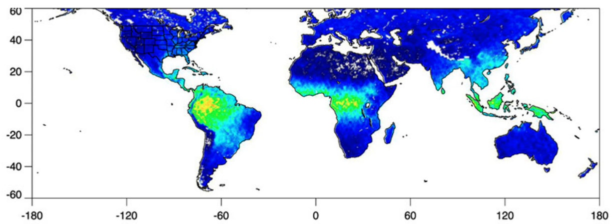
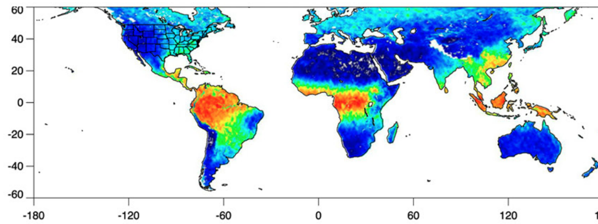
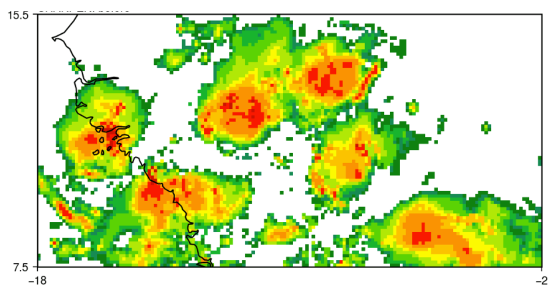
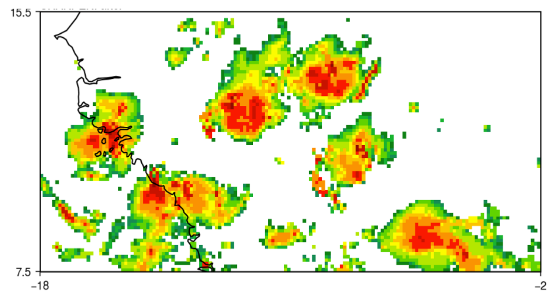
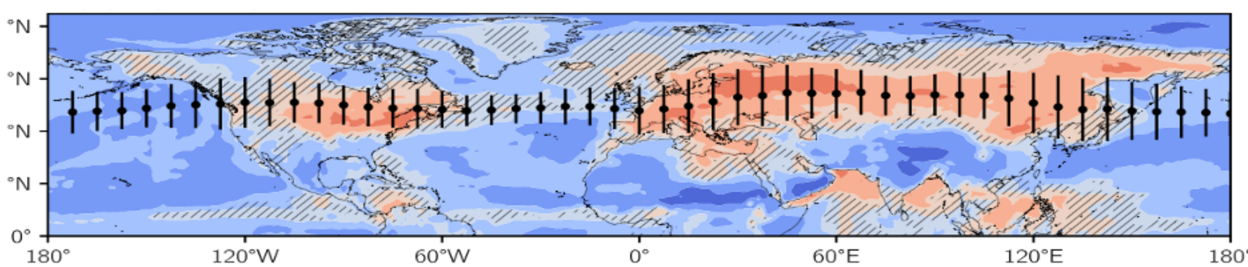
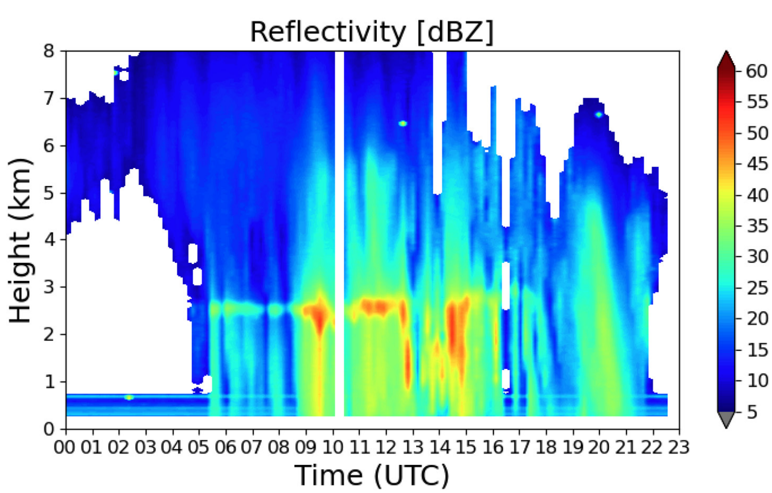
NASA/TM–20220019078

Atmospheric Research 2021 Technical Highlights

January 2022

On the Cover

Top: The operational passive microwave precipitation retrieval for the Global Precipitation Measurement Mission (GPM) requires model constraints over land surfaces where the surface signal is strong, making light precipitation estimation difficult. Incorporating the surface signal via an optimal estimation retrieval allows decreases in the false alarm rates (right). Model data dependence is reduced and retrieval validation metrics improved, including decreasing probability of false detection by 50%.

Sarah Ringerud (NASA/GSFC, Code 612, UMD), sarah.e.ringerud@nasa.gov

Middle Top: A key strategy in obtaining complete global coverage of high-resolution precipitation is to combine observations from multiple fields, such as the intermittent passive microwave observations, precipitation propagated in time using motion vectors, and geosynchronous infrared observations. These separate precipitation fields can be combined through weighted averaging, which produces estimates that are generally superior to the individual parent fields. However, the process of averaging changes the distribution of the precipitation values, leading to an increase in precipitating area and a decrease in the values of high precipitation rates. A phenomenon observed in IMERG. A new scheme, called SHARPEN, mitigates the issue of a distortion in the distribution of precipitation values as a result of averaging multiple precipitation fields in the IMERG algorithm. This scheme is able to correct for the inflation of precipitation area and suppression of peak precipitation due to averaging, leading to a distinct improvement in precipitation detection skill.

Jackson Tan (NASA/GSFC, Code 613, UMBC), jackson.tan@nasa.gov

Middle Bottom: Understanding the relationship of surface level ozone (O_3) with temperature is a prerequisite for understanding O_3 pollution events and how O_3 may change under future warming. A GMI CTM study shows the O_3-temperature relationship on daily timescales varies substantially over the Northern Hemisphere. For example, O_3 increases (bright to light red) with increasing temperature over continental midlatitudes but decreases (light to dark blue) over the oceans with increasing temperature. This relationship outside the tropics is related to the north-south movement of the jet stream and associated changes in the surface-level meridional flow, which impact the northward and southward advection of O_3 and temperature. Hatching denotes regions where the correlation is not statistically significant, determined using moving block bootstrap resampling to estimate the 95% confidence interval. Scatter points and vertical bars specify the mean position and variability of the jet stream, respectively.

Dr. Susan E. Strahan, (NASA/GSFC, Code 614, UMBC), susan.e.strahan@nasa.gov

Bottom: NASA POLarimetric Radar (NPOL) observed a significant winter storm over the mid-Atlantic region in support of the Global Precipitation Measurement (GPM) Ground Validation (GV) program. This composite image of radar reflectivity was generated from a time-series of 20° antenna elevation sweeps and is referred to as a Quasi-Vertical Profile (QVP). The reflectivity data (top left) shows the precipitation started as snow aloft and melted at a height of about 2.5 km before reaching the surface as rain during the 05-13 UTC period. The melting layer (with mixed phase precipitation) is shown by the enhanced power values near 2.5 km altitude. Colder air was pulled into the system by the 13 UTC hour and mixed phase (primarily sleet and rain mix) fell to the surface between 13-16 UTC as the atmosphere transitioned to mixed phase or sleet, which is highly reflective. By 16z, the reflectivity values became more uniform as the precipitation turns to snow.

David B.Wolff (NASA/GSFC Wallops, Code 610W), david.b.wolff@nasa.gov

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Atmospheric Research 2021 Technical Highlights

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

January 2022

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

Dear Reader,

Welcome to the 2021 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 266 personnel in Code 610AT consist of 53 civil servants and 213 cooperative agreement associates, postdoctoral fellows and contractors.

Satellite missions: On June 31, an engineering model unit of the TROPICS pathfinder satellite, was launched via a rideshare opportunity with SpaceX. It is one of the first CubeSat missions that NASA is funding.

Terra is currently in extended operations. The Terra Project fully expects the Terra platform and all five instruments to operate past 2026, allowing them to maintain their status as leaders in Earth science data production.

Aqua data and imagery monitored major environmental events around the world, from Hurricane Delta as it approached the U.S. Gulf Coast in early October 2020 to the volcanic emissions from the eruption of Cumbre Vieja on the Canary Island of La Palma in September 2021.

Using NASA satellite data (CERES/AIRS), the first observational diagnosis of radiative forcing provided the first observational evidence that radiative forcing has been increasing on the global scale, namely the component of Earth's radiative energy imbalance directly caused by a change in the composition of the atmosphere. The steadily increasing global radiative forcing from 2003-2018 is direct evidence of the human impact on climate through a combination of rising greenhouse concentrations and, to a lesser extent, reduced aerosol emissions. https://doi.org/10.1029/2020GL091585

In 2020 and 2021, numerous researchers (as indicated by publications) have benefited from the long, stable Aura OMI record in their studies of the impacts of the global pandemic on various air pollutants and their impacts on atmospheric chemistry and human health.

