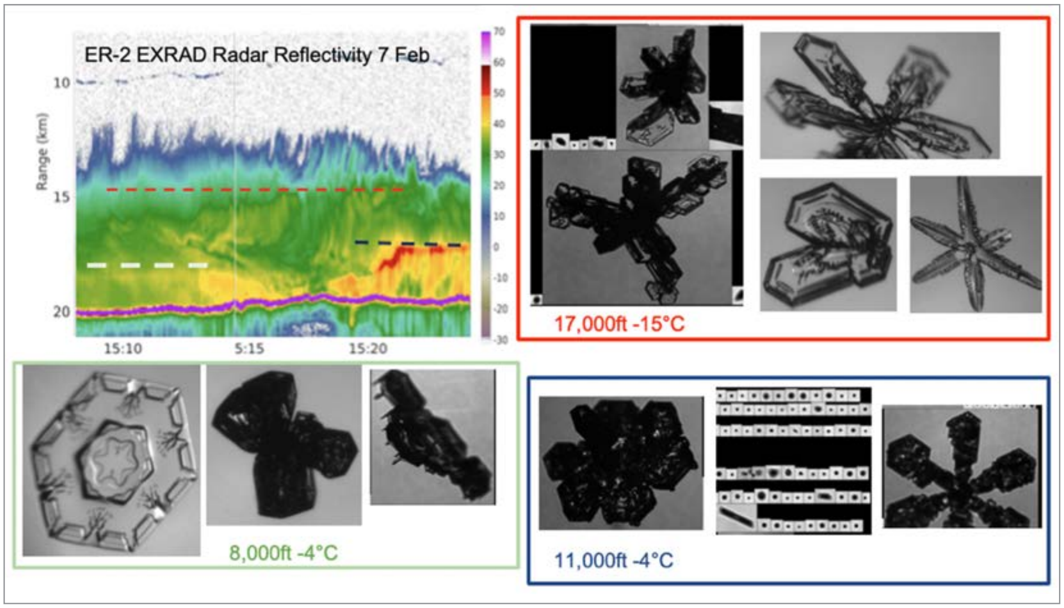


Figure 4.8.1: *Data collected during 7 February 2020 flight that an excellent snow case in central New York State. Image from EXRAD radar reflectivity data (upper left) and images from ice particle measurements from coordinated P-3 flight legs (dashed lines) in EXRAD image.*

5. Code 610 Web Development Team—Significant 610AT Accomplishments

5.1. Highlights

- Completed full redevelopment of the PUMAS website (http://pumas.gsfc.nasa.gov) in Drupal 8, a resource for educators that provides peer-reviewed practical examples demonstrating how math and science topics taught in K-12 classes can be used in everyday life
- In April, the team quickly responded to a request to add many new images and NO_2 data visualizations related to the COVID-19 pandemic. This included adding two news pages with Portuguese and Spanish translations to the air quality website (https://airquality.gsfc.nasa.gov)
- In May, the web team responded to a high priority request to be able to provide a Goddard site for Aerosol, Cloud, Convection and Precipitation (ACCP) study information. The team worked with the ACCP team to create a mission an interim subsection on the Earth labs website, https://earth.gsfc.nasa.gov/missions/accp, and quickly deployed it to production for use at the June 22nd quarterly forum. The URL now re-directs to a full ACCP website that was not developed by the team.

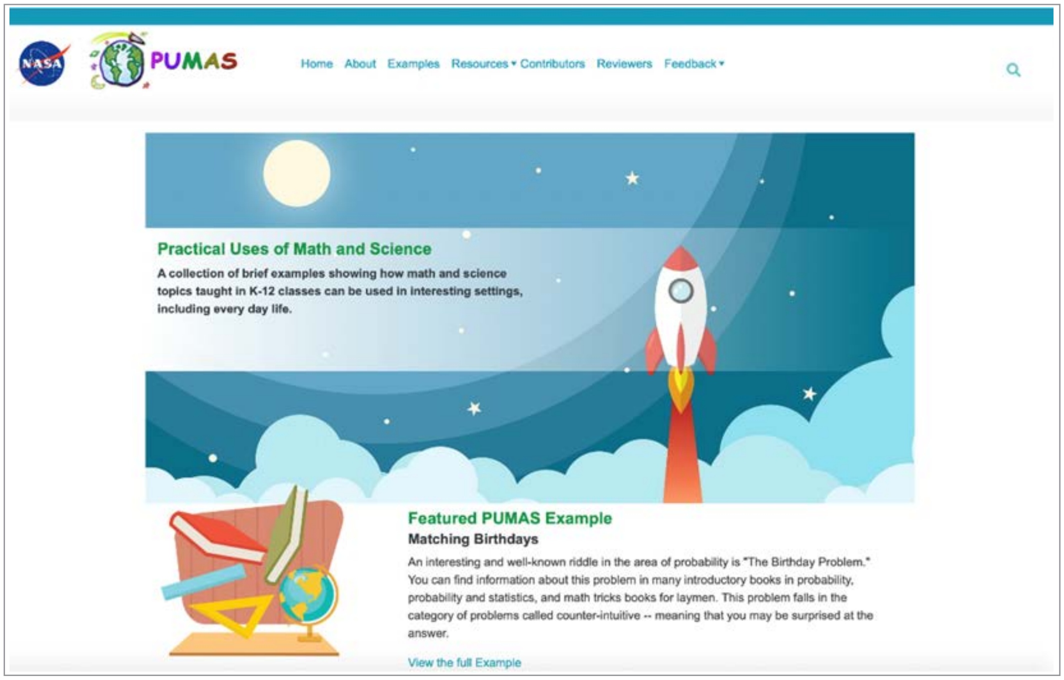
5.2. New Development

5.2.1. Earth Science Laboratories

Completed post-deployment activities and change order requests. Performed mobile testing and remediation. Redesigned the Science Highlights displays for all labs (e.g., https://earth.gsfc.nasa.gov/cryo/highlights). Created and tested limited-access curation roles on a per need basis. Performed innumerable content updates and provided training and helpdesk support for designated curators.

5.2.2. PUMAS

Full redevelopment in Drupal 8. Created new design mockups, graphics, and revised the information architecture. Wrote custom Drush content importers to migrate bulk contents from the legacy database into Drupal 8 where indicated. Designed and tested a robust content moderation administration workflow for examples to meet specifications provided by Ralph Kahn. Performed mobile review and remediation as needed. Performed 508 Compliance testing and remediation where feasible.



5.2.3. Air Quality

Added new NO_2 data visualizations and news for COVID-19 datasets. Provided ongoing helpdesk support, new homepage widget to automatically display recent data visualizations or videos, customized news sorting, and multilingual articles per request.

5.2.4. ACCP

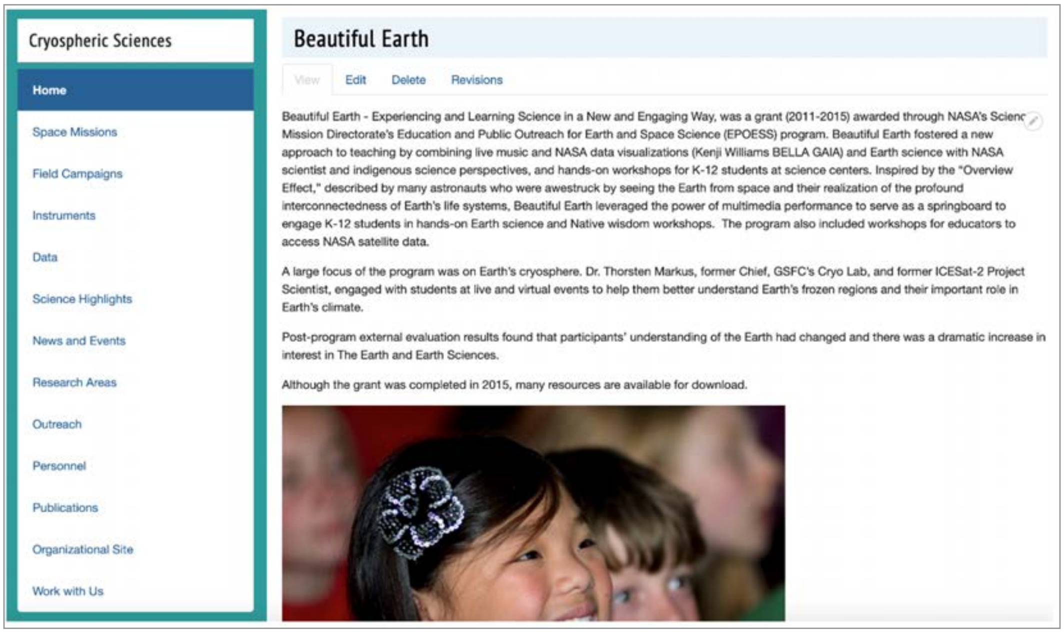
Created and customized a ‘Mission’ subsection for ACCP per request and provided ongoing helpdesk support. Provided guidance on 508 Compliance requirements as needed.

5.2.5. LIS

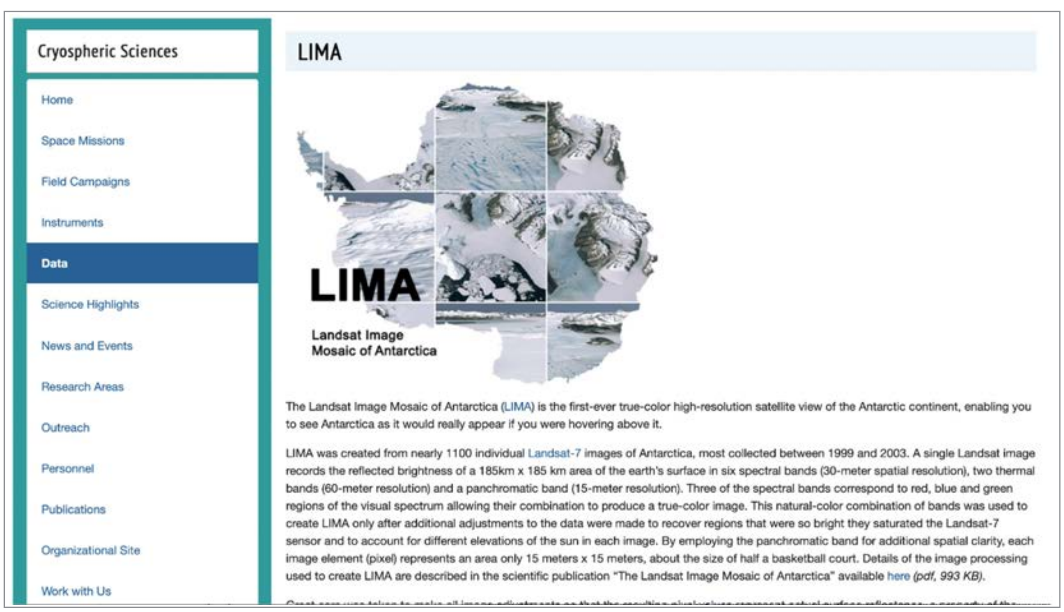
Created a base installation profile to speed up setup of new Drupal sites, using LIS as a reference. Performed R&D on various methodologies for sharing and reusing configuration across different Drupal websites. Customized our base Drupal 8 theme to better align with the preexisting look and feel for LIS. Migrated all basic contents from the Drupal 7 website to the new Drupal 8 version in development. Coordinated with stakeholders on Projects.

5.3. Decommissioned or Consolidated

- ARSET (consolidated to HQ Applied Sciences)
- Beautiful Earth (consolidated to 615 Lab Site)



- Forest (decommissioned)
- LIMA (consolidated to Code 615 lab site)



5.4. Maintenance, Security, Web Support

- *Service Desk:* Completed 574 ad hoc requests.
- *Repositories:* Made 741 commits to custom repositories.
- *Drupal:* Upgraded 1078 cores, modules, and libraries to new versions.
- *WordPress:* Updated 57 cores and plugins.
- *Laravel:* Performed three full rounds of software framework upgrades for EPIC.
- *Launchpad:* Completed eight additional integrations before halting further work due to unpatched software bugs on the Launchpad IdP application. Completed and tested Launchpad Integration solution for Drupal 8 websites.
- *Section 508 Compliance:* Tested various available testing tools to determine viability of testing. Performed testing and targeted remediation for the PUMAS Development site.
- *Bamboo Automation:* Tested and implemented new Continuous Integration methods for deploying updates for Drupal 8 websites using Bamboo, Bitbucket and Composer.
- *Security:* Responded to SOC + DCSEs regarding possible 'Denial of Service' vulnerability in WordPress. Responded to DCSEs regarding password complexity rules. Performed security upgrades to jQuery libraries on all websites. Responded to a 'Denial of Service' outage on EPIC due to spike in API usage. Responded to a SOC report of a WordPress XMLRC vulnerability. Responded to a DHS report regarding NOCA certs. Responded to a SOC report regarding lack of publicly accessible TLS cert on a non-public website. Investigated spam-related problems in JIRA. Investigated Symfony CVE vulnerabilities. Performed follow-up investigation into repercussions of SA-CORE-2020-012 update for Drupal. Responded to questions regarding a Privacy Threshold Analysis and possible Privacy Impact Assessment for PUMAS.
- *Server Rebuilds:* Requested and monitored software upgrades to PHP 7.2 on all servers. Coordinated with system administrators on required CentOS 6 upgrades. Requested upgrades to PHP 7.3 and to MySQL/MariaDB to meet current minimum standards. Tested a new 612 development server to help facilitate upgrades. Worked to migrate 610AT development websites to new server and performed further testing.
- *Team members:* Susannah Pearce, Nathan Perrin, Rashida Holland (GST)

For further information, please contact Ernest Pittarelli (ernest.j.pittarelli@nasa.gov).