Significant milestones and activities were met for GPM in 2021 including: final preparation by algorithm teams for reprocessing of GPM products to Version 07 in late 2021 and early 2022, continuation of vigorous outreach and educational efforts, numerous video and online features, website updates for all big weather events, presentations to educators and students, and more.

A new capability was developed for simultaneous retrieval of aerosol optical depth (AOD) and spectral absorption of biomass burning smoke and mineral dust from DSCOVR EPIC observations in the UV-Visible part of spectrum. It is integrated in version 2 (v2) MAIAC EPIC atmospheric correction algorithm which recently completed re-processing of the EPIC 2015-2020 data record. Alexei Lyapustin (NASA/GSFC, Code 613).

Suborbital deployments: MPLNET added several new sites in 2021: Houston, TX; OPAL (Eureka, CA); and Tazacorte, Canary Islands. MPLNET also supported the NASA TRACER-AQ field campaign with the new Houston site. Several sites are in planning phase: Halifax, CA; Amazon, Brazil; NASA Ames; Thule, Greenland; and Boulder, CO.

An estimated total of 350 SHADOZ ozonesonde profiles were collected in 2021, bringing the grand total to over 9400 for the 24-year record of the network. The 2021 numbers represent almost a full recovery in data collection compared to 2020. In June, Dr. Ryan Stauffer (NASA/GSFC, Code 614) assumed the PI role from Dr. Anne Thompson (NASA/GSFC, Emeritus), the founding PI who oversaw network operations for nearly 24 years.

Pandora 2021 was marked by the Covid-19 partial closure and limited access. Lab calibrations at GSFC were allowed on a limited basis during the early part of the year. Full access in the second-half improved productivity, especially in calibrations. Operations of the network proceeded with minimal impact by working at home and remote locations. 43 instruments were added to the PGN during 2021, bringing the total to 100+.

Ed Nowottnick (NASA/GSFC, Code 612) and Pete Colarco (NASA/GSFC, Code 614) provided flight planning and forecasting support for CPEX-AW 21 to target interactions between Saharan dust and convection in the Caribbean and tropical North Atlantic regions. The program was a joint effort between NASA and the European Space

Agency (ESA) focused on calibration and validation of ESA's Atmospheric Dynamics Mission-Aeolus (ADM-AEOLUS) Earth observation wind lidar satellite, specifically over St. Croix in the Caribbean Sea.

Kudos: Anne Thompson was elected to the prestigious American Academy of Arts and Sciences. This is a wonderful recognition and acknowledgement of Thompson's outstanding career. Thompson joins Claire Parkinson (NASA/GSFC, Code 610) and John Mather (NASA/GSFC, Code 660) as current GSFC members of the Academy. Also, elected this year was GSFC and Earth Sciences Division alumni Marshall Shepherd, currently at the University of Georgia.

Dr. Paul A. Newman (NASA/GSFC, Code 610), chief scientist for Earth sciences has been awarded the Cleveland Abbe Award for Distinguished Service to the Atmospheric and Related Sciences, by the American Meteorological Society. The Cleveland Abbe Award for Distinguished Service to the Atmospheric and Related Sciences by an Individual is presented on the basis of activities that have materially contributed to the progress of the atmospheric and related sciences or to the application of the atmospheric and related sciences to general, social, economic, or humanitarian welfare.

Dr. Mian Chin (NASA/GSFC, Code 614) and Dr. Gerald (Gerry) Heymsfield (NASA/GSFC, Code 612) of NASA's Goddard Space Flight Center in Greenbelt, Maryland, have each been named Fellows of the American Meteorological Society (AMS) for 2022.

Please join me in congratulating Mian Chin for her selection as a 2022 AGU Fellow. This announcement follows on her selection as a 2022 AMS Fellow. Dr. Chin is having a banner year.

Joanna Joiner (NASA/GSFC, Code 614) and Alexei Lyapustin (NASA/GSFC, Code 613), were among eight Code 610 Directorate scientists selected as 2021 Highly Cited Researchers by Clarivate (Web of Science).

Chris Kidd (NASA/GSFC, Code 612, UMD) has accepted his nomination to sit on the National Academies Committee on Radio Frequencies (CORF).

Civil servant personnel: I am happy to welcome Dr. Ryan M. Stauffer to the Chemistry and Atmospheric Dynamics Laboratory (NASA/GSFC, Code 614). He received a PhD in meteorology from Pennsylvania State University in 2016. Stauffer started working with ozonesondes in 2010, when Thompson, then a professor at Penn State, was his PhD advisor. As a member of ESSIC, he has participated in numerous NASA-sponsored field projects focused on near-surface and tropospheric air quality and pollution, involvement in field projects and measurement networks. In June, Stauffer succeeded Anne Thompson as leader of SHADOZ following her transition to emeritus.

I am also happy to welcome Dr. Adrian Loftus (NASA/GSFC, Code 612). He received his PhD in atmospheric science from Colorado State University in 2012. He came to NASA GSFC in 2012 under the NASA Postdoctoral Program. He has a background in numerical modeling, cloud microphysics parameterization development, aerosol-cloud-precipitation interactions, and radar remote-sensing operations. He collaborated closely on calibration and multi-frequency radar exercises with the GPM/GV team at WFF, and has recently begun working with the GSFC High Altitude Radar group. In his new role as a civil servant, Dr. Loftus will lead the Code 612 modeling group, help advance microwave remote sensing (primarily radar) capabilities, and serve as Mission Scientist for the ongoing IMPACTS 2022 field campaign.

I am also delighted to welcome Dalia Kirshenblat (NASA/GSFC, Code 610, ASRC) to our front office as our new admin. Dalia comes to us as an Ithaca College graduate where she was most recently working with the Cornell Center for Astrophysics and Planetary Science and the Ithaca Sciencenter (as part of a NASA partnership). Kirshenblat will also be supporting EIS activities part-time (Alexey Shiklomanov et al.).

John Yorks (NASA/GSFC, Code 612) has been named the ACCP/AtmOS (Aerosols and Clouds, Convection and Precipitation)/(Atmosphere Observing System) Deputy Project Scientist for Inclined Orbit. AtmOS is being planned as having one inclined and one polar orbit satellite, each with somewhat different instrumentation to address different parts of the ACCP decadal survey high-priority questions.

Rob Levy (NASA/GSFC, Code 613) has been selected as the new GOES-R Flight Project Scientist. Levy has been the GOES-R Flight Deputy Project Scientist since 2019. In addition, his science experience with the GOES-R series involves the development of aerosol retrieval algorithms for ABI (and the similar AHI instrument) that includes producing diurnal aerosol data records via a MEaSUREs 2017 project and other ROSES-funded efforts. My appreciation to Levy for taking on his new role. And many thanks to Joel Susskind for his GOES-R service and best wishes with GeoXO. Congratulations to them both.

Nick Krotkov (NASA/GSFC, Code 614) has been selected for the role of Aura DPS position, Krotkov's expertise with OMI instrument evaluation and product development (SO_2, NO_2), radiative transfer, and related domestic/international satellite mission efforts will be an excellent complement to Bryan Duncan (NASA/GSFC, Code 614) (Aura Project Scientist).

Dave Wolff (NASA/GSFC, Code 610W) has been selected to fill the role of GPM Deputy Project Scientist for Ground Validation (GV). Wolff started his Goddard career in 1988 working in the TRMM Ground Validation program and has been involved in TRMM/GPM GV activities ever since. His expertise is in ground-based precipitation estimates (radar, gauges, disdrometers) and satellite retrieval evaluation. Wolff is currently the GPM GV site system manager at Wallops as well as the Chief of 610W. Wolff's expertise will be a great complement to Scott Braun (NASA/GSFC, Code 612) and George Huffman (NASA/GSFC, Code 612) (Project and Deputy Project Scientists, respectively).

We mourn the loss of Dr. Gail Skofronick-Jackson (NASA/GSFC, Code 612). Skofronick-Jackson has been part of NASA's Earth Science Program since 1997. She began her NASA career at Goddard Space Flight Center in 2014 and served as Chief of the NASA Goddard Mesoscale Atmospheric Processes Laboratory, and as Project Scientist for the NASA Global Precipitation Measurement (GPM) mission. She was a brilliant, deeply principled and passionate scientist, and a beloved co-worker and friend. Her impact lives on in our work. Read a tribute to Skofronick-Jackson on the International Precipitation Working Group (IPWG) website (http://ipwg.isac.cnr.it/obituaries/Skofronick-Jackson/Gail.html).

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

October 2022

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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

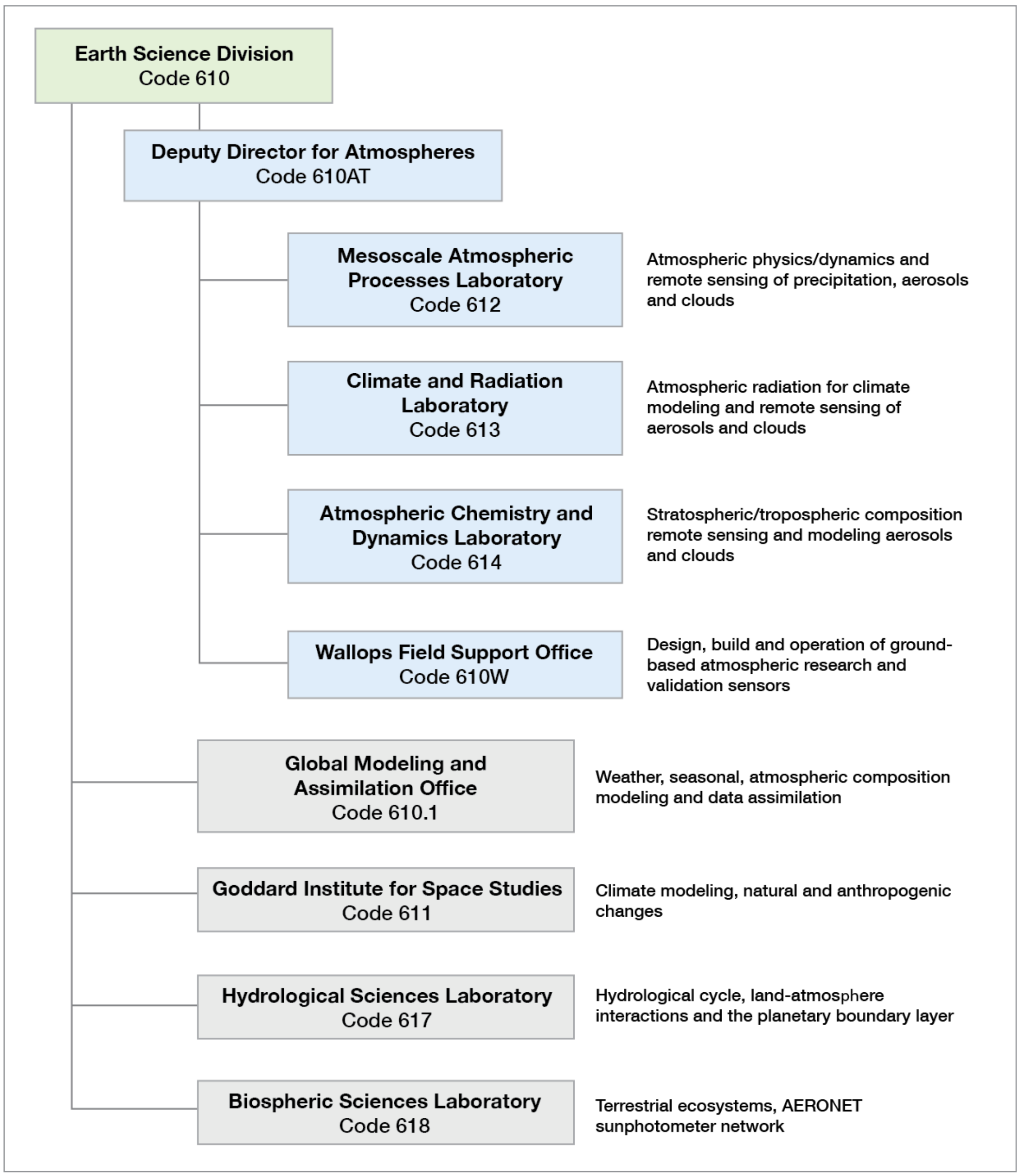

Figure 1.1: *Relationship of 610AT organization to other 610 laboratories and offices performing atmospheric research, and their primary activities.*

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.

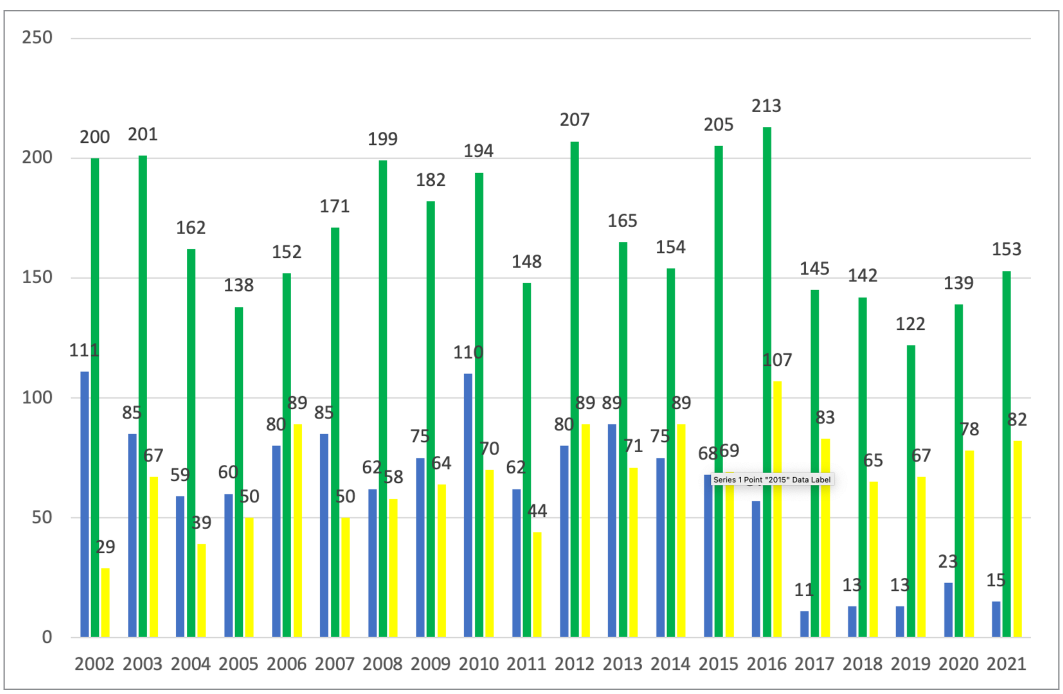

Figure 1.2: *Number of proposals and refereed publications by atmospheric sciences members over the years. The green bars are the total number of publications, and the blue bars are the number of publications where a laboratory member is first author. Proposals submitted are shown in yellow.*

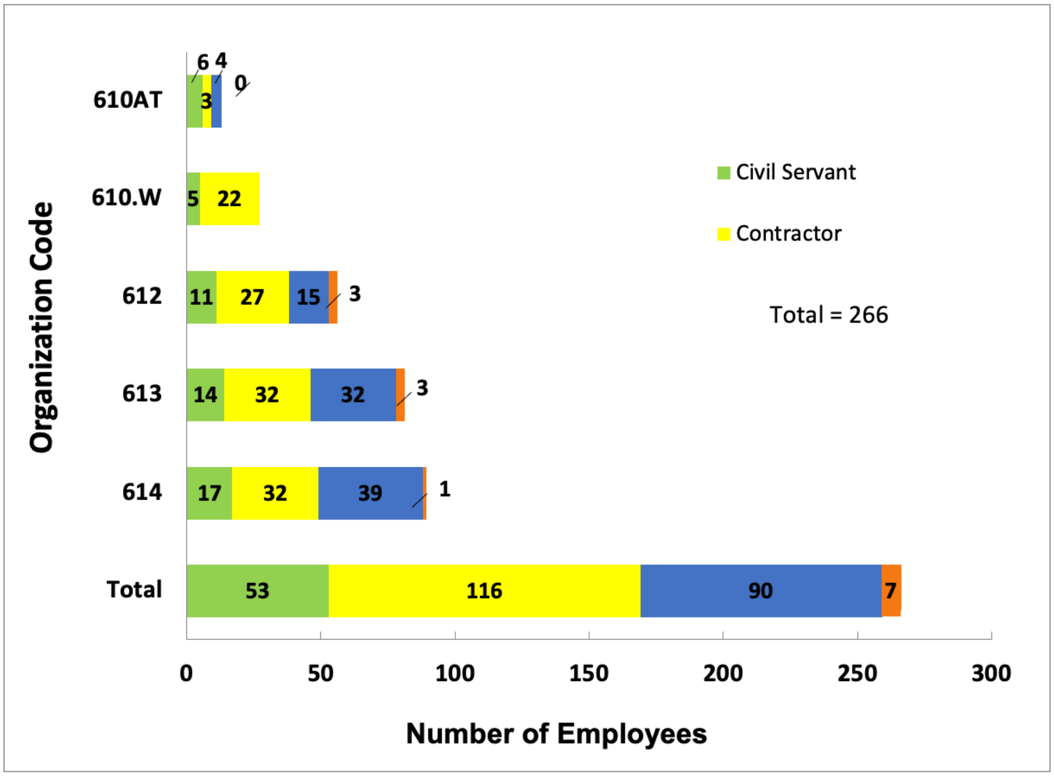

Figure 1.3: *Breakdown of the organizational employee mix.*

2. SCIENCE HIGHLIGHTS

Atmospheric research at Goddard has a long history (more than 60 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 is 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). The Earth Science and Applications from Space (ESAS) is the 2017-2027 Decadal Survey that will help shape science priorities and guide agency investments into the next decade. Many of our scientists are expected to contribute to surveys and other functions.