6. Awards and Special Recognition

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

6.1. Agency Honor Awards

Honor Award	Recipient	Citation
EAM (Exceptional Achievement Medal)	John Yorks	For outstanding leadership in developing the CATS instrument and applying it to create and analyze key cloud and aerosol datasets.
Outstanding Leadership Medal	Anne Thompson	For exceptional sustained leadership of the international SHADOZ network providing critical data for understanding and interpreting NASA satellite ozone data.
Group Achievement Award	Operation Icebridge (David Wolff)	Recognizing their 10 years of successful campaigns in the polar regions to bridge ICESat and ICESat-2.
Exceptional Scientific Achievement Medal	Joanna Joiner	For outstanding sustained contributions using satellite observations to improve our understanding of the Earth's atmosphere and global carbon cycle.

6.2. Robert H. Goddard Awards

Atmospheric Research team members received the following individual awards.

Robert H. Goddard Award	Recipient	Citation
Legacy Award	Joel Susskind	For exceptional career-long contributions in developing infrared hyperspectral Earth atmospheric sounding products and their scientific analyses.

Robert H. Goddard Award	Recipient	Citation
Mentoring	Robert Swap	For exceptional mentoring of early career scientists and students in programmatically important Goddard Earth Science ground observations and data analysis.
Science	OMI COVID-19 response team (Zachary Fasnacht)	For exceptional effort to enable the space-based assessment of the impact of the COVID-19 pandemic on air pollution associated with fossil fuel use and, by proxy, the global economy.
Science	Peter Colarco	For exceptional contribution to Goddard's aerosol enterprise by leading unique initiatives for synergizing satellite, airborne and modeling capabilities.
Science	Tianle Yuan	For exceptional record in using machine learning algorithms and crowdsourcing techniques to enhance the value of NASA data for broad scientific and societal applications.
Science	Stephen Munchak	For exceptional contributions to advancing the state of the art in passive and active microwave measurements for retrieving cloud and precipitation properties.
Science	Robert Levy	For exceptional commitment in improved retrievals of aerosol properties from space that have facilitated countless scientific investigations.
Science	Can Li	For exceptional atmospheric composition retrievals development, and for promotion of NASA satellite data to the scientific and applied sciences communities.

6.3. External Awards and Recognition

The IMPACTS Team was awarded the Engineering Excellence Group Award by the Instrument Systems and Technology Division for "Outstanding dedication and support of the IMPACTS mission 2020 deployment". Members of the Mesoscale Atmospheric Processes Lab include: Gerald Heymsfield (612), Gerald McIntire (612/SGT), Charles Helms (612/USRA), and Peter Pantina (612/SSAI).

Ed Nowottnick (612) was accepted to serve as an Associate Editor for Atmospheric Measurement Techniques.

The Council of the American Meteorological Society, voted to award Jackson Tan (613/USRA) an Editor's Award for his reviews in the Journal of Hydrometeorology. The citation reads "For insightful and timely reviews of numerous manuscripts in the field of precipitation remote sensing."

The Hyper-Angular Rainbow Polarimeter (HARP) CubeSat has won the award as "Small Satellite Mission of the Year". The award is presented annually by the AIAA to the mission that has demonstrated a significant improvement in the capability of small satellites. The PI is Vanderlei Martins (613/UMBC) and more can be read about HARP at: https://www.nasa.gov/image-feature/goddard/2020/tiny-nasa-satellite-captures-first-image-of-clouds-and-aerosols.

Alexei Lyapustin (613) was selected as a 2020 Highly Cited Researcher by Web of Science. Recipients are recognized for their exceptional research influence, demonstrated by the production of multiple highly-cited papers that rank in the top 1% by citations for field and year in Web of Science. https://recognition.webofscience.com/awards/highly-cited/2020/.

Geoff Bland (610.W), pictured right, and the Aeropod Team (Ted Miles, Kay Rufty, Andy Henry, and Sallie Smith) were awarded the Federal Laboratories Consortium (FLC) Mid-Atlantic Region's Educational Institution and Federal Laboratory Partnership Award for 2020. This award recognizes the efforts of federal science and technology employees and educational institutions in the region who have collaboratively accomplished outstanding work in the process of transferring a technology. https://federallabs.org/regions/mid-atlantic/awards/mid-atlantic-regional-awards.

Geoff Bland

William K.M. Lau (GSFC Emeritus) was elected Fellow of the AAAS: "For profound contributions to the understanding of atmospheric low frequency oscillations, monsoon dynamics, aerosol-monsoon interaction, and hydroclimate variability and change, through original data analysis and modeling". https://www.aaas.org/news/aaas-announces-leading-scientists-elected-2020-fellows.

Joanna Joiner (614) and Alexei Lyapustin (613), were among a group of GSFC scientists recognized as 2020 Highly Cited Researchers by Clarivate Web of Science: "Recognizing the true pioneers in their fields over the last decade, demonstrated by the production of multiple highly-cited papers that rank in the top 1% by citations for field and year in the Web of Science." Access the recognition here: https://recognition.webofscience.com/awards/highly-cited/2020/.

Santiago Gassó (613/UMD) was reappointed as a member of the Scientific Steering Committee of the Surface Ocean–Lower Atmosphere Study (SOLAS) for another 3-year term. SOLAS is an international research initiative sponsored by Future Earth, iCACGP, and WRCP which aims to understand the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere. The committee facilitates networking, organizes workshops and capacity training for students and researchers in all matters regarding the processes to understand the atmosphere-ocean interface.

6.4. William Nordberg Award

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

Joanna Joiner (614) was announced as winner of the 2020 William Nordberg Memorial Award. Of particular note is Dr. Joiner's innovative application of inelastic rotational Raman scattering (the Ring Effect) in UV remote sensing to derive trace-gas vertical profiles and to measure the Solar Induced Fluorescence (SIF) of chlorophyll as a means of estimating gross primary production (GPP) over land surfaces. These contributions, and insights that have produced additional improvements to SO_2 retrieval, represent major advances in the field of UV remote sensing, having wide practical implications.

Dr. Joiner will be presented with the William Nordberg Memorial Award during a future Scientific Colloquium that will be scheduled once we are all back on Center.

Allow me to promptly echo Mark Clampin's congratulations to Joanna Joiner for her selection as the 2020 Nordberg Award recipient. As cited by Mark, Joanna's research is impactful and represents the high standards of the Nordberg Award. I look forward to returning to site for many reasons including the presentation of the Award to Joanna.

Jim Irons, Chief, Earth Sciences Division.

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
Ralph Kahn	2019
Joanna Joiner	2020

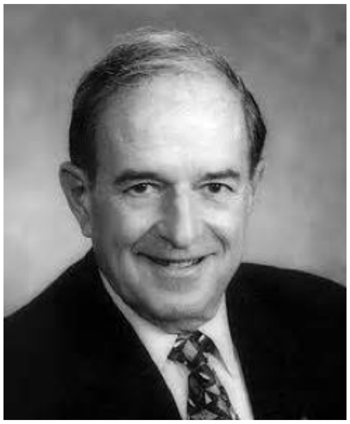
6.5. American Meteorological Society

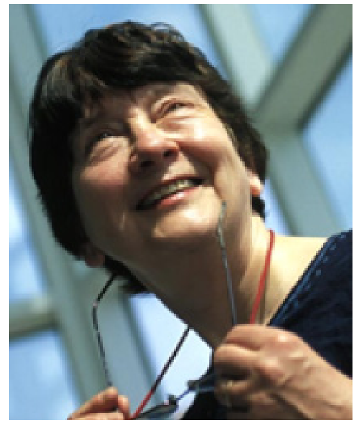
6.5.1. Special Award for the OMI Team

The International Ozone Monitoring Instrument (OMI) team was selected by the Council of the American Meteorological Society (AMS) for a Special Award this year. The citation reads "For providing a stellar example of international collaboration to produce novel satellite observations that have transformed atmospheric chemistry research, especially air quality and health applications." A large portion of the US OMI science team resides in the Atmospheric Chemistry and Dynamics Laboratory (Code 614). The formal presentation of the award occurred in conjunction with the 101st AMS Annual Meeting.

6.5.2. 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.

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

6.6. American Geophysical Union

6.6.1. Union Fellows

The Earth Sciences Division was thrilled to announce the election of Ralph Kahn as a 2020 Fellow.

Ralph Kahn

The following statements from AGU honors Ralph and other 2020 winners "The members of this year's class of Fellows have made exceptional contributions in our Earth and space sciences community through breakthrough, discovery, or innovation in their disciplines. Since 1962, AGU has elected fewer than 0.1% of members to join this prestigious group of individuals. Thanks to their dedication and sacrifice, AGU Fellows serve as global leaders and experts who have propelled our understanding of geosciences."

That describes Ralph perfectly and we are honored to have another AGU Fellow in the Division, statement by Jim Irons, Chief, Earth Sciences Division.

Ralph Kahn has dedicated most of his scientific career to studying aerosols and their major influences on air quality, aviation safety, cloud properties, and global climate. He has conducted pioneering work to greatly advance our understanding of aerosol interactions with their environment and to influence relevant research directions of GSFC, NASA, and the Earth science community as a whole. His work as MISR aerosol scientist has resulted in more than 15 years of global high quality aerosol observations from MISR. Ralph has validated detection algorithms of key sources of biomass burning aerosols, characterized their strength and injection heights into the atmosphere, and showed how to identify and track ash plumes from volcanic eruptions. These techniques are routinely used by aerosol scientists worldwide. Kahn has built an enduring legacy at GSFC for his outstanding ability to build collaborations between NASA mission teams. He has been instrumental in bringing together the aerosol teams of MISR, MODIS, CALIPSO, and OMI and urged the modeling and satellite communities to come together. Kahn's scientific influence is also evident in his prodigious publication record. Publication prowess is only one facet of his scientific reputation and standing. Kahn entertains a ceaseless stream of invitations for talks at scientific meetings and educational/research institutions. Ralph also cares deeply about community outreach and mentoring early-career scientists. His educational credentials include contributions to the Encyclopedia of Remote Sensing, lending frequently his expertise for Earth Observatory stories, and being a founder and editor of PUMAS, an on-line journal providing pre-college teachers peer-reviewed enrichment material (Outstanding Education Product Award in 1999). Many of his former mentees have moved on to successful positions in academia and government.

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

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	Ralph Kahn	2020

6.6.2. Yoram J. Kaufman Unselfish Cooperation in Research Award

The Atmospheric Sciences Section of the American Geophysical Union established the Yoram J. Kaufman Unselfish Cooperation in Research Award in 2009. This award is named in honor of Yoram J. Kaufman from NASA Goddard Space Flight Center, 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 to increase the public's understanding of why and how such advances affect their lives through formal and informal education as well as public outreach avenues. This year's activities included: continuing and establishing collaborative ventures and cooperative agreements; providing resources for lectures, classes, and seminars at educational institutions; and mentoring or academically-advising all levels of students. The following sections summarize many such activities.

7.2. University and K-12 Interactions

January 8-9, Brian Campbell (610W/GST) gave several presentations and led hands-on demonstrations with 58 11th and 12th grade Earth science students at the Kent Island High School in Stevensville, MD. During the presentations, Campbell focused on NASA Earth science, the ICESat-2 mission, climate change, the GLOBE Program and the NASA GLOBE Observer App. Several hands-on demonstrations focused on the interconnectedness of our oceans and atmosphere. Campbell will be returning the Kent Island Middle School in April to do a more in-depth look at the NASA GLOBE Observer with outdoor observations of tree height and land cover.

January 16, Brian Campbell (610W/GST) gave a presentation at the Inaugural Wallops Directors Colloquia Series at the NASA Wallops Flight Facility to approximately 100 people. Campbell's talk, entitled *Students, Teachers, Citizen Scientists, and NASA Observing the Height of our Planet One Tree at a Time with ICESat-2 and the GLOBE Program* focused on the collaboration between several NASA and GLOBE programs. Campbell was asked by Code 610W management to represent Wallops Earth science during the colloquium.

January 14, Dorian Janney (612/ADNET) gave a presentation entitled *From Satellites to Your Backyard* for the Rockville Science Center's Senior Center Science Tuesday's program. There were 42 seniors who attended this talk which focused on the Global Precipitation Measurement mission and showed participants how to use the GLOBE Observer app as citizen scientists to assist with data important to NASA scientists. https://www.rockvillesciencecenter.org/event/science-tuesday-from-satellites-to-your-backyard/

January 31, Anne Thompson (610) was the guest of Prof Maria Tzortziou (CCNY Departent of Earth and Atmospheric Sciences in New York) giving a seminar in the Environmental Science Series in the College of Sciences entitled: *SCOAPE (Satellite*

Coastal Oceanic and Atmospheric Pollution Experiment) May 2019: An Air Quality and Remote Sensing Cruise in the Gulf of Mexico. They followed a Q and A with discussion about CCNY-related coastal work on Long Island Sound. Among local participants was George Tselioudes (611).

February 3, Dorian Janney (612/ADNET) went to International School at Largo to meet with teachers from the school, their principal, and staff from the PGCPS main science office to discuss the potential of using the GLOBE program resources in their ongoing Environmental Education and Biomedical high school courses.