The following sections summarize some of the scientific highlights of each laboratory and the Wallops Field Office for the year 2021. 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. Beginning in August, highlights can be found at the NASA Research Portal: 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 below.

2.1.1. Analysis of GPM Microwave Imager Lake Effect Snow Retrievals Provides Improvements to the GPROF Operational Algorithm

Lake effect snow events have the potential to produce massive quantities of snow, severely impacting travel and commerce. Given the value of space-based observations of precipitation, especially in orographically complex regions, accurate quantification of snowfall is vital for local emergency management officials to ensure public safety. However, the shallow nature of these events and poorly characterized surface backgrounds present particular challenges for spaceborne precipitation sensors. This study focuses on the ability of the Global Precipitation Measurement (GPM) passive microwave sensors to detect and quantify extreme lake-effect snowfall events over the United States lower Great Lakes region. GPM Microwave Imager (GMI) high frequency channels can clearly detect intense shallow convective snowfall events. However, the GMI Goddard Profiling (GPROF) retrievals produce inconsistent results when compared against the Multi-Radar/Multi-Sensor (MRMS) ground-based radar reference dataset. This study suggests that it is particularly important to have more accurate GPROF surface classification and better representativeness of the *a priori* databases to improve intense lake-effect snow detection and retrieval performance. The results of this work will be particularly useful for the Aerosols, Clouds, Convection, and Precipitation Decadal Survey concept that will pair relevant radiometer bands with radars much more suited for observing snowfall than the current generation of spaceborne cloud and precipitation radars.

Contributors: Lisa Milani (NASA/GSFC, Code 612,UMD), M.S. Kulie (NOAA), D. Casella (ISAC-CNR), P.E. Kirstetter (NOAA), G. Panegrossi (ISAC-CNR), V. Petkovic (UMD), S.E. Ringerud (NASA/GSFC, Code 612/UMD), J-F. Rysman; P. Sanò (ISAC-CNR), N-Y. Wang (NOAA), Y. You (UMD), G. Skofronick-Jackson (NASA/HQ)

Reference: Milani, L., et al., 2020: Extreme lake-effect snow from a GPM microwave imager perspective: Observational analysis and precipitation retrieval evaluation. *J. Atmos. Oceanic Technol.*, doi: 10.1175/jtech-d-20-0064.1.

2.1.2. Inclusion of Dynamic Surface Information Improves GPM Precipitation Retrievals

Improving estimates of global precipitation is of fundamental importance for countless applications, ranging from real-time hazard monitoring to numerical weather prediction and global energy budgets. Accurate, physically based precipitation retrieval over global land surfaces is an important goal and a difficult problem for the passive microwave constellation, as the signal over radiometrically warm land surfaces in the microwave frequencies means that the measurements used are indirect, and typically require inferring some type of relationship between an observed scattering signal and precipitation at the surface. GPM, with collocated radiometer and dual-frequency radar, is an excellent tool for tackling this problem and improving global retrievals. Validation efforts suggest that the operational GPM passive microwave algorithm, the Goddard Profiling Algorithm (GPROF) tends to overestimate precipitation at the low (< 5 mm/h) end of the distribution over land. In this work, retrieval sensitivities to dynamic surface conditions are explored through enhancement of the algorithm with dynamic, retrieved information from a GPM-derived optimal estimation scheme. The retrieved parameters describing surface and background characteristics replace current static or ancillary GPROF information including emissivity, water vapor, and snow cover. Results show that adding this information decreases probability of false detection by 50% and, most importantly, the enhancements with retrieved parameters move the retrieval away from dependence on outside ancillary datasets (such as snow cover) and lead to improved physical consistency.

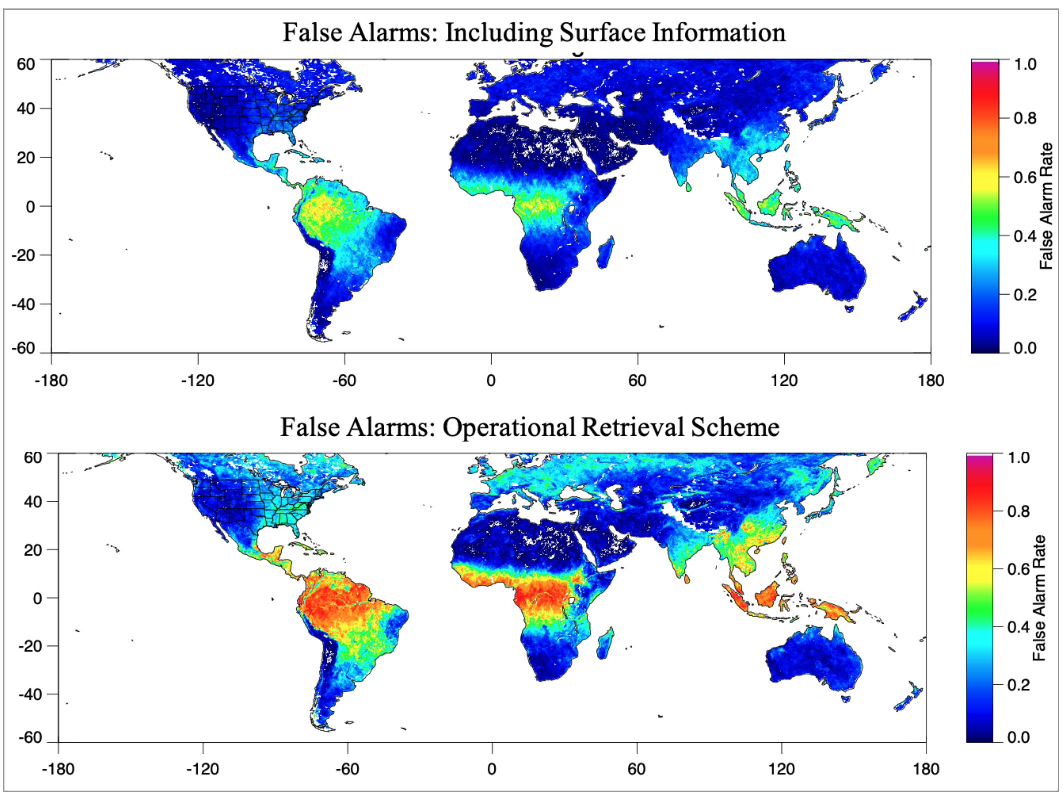

Figure 2.1.2: *Ratio of retrieval false alarms to all observations for the one-year period, September 2015-August 2016. The bottom panel shows results using the GPROF classification scheme, while the upper panel shows results using the hybrid retrieval incorporating dynamic surface emissivity information, demonstrating the global decrease in false alarms over land using the emissivity information.*

Contributors: Sarah Ringerud (NASA/GSFC, Code 612,UMD), Christa Peters-Lidard (NASA/GSFC, Code 610), S. Joe Munchak (NASA/GSFC, Code 612), Yalei You (UMD)

Reference: Ringerud, S., C. Peters-Lidard, S. J. Munchak, Y. You, 2020: Applications of Dynamic Land Surface Information for Passive Microwave Precipitation Retrieval, *J. Atmos. Oceanic Technol.*, doi: 10.1175/JTECH-D-20-0048.1.

2.1.3. Polarized Micro Pulse Lidar Retrievals Provide Vertical Observations of Cloud Thermodynamic Phase

A new algorithm developed by MPLNET distinguishes cloud thermodynamic phase based on the volume depolarization ratio, which is a proxy for particle shape. Ice particles, which are irregularly shaped, have higher volume depolarization ratios than spherically-shaped liquid water droplets. In between -40°C and 0°C, clouds can exist as liquid, ice, or mixed phase. A comparison to satellite-derived supercooled liquid water fractions (SLF) from CALIOP shows good agreement. Future changes in Earth's climate may result in changes in the occurrence and global distribution of cloud types. So, it is important to record and monitor cloud phases across all climate regions. Furthermore, more frequent and diverse observations of cloud phase (in particular, ice and mixed phase) are needed to improve cloud parameterizations in numerical weather prediction and climate models. The ability to provide continuous observations of cloud properties, including thermodynamic phase, across all climate regions using a standardized instrument and retrieval process is a distinctive feature of MPLNET. In future studies, we endeavor to explore how cloud properties differ amongst MPLNET sites and explain the differences between satellite and ground-based lidar measurements. This work also aligns with a goal of the Aerosols, Clouds, Convection and Precipitation (ACCP) mission to improve our understanding of cold (supercooled liquid, ice, and mixed phase) cloud processes.

Contributors: Jasper Lewis (NASA/GSFC, Code 612, UMBC/JCET), Ellsworth Welton (NASA/GSFC, Code 612), James Campbell (NRL), Sebastian Stewart (NASA/GSFC, Code 612, SSAI), Ivy Tan (McGill Univ.), Simone Lolli (CNR-IMAA)

Reference: Lewis, J. R., J. R. Campbell, S. A. Stewart, I. Tan, E. J. Welton and S. Lolli, 2020: Determining cloud thermodynamic phase from the polarized Micro Pulse Lidar. *Atmos. Meas. Tech.*, 13, 6901-6913. https://doi.org/10.5194/amt-13-6901-2020.