February 4, Dorian Janney (612/ADNET) organized and presented a webinar for the NASA Solar System Ambassador and Museum Alliance groups. There were three presentation which all focused on the Global Precipitation Measurement (GPM) mission. Dalia Kirschbaum (617) gave a presentation on the science and technology behind the mission, followed by Andrea Portier (612/SSAI) who discussed the real-world applications and end users of GPM data, and Janney finished the webinar by sharing the various resources that participants could use to share this information with others in their various audiences. We had 58 participants from all over the United States and its territories who attended. https://solarsystem1.jpl.nasa.gov/nnw/telecon-display.cfm?TeleconID=4142

February 6, Dorian Janney (612/ADNET) set up and ran the YLACES and GLOBE table for the Maryland Association for Environmental and Outdoor Education (MAEOE), conference. She gave a three-hour workshop entitled *Studying Climate Change with NASA EOS missions*. There were 16 adult participants who attended this workshop. https://maeoe.org/uploads/files/2020-MAEOE-Conference-Program.pdf

February 7, Dorian Janney (612/ADNET) and Todd Toth (160/ADNET) ran a three-hour workshop at the MAEOE conference, which focused on using the GLOBE Program in both formal and information education settings. There were 14 adult participants at this workshop. Dixon Butler was also present and he made some remarks during the introduction. https://maeoe.org/uploads/files/2020-MAEOE-Conference-Program.pdf

February 13, Dorian Janney (612/ADNET) met with the Environmental Club at the International School at Largo located in Largo, Maryland, to assist them with using the GLOBE Observer app and tools. She gave a presentation explaining how and why these data were useful to scientists and others, and showed the students the various places around the world were data was being collected. There were 19 high school students and one teacher at this event.

February 16, Dorian Janney (612/ADNET) assisted with the GSFC *Sunday Experiment*. She brought two high school students to share their hologram to the ~ 200 adults and children who participated in this event. She also had two virtual reality headsets that she shared with the participants to show them the inside of the ISS and the data from the GPM mission.

February 24-25, Santiago Gassó (613/UMD) was invited to speak at the University of Texas at El Paso, Geological Sciences Department. He gave a presentation entitled *Just Paying Attention: Finding Overlooked Volcanic Activity and Dust Storms with Satellite Sensors.* He met with several faculty members and students and advised on using satellite aerosol data. In addition, he was exposed to interesting, cutting edge applications using machine learning with webcams to detect various geophysical phenomena.

February 26-27, David Wolff and the GPM GV team (610.W) presented GPM activities at the Junior Achievement INSPIRE program, Ocean City, MD. JA INSPIRE is a coalition of educators and industry leaders, led by Junior Achievement of the Eastern Shore. This event (https://www.juniorachievement.org/web/ja-easternshore/ja-inspire) hosted nearly 3,000 8^{th} grade students from the Eastern Shore of Maryland.

February 11, Dorian Janney (612/ADNET) met with the GLOBE Education Working Group to discuss ongoing projects and potential activities for the upcoming year.

February 19, Dorian Janney (612/ADNET) assisted with Whetstone Elementary School's *Family STEM and Math Night* program in Montgomery Village, Maryland. She showed the family groups how to upload and use the GLOBE Observer app, and also described the science, technology, and applications for the GPM mission. There were ~ 200 participants at this school which serves students from primarily underserved communities.

February 21, Dorian Janney (612/ADNET) gave three presentations and engaged participants in hands-on activities at the Montgomery County Public School's Outdoor Environmental Education Center's annual *Astronomy Night* event. She shared information and activities to help the ~125 participants understand how and why NASA missions study Earth, and she also showed them how to use the GLOBE Observer app and tools.

February 26, Brian Campbell (610.W/GST) was notified by the American Geophysical Union (AGU) that his interview, as part of the AGU 100 Years Narrative Project, was selected by StoryCorps as a featured voice of NASA. The StoryCorps Archive comprises one of the largest born-digital collections of human voices, featuring conversations recorded across the United States and around the world. The full collection is housed at the American Folklife Center at the Library of Congress in Washington, D.C. Campbell's interview can be found at http://bit.ly/2T68gkX.

February 26-27, Brian Campbell (610.W/GST) led the planning and implementation of the NASA Wallops Earth Science presence at the 2020 Junior Achievement INSPIRES event, at the Roland E. Powell Convention Center in Ocean City, MD, for 3,000 8^{th}

graders and over 200 educators from six Maryland Eastern Shore counties. Representing NASA Wallops Earth Science for Operation IceBridge were Alexey Chibisov (615/SSAI), Kyle Krabill (615/SSAI), Serdar Manizade (615/SSAI), Matthew Linkswiler (615/SSAI), John Scott (615/SSAI), and Craig Swenson (615/SSAI). Representing GPM Ground Validation were Brandon Jameson (610.W/ASRC), Michael Hinton (610W/Orbital), and David Wolff (610.W). GPM was covered by Andrea Portier (612/SSAI) and Ozonesondes by Katherine Wolff (614/SSAI). Campbell represented ICESat-2, SMAP, and the GLOBE Program.

February 26, Dorian Janney (612/ADNET) served as a "Scientist Reviewer" for the Cedar Grove Science Fair in Clarksburg, Maryland. She interacted with 16 elementary school students and asked questions about their research, and handed out GPM droplets and stickers to thank them for their hard work.

February 27, Dorian Janney (612/ADNET) did a virtual presentation for the students in Pine Grove Middle School's Environmental Club to show 17 students how to download and use the GLOBE Observer app. They met virtually and went over the app and the four tools.

March 5, Robert Levy (613) gave a presentation to 8th grade students at the Charles E. Smith Jewish Day School in Rockville, Maryland. He described his position as a NASA aerosol scientist and demonstrated the principles of remote sensing.

March 10, Brian Campbell (610.W/GST) gave a talk to a group of 32 senior citizens from the Salisbury University Institute of Retired Persons (IRP) at the Salisbury University in Salisbury, Maryland. The talk was all about Campbell's work in NASA Earth Science, NASA Wallops, and Citizen Science for All with the NASA GLOBE Observer App. Several participants downloaded the NASA GLOBE Observer App during the talk.

March 17, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), and Christopher Shuman (615/UMBC) planned and implemented the *19th Trees Around the GLOBE Student Research Campaign* virtual webinar. During the webinar, Dr. Latha Baskaran (JPL) presented results from a study over the Angeles National Forest where she and her fellow scientists used canopy height derived from LiDAR, along with airborne imaging spectrometer data, to map forest habitats in a post-fire environment and Peder Nelson, from Oregon State University, highlighted the use of the Collect Earth online tool to view and analyze past GLOBE Program data for research purposes and was attended by 35 participants (including 11 students) from eight countries (United States, Argentina, France, Lithuania, Bulgaria, Saudi Arabia, India and Croatia).

Dorian Janney (612/ADNET) collated and shared a comprehensive listing of GPM's educational and outreach resources to support the *NASA Earth Day @ Home* efforts being undertaken by NASA HQ. The list contains 41 resources as well as numerous videos and animations which have been produced by the GPM E/PO team.

The GPM Precipitation Education website (https://gpm.nasa.gov/education) was shared as a resource on the new *NASA at Home* webpage (https://www.nasa.gov/nasa-at-home-for-kids- and-families), which was created by NASA Communications to share at-home activities for children and families home-schooling, due to the Coronavirus.

March 25, Brian Campbell (610.W/GST) gave a fun and engaging virtual talk to a class of fifteen students and one educator from Ossining High School in Ossining, New York. The interactive talk focused on the ICESat-2 mission, trees, and tree height. The talk culminated with demonstration of how students can compare existing tree height data from the GLOBE Program and the NASA GLOBE Observer Trees Tool to the ICESat-2 data, by investigating the canopy heights from specific 13m-diameter laser photon footprints on the ground.

March 24, Dorian Janney (612/ADNET) met with Kirsten Jackson of the Maryland State Department of Education, to provide suggestions and NASA education/outreach resources, including GPM, that could be used by schools and educators throughout Maryland.

March 30 and April 1, Brian Campbell (610.W/GST) gave two interactive, virtual talks to a group of 72 middle school students, four educators, and the district superintendent, from the Shumate Middle School in Gibraltar, Michigan and to 17 high school students and one educator from the Hawkins High School in Hawkins, Texas. Both talks focused on the ICESat-2 mission, trees, and tree height. The talk ended with demonstration of how students can compare existing tree height data from the GLOBE Program and the NASA *GLOBE Observer Trees Tool* to the ICESat-2 tree canopy height data on the online *Open Altimetry* tool.

April 4, Dorian Janney (612/ADNET) presented during the virtual National Environmental Science Teachers' Association (NESTA) *Share-A-Thon* for the National Science Teachers' Association (NSTA) annual conference. She shared resources that are available on the Global Precipitation Measurement (GPM) mission's *Precipitation Education* website. There were 98 participants in the virtual share-a-thon. https://www.nestanet.org/cms/content/conferences/nsta/shareathons.

April 4, Brian Campbell (610.W/GST) participated in the National Earth Science Teachers' Association's (NESTA) Virtual Conference. Campbell discussed how to compare existing GLOBE Program and NASA GLOBE Observer tree height to ICESat-2 tree canopy height data using the *Open Altimetry* online tool. There were 100 educators that were part of the virtual conference

April 8, Dorian Janney (612/ADNET) gave a virtual presentation about GPM to 10 students in Barrenquilla, Colombia and their teacher. The students then presented their GLOBE International Virtual Science Fair projects and she gave them feedback and asked questions.

April 14, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), and Christopher Shuman (615/UMBC) planned and implemented the 20th Trees Around the GLOBE Student Research Campaign virtual webinar, entitled, *GLOBE Student Tree Research Extravaganza: Students from around the GLOBE* share their amazing tree research. During the webinar, students and educators from Malta, Croatia, and the United States shared their tree research, tree culture, and personal tree stories. From tree heights, land cover, greenings, and phenology, they heard about research projects that showcase measurements methods, results, and applications. 67 participants, including 12 students, from 16 countries: Argentina, Brazil, Croatia, Czech Republic, Estonia, India, Ireland, Italy, Kyrgyz Republic, Malta, Nigeria, Poland, Saudi Arabia, Switzerland, Thailand, and the United States. https://youtu.be/BCR2HcCP2j8 Christopher Shuman created several slides; archived recording of the webinar and presentations can be viewed at: https://www.globe.gov/web/trees-around-the-globe/overview/webinars

April 17, Dorian Janney (612/ADNET) gave two virtual class presentations to the 7th grade at Moromoy Middle School in Harwich, Massachusetts. The presentations focused on the science and technology surrounding the Global Precipitation Measurement mission. There were two teachers and 86 students present for the presentations.

April 18, Dorian Janney (612/ADNET) gave a virtual presentation about the many resources that are available for Earth Day through *NASA at Home* to the S.I.C.E. (Students Involved with Technology and Engineering Club) in Barraquilla, Colombia. She focused on accessibility to fresh water using resources from the Global Precipitation Measurement mission's Precipitation Education website. There were 18 secondary level students and two teachers present.

April 22, Dorian Janney (612/ADNET) developed four lesson plans to share the real-world applications of the Global Precipitation Measurement mission. These lesson plans are aligned with *Next Generation Science Standards* for grades 3, 5, middle school, and high school, and use GPM-created resources to help students understand how and why NASA's Earth observations are used to improve life on Earth. https://gpm.nasa.gov/articles/celebrating-earth-day-gpm

April 22, Brian Campbell (610.W/GST) and Dorian Janney (612/ADNET) were invited to a special, virtual Earth Day session with students and educators from Shumate Middle School in Gibraltar, Michigan. During the session, all the participants watched the GLOBE Program's Earth Day message and selection of the top GLOBE student research projects for the International Virtual Science Symposium. During the current school year, both Campbell and Janney served as student research advisors to several student research teams, focusing research on precipitation, mosquitoes, clouds, and soil moisture at Shumate Middle School.

April 24, Dorian Janney (612/ADNET) was invited to participate in a special, virtual GLOBE 25th anniversary event with students and educators from Notre Dame School, Dominican Republic. She had a chance to hear many students present their International virtual Science Symposium projects

April 27, Dorian Janney (612/ADNET) gave a virtual class presentation to the 7th grade students at Monomoy Middle School in Harwich, Massachusetts. The presentations shared information about the science and technology behind the Global Precipitation Measurement mission. There were two teachers and 47 students present for the presentations, which was recorded and replayed for an additional 86 middle school students.

April 27, Brian Campbell (610.W/GST) learned that the team he mentored in the 2020 Real World Design Challenge took 4th in the world's international rankings. Campbell served as a mentor to Team 7 Shuttle from the Batasan Hills National High School in Quezon City, Philippines, by assisting the students with questions about NASA Earth science, satellite technology and engineering, specifically active and passive remote sensing. The competition received hundreds of entries from over 40 countries.

April 29, Brian Campbell (610.W/GST) created a virtual presentation for the Maryland STEMFest Program for Worcester County, Maryland, middle school students. During this year's virtual program entitled, *Technology: Past and Present*, Campbell highlighted past aerial photography and current satellite imagery of the major towns within Worcester County, Maryland. Campbell also focused on several satellite missions, including ICESat-2 and GPM, highlighting the advanced technology associated with each.

April 30, Dorian Janney (612/ADNET) gave two virtual class presentations to the 7th grade at Monomoy Middle School in Harwich, Massachusetts. The presentations focused on understanding Earth's freshwater resources and why knowing when it will rain is important for farmers. There were two teachers and 76 students present for the presentations. The presentation was recorded and was used with 86 additional 7th grade students the following day.

May 1, Brian Campbell (610.W/GST) developed a new activity, entitled *16 Years of Ice Loss from Greenland and Antarctica: A Comparison Activity* to accompany the release of a NASA feature story about the last 16 years of ice loss from the Greenland and Antarctic ice sheets. The activity can be found at https://go.nasa.gov/35krtDJ.

May 1, Dorian Janney (612/ADNET) gave a virtual presentation to 97 11th and 12th grade students and four teachers at Notre Dame High School in the Dominican Republic. She taught these students and their teachers about the Global Precipitation Measurement mission and the inequitable distribution of Earth's freshwater resources.