2.1.4. Elucidating Impacts of Aerosol and Environmental Conditions on Maritime and Continental Deep Convective Systems Using a Bin Microphysical Model

Improving our physical understanding and model representations of cloud, precipitation and dynamical processes within deep convective storms is an overarching ACCP goal. A series of model simulations using the Weather Research and Forecasting (WRF) model with detailed bin cloud microphysics were conducted to investigate the effects of cloud condensation nuclei (CCN) loading as well as thermodynamic condition on tropical maritime and mid-latitude continental deep convection systems. The results showed that surface precipitation rates monotonically increase with increasing CCN loading for both the maritime and continental situations, while these monotonic increases are disrupted in the simulations with reduced convective available potential energy (CAPE). The increase in precipitation is in the form of convective precipitation, at the expense of stratiform precipitation. CCN loading increases in supercooled cloud water, in agreement with previous modeling studies. However, in the simulations investigated herein, the changes in supercooled water have different impacts on the cloud microphysics in the maritime and continental simulations. Increased supercooled water contents lead to more hail (more dense and solid) and less graupel (soft and less dense) in the continental convection system. For the maritime simulation, on the other hand, enhanced supercooled cloud water contents promote an increase in graupel since little or no hail is produced. This distinction is due to the difference in relative magnitudes and peak altitudes of supercooled water and snow amounts, which is further attributable to the difference in the vertical structure of humidity and dynamics in the maritime and continental conditions.

Contributors: Takamichi Iguchi (NASA/GSFC, Code 612, UMD), Wei-Kuo Tao (NASA/GSFC, Code 612), Toshihisa Matsui (NASA/GSFC, Code 612, UMD), Stephen E. Lang (NASA/GSFC, Code 612, SSAI), Steven A. Rutledge (CSU), Brenda Dolan, Julie Barnum (CSU)

Reference: Iguchi, T., S. A. Rutledge, W. -K. Tao, T. Matsui, B. Dolan, S. E. Lang and J. Barnum, 2020: Impacts of aerosol and environmental conditions on maritime and continental deep convective systems using a bin microphysical model. *J. Geophys. Res.: Atmos.*, 125, e2019JD030952, https://doi.org/10.1029/2019JD030952.

2.1.5. PACRAIN Atoll Gauge Observations Validate High Quality Monthly IMERG Precipitation Estimates over the Data-Sparse Open Ocean

Satellite precipitation products provide key input to environmental applications and global water and energy cycle studies. Precipitation over land and ocean are intricately linked. Therefore, performing validation over open ocean is important. However, validation over the vast expanses of the oceans is difficult due to the general lack of surface data. The Integrated Multi-Satellite Retrievals for the Global Precipitation Measurement (GPM) mission (IMERG) dataset provides a nearly unbiased estimate of precipitation across the tropical Pacific Ocean when compared to rain gauges positioned on 37 low-lying atolls. This thin scatter of islands is considered an approximation of open-ocean conditions, and therefore provides the best validation for the highly used IMERG data in this important but data sparse region. IMERG is the most highly used GPM product and is in current use for a broad range of applications, e.g., monitoring severe weather and understanding climate variability. As such, it is important to characterize its performance in various climate zones, including the tropical oceans. This work is significant not only from the standpoint of informing current users of products' characteristics, but also for providing valuable information for future upgrades to IMERG.

Contributors: David T. Bolvin (NASA/GSFC, Code 612, SSAI), George J. Huffman (NASA/GSFC, Code 612), Eric J. Nelkin (NASA/GSFC, Code 612, SSAI), Jackson Tan (NASA/GSFC, Code 613, USRA)

References: Bolvin, D. T., G. J. Huffman, E. J. Nelkin, and J. Tan, 2021: Comparison of Monthly IMERG Precipitation Estimates with PACRAIN Atoll Observations. *J. Hydrometeorol.*, accepted. doi:10.1175/JHM-D-20-0202.1.

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

Snow provides much of the water we drink and use for irrigation, and large snowfall events can have significant impacts on commerce and public safety. Additionally, both falling and ground-cover snow are important components of climate variability and change. Thus, the ability to properly sample and quantify snowfall and maintain long-term, consistent records is key for snow science and applications. The Cloud Profiling Radar (CPR) on board CloudSat is sensitive to snowfall, and other satellite missions (e.g., GPM) and climatological models have used snowfall properties measured by it for evaluating and comparing against their snowfall products. Since a battery anomaly in 2011, the CPR has operated in a Daylight-Only Operations (DO-Op) mode, in which it makes measurements primarily during only the daylit portion of its orbit. For multi-year global mean values, the snowfall fraction during DO-Op changes by -10.16% and the mean snowfall rate changes by -8.21% compared with Full-Op. The results highlight the need to sample consistently with the CloudSat observations or to adjust snowfall estimates derived from CloudSat when using DO-Op data to evaluate other precipitation products.

Contributors: Lisa Milani (NASA/GSFC, Code 612, UMD), Norman B. Wood (SSEC/UW-Madison)

Reference: Milani, L., and N. B. Wood, 2021: Biases in CloudSat Falling Snow Estimates Resulting from Daylight-Only Operations. *Remote Sens.*, 13, 2041. https://doi.org/10.3390/rs13112041.

2.1.7. Aerosol and Cloud Detection Using Machine Learning Algorithms and Space-Based Lidar Data

For the first time, machine learning (ML) techniques were applied to space-based lidar data by denoising Cloud-Aerosol Transport System (CATS) data and using CATS data to train a Convolutional Neural Network (CNN). These ML techniques (1) increased the CATS signal-to-noise ratio by 75%; (2) increased the number of atmospheric features detected by 30%; and (3) improved the horizontal resolution of daytime feature detection by a factor of 12. These ML tools can be infused into future lidar instruments to improve data product latency, resolution, and accuracy. Utilizing a combination of traditional techniques and these ML methods can improve the accuracy, resolution, and utility of existing and future space-based lidar datasets, especially during daytime. Such improvements enable researchers to combine passive daytime measurements more confidently with lidar observations for accurate data analysis. ML algorithms can also be incorporated into future space-based lidar missions and performed on raw data to enable near-real time (NRT) atmospheric feature height and type data products that have short latencies (< 1 h processing time). Such NRT data products can be used as aerosol model input to improve monitoring and forecasting of volcanic and smoke plumes.

Contributors: John Yorks (NASA/GSFC, Code 612), Matt McGill (NASA/GSFC, Code 610), Ed Nowottnick (NASA/GSFC, Code 612), Patrick Selmer (NASA/GSFC, Code 612, SSAI), Andrew Kupchock (NASA/GSFC, Code 612, SSAI)

Reference: Yorks, J. E., P. A. Selmer, A. Kupchock, E. P. Nowottnick, K. Christian, D. Rusinek, N. Dacic, and M. J. McGill, 2021: Aerosol and Cloud Detection Using Machine Learning Algorithms and Space-Based Lidar. *Atmos.*, accepted.

2.1.8. Quantitative Investigation of Radiometric Interactions Between Snowfall, Snow Cover, and Cloud Liquid Water Over Land

https://esdresearch.nasa.gov/result/quantitative-investigation-radiometric-interactions-between-snowfall-snow-cover-and-cloud

Reference: Takbiri, Z., L. Milani, C. Guilloteau and E. Foufoula-Georgiou, 2021: Quantitative Investigation of Radiometric Interactions between Snowfall, Snow Cover, and Cloud Liquid Water over Land. *Remote Sens.*, 13, 2641. https://doi.org/10.3390/rs13132641.

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

https://esdresearch.nasa.gov/result/improving-cross-track-scanning-radiometers-precipitation-retrieval-over-ocean-morphing

Reference: You, Y., C. Peters-Lidard, S. J. Munchak, J. Tan, S. Braun, S. Ringerud, W. Blackwell, J. X. Yang, E. Nelkin and J. Dong, 2021: Improving Cross-track Scanning Radiometers' Precipitation Retrieval over Ocean by Morphing. *J. Hydrometeorol.*, 22(9), 2393-2406. https://doi.org/10.1175/JHM-D-21-0038.1.

2.1.10. SHARPEN: A Scheme to Restore the Distribution of Averaged Precipitation Fields

https://esdresearch.nasa.gov/result/sharpen-scheme-restore-distribution-averaged-precipitation-fields

Reference: Tan, J., G. J. Huffman, D. T. Bolvin, E. J. Nelkin and M. Rajagopal, 2021: SHARPEN: A Scheme to Restore the Distribution of Averaged Precipitation Fields. *J. Hydrometeorol.*, 22(8), 2105-2116. https://doi.org/10.1175/JHM-D-20-0225.1.

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 I 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 PIs 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 of 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 2021 are summarized below.

2.2.1. Spectral Aerosol Absorption from DSCOVR EPIC

We developed a new capability for simultaneous retrieval of aerosol optical depth (AOD) and spectral absorption of biomass burning smoke and mineral dust from DSCOVR EPIC observations in the UV-Visible part of spectrum. It is integrated in version 2 (v2) MAIAC EPIC atmospheric correction algorithm which recently completed re-processing of the EPIC 2015-2020 data record. Besides AOD, spectral surface reflectance and BRDF, v2 MAIAC reports at 10km resolution aerosol single scattering albedo (SSA) at 443nm, imaginary refractive index at 680nm (k_0) and spectral absorption exponent (b) characterizing dependence $k(\lambda)$. Aerosol absorption has a high natural variability and is poorly constrained in models. This makes it one of the largest sources of uncertainty in assessments of aerosol direct radiative effects and in current climate projections [IPCC 2013]. Information on spectral dependence of aerosol absorption provides a pathway to the speciation of absorbing aerosol components [e.g., Schuster et al., 2016]—information required in climate modeling and in air quality research. In v2 MAIAC EPIC algorithm, we developed a capability to simultaneously retrieve AOD and spectral aerosol absorption using the following model for spectral imaginary refractive index $k_\lambda = k_0 (\lambda/\lambda_0)$-b, where λ_0 = 680nm. An initial validation of single scattering albedo over North America and northern Africa in 2018 shows good agreement with AERONET, typically within the AERONET uncertainty of ±0.03.

Contributors: A. Lyapustin (NASA/GSFC, Code 613), S. Go, (NASA/GSFC, Code 613), Y. Wang, (NASA/GSFC, Code 613), S. Korkin (NASA/GSFC, Code 613)

References: Lyapustin, A., S. Go, S. Korkin, Y. Wang, O. Torres, H. Jethva, A. Marshak, 2021: Retrievals of Aerosol Optical Depth and Spectral Absorption from DSCOVR EPIC. *Front.Remote Sens.*, in review.

Lyapustin, A., Y. Wang, S. Korkin and D. Huang, 2018: MODIS Collection 6 MAIAC Algorithm. *Atmos. Meas. Tech.*, 11, 5741-5765. https://doi.org/10.5194/amt-11-5741-2018.

Torres, O., C. Ahn, and Z. Chen, 2013: Improvements to the OMI near-UV aerosol algorithm using A-train CALIOP and AIRS observations. *Atmos. Meas. Tech.*, 6(11), 3257-3270. https://doi.org/10.5194/amt-6-3257-2013.

Schuster, G., O. Dubovik and A. Arola, 2016: Remote sensing of soot carbon–Part 1: Distinguishing different absorbing aerosol species. *Atmos. Chem. Phys.*, 16, 1565-1585. doi:10.5194/acp-16-1565-2016.

2.2.2. Satellite Observations Reveal that Mesoscale Dynamics and Precipitation Life Stage Have Strong Links to Ice Crystal Microphysics

NASA's 2017 Earth Science Decadal Survey prioritized cloud convection precipitation (CCP) as one of the five designated observables for future mission planning. This work provides a novel way of using polarized passive microwave measurements to study interlinked CCP processes. Leveraging on collocated spaceborne GPM-GMI, GPM-Ku, GPM-Ka and CloudSat-band radars together with auxiliary temperature and wind information, we found that the differences between GMI 166 GHz polarized radiances are linked to ice microphysics (shape, size, orientation and density), mesoscale dynamic and thermodynamic structures, as well as surface precipitation stage (developing, mature or decaying). We conclude that passive sensors with multiple polarized channel pairs at microwave, sub-millimeter, infrared and visible wavelengths may be less expensive and greater spatiotemporal coverage substitutes for spaceborne multi-frequency radars for probing CCP processes. This work calls for more comprehensive understanding and modeling of radiative transfer involving non-spherical frozen hydrometeers with preferential alignment especially at microwave and sub-millimeter spectrum, as well as, more in-situ observations to resolve the ambiguity caused by large footprints and sparse/imperfect collocations between CloudSat and GPM..

Contributors: Jie Gong (NASA/GSFC, Code 613, USRA) and Dong L. Wu (NASA/GSFC, Code 613)

Reference: Gong, J., X. Zeng, D. L. Wu, S. J. Munchak, X. Li, S. Kneifel, D. Ori, L. Liao and D. Barahona, 2020: Linkage among ice crystal microphysics, mesoscale dynamics, and cloud and precipitation structures revealed by collocated microwave radiometer and multifrequency radar observations. *Atmos. Chem. Phys.*, 20, 12633-12653, doi: 10.5194/acp-20-12633-2020.

2.2.3. Global Daytime Variability of Clouds From DSCOVR/EPIC Observations

Knowledge of the daytime variability of cloud fraction is pivotal for the accurate determination of the atmosphere's energy balance. Leveraging EPIC observations from the Lagrange L1 point, allows us to overcome common limitations of measuring global cloud variability such as (1) The fixed daytime acquisition time of polar orbit observations; (2) The regionality of geostationary satellites; and (3) The combination of different sources of observations (as in ISCCP—the International Satellite Cloud Climatology Project). Our diurnal values of cloud fraction with hourly resolution come from a single sensor and can be used to benchmark for GCMs and improve our knowledge of the effect of diurnal cloud fraction variability on climate evolution. These findings show that there are more liquid water clouds overland and fewer over ocean around noon compared to morning and afternoon. In contrast, the daytime cycle of ice clouds is independent of the underlying surface type, with larger cloud fraction in the morning and afternoon compared to noon.

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

Reference: Delgado-Bonal, A., A. Marshak, Y. Yang and L. Oreopoulos, 2020: Global daytime variability of clouds from DSCOVR/EPIC observations. *Geophys. Res. Lett.*, 48, e2020GL091511. https://doi.org/10.1029/2020GL091511.

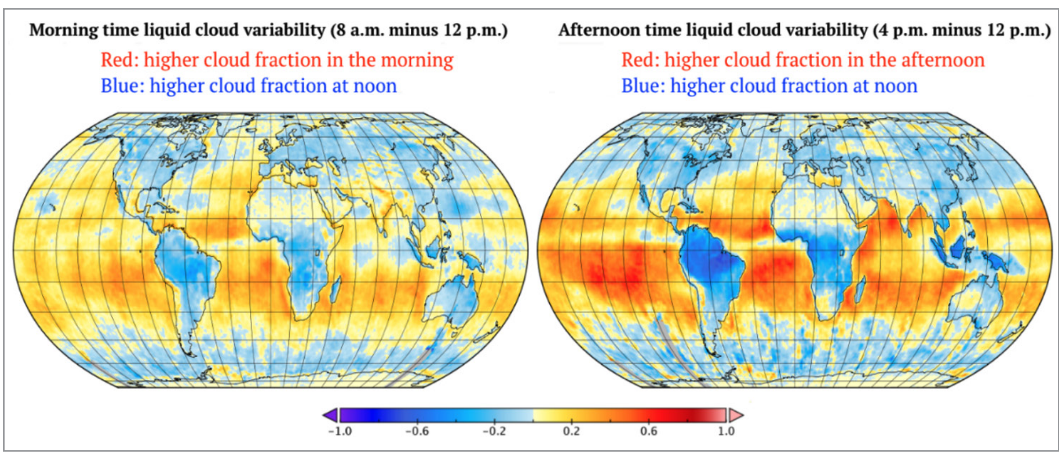

Figure 2.2.3: *The figures present the morning (left) and afternoon (right) global variability of cloud fraction for boreal spring (March-April-May). The EPIC instrument aboard the DSCOVR satellite observes the recurring sunlit disc reflectance at 10 wavelengths (317, 325, 340, 388, 443, 551, 680, 688, 764 and 780 nm) either every hour (boreal winter) or every two hours (boreal summer).*

2.2.4. Study of Antarctic Blowing Snow Storms Using MODIS and CALIOP Observations With a Machine Learning Model

BLSN (Blowing Snow) storms have significant impacts on the Antarctic surface mass balance, radiation budget, and planetary boundary processes. CALIPSO has been playing an essential role in BLSN observations. However, the single pixel width of CALIPSO observations has limited our knowledge of the spatial extent of BLSN storms. This study developed a framework for BLSN storm analysis using MODIS observations. A machine learning model based on the random forest algorithm is developed for the classification of MODIS pixels into clear, cloudy and BLSN. CALIPSO observations are used as the ground truth for the training of the machine learning model. BLSN storms are identified using the classified MODIS images with the DBSCAN clustering algorithm. The framework is applied to MODIS observations during the month of October 2009. The MODIS based BLSN storm frequency map extends the CALIPSO BLSN coverage limit from 82°S to the South Pole. The BLSN storm belt from the South Pole region to the coastal area between 130°E and 160°E along the Transantarctic Mountains provides a potential pathway of snow transport. Results also show that BLSN storms have a large range of sizes, covering areas as large as hundreds of thousands km^2. This is the first time that the spatial distribution of BLSN storms over the entire Antarctic continent is obtained from observations.