May 1, Dorian Janney (612/ADNET) gave the GLOBE Program Water Cooler talk, which focused on how to access and use the new applications focused lesson plans, *Water for Wheaties?* to the 20 participants who attended this virtual event.

May 5, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), and Christopher Shuman (615/UMBC) planned and implemented the 21st Trees Around the GLOBE Student Research Campaign virtual webinar entitled, *New Jersey Pinelands: The Nation's First National Preservation Area* attended by 26 participants from five countries; Argentina, Croatia, Switzerland, Poland, and the United States. During this webinar, John D. Moore, Executive Director for the Institute for Earth Observations at the Palmyra Cove Nature Park in Palmyra Cove, New Jersey, discussed how the Pineland National Reserve (PNR) is listed as the first National Reserve in the nation and its significance to research within the 1.1 million acres spanning portions of seven counties and all or part of 56 municipalities in New Jersey. Campbell led the webinar, focusing on campaign metrics and showcasing a NASA feature on 25 Years of Forest Dynamics and upcoming campaign events, Janney highlighted feature champion trees from the PNR and Shuman showcased a new *Tree in the News* feature, and discussed current and future changes to the landscape and climate in Minnesota.

May 6, Dorian Janney (612/ADNET) was invited by the Estherville Public Library in Iowa to give a virtual presentation on the science, technology, and applications of the Global Precipitation Measurement mission. There were 25 participants who attended virtually for this 45-minute presentation.

May 6, Brian Campbell (610.W/GST) gave a one-hour Facebook Live event for the 2020 Center of Science and Industry (COSI) Virtual Science Festival. Campbell's live discussion entitled, *The NASA ICESat-2 Mission: Talking Lasers, Tree Height, and the Open Altimetry Online Tool*, emphasized how the ATLAS instrument onboard ICESat-2 works, the importance of tree height, and how you can visualize the ICESat-2 data, for global locations, using the *Open Altimetry* online tool. The FB Live video (accessible at https://bit.ly/3dn6Idx) has been viewed approximately 2,000 times within the first 24-hours following the live event.

May 7, Dorian Janney (612/ADNET) gave a virtual presentation for the 184 7th grade students and two teachers at Monomoy Middle School in Massachusetts. She used several Global Precipitation Measurement resources to teach them about Earth's freshwater resources and helped them understand how these are used for agricultural purposes.

May 7, Dorian Janney (612/ADNET) helped to organize and presented during the GLOBE Mission Mosquito May webinar. There were 80 participants from 22 different states and 18 different countries. https://youtu.be/SqH6rQ9v8Zc

May 8, Dorian Janney (612/ADNET) gave a virtual presentation for the Center of Science and Industry's Virtual Science Festival. Her presentation focused on the Global Precipitation Measurement mission and how to access, download, and analyze IMERG data.

May 12, Dorian Janney (612/ADNET) reviewed 25 of the Prince George's County Public School's Science Fair projects and selected the winner for the NASA Earth Science Systems award.

May 14, Dorian Janney (612/ADNET) worked virtually with 189 7th grade students from the Monomoy Middle School in Massachusetts. She showed them how to analyze and interpret Global Precipitation IMERG data to use for real-world agricultural applications.

May 20, Brian Campbell's (610.W/GST) virtual video presentation, entitled, *Technology: Past and Present*, highlighting past aerial photography and current satellite imagery of the major towns within Worcester County, Maryland, for the Maryland STEMFest Program for Worcester County, Maryland was distributed to all 6th grade science and technology students in Worcester County, Maryland, as part of the learning from home efforts in Maryland.

June 2, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), and Christopher Shuman (615/UMBC) planned and implemented the 22nd Trees Around the GLOBE Student Research Campaign virtual webinar entitled, *GLOBE IVSS and Club de Ciencias Huechulafquen in Argentina: An overview of the combination of trees, land cover, water quality, and mosquito habitats* attended by 44 participants (including five students) from 17 countries (Argentina, Benin, Brazil, Croatia, Czech Republic, Estonia, India, Italy, Japan, Kenya, Madagascar, Poland, South Africa, Switzerland, Thailand, Trinidad and Tobago, and the United States). Campbell led the webinar, focusing on campaign metrics and showcasing a NASA feature on *40 Years of Forest Recovery of Mount St. Helens* and upcoming campaign events; Janney highlighted champion trees from Argentina; and Dr. Shuman showcased a *Tree in the News* feature discussing bacteria decimating olive trees in the southern Europe.

June 1, Dorian Janney (612/ADNET) gave a virtual presentation to the GLOBE Program Country Coordinators from Asia and the Pacific. She described both the GLOBE *Mission Mosquito* campaign and the Zika Education and Prevention Program, and showed many examples of these efforts in action.

June 1, the Climate & Radiation Laboratory (613) welcomed five undergraduate summer interns under the mentorship of Yuekui Yang (Daniel Kiv), Robert Levy (Travis Twigg), Tianle Yuan/UMBC (Siobhan Light), Mariel Friberg/NPP (Tyler Summers) and Yaping Zhou/UMBC (Anna Murphree). On June 29, an additional five high school interns will join the Laboratory under the mentorship of Hongbin Yu (Jerry Shen and Lillian Zhou), Yaping Zhou/UMBC (Jerry Xiong) and Jie Gong/USRA (Spandan Das and Bryan Li). The virtual summer internship program concluded on August 7.

June 3, Brian Campbell (610.W/GST) was interviewed and featured in a two-hour special expert panel in the Czech Republic. During this special panel feature *Countries in Need - Lessons from the Crisis with a Focus on Education: An Expert Live debate*, Campbell talked about NASA Earth Science themes and observations of Earth system science spheres, The GLOBE Program, NASA GLOBE Observer, and the need for citizen science as well as the need for student exploration of science at a young age. You can view the feature at https://bit.ly/3gMP5Gu, and Campbell's sections can be found at 32:36 - 36:30.

June 4, Dorian Janney (612/ADNET) organized and presented during the GLOBE *Mission Mosquito* monthly webinar. Dr. Assaf Anyamba (618/GSFC) gave the keynote presentation to describe the relationship between precipitation and mosquito-transmitted disease. Janney showed the 97 participants from around the country and around the world how to access and interpret Global Precipitation Measurement IMERG data.

June 11, Dorian Janney (612/ADNET) invited Global Precipitation Measurement mission Applications Lead Andrea Portier, and end-users Faisal Hossain, of University of Washington, and Iker Llabres, of Micro Insurance, to join the 189 7th grade students and their two science teachers at Monomoy Middle School for the students virtual presentation of their final projects related to the *Water for Wheaties?* lesson plan.

June 26, Dorian Janney (612/ADNET) was the featured presenter for Purdue University's College of Science *Inspiring Ideas for the Classroom on the Superheroes of Science* YouTube channel. She shared information about the Global Precipitation Measurement mission and shared the resources on *Precipitation Education* website: https://www.youtube.com/c/SuperheroesofScience.

July 8, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), and Christopher Shuman (615/UMBC) planned and implemented the twenty-third Trees Around the GLOBE Student Research Campaign virtual webinar entitled, *The Baobab Trees in South Africa as a Symbol of Life and Positivity: A historical link to humans through medicine and food*, which was attended by 24 participants from 11 countries (Argentina, Brazil, Costa Rica, Czech Republic, India, Italy, Kenya, Pakistan, South Africa, Switzerland, and the United States).

July 8, Dorian Janney (612/ADNET) and Todd Toth (160/ADNET) co-taught a class with NOAA Education Specialists, Bart Merrick and John McLaughlin, to 13 formal and informal educators who were taking *EXPLORING THE LOCAL ENVIRONMENT THROUGH FIELD STUDY* to 13 formal and informal educators. The purpose of this course was to provide educators with the information, resources, and experience necessary to engage students in meaningful watershed experiences as defined by the *Maryland Partnership for Children in Nature*. Janney and Toth focused on showing participants how and why to use the *GLOBE Observer* app and four associated tools.

July 9, Brian Campbell (610.W/GST) gave a virtual presentation to NASA Summer Camp Program directors, in collaboration with personnel at the NASA Langley Research Center. Campbell's talk, *GLOBE Trees, ICESat-2 and the GLOBE Make Every Tree Count Challenge* focused on showcasing how student camp participants can build a hand-held paper clinometer, take tree height measurements using the hand-held clinometers and the NASA GLOBE Observer *Citizen Science* app, and compare this data, for their camp locations, to the tree and canopy heights from ICESat-2.

July 9, Dorian Janney (612/ADNET) presented during the GLOBE Mission Mosquito webinar entitled *Meet Up and Do Science: Bzzz*. The purpose of this webinar was to walk participants through how to do larvae identification while using the GLOBE Observer *Mosquito Habitat Mapper* (MHM) tool. Janney shared the most recent metrics for the MHM tool as well as examples of students' International Virtual Science Symposium (IVSS) reports which used mosquito larvae identification as an essential aspect of their investigations. There were 90 participants from all over the United States as well as representing 11 different countries.

July 13-16, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), Christopher Shuman (615/UMBC), Holli Kohl (610/SSAI), Kristen Weaver (610/SSAI), Tassia Owens (618/SSAI), Heather Mortimer (610/SSAI), Trena Ferrell (610) and many other Earth Scientists attended and presented at the 25th Anniversary GLOBE Conference via the web.

July 22, Dorian Janney (612/ADNET) was an invited presenter during the *Infiniscope Virtual Universal Design for Learning* educator professional workshop. She presented on the new STEM career focused lesson plans released by the Global Precipitation Measurement (GPM) mission's Outreach team recently released. There were 106 educators from both formal and informal educational settings.

July 22, Dorian Janney (612/ADNET) wrote a blog for The GLOBE Program entitled *Using NASA and GLOBE Data to Predict Outbreaks of Disease*. This blog was viewed 121 times and shared via social media within a few days of its release.

Lisa Milani (612/UMD), as the chair of the AGU Precipitation students and early career scientists sub-committee, wrote an article on the July newsletter of the AGU Hydrology section Newsletter. https://higherlogicdownload.s3.amazonaws.com/AGU/31ea296c-2c70-4dad-92ef-c4681bc6a288/UploadedImages/HS_NL_JUL_2020_final.pdf

July 26-31, Dorian Janney (612/ADNET) attended the virtual Chesapeake Bay Foundation's "Teacher on the Estuary" course to network and interact with how formal and informal educators are learning about the Chesapeake Bay region. She gave a presentation on The GLOBE Program and shared how to download and use The GLOBE Observer app. There were 28 adults who attended this course.

August 4, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), and Christopher Shuman (615/UMBC) planned and implemented the twenty-fourth Trees Around the GLOBE Student Research Campaign virtual webinar entitled, *Preparing for Year 3 of the Trees Around the GLOBE Student Research Campaign, Student Research Scaffolding, and highlighting the use of online tools*. The webinar was attended by 32 participants from 8 countries (Argentina, Croatia, Estonia, India, Kenya, Switzerland, United States, and Uruguay).

August 10, Brian Campbell (610.W/GST) gave a virtual presentation to students and educators at the 2020 Estonia GLOBE Learning Expedition in Viljandi, Estonia. The presentation, *Let's Talk GLOBE Trees: Tree Height, Trees Around the GLOBE Student Research Campaign, NASA GLOBE Observer Trees Tool, and the NASA Missions*, was presented to 100+ students. The students will become part of the Trees Around the GLOBE Student Research Campaign and many will work on collaborative projects for the 2021 GLOBE International Virtual Student Symposium (IVSS).

August 13, Dorian Janney (612/ADNET) planned and presented during the GLOBE *Mission Mosquito* webinar which focused on sharing the work that was done this summer by the SEES virtual high school interns. There were 85 participants from all over the USA as well as from 11 other countries.

August 19, Dorian Janney (612/ADNET) was the featured speaker for the Maryland Association of Environmental and Outdoor Educators (MAEOE) *Lunch and Learn*. She gave a 45-minute presentation describing how NASA satellites, such as the Global Precipitation Measurement (GPM) mission have data which are used to help predict, monitor, and respond to mosquito-transmitted disease. She also shared information about The GLOBE Program and showed participants how to download and use the GLOBE Observer *Mosquito Habitat Mapper* tool. There were 26 participants from Maryland online during this virtual presentation

August 24, Dorian Janney (612/ADNET) created the *2020 Hurricane Season StoryMap* which was shared on various NASA platforms and posted on the Precipitation Education website.

September 4, Scott Braun (612) gave a virtual invited presentation to the Seth Anandaram Jaipuria College in Calcutta, India, entitled *Hurricane Hunting NASA Style*, describing how NASA uses satellite and airborne observations to collection valuable information of the environmental and in-storm conditions that impact storm formation and intensification. The audience consisted of students and faculty from a wide range of disciplines.

September 14, Dorian Janney (612/ADNET) was the first presenter for the North Carolina's museum of Science "Bugfest" weeklong virtual program. She presented on how data from NASA's Global Precipitation Measurement mission and several other NASA missions are being used to help predict, monitor, and respond to mosquito-transmitted disease. She also showed participants how to use the GLOBE Observer *Mosquito Habitat Mapper* tool. There were 53 participants during the virtual event, and the recording can be viewed on their website. https://youtu.be/7aSJoQjhJe0

September 15, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), and Christopher Shuman (615/UMBC) planned and implemented the 25th Trees Around the GLOBE Student Research Campaign virtual webinar entitled, *Kicking Off Year 3 With Tree Height Research Using Satellites and Ground-Based Instruments: The importance of tree and vegetation research to help us understand our changing planet*. The webinar was attended by 38 participants from ten countries, including Argentina, Chile, Colombia, Croatia, India, Kenya, Pakistan, Poland, Switzerland, and the United States. The featured speaker was Dr. Nancy Glenn, a tree and vegetation researcher at Boise State University and an ICESat-2 Early Adopter.

September 17, Brian Campbell (610.W/GST) presented at the *2020 GLOBE Student Investigations with NASA* webinar to 96 participants from around the globe. Campbell's presentation, entitled *Year 3 Theme for Student Research: Why are or why aren't there trees in my local environment?* focused on the Trees Around the GLOBE Student Research and how students, formal and informal educators and citizen scientists can be part of the campaign.

September 17, Dorian Janney (612/ADNET) helped to organize and present during the GLOBE *Mission Mosquito* monthly webinar. This webinar focused on *GLOBE Student Investigations with NASA* and enabled the 95 participants to learn about resources and events that can support GLOBE student research during the 2020-2021 school year and prepare students to enter the GLOBE International Virtual Science Symposium (IVSS).

September 18, Dorian Janney (612/ADNET) gave a virtual presentation to 96 high school students from James Bennett High School in Salisbury, Maryland. She told them about her career with NASA as an Education and Outreach Specialist, described the Global Precipitation Measurement mission's science and engineering objectives as well as the many ways in which NASA data are being used to improve life around the world, and she showed them how to download and use the GLOBE Observer app and four associated tools.

September 21, Dorian Janney (612/ADNET) and Brian Campbell (610.W/GST) attended at the latest GLOBE European Phenology Campaign webinar with a presentation entitled *The European Phenology Campaign Collaboration*. Campbell is leading the *Trees Around the GLOBE* Student Research Campaign and is focusing part of the campaign on a multi-campaign collaboration with the European Phenology campaign, which looks at Greenings—green up (budburst) and green down (color changes) of leaves from trees, shrubs, and other vegetation. The campaign will focus on doing coinciding measurement of greenings, tree height, and land cover.

October 13, Dorian Janney (612/ADNET) assisted with the planning and gave a presentation on how to develop a StoryMap for the monthly *Trees Around the GLOBE* webinar. There were 28 participants from the United States and many other GLOBE countries. https://arcg.is/nKraD

October 13, Dorian Janney (612/ADNET) gave an hour-long virtual presentation to 54 members of the Virginia Master Naturalist Association. The talk was entitled *What's the Buzz? From Satellites to Cell Phones to Fight Mosquitoes!* and it covered how and why NASA satellite data are used to reduce the threat of mosquito-transmitted disease, as well as how to use the GLOBE Observer *Mosquito Habitat Mapper* tool.

October 16, Dorian Janney (612/ADNET) gave a virtual presentation to members of the Potomac Valley Ski Club who expressed an interested in being part of a six-week pilot program to test out using the GLOBE Observer *Tree Height* tool with senior citizens to gauge their interest and some best practices for working with this group. They worked together to learn about how to download the GLOBE Observer app, how to use the *Tree Height* tool, and generated ideas for conducting their research over the next six weeks.

October 16, Santiago Gassó (613/UMD) gave an online presentation to AP Environmental Science students at the Blair High School in Montgomery County. The presentation was a general overview of aerosols (including some slides about their relationship with the current pandemic and importance of masks) and the NASA satellites used for observing aerosols. A Q&A session about what it is like to be a scientist followed the talk.

October 21, Anne Thompson (610) spent a virtual seminar day at Penn State University's Meteorology and Atmospheric Sciences Department. She had an hour session each with faculty and with graduate students before presenting a colloquium to 60 department members. For the students, Thompson described GSFC Earth sciences and encouraged students to apply for NASA Graduate Fellowships and to the NPP (Post-doc) program. Her colloquium was entitled, *The SCOAPE (Satellite Coastal* *and Oceanic Atmospheric Pollution Experiment) Cruise, May 2019: Gulf of Mexico Air Quality near Oil and Natural Gas Operations*.

October 21, Brian Campbell (610.W/GST) had a virtual discussion with two educators and 28 middle school students from Shumate Middle School in Gibraltar, Michigan. During the discussion, students talked about the remote sensing work they have started using the NASA AEROKATS and ROVER Education Network (AREN) kites, Aeropods, and Rovers and using online tools like *NASA WorldView* and *Open Altimetry* to visualize existing NASA data. Campbell discussed NASA Earth science remote sensing, laser altimetry with ICESat-2, and the importance of math and science in the real world. Students are focusing their research in their local environments and comparing their data with that from other school locations as part of the GLOBE Program.

October 21, Dorian Janney (ADNET/612) gave a virtual presentation to the 32 adult participants of the Arlington Public Schools—B-WET MWEE Training for Eco-Schools USA and The GLOBE Program. She described ways in which NASA Earth observing satellite data are being used to predict, monitor, and respond to mosquito-transmitted disease around the world, and showed participants how they could be involved by using the GLOBE Observer *Mosquito Habitat Mapper* tool.

October 28, Dorian Janney (612/ADNET) gave a virtual presentation for the GLOBE Nigeria's *Unique Mapper Network* to 27 participants. She presented about the opportunities for citizen science participation through use of the GLOBE Observer app and presented information on each of the four tools. She spent time describing how to use the *Mosquito Habitat Mapper* tool.

November 4, Dorian Janney (ADNET/612) was the guest presenter Girl Scout troop 33086 in Montgomery Village, MD. She delivered a virtual presentation to the 15 elementary school aged girls about the various things that NASA studies. These included NASA-related STEM career choices, and how the girls and their families could get involved at Citizen Scientists with the GLOBE Observer Program

November 5, Brian Campbell (610.W/GST) gave a Facebook Live presentation entitled, *The Importance of Ground-based and Space-based Tree Height to NASA, the GLOBE Program, and the Rest of the World* as part of the *Science with Nonnie* Facebook page. Created as an extracurricular resource, this Facebook page was designed to provide support to families now educating their children at home during the COVID-19 pandemic.

November 6, Dorian Janney (ADNET/612) assisted in the development of the NASA SMD Earth science virtual booth for the upcoming American Geophysical Union meeting. She is the lead for organizing the content for the "Opportunities" section, which will share the many opportunities which NASA offers for undergraduate, graduate, and early career professionals.

November 11, Brian Campbell (610.W/GST), Dorian Janney (612/ADNET), Christopher Shuman (615/UMBC), Peter Falcon (JPL), and Peder Nelson (OSU) planned and implemented the 27th Trees Around the GLOBE Student Research Campaign virtual webinar entitled *Trees: The Lungs of the Earth* that was attended live by 37 GLOBE participants from Colombia, Croatia, Czech Republic, Estonia, India, Israel, Pakistan, Philippines, Republic of Korea, and the United States. The featured presenter, Dr. Erika Podest (JPL), discussed the carbon cycle, the role of trees in it, and how scientists are using satellite data to better understand these processes. Dr. Shuman discussed timely articles about tree activities in Norway and Amazon deforestation through a visual time series, Janney continued her StoryMap features that can assist student in their Trees Campaign Research, and Peder Nelson highlighted the NASA Worldview and GLOBE Visualization System for analyzing carbon cycle data.

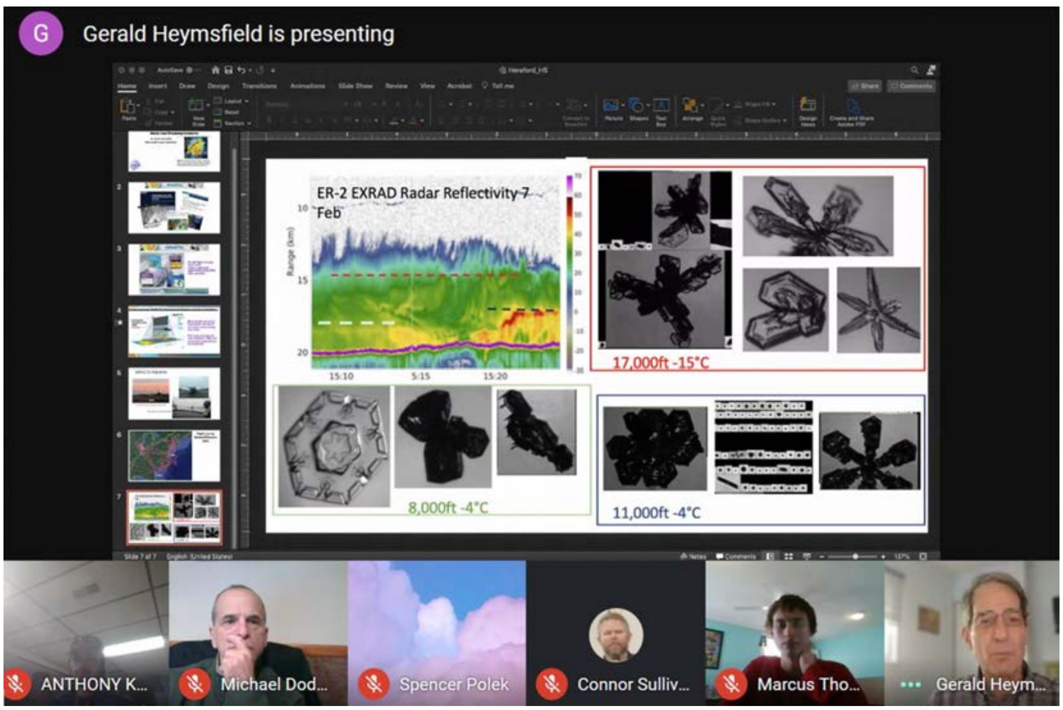


Figure 7.2: *Presentation to students in a science class at Hereford High School near Baltimore on the snow storms studied during the IMPACTS 2020 field deployment. Shown are teacher Michael Ododd-o and few of his students, and Gerald Heymsfield/612.*

November 17, Gerald Heymsfield (612) presented a talk on I*nvestigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS)* to 52 students from Hereford High School in Baltimore County. The students were particularly interested, since their school is in the Hereford Zone that gets higher amounts of snow compared to Baltimore City. The presentation was organized through Linda Sherman (200.C) from Wallops.

November 19, Dorian Janney (612/ADNET) presented during the GLOBE *Mission Mosquito* monthly webinar. She shared the recent metrics for the mosquito habitat mapper tool, and the webinar focused on showing participants how to access and analyze GLOBE Observer visualization data.

November 20, Dorian Janney (612/ADNET) participated in the GEO Health Small Group Lead meeting to begin work toward the GEO Health Community of Practice in support of EO4HEALTH Initiative. She is serving as the Lead for Food Security and Safety, which is focusing on environmental factors influencing food production and safety (vegetation, water, air, and diseases).

November 24, Brian Campbell (610.W/GST) gave a virtual presentation to 5th grade students in Dorchester County, Maryland. The presentation, entitled, *Looking at NASA Earth Science, the big picture, and the need for future scientists to continue the knowledge of our planet and how it responds to change*, was given to two 5th grade classrooms and four educators focusing on Earth science near or around the Delmarva Peninsula. Satellite imagery and the use of NASA Worldview to look at local vegetation indices was showcased, as well as NASA visualizations from ICESat-2, GPM, and sea level rise.

December 3 and December 9, Kristen Weaver (612/SSAI) gave virtual presentations (in Spanish) about how to use the GLOBE Observer *Eclipse* tool to take citizen science observations of clouds and air temperature during the upcoming total solar eclipse in South America. The audience for the first presentation was teachers and youth participating in a Camera Obscura competition organized by GLOBE Argentina and the U.S. Embassy in Argentina, and for the second, members of an adult astronomy club in San Martín de los Andes, Argentina. Attendance at each webinar was approximately 45 participants.

December 11, Brian Campbell (610.W/GST) gave the virtual keynote address for the 2021 Virtual Tournament for the Delaware Science Olympiad. The keynote address, *Looking at NASA Earth Science through STEM, the big picture, and the need for future scientists to continue the knowledge of our planet and how it responds to change* focused on STEM and the future of NASA Earth Observations and the need for our next generation of scientists, engineers, and explorers. The virtual keynote was seen by hundreds of students, educators, and parents.

NASA ARSET recently completed an advanced online training entitled *Remote Sensing for Mangroves in Support of the UN Sustainable Development Goals*. This three-part training series taught users how to use NASA satellite data to classify mangrove ecosystems and how this relates to Indicator 6.6.1 of UN Sustainable Development Goal 6. The training was delivered by Abigail Barenblitt (618/UMD) and Lola Fatoyinbo (618), in collaboration with ARSET team members Brock Blevins (614/SSAI), Selwyn Hudson-Odoi (614/UMBC), David Barbato (614/UMBC), Jonathan O'Brien (614/SSAI), and Ana Prados (614/UMBC). In attendance were 1,279 participants from 105 countries and 34 US states. Approximately 900 unique organizations were represented. You can learn more about the training and access the materials in both English and Spanish at: https://appliedsciences.nasa.gov/join-mission/training/english/remote-sensing-mangroves-support-un-sustainable-development-goals

Dorian Janney (612/ ADNET) wrote a blog for the GLOBE Program to share a wide variety of NASA opportunities that are available to students, teachers, and others on a wide continuum. https://science.nasa.gov/earth-science/agu2020/find-your-place

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 in 2020 among the various laboratories.