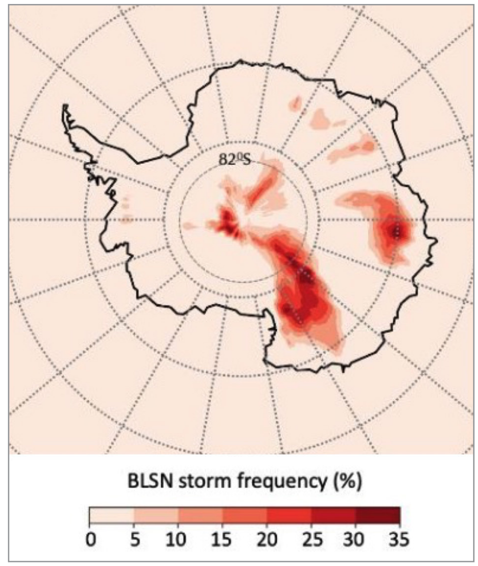

Figure 2.2.4: *Antarctic BLSN storm frequency over the Antarctic continent for the month of October 2009. 82°S is the southernmost latitude of CALIPSO observations.*

Contributor: Yuekui Yang (NASA/GSFC, Code 613)

Reference: Yang, Y., A. Anderson, D. Kiv, J. Germann, M. Fuchs, S. Palm and T. Wang, 2021: Study of Antarctic blowing snow storms using MODIS and CALIOP observations with a machine learning model. *Earth Space Sci.*, 8, e2020EA001310. https://doi.org/10.1029/2020EA001310.

2.2.5. Observational Evidence of Increasing Radiative Forcing

This work provides the first observational evidence that radiative forcing has been increasing on the global scale. This is arguably the most direct evidence ever produced that human activity, largely by increasing greenhouse gas emissions, is changing the climate. Using NASA satellite data, we provide the first observational diagnosis of radiative forcing, namely the component of Earth's radiative energy imbalance directly caused by a change in the composition of the atmosphere. The steadily increasing global radiative forcing from 2003-2018 is direct evidence of human impact on climate through a combination of rising greenhouse concentrations and, to a lesser extent, reduced aerosol emissions.

Contributors: Ryan Kramer (NASA/GSFC, Code 613, UMD) and Lazaros Oreopoulos (NASA/GSFC, Code 613)

Reference: Kramer, R. J., H. He, B. J. Soden, L. Oreopoulos, G. Myhre, P. M. Forster and C. J. Smith, 2021: Observational Evidence of Increasing Global Radiative Forcing. *Geophys. Res. Lett.*, 48(7). https://doi.org/10.1029/2020GL091585.

2.2.6. Observing Water Vapor Changes Near Clouds with Ground-Based Shortwave Spectrometers

The transition zone between cloudy and clear air is a region of strong aerosol-cloud interactions where aerosol particles humidify and swell when approaching the cloud, while cloud drops evaporate and shrink when moving away from the cloud. Thus, cloud droplets, aerosol particles, and water vapor coexist and interact in this special region. We developed a new technique to retrieve column water vapor amount from a ground-based spectroradiometer with narrow FOV and high sampling frequency that resolves the fine structure of the transition zone. The new technique is able to retrieve precipitable water vapor (PWV) amount in the clear-cloud transition zone using ground-based measurements of the relative difference in zenith radiance at the 720nm water vapor band and the adjacent non-absorbing band at 750nm. By being able to infer PWV variations in the cloud-clear transition zone we will be better positioned to understand aerosol-cloud interactions. Quantifying water vapor variation complements our earlier studies which focused on cloud optical depth and droplet size variation in the clear-cloud transition zone. It can potentially lead to improvements in space-based estimates of aerosol radiative forcing and aerosol indirect effects.

Contributors: Guoyong Wen (NASA/GSFC, Code 613, MSU) and Alexander Marshak (NASA/GSFC, Code 613)

References: Wen., G. and A. Marshak, 2021: Precipitable Water Vapor Variation in the Clear-Cloud Transition Zone From the ARM Shortwave Spectrometer. *IEEE Geosci. Remote Sens. Lett.*, doi:10.1109/LGRS.2021.3064334.

Pinsky, M., and A. P. Khain, 2018: Theoretical analysis of the entrainment–mixing process at cloud boundaries. Part I: Droplet size distributions and humidity within the interface zone. *J. Atmos. Sci.*, 75, 2049-2064. https://doi.org/10.1175/JAS-D-17-0308.1.

2.2.7. The Sun Glints of Ice Clouds, Oceans, and Lakes as seen by DSCOVR

DSCOVR EPIC images often feature sun glints caused by the specular reflection of sunlight by the surface water of calm oceans and lakes and from horizontally oriented ice crystals in high clouds. Spatial, spectral, and seasonal variations in glints help characterize the observed scenes and evaluate the accuracy of EPIC image geolocation. Characterizing glint behavior helps us better understand variations in the properties and radiative impacts of ice clouds over both land and ocean. The results demonstrate that satellite observations of sun glint enable more accurate determination of pixel location in satellite images, which can be especially important in areas lying far from coastlines typically used for verifying and refining pixel locations. Glints also provide insight about ice crystal structure.

References: Várnai, T., A. Kostinski and A. Marshak, 2020: Deep space observations of sun glints from marine ice clouds. *IEEE Remote Sens. Lett.*, 17, https://doi.org/10.1109/LGRS.2019.2930866.

Várnai, T., A. Marshak and A. Kostinski, 2020: Deep space observations of sun glints: spectral and seasonal dependence. *IEEE Remote Sens. Lett.* https://doi.org/10.1109/LGRS.2020.3040144.

Kostinski, A., A. Marshak and T. Várnai, 2021: Deep space observations of terrestrial glitter. *Earth Space Sci.*, 8, e2020EA001521. https://doi.org/10.1029/2020EA001521.

2.2.8. Observation and Modeling of the Historic "Godzilla" African Dust Intrusion into the Caribbean Basin and the Southern U.S. in June 2020

https://esdresearch.nasa.gov/result/observation-and-modeling-historic-godzilla-african-dust-intrusion-caribbean-basin-and

Reference: Yu, H., et al., 2021: Observation and modeling of the historic "Godzilla" African dust intrusion into the Caribbean Basin and the southern U.S in June 2020. *Atmos. Chem. Phys.*, 21, 12359-12383. https://doi.org/10.5194/acp-21-12359-2021.

2.2.9. Aerosol Properties in Cloudy Environments from Remote Sensing Observations: Review of Current State of Knowledge

https://esdresearch.nasa.gov/result/aerosol-properties-cloudy-environments-remote-sensing-observations-review-current-state

Reference: Marshak, A. Ackerman, A. Da Silva, T. Eck, B. Holben, R. Kahn, R. Kleidman, K. Knobelspiesse, R. Levy, A. Lyapustin, L. Oreopoulos, L. Remer, O. Torres, T. Varnai, G. Wen and J. Yorks, 2021: Aerosol properties in cloudy environments from remote sensing observations: review of current state of knowledge. *Bull. Am. Meteorol. Soc.*, 102, 11 (submitted Feb. 2021, accepted June 24, 2021). doi: 10.1175/BAMS-D-20-0225.1.

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 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. Calculating the Height of Volcanic Cloud SO_2 With a Lagrangian Trajectory Tool: Raikoke (2019) and Pinatubo (1991) Cases

We have developed a new trajectory tool to predict the position and heights of SO_2/aerosol clouds ejected by a volcanic eruption. We initialize the model using SO_2 or aerosol column 2D observations from nadir looking satellite UV spectrometers, such as SNPP/OMPS, Aura/OMI or Sentinel-5 Precursor (TROPOMI) within 1-2 days after a volcanic eruption. Next, we create a 3D model of the volcanic cloud at the overpass time, reconstructing the vertical distribution using backward trajectories to the volcano location.

For near real-time cloud predictions (which is important for the protection of the population and aircraft), we use forward trajectory modeling with input wind fields from the Goddard Earth Observing System (GEOS) model. This allows us to create a short-term 4D concentration forecast to improve SO_2/aerosol satellite retrievals and to assimilate into GEOS model. We demonstrate our tool for predicting the dispersion of SO_2 clouds after the June 21, 2019, Mt. Raikoke eruption. We created an initial 3D model of the cloud based on the SNPP/OMPS column SO_2 observations and then compared this to SO_2 observations by TROPOMI. Good agreement between the predicted and observed 2D distributions SO_2 shows that this method can be used for near real time prediction of the dispersion of volcanic gases and aerosols for air quality alerts and aviation avoidance.

Contributors: Nick Gorkavyi (NASA/GSFC, Code 619, SSAI), Nickolay A. Krotkov (NASA/GSFC, Code 614), C. Li, Leslie R. Lait (NASA/GSFC, Code 614), Alexander P. Vasilkov (NASA/GSFC, Code 614, SSAI), Peter R. Colarco (NASA/GSFC, Code 614), Joanna Joiner (NASA/GSFC, Code 614), M. Schoeberl, S. Carn, Bradford L. Fisher (NASA/GSFC, Code 614, SSAI)

Reference: Gorkavyi, N., N. Krotkov, C. Li, L. Lait, A. Vasilkov, P. Colarco, J. Joiner, J., M. Schoeberl, S. Carn, B. Fisher: Calculating the Height of Volcanic Cloud SO_2 With a Lagrangian Trajectory Tool: Raikoke (2019) and Pinatubo (1991) Cases. (Presentations for AGU-2020 and AMS-2021; paper in preparation).