Table 7.3.1: Atmospheric Sciences Distinguished Lecture Series
Seminar series coordinator: Luke Oman

Date	Speaker	Title
February 26	Jennifer Francis	Use of In-situ Cloud Microphysical Observations for Quantifying Ice Cloud Microphysical Properties and Processes, and their Uncertainties

Table 7.3.2: Mesoscale Atmospheric Processes Laboratory

Date	Speaker	Title
January 22	Dr. Kaustav Chakravarty	Cloud Morphology and Microphysical characteristics of severe rainfall events over

Table 7.3.3: Climate and Radiation
Seminar series coordinators: January - June 2020 Hongbin Yu and Lauren M. Zamora (UMD) and June - December 2020, Yuekui Yang (613) and Jae N. lee (UMBC)

Date	Speaker	Title
January 8	Dong L. Wu Code 613, Goddard Space Flight Center and James L. Carr, Carr Astronautics Corporation	GEO-GEO and GEO-LEO Stereo 3D Winds

Date	Speaker	Title
January 22	Jie Gong Code 613, USRA	Can we learn vertical structure of ice microphysics from passive microwave observations?
February 5	Ryan Honeyager UCAR/NOAA Environmental Modeling Center	Challenges in Building Better Snowflake Models
February 19	Ryan Kramer Code 613, NPP/USRA	What makes radiative forcing different across climate models and what can observations teach us?
February 28	Daniel McCoy Institute for Climate & Atmospheric Science University of Leeds	Empirical constraints on midlatitude cloud feedbacks and aerosol-cloud interactions
March 4	Robert C. Levy Code 613, Goddard Space Flight Center	20 years of Terra-MODIS aerosol retrievals: the start of an aerosol climate data record
April 15	W. Reed Espinosa Code 613, Goddard Space Flight Center	Exploring the capabilities of synergistic passive and active remote sensing with a new aerosol retrieval testbed
April 22	Santiago Gassó Code 613, University of Maryland/ESSIC	What is it like participating in a ship transect from the South Atlantic to North Sea?
May 6	Daniel J. Miller Code 613, UMBC-JCET	An exploration of applications using retrievals of droplet size distribution dispersion from space
May 20	Charles K. Gatebe Code 613, USRA	Are BRDF measurements the work of art?
June 3	Timothy J. Canty Department of Atmospheric & Oceanic Science University of Maryland	Air quality modeling and data analysis: The intersection of research and policy
June 10	Aviad Levis Postdoctoral Fellow, Caltech Jet Propulsion Laboratory	Multi-view polarimetric scattering cloud tomography and retrieval of droplet size
June 24	Tyler Thorsen NASA/Langley Research Center	Uncertainty in observational estimates of the aerosol direct radiative effect and forcing
July 1	Maria Hakuba Colorado State University Jet Propulsion Laboratory	Earth's energy balance: Measurement, assessment, processes
August 5	Yolanda L. Shea NASA/Langley Research Center	Unraveling Climate Change Mysteries from Space: The testimony of Earth-reflected radiation

Date	Speaker	Title
August 19	Gregory Elsaesser Columbia University NASA Goddard Institute for Space Studies	Using Pixel-Level Satellite Data to Improve a Coarse-Resolution Global Climate Model
October 21	Belay Demoz Director, Joint Center for Earth Systems Technology/ University of Maryland, Baltimore County	Observing the Weather and Climate….
November 4	Nathan Arnold Code 610.1, Goddard Space Flight Center	The planetary boundary layer in the GEOS model: current parameterizations and future development
November 18	Bing Pu Dept. of Geography & Atmospheric Science University of Kansas	A record-breaking trans-Atlantic African dust plume associated with atmospheric circulation extremes in June
December 2	Kathleen Schiro Department of Environmental Sciences University of Virginia	Environmental controls on tropical mesoscale convective system precipitation intensity

Table 7.3.4: Atmospheric Chemistry and Dynamics

Date	Speaker	Title
January 9	Sunny Choi/SSAI and Anne Douglass/614	SPECIES Group AMS practice
January 23	Mark Schoeberl/ STC	The American Monsoon and Sunburn
January 30	Mark Gibson/Green Street Environmental	Seasonal cycles in Ocean primary productivity and relationship with Ultrafine particle observations on Sable Island.
February 6	Jonathan Hickman/GISS	Natural and anthropogenic influences on nitrogen trace gas dynamics in Sub-Saharan Africa: views from space and from the ground.
February 13	614 Group	"614 Efforts to Constrain Tropospheric OH"?
February 27	Anne Marie Carlton?UC-Irvin	The clear sky bias in particle composition and size.
March 26	Paul Newman/610	The 2020 Arctic Ozone Depletion
April 2	Junhua Liu/GESTAR	Quantifying the stratospheric contribution to tropospheric ozone radiative forcing
April 9	614 Group/Open Session	Response of the Earth System to the COVID-19 Pandemic Control Requirements

Date	Speaker	Title
April 16	Olga Tweedy/GESTAR	Seasonality of the MJO Impact on the Upper Troposphere and Lower Stratosphere examined through the lens of MLS observations and MERRA2 reanalysis.
April 23	Stacey Frith/SSAI	Model-based Climatology of Diurnal Variability in Stratospheric Ozone as a Data Analysis Tool
April 30	Mian Chin/614	Interactions between Asian air pollution and the monsoon system: Effects on air quality and atmospheric composition in the UTLS
May 14	Bob Swap/610 and Juia Breed/101	Are you the next Earth Science mission PI?
May 21	Ghassan Taha/GESTAR	OMPS LP Version 2.0 Multi-wavelength Aerosol Extinction Coefficient Retrieval Algorithm and data products
May 28	Daniel Murphy and Christina Williamson/NOAA	Some particle properties and experiments relevant to virus transmission and masks
June 25	Parker Case/University of Colorado	Improving the simulation of background and volcanic stratospheric sulfate aerosols in GEOS-5 by coupling CARMA microphysics to the GEOS-Chem chemistry mechanism
July 2	Qing Liang/614	The Asian Summer Monsoon Chemical and Climate Impact Project
July 9	Jerry Ziemke/GESTAR	Three Tropospheric Ozone Products from NASA GSFC as a Pathway for the New Geostationary.
July 16	Jin Liao/USRA	Formaldehyde evolution in the wildfires during FIREX-AQ field campaign
July 30	Xiaohua Pan/GESTAR	Fires emissions and their linkage with climate: a perspective from both observations and models
August 6	Alexis Wilson, Katrina Cone and Trong Nguyen	Summer Intern Presentations
October 1	Joanna Joiner and Bryan Duncan	Summary of the 2020 Senior Review Results for the Aura Mission
October 8	Bryan Duncan/614 (Moderator)	The California Fires as Observed from Space
November 8	Paul Newman/610, Pete Colarco/614, Olga Tweedy/GESTAR	Fall AGU practice talks
November 19	R. Hannun/UMD, K. Cone/UC-Berkley, H.Nguyen/UCF	Fall AGU practice talks
December 17	Sarah Strode?GESTAR, Olga Tweedy,GESTAR, J.Nicely/UMD	SPECIES - AMS Practice Presentations

Table 7.3.5: Wallops Field Support Office

Date	Speaker	Title
January 28	Wolff D. B.	An Overview of Wallops Flight Facility SSAI Lecture Lab Series
January 28	Marks D. B.	Calibration of the NPOL radar SSAI Lecture Lab Series
January 28	Pabla C.	Wallops GPM Ground Validation SSAI Lecture Lab Series
August 6	Moisan, J. M.	GP development of satellite algorithms SBG Cal/Val Working Group Webinar (11) series
August 19	Moisan, J. M.	NASA Evolutionary Programming Analytic Center (NEPAC) for Climate Data Records, Science Products and Models

7.3.1. AeroCenter Seminars

Aerosol research is one of the nine cross-cutting themes of the Earth Sciences Division at NASA's Goddard Space Flight Center. AeroCenter is an interdisciplinary union of researchers at NASA Goddard and other organizations in the Washington DC metropolitan area (including NOAA, 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 aerosol role 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. More information on AeroCenter activities can be found at https://aerocenter.gsfc.nasa.gov/.

Table 7.3.1.1: AeroCenter Seminars
Seminar series coordinators: DaDavid Giles, Jasper Lewis, Ed Nowottnick, and Yingxi Shi

Date	Speaker	Title
February 4	Verity Flower	The evolution of Icelandic volcanic emissions, as observed from space: A multi-sensor satellite technique for eruption assessment.
April 7	Ghassan Taha	AeroCenter
November 17	Alfonso Delgado Bonal	Global daytime variability of clouds from DSCOVR/ EPIC observations.
December 1	Wei Jing	AeroCenter Seminar

7.3.2. Cloud Precipitation Center

NASA GSFC Cloud-Precipitation Center (CPC), established in 2016, is a cross-laboratory union for cloud-precipitation researchers mainly at NASA GSFC. 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 i) cloud-precipitation processes and interactions with surface process, aerosols, mesoscale dynamics, and large-scale circulations, ii) remote sensing, radiative transfer, and scattering theory of cloud and precipitation particles, iii) cloud microphysics and convection measurements and parameterizations, and iv) satellite missions and field campaigns associated with cloud and precipitation processes. In the 2020 season CPC hosted 7 seminars, and the current CPC member list holds 80 members.

Table 7.3.2.1: Cloud Precipitation Center

Seminar series coordinators: Toshi Matsui and Kerry Meyer

Date	Speaker	Title
January 23	Kaustav Chakravarty	A case study of a Dust Storm as observed by Dual-Polarised Doppler Weather Radar and other Instruments over New Delhi, India.
March 31	Sampa Das	The Influence of Biomass Burning Aerosols on Stratocumulus Clouds and on the Stratosphere through Pyrocumulonimbus (PyroCb) Injections
October 13	Lisa Milani	Biases in CloudSat Falling Snow Estimates Resulting from Daylight-Only Operations
October 27	Peter Marinescu	Impacts of Varying Concentrations of Cloud Condensation Nuclei on Deep Convective Cloud Updrafts – A Multimodal Assessment
November 10	Scott Braun	Current Status of the Aerosols-Clouds-Convection-Precipitation (ACCP) Decadal Survey Study
November 17	Alfonso Delgado Bonal	Global daytime variability of clouds from DSCOVR/EPIC observations
November 24	Daeho Jin	Cloud-Precipitation Hybrid Regimes and their Projection onto IMERG Precipitation Data

7.4. Outreach

7.4.1. Introduction

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 AT scientists donate time to public activities to communicate the importance and benefits of NASA's Earth Science research through engagement with local, regional, and national originations and institutions. Target audiences may include policy makers, resource managers, teachers, students, citizens, and particular professional groups. The Earth Observatory's site shares the images, stories, and discoveries that emerge from NASA research about the environment, Earth systems, and climate. 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.

7.4.2 Earth Observatory Group

The Earth Observatory Group publishes over 400 stories and images annually about NASA's Earth, environmental, and climate change research on its award-winning website, the Earth Observatory. The group works with scientists and staff from across NASA's Earth Science Division as well as affiliated institutions and organizations. Imagery from the Earth Observatory regularly appear in the popular media, science magazines, textbooks, and blogs. Since its founding in 1999, the Earth Observatory continues to be one of the primary outlets for Earth science communications within the agency and has maintained a dedicated community of subscribers and followers. The website is consistently one of the top 10 websites within the entire agency with respect to annual views and readers.

The Earth Observatory Group also continues to maintain the NASA Earth Observations (NEO) repository of global data visualizations and the Visible Earth visualization archive, which includes over 79,000 images, including those produced for the Earth Observatory website.

In 2020, 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 on multiple NASA flagship social media channels. Other highlights from 2020 include:

- The Earth Observatory website experienced its busiest year in its 21-year history, serving on average over 900,000 visitors per month during 2020.

- EO staff produced several narrative stories and visualizations explaining what NASA can see as a result of the changes in human behavior due to the COVID-19 pandemic.

- The EO team conceived, developed and deployed the EO Explorer application which gives users the ability to browse over 11,400 stories from the Earth Observatory collection using a map-driven interface.

- In 2020, the EO team revived Tournament Earth—the annual promotion that encourages readers to vote for their favorite images. This year was focused on the entire Earth Observatory collection and over 238,000 votes were cast over the five rounds of voting.

- Special content produced this year included a three-part video series—Picturing Earth—about astronaut photography, and participation in the agency communications campaign focused on sea level rise and the launch of the Sentinel 6 Michael Freilich mission.

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

7.4.3 Outreach

January 16, Brian Campbell (610W/GST) gave a presentation at the Inaugural Wallops Directors Colloquia Series at the NASA Wallops Flight Facility to approximately 100 people. Campbell's talk, entitled *Students, Teachers, Citizen Scientists, and NASA Observing the Height of our Planet One Tree at a Time with ICESat-2 and the GLOBE Program* focused on the collaboration between several NASA and GLOBE programs. Campbell was asked by Code 610W management to represent Wallops Earth Science during the colloquium.

January 21, Dorian Janney (612/ADNET) gave a presentation at the Traperzaria restaurant in Rockville, MD entitled *From Satellites to Your Backyard* for the Rockville Science Center's *Science Cafe* program. There were 29 adults who attended this talk which focused on the Global Precipitation Measurement mission and showed participants how to use the GLOBE Observer app as citizen scientists to assist with data important to NASA scientists. https://www.rockvillesciencecenter.org/event/14783/.

January 28, George J. Huffman (612) presented *Rain and Snow, from Your Backyard to the Whole Globe* to the Columbia Rotary Club Meeting, Columbia, MD. He described how precipitation is observed around the globe and showed results from the GPM datasets.

January 29, Rob Levy (613) and Pawan Gupta (MSFC/USRA) attended the Air Quality Citizen Science Workshop in Raleigh, North Carolina. Levy presented a talk entitled *Introduction to Satellite Data for Air Quality Applications and Gupta presented Interacting with Satellite Data: Worldview Demonstration*. The objective of the workshop was to recruit and train citizen scientists to use low-cost air quality monitors at their home/work. The workshop was conducted with the support of NASA under the "Citizen Science" grant. Ryan Stauffer (614/UMD) was featured in a story by the *Washington Post's Capital Weather Gang* on the thick smoke observed in the DC and Baltimore region on 8 March. Smoke from a controlled burn near Quantico, Virginia, drifted into DC midday and into Baltimore by late evening Sunday, and led to particulate pollution and poor air quality at the surface. The story can be found here: https://www.washingtonpost.com/weather/2020/03/08/controlled-burn-near-quantico-causes-smoky-conditions-across-washington-region/.

February 8, Dorian Janney (612/ADNET) gave a one-hour presentation at the MAEOE conference entitled, *What's the Buzz? Using the Mosquito Habitat Mapper to Reduce the Threat of Mosquito-transmitted disease*. There were 41 adult participants in attendance. https://maeoe.org/uploads/files/2020-MAEOE-Conference-Program.pdf.

February 9, Dorian Janney (612/ADNET) met with Amy Barra, Wallops Visitor Center director, to discuss the possibility of developing a mosquito habitat mapper focused exhibit for the Wallops. They also discussed some possible summer programming at Wallops to share information on the Global Precipitation mission, the use of NASA EOS data to predict, monitor, and respond to mosquito-transmitted diseases, and to show participants how to use the *Mosquito Habitat Mapper*.

March 10, Dorian Janney (612/ADNET) helped organize and then presented during the GLOBE *Mission Mosquito* webinar. During this webinar, there were 41 participants from countries all around the world who joined to learn about the intersection between the *Land Cover* and *Mosquito Habitat Mapper* tools. You can view the archived webinar here: https://www.globe.gov/web/mission-mosquito/overview/webinars-and-recordings.

March 11, Dorian Janney (612/ADNET) gave the March Education and Public Outreach presentation. She presented on NASA's efforts to better predict, monitor, and respond to mosquito-transmitted disease and the GLOBE Observer *Mosquito Habitat Mapper* tool that is being used by scientists and public health officials around the world to reduce the threat of mosquito-transmitted disease.

April 2, Dorian Janney (612/ADNET) presented during the GLOBE *Mission Mosquito* webinar entitled *Meet up and do science with GLOBE Observer and Do your own spatial analysis of a mosquito breeding* site. https://www.youtube.com/watch?v=-SUCJNWh3rU#action=share May 6, Bryan Duncan (614) gave an invited talk as part of the Electric Power Research Institute's webinar series. The title was *Changes in Air Pollution Reflect the Magnitude of Efforts to Slow the Spread of COVID-19*.

April 9, Joanna Joiner (614) and Bryan Duncan (614) reported that the US OMI NO_2 team—based at GSFC—expanded air pollutant monitoring capabilities with a new webtool (https://so2.gsfc.nasa.gov/no2/no2_index.html) featuring data from the NASA Aura Ozone Monitoring Instrument (OMI). A small team developed the capability to track recent changes in nitrogen dioxide (NO_2), an EPA criteria pollutant, for over 200 cities worldwide. The tracking tool is developed primarily for scientists and is used to identify cities and regions for more focused studies. A link is provided from a landing page on the GSFC air quality site (https://airquality.gsfc.nasa.gov) that will be updated regularly to show recent changes in air quality. Please see this page for a new graphic and explanation of recent NO_2 decreases over the northeast US produced by the SVS at GSFC and featured on NASA's high level communications page. A cautionary note regarding the use of satellite-based NO_2 (provided as column amounts) for inferring changes in emissions is also provided.

May 12, Santiago Gassó (613/UMD) was the surprise guest speaker at the Global Imagery Browse Services (GIBS)/Worldview Tele-Summit–Spring 2020 Edition, where he presented a talk entitled *Worldview or How I Learned to Stop Worrying and Love it,* an appreciation of the Worldview portal and its impact in research and in the dissemination of Earth imagery.

May 27, Dorian Janney (612/ADNET) worked virtually with 168 7th grade students from the Monomoy Middle School in Massachusetts. She shared information about how data from the Global Precipitation Measurement mission is being used by microinsurance companies in Central America to help insure small farmers in case of precipitation-related extreme events. The students are part of an on-going pilot of some new educational resources that have been developed by the GPM Outreach team.

The NASA Scientific Visualization Studio released a new video, produced by Ryan Fitzgibbons (130/URSA) about GPM data being used to help farmers facing drought conditions in Central America's Dry Corridor (https://www.youtube.com/watch?v=WH-tzUVk9eE&feature=emb_title). The video was shared on the GPM website and social media accounts, and on the @NASAEarth Twitter and Facebook accounts. The video was also translated to Spanish and shared to the NASA Español website and social media accounts (https://ciencia.nasa.gov/satelites-nasa-ayudan-agricultores-en-el-corredor-seco).

June 26, Santiago Gassó (613/UMD) was interviewed by CNN Español regarding the impacts and importance of the immense Sahara Desert dust cloud entering the US through the Gulf of Mexico.

July 5, Charles Gatebe (613/USRA) gave a radio interview hosted by Royal Media Services (INOORO FM), in Nairobi, Kenya, which was broadcast live to more than 2 million listeners in Kenya and around the world via Facebook Live streaming. The interview was conducted in his native language Kikuyu and covered a wide range of topics such as NASA's scientific endeavors, his own specific activities within NASA, the importance of STEM education for a country's economic growth and future job opportunities, and how to encourage more students, and especially girls, to participate in STEM curricula.

July 17, Peter Colarco (614) presented a virtual webinar entitle The *NASA GEOS Aerosol Forecasting System and its Applications to Saharan Dust Transport* at the EcoExploratorio Museo de Ciencias de Puerto Rico (the Puerto Rico Museum of Science).

The @NASAEarth Facebook and Twitter accounts shared a video *Satellites See Hurricanes Douglas and Hanna* that included two visualizations of GPM overpasses generated by the NASA Scientific Visualization Studio. These GPM visualizations were created by Alex Kekesi (606.4/GST) and Greg Shirah (606.4/AST). The video received 29k views, 2.5k engagements and 296 shares on Facebook, and 84 retweets and 250 likes on Twitter. The video was also shared by Jacob Reed (617/Telophase) on the NASARain Facebook and Twitter account.

NASA ARSET recently completed an advanced, online training: *Using Earth Observations to Monitor Water Budgets for River Basin Management II*. This three-part training series taught participants how to estimate water budgets in river basins using GRACE-FO terrestrial groundwater storage, IMERG precipitation, MODIS evapotranspiration, and GLDAS. Analysis was performed in QGIS. In attendance were 1,084 participants from 62 countries and 34 US states. Around 700 unique organizations were represented. Amita Mehta (612/UMBC) and Sean McCartney (610/SSAI) led the training. Brock Blevins (614/SSAI), Selwyn Hudson-Odoi (614/UMBC), Jonathan O'Brien (614/SSAI), and Ana Prados (614/UMBC) supported the training. Materials can be found at: https://appliedsciences.nasa.gov/join-mission/training/english/using-earth-observations monitor-water-budgets-river-basin-0.

The GPM outreach team coordinated the creation, posting, and promotion of multiple articles and visualizations showing how the GPM mission observed Hurricane Laura as it made landfall. Text was written by Stephen Lang (612/SSAI) and Jacob Reed (617/Telophase) and posted to social media (@NASARain, @NASAEarth, @NASAHurricane and @Dr_ThomasZ).

- A rendering of GPM's 8/27/20 overpass several hours after landfall produced by Alex Kekesi (606.4/GST), Scientific Visualization Studio: https://svs.gsfc.nasa.gov/4855.

- Several animations of IMERG accumulations produced by Jason West and Owen Kelley (610.2/Adnet), Precipitation Processing System (PPS). Most recent IMERG animation: https://gpm.nasa.gov/sites/default/files/2020-08/Laura_Aug28.mp4.

- An interactive visualization in STORM Event Viewer of GPM's 8/26/20 overpass shortly before landfall produced by Jason West (610.2/Adnet), Precipitation Processing System: https://gpm.nasa.gov/storm-viewer/EventViewer.html?position=-92.78,25.57,1328359&view=6.16,-1.29,6.28&fname=20200827-S024128-E031127.

Several still images of GPM overpasses produced by Joe Munchak (612): https://gpm.nasa.gov/applications/weather/gpm-flies-over-cat-4-hurricane-laura-twice-it-makes-landfall-louisiana.

September 11, Dorian Janney (612/ADNET) and Andrea Portier (612/SSAI) gave a presentation to the Solar System Ambassador and Museum Alliance programs that focused on the Global Precipitation Measurement mission's applications and the newly released application packages and resources created by the GPM Outreach team. There were 58 participants during this virtual presentation, and the recording is available to be viewed on both the Solar System Ambassador and Museum Alliance websites.

September 14, Dorian Janney (612/ADNET) was the first presenter for the North Carolina's museum of Science "Bugfest" weeklong virtual program. She presented on how data from NASA's Global Precipitation Measurement mission and several other NASA missions are being used to help predict, monitor, and respond to mosquito-transmitted disease. She also showed participants how to use the GLOBE Observer *Mosquito Habitat Mapper* tool. There were 53 participants during the virtual event, and the recording can be viewed on their website.

The GPM outreach team published a video and story to the GPM website on heavy rainfall from Hurricane Sally (https://gpm.nasa.gov/applications/weather/hurricane-sally-extremely-heavy-rain-northern-gulf-coast), which included an animation of IMERG rainfall totals generated by Jason West (610.2/Adnet) with meteorological analysis written by Steve Lang (612/SSAI) and Jason West. The story was shared to the @NASARain social media accounts by Jacob Reed (617/Telophase).

October 22, Cynthia Hall (613/SSAI) co-hosted a virtual workshop at the Geological Society of America Annual Meeting. The workshop was titled *NASA Data Made Easy: Getting Started with SAR* and provided an introduction to synthetic aperture radar (SAR), information on earthdata.nasa.gov's new *Disasters Data Pathfinder and Data Toolkit* to help new and expert data users more intuitively access NASA data, information about the GeoGateway program, which provides InSAR data for monitoring ground deformation from earthquakes, and a tutorial on mapping flood inundation using SAR data.

GPM: Several articles and images were shared online showing GPM imagery in support of Hurricane Zeta. Alex Kekesi (606.4/GST) of the NASA Goddard Scientific Visualization Studio produced two visualizations of GPM overpasses of

Zeta from October 25 and October 28. Jason West (610.2/ADNET) produced two interactive visualizations of the same overpasses using STORM Event Viewer. These visualizations were accompanied by text written by Jacob Reed (617/Telophase), Steve Lang (612/SSAI), and Joseph Munchak (612), and were posted at https://gpm.nasa.gov/applications/weather/nasa-prepares-hurricane-zeta and shared to gpm.nasa.gov, disasters.nasa.gov, appliedsciences.nasa.gov, https://blogs.nasa.gov/disaster-response/, and https://blogs.nasa.gov/hurricanes/. The articles and visualizations were also shared on social media by @NASARain, @NASAEarth, and @NASAGoddard.

November 2, 4, and 5, Andrea Portier (612/SSAI) and Dalia Kirschbaum (617) led a *Virtual Transportation and Logistics* workshop. The workshop brought together stakeholders from across the transportation, aviation, logistics, and maritime operations space to engage on how they use (or could use) data from the Global Precipitation Measurement (GPM) mission and discuss needs and opportunities for the Aerosols, Clouds, Convection and Precipitation (ACCP) Study. Scott Braun (612) presented on Decadal Observatory and the ACCP Study and George Huffman (612) presented on the GPM mission, with a focus on the Integrated Multi-satellitE Retrievals for GPM (IMERG), which is the most commonly used. Information on this workshop is available at: https://gpm.nasa.gov/science/meetings/2020-transportation-workshop.

October 30, Dorian Janney (612/ADNET) led the Potomac Valley Ski Club Tree Research group as they explored how to access and download Global Precipitation Measurement (GPM) IMERG data to get a better understanding of how much precipitation falls seasonally in their location. The eight participants also learned how to use the *Tree Height* GLOBE Observer tool.

November 9, Paul A. Newman (610) gave a radio interview on chlorofluorocarbons, the Antarctic ozone hole, and the Montreal Protocol for the *Constant Wonder* program on BYU Radio

Several articles and visualizations were shared online showing GPM imagery for Hurricane Eta. Alex Kekesi (606.4/GST) and the NASA Goddard Scientific Visualization Studio produced two visualizations of the GPM overpasses of Hurricane Eta from November 8^{th} and 10^{th}: https://gpm.nasa.gov/applications/weather/gpm-eyes-eta-over-florida, https://gpm.nasa.gov/applications/weather/gpm-sees-eta-make-second-florida-landfall.

These visualizations were accompanied by text written by Stephen Lang (612/SSAI) and were shared on the web and to social media by Jacob Reed (617/Telophase Corp.), including coverage by @NASARain and @NASAHurricane.

November 10 and 13, Dorian Janney (ADNET/612) gave a virtual presentation for the National Association of Interpreters (NAI) annual conference. She presented information about the science and technology behind the Global Precipitation Measurement (GPM) mission as well as information about the many ways in which these data are being used in real-world applications. She also shared several resources which the GPM Outreach Team has created related to hurricanes and applications.

November 23-27, Paul A. Newman (610) attended the online joint 32nd Meeting of the Parties to the "Montreal Protocol on Substances that Deplete the Ozone Layer," and the 12th Meeting of the Parties to the "Vienna Convention for the Protection of the Ozone Layer." Newman gave a presentation to the Parties on the progress of the "Scientific Assessment of Ozone Depletion: 2022," and the "Report on Unexpected Emissions of CFC-11". Dr. Newman also briefed the Parties on the 2020 Antarctic ozone hole and its impact on the Southern Hemisphere.