2.3.2. The Jet Stream Controls the Summer Surface O_3-temperature Relationship

Scientific significance, societal relevance, and relationships to future missions: the NASA GMI CTM and in-situ observations indicate significant spatial variations in the sign and strength of the correlation of O_3 with temperature. In continental regions of the midlatitudes, O_3 and temperature are significantly positively correlated, while the correlation is negative over the ocean basins and weak at high latitudes and in the tropics. Sensitivity simulations of the GMI CTM indicate that daily variations in the O_3-temperature relationship are largely driven by transport-related phenomena. The variability of O_3 and temperature are linked to the meridional movement of the jet stream in the Northern Hemisphere midlatitudes. Overland in the midlatitudes, a poleward (equatorward) shift of the jet is associated with increased (decreased) surface-level O_3 and temperature. Over oceans, temperature responds to this meridional movement of the jet in the same fashion as over land, but the poleward (equatorward) movement of the jet decreases (increases) O_3. The jet influences the O_3-temperature relationship through its effects on the surface-level meridional flow, which acts on the background latitudinal gradients of O_3 and temperature, and not due to cyclones and the associated frontal activity, as has been previously suggested. This research is directly responsive to Science and Application Objective W-7 put forth in the 2017 Decadal Survey to understand processes that control tropospheric O_3 variations and trends as well as their impact on atmospheric composition. Our results underscore the importance of considering the role of the jet stream and surface-level flow for understanding the O_3-temperature relationship, especially in light of expected changes to these features under climate change.

Contributors: Gaige Kerr (GSFC Student Research Collaborator) Darryn Waugh (Johns Hopkins University), Sarah Strode (NASA/GSFC, Code 614, MSU), Steven Steenrod (NASA/GSFC, Code 614, UMB), Luke Oman (NASA/GSFC, Code 614), and Susan Strahan (NASA/GSFC, Code 614)

References: Kerr, G. H., D. W. Waugh, S. A. Strode, S. D. Steenrod, L. D. Oman, and S. E. Strahan, 2019: Disentangling the drivers of the summertime ozone-temperature relationship over the United States. *J. Geophys. Res. Atmos.*, 124(19):10503-10524. https://doi.org/10.1029/2019JD030572.

Kerr, G. H., D. W. Waugh, S. D. Steenrod, S. A. Strode, and S. E. Strahan, 2020: Surface ozone-meteorology relationships: Spatial variations and the role of the jet stream. *J. Geophys. Res. Atmos.*, 125(21):e2020JD032735. https://doi.org/10.1029/2020JD032735.

2.3.3. Using NASA Aura MLS and GMAO MERRA-2 Data to Resolve Seasonal Differences in Lower Stratospheric Temperature, Circulation, and Composition Due to the MJO

The intraseasonal (20-90 day) variability of the tropical upper-troposphere and lower-stratosphere (UTLS) is dominated by the Madden–Julian Oscillation (MJO). The MJO's impact on UTLS chemical constituents (such as ozone (O_3), which shields all living organisms from harmful Ultra-Violet (UV) radiation, and water vapor (H_2O), which is an important greenhouse gas) extends far beyond the tropics. Trace gas response is significantly different during boreal winter than summer, and is in agreement with the MJO-induced changes in the temperature and circulation. The analysis of MLS observations presented in this study is useful for evaluation and validation of the MJO-related physical and dynamical processes in models. For instance, it is highly desirable to examine the ability of a range of models to simulate seasonal differences in the UTLS temperature and circulation due to the MJO. The inability of the CCMs to accurately generate shorter-time-scale variability such as that from the MJO, can potentially lead to the lack of or much weaker variability in tropical and extratropical composition of the UTLS. A more realistic representation of the spectrum of variability in climate models will provide a better estimate of future projections. Thus, this study emphasizes the crucial need to continue collecting and evaluating high quality satellite measurements to trace the impact of changes in the UTLS circulation.

Contributors: Olga V. Tweedy et al., NASA/GSFC and NPP/USRA

Reference: Tweedy, O. V., L. D. Oman and D. W. Waugh, 2020: Seasonality of the MJO impact on upper troposphere/lower stratosphere temperature, circulation and composition. *J. Atmos. Sci.*, JAS-D-19-0183.1. https://doi.org/10.1175/JAS-D-19-0183.1

2.3.4. Impacts of the Quasi-Biennial Oscillation (QBO) on Surface N_2O

This work takes a giant step beyond Hamilton and Fan's (2000) original modeling work where the GFDL SKYHI GCM was used with ingenious tracer experiments to show that the stratospheric quasi-biennial oscillation (QBO) produced tropospheric variability in N_2O. In the 20 years since, we have acquired observational datasets showing QBO-like variability in N_2O's stratospheric loss and in the surface abundances. Since then, we have built more numerically accurate chemistry transport models (CTMs) and historical records of the atmospheric circulation (assimilated/analyzed wind fields) that can drive them. This work brings together three independent CTMs, using three different meteorological datasets, plus the NASA Aura satellite observations of stratospheric N_2O, and the NOAA surface measurements. We find that all the models are able to reproduce most of the variability in N_2O from the upper stratosphere down to the surface. This verification of our ability to model chemistry and transport on this scale is exciting. We have mapped out the average effect of the QBO over several cycles on the surface variability of N_2O. This provides a stringent and important test of the stratosphere-troposphere exchange that should be a standard metric in evaluating chemistry-climate models. Being able to remove the chemistry and transport signals from the observed surface record using physically based models as a baseline (instead of statistical fits) allows us to unveil the unique signal of El Niño on N_2O emissions, thus allowing more accurate inverse modeling of the anthropogenic emissions.

Contributors: Daniel Ruiz (UC Irvine), Michael Prather (UC Irvine), Susan Strahan(NASA/GSFC, Code 614, UMBC), Rona Thompson (NILU), Lucien Froidevaux (JPL), Stephen Steenrod (NASA/GSFC, Code 614, UMBC)

Reference: Ruiz, D. J., M. J. Prather, S. E. Strahan, R. L. Thompson, L. Froidevaux, and S. D. Steenrod, 2021: How atmospheric chemistry and transport drive surface variability of N_2O and CFC-11. *J. Geophys. Res.: Atmos.*, 126, e2020JD033979. https://doi.org/10.1029/2020JD033979.

2.3.5. Solar Activity and Responses Observed in Balmer Lines

Daily solar irradiance measurements from Aura/OMI and TROPOMI show that some prominent Fraunhofer lines behave differently from the majority of UV-visible spectral transitions. This finding may ultimately help in deciphering the complex stellar-activity patterns in the search for exo-planets, which requires precise characterization of intrinsic variability patterns of the hosting stars to discriminate planetary signals. The precisions of OMI and TROPOMI are essential for our conclusion that the studied Balmer lines defy the general trends and show high sensitivity to the rise and gradual decay of big sunspot groups, instead of the anticipated governance by hotter solar areas. These lines have been used in numerous astrophysical applications for over a century. We employ the line-index approach (i.e., core-to-wing ratio) in order to minimize instrumental effects, which enables very high individual-measurement precision: ~80 ppm (part-per-million) for the OMI data shown here, and ~30 ppm in the TROPOMI measurements. This precision is essential for our conclusion that the studied Balmer lines defy the general trends and show high sensitivity to the rise and gradual decay of big sunspot groups, instead of the anticipated governance by hotter solar areas. Our result may help in deciphering the complex stellar-activity patterns in search for exoplanets.

Contributors: Sergey V. Marchenko (NASA/GSFC, Code 614, SSAI), Serena Criscuoli (NSO), Matthew T. DeLand (NASA/GSFC, Code 614, SSAI), Debi P. Choudhary (SFO), Greg Kopp (Laboratory for Atmospheric and Space Physics)

Reference: Marchenko, S., S. Criscuoli, M. T. DeLand, D. P. Choudhary, G. Kopp, 2021: Solar Activity and Responses Observed in Balmer Lines. *Astron. Astrophys.*, 646, 81-86, 2021. https://doi.org/10.1051/0004-6361/202037767.

2.3.6. Spatial and Temporal Variability in the Hydroxyl Radical (OH): Understanding the Role of Large-scale Climate Features and Their Influence on OH through its Dynamical and Photochemical Drivers

Tropospheric OH is the dominant sink of CH_4, the second-most important anthropogenic greenhouse gas. Understanding spatial and temporal variability of OH is therefore necessary to understand recent trends in methane, whose atmospheric abundance can be controlled both by changes in emissions and changes in sinks. Observations of OH are sparse, however, as it is low in abundance and short-lived. OH has traditionally been constrained on a global and hemispheric basis by observations of methyl chloroform (MCF). Because of recent declines in MCF concentration, which is now at or below instrumental detection limits, alternative constraints on OH are necessary. Here, based on analysis of the GEOSCCM model, we show that the El Niño Southern Oscillation (ENSO) is the dominant mode of OH variability across all seasons and that satellite retrievals are capable of capturing the ENSO