November 10, Ryan Stauffer (614/UMD) gave an interview to Fox43 TV in York, PA, describing the multi-day particle pollution event over the Northeast and Mid-Atlantic that peaked over the weekend of November 7-8. The event marked just the third time in the past decade that Lancaster, PA, observed a "Code Red" day for particle pollution: https://www.fox43.com/article/weather/recent-stretch-of-gorgeous-weather-leads-to-some-of-the-poorest-air-quality-in-the-last-decade/521-797fd2cd-5749-421a-812a-91005a904fcd.

The Earth Observatory (613/SSAI) published the final installment of their video series *Picturing Earth*. For 20 years, astronauts have been shooting photos of Earth from the International Space Station. Like everything the astronauts do, they are trained for this job. And like everything they do, there is purpose and intention behind it. This series was produced in coordination with the ISS Crew Earth Observations Facility and the Earth Science and Remote Sensing Unit, Johnson Space Center. The three episodes are *Astronaut Photography in Focus, Window on the World, and Behind the Scenes.*

8. Atmospheric Sciences in the News

The following pages contain links to press releases that describe some of the laboratory's activities during 2020:

MISR First Light Image
https://earthobservatory.nasa.gov/images/530/misr-first-light-image

MODIS First Light Image
https://earthobservatory.nasa.gov/images/526/modis-first-light-image

NASA Animates World Path of Smoke and Aerosols from Australian Fires
https://www.nasa.gov/mission_pages/NPP/main/index.html

Arctic stratospheric ozone levels hit record low in March
https://www.sciencedaily.com/releases/2020/04/200416135944.htm

NASA data aids ozone hole's journey to recovery
https://phys.org/news/2020-04-nasa-aids-ozone-hole-journey.html

NASA images show fall in China pollution over virus shutdown
https://www.sciencedaily.com/releases/2020/06/200627112428.html

Satellite analyzes Saharan dust aerosol blanket
https://www.sciencedaily.com/releases/2020/06/200627112428.html

Watching Thunderstorms March Across Lake Victoria
https://earthobservatory.nasa.gov/images/147231/watching-thunder-storms-march-across-lake-victoria

NASA observations aid efforts to track California's wildfire smoke from space
https://phys.org/news/2020-09-nasa-aid-efforts-track-california.html

Large, deep Antarctic ozone hole to persist into November
https://phys.org/news/2020-11-large-deep-antarctic-ozone-hole.html

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.

1DVAR	1-Dimensional VARiational retrieval
7-SEAS	Seven South East Asian Studies

A

AAAS	American Association for the Advancement of Science
A-CCP	Aerosol, Cloud, Convection and Precipitation
ABI	Advanced Baseline Imager
ACCP	Aerosol, Cloud, Convection and Precipitation
AERONET	Advancing Earth Research Observation Kites and Atmospheric/Terrestrial Sensors
AGU	American Geophysical Union
AHI	Advanced Himawari Imager
AIAA	American Institute of Aeronautics and Astronautics
AirMSPI	Airborne Multiangle SpectroPolarimetric Imager
AIRS	Atmospheric InfraRed Sounder
AMS	American Meteorological Society
AMSU	Advanced Microwave Sounding Unit
AoA	Age of Air
AOD	Aerosol Loading
AOD	Aerosol Optical Depth
AOT	Aerosol Optical Thickness
API	Application Programming Interface
AQ	Air Quality
AREN	AEROKATS and ROVER Education Network
ARSET	Applied Remote Sensing Training
ASHE	Aerosol Single-scattering albedo and Height Estimation
ASOPOS	Assessments of Standard Operating Procedures for OzoneSondes
AST	Aerospace Technology
ATBD	Algorithm Theoretical Basis Documents
ATLAS	Advanced Topographic Laser Altimeter System
ATMS	Advanced Technology Microwave Sounder
AVIRIS-C	Airborne Visible and InfraRed Imaging Spectrometer

B

B-WET	Bay Watershed Education and Training
BASELInE	Biomass-burning Aerosols & Stratocumulus Environment: Lifecycles & Interactions Experiment
BOEM	Bureau of Ocean Energy Management
BRDF	Bidirectional Reflectance Distribution Function

C

CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CARMA	Community Aerosol and Radiation Model for Atmospheres
CATS	Cloud Aerosol Transport System
CCNY	The City College of New York
CDR	Climate Data Records
CERES	Cloud and Earth Radiant Energy System
CFCs	Chlorofluorocarbons
CO	Core Observatory
CONUS	Continental U.S.
COSI	Center of Science and Industry
CoSMIR	Conical Scanning Millimeter-wave Imaging Radiometer
COVID	Coronavirus Disease
CPC	Cloud-Precipitation Center
CPI	Cloud Particle Imager
CPL	Cloud Physics Lidar
CrIS	Cross-track Infrared Sounder
CRM	Cloud-resolving Model
CRS	Commercial Resupply Service
CRTM	Community Radiative Transfer Model
CSAPR	C-band scanning precipitation radar
CSH	Convective-stratiform Heating
CSV	Comma Separated Values
CVE	Common Vulnerabilities and Exposures

D

D3R	Dual-polarized Doppler Radar
DCC	Deep Convective Cloud

DCSE	Directorate Computer Security Engineer
DHS	Department of Homeland Security
D_{mass}	Mass Weighted Mean Drop Diameter
DMS	dimethyl sulfide
DOE	Department of Energy
DRAGON	Distributed Regional Aerosol Gridded Observation Networks
DSCOVR	Deep Space Climate Observatory
DT	Dark Target

E

E/PO	Education and Public Outreach
EAS	European Space Agency
eMAS	Enhanced MODIS Airborne Simulator
EO	Earth Observatory
EO4HEALTH	Earth Observations for Health
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPIC	Earth Polychromatic Imaging Camera
ESA	European Space Agency
ESAS	Earth Science and Applications from Space
ESSIC	Earth System Science Interdisciplinary Center
EVS-3	Earth-Venture Suborbital-3
EXRAD	ER-2 X-band Doppler Radar
FB	Facebook
FIREX	Fire Influence on Regional to Global Environments Experiment
FIREX-AQ	FIREX - Air Quality
FLC	Federal Laboratories Consortium

G

GCMs	Global Climate Models
GEMS	Geostationary Environment Monitoring Spectrometer
GEO	Geosynchronous Earth Orbit
GEO	Group on Earth Observations
GEO-XO	Geostationary and Extended Orbits
GEOS	Goddard Earth Observing System
GEOS-Chem	GEOS-Chemistry
GESTAR	Goddard Earth Sciences Technology Center and Research
GIBS	Global Imagery Browse Services
GISS	Goddard Institute for Space Studies
GLER	Geometry-dependent surface Lambertian Equivalent Reflectivity
GLM	Geostationary Lightning Mappers
GLOBE	Global Learning and Observations to Benefit the Environment
GMAC	Global Monitoring Annual Conference
GMAO	Global Modeling and Assimilation Office
GMAP	GEMS Map of Air Pollution
GMI	GPM Microwave Imager
GMI	Global Modeling Initiative
GOES	Geostationary Operational Environmental Satellites
GPCB	Gujarat Pollution Control Board
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GPP	Gross primary production
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSFC	Goddard Space Flight Center
GV	Ground Validation

H

H_2O	Water
HARP	Hyper-Angular Rainbow Polarimeter
HATS	Histogram Anomaly Time Series
HCHO	Formaldehyde
HID	Hydrometeor Identification
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
HMA	High Mountain Asia
HRAC-Precip	High-Resolution Altitude-Correction Precipitation

I

ICACGP	International Commission on Atmospheric Chemistry and Global Pollution
ICESat	Ice, Cloud, and land Elevation Satellite
ICIMOD	International Centre for Integrated Mountain Development
IMERG	Multi-satellitE Retrievals for the Global Precipitation Measurement
IMPACTS	Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms
InSAR	Interferometric Synthetic Aperture Radar

INSPIRE	Interdisciplinary National Science Project Incorporating Research and Education Experience
IOP	Intensive Observation Periods
IOTD	Image of the Day
IR	Shortwave Infrared
ISCCP	International Satellite Cloud Climatology Project
ISS	International Space Station
IVSS	International Virtual Student Symposium

J

JA	Junior Achievement
JAXA	Japan Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System

K

KML	Keyhole Markup Language

L

L1	Lagrangian
LAPAN	Indonesian Space Agency
LEO	Low Earth Orbit
LH	Laten Heating
LiDAR	Light Detection and Ranging
LIMA	Landsat Image Mosaic of Antarctica
LIS	Land Information System
LLNL	Lawrence Livermore National Laboratory
LNY	Lunar New Year
LP	Limb Profiler
LUT	Lookup Table

M

MAEOE	Maryland Association for Environmental and Outdoor Education
MASTAR	Multi-Angle Stratospheric Aerosol Radiometer
MAX-DOAS	Multi-Axis Differential Optical Absorption Spectroscopy
MEaSUREs	Making Earth System Data Records for Use in Research Environments
MERRA	Modern-Era Retrospective analysis for Research and Applications
MHM	Mosquito Habitat Mapper
MISR	Multi-angle Imaging SpectroRadiometer
MJO	Madden Julian Oscillation
ML	Mixed Layer
MLS	Microwave Limb Sounder
MODIS	MODerate-resolution Imaging Spectrometer
MPLCAN	Micro Pulse Lidar Canada
MPLNET	Micro Pulse Lidar Network
MSFC	Marshall Space Flight Center
MWEE	Meaningful Watershed Educational Experiences

N

N-POL	NASA's S-band dual-POLarimetric radar
N_2O	Nitrous oxide
NAI	National Association of Interpreters
NASA	National Aeronautics and Space Administration
NAST-I	National Airborne Sounder Testbed - Interferometer
NCAR	National Center for Atmospheric Research
NDACC	Network for the Detection of Atmospheric Composition Change
NEO	NASA Earth Observations
NESTA	National Environmental Science Teachers' Association
NIER	Korean National Institute of Environmental Research
NISTAR	National institute of Standards and Technology Advanced Radiometer
NO_2	Nitrogen Dioxide
NO_2 TVCDs	NO_2 Tropospheric Vertical Column Densities
NOAA	National Oceanic and Atmospheric Administration
NEPAC	NASA Evolutionary Programming Analytic Center
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPOL	Naval Physical and Oceanographic Laboratory
NPP	NASA Postdoctoral Program
NPP	National Polar-orbiting Partnership
NSTA	National Science Teachers' Association
NU	Nunavut
Nu-WRF	NASA Unified-Weather Research and Forecasting
NWP	Numerical Weather Prediction

O

O_3	Ozone
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
ONR	Office of Naval Research
OSCAR	WMO Observing Systems Capability Analysis and Review Tool
OSU	The Ohio State University

P

PACE	Plankton, Aerosol, Cloud and ocean Ecosystem
PBL	Planetary Boundary Layer
PGN	Pandonia Global Network
PGPS	Prince George's Public Schools
PHP	Hypertext Preprocessor
PI	Principle Investigator
PNR	Pinelands National Reserve
POES	Polar-orbiting Operational Environmental Satellites
POLARRIS	POLArimetric Radar Retrieval and Instrument Simulator
PR	Precipitation Radar
PUMAS	Practical Uses of Math And Science

R

R&D	Research and Development
RAJO-MEGHA	Radiation, Aerosol Joint Observation-Modeling Exploration over Glaciers in Himalayan Asia
REPS	Retrieved Effective Particle Size
RH	Relative Humidity
RSP	Research Scanning Polarimeter

S

SAGE	Stratospheric Aerosol and Gas Experiment
SAR	Synthetic-Aperture Radar
SBG	Surface Biology and Geology
SBI	Surface-based Inversion
SCOAPE	Satellite Coastal Oceanic and Atmospheric Pollution Experiment
SEA	Southeast Asia
SEAC4RS	Southeast Asia Composition, Cloud, Climate Coupling Regional Study
SFAD	Stacked Frequency of Altitude Diagrams
SGT	Stinger Ghaffarian Technologies
SHADOZ	Southern Hemisphere Additional Ozonesondes
SICE	Students Involved with Technology and Engineering Club
SIF	Solar Induced Fluorescence
SMARTS-s	Spectral Measurements for Atmospheric Radiative Transfer-spectroradiometer
SMD	Science Mission Directorate
SNPP	Suomi National Polar-orbiting Partnership
SO2	Sulphur Dioxide
SOC	Security Operations Center
SOLAS	Surface Ocean – Lower Atmosphere Study
SSAI	Science Systems Applications, Inc.
SORCE	Solar Radiation and Climate Experiment
SSI	Solar Spectral Irradiance
STC	Science and Technology Corporation
STEM	Science, Technology, Engineering, and Mathematics
SVS	Scientific Visualization Studio
SWE	Software Engineering

T

TEMPO	Tropospheric Emissions: Monitoring of Pollution
TMPA	TRMM Multi-satellite Precipitation Analysis
TRMM	Tropical Rainfall Measurement Mission
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
TROPOMI	Troposphere Ozone Monitoring Instrument
TVCD	tropospheric vertical column densities

U

UAS	Unmanned Aircraft System
UC	University of California
UCF	University of Central Florida
UMBC	University of Maryland, Baltimore County
UMD	University of Maryland
UN	United Nations
USAF	United States Air Force
USRA	Universities Space Research Associates
UTLS	Upper Troposphere and Lower Stratosphere
UV	Ultraviolet
UVAI	UV Aerosol Index

V

V3	Version 3
VAD	Velocity-azimuth Display
VIIRS	Visible Infrared Imaging Suite
VLIDORT	Vector Linearized Discrete Ordinate Radiative Transfer Model
VRW	Vortex Rossby Wave

W

WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization
WRCP	World Climate Research Programme

Y

YLACES	Youth Learning as Citizen Environmental Scientists

APPENDIX 1: REFEREED ARTICLES

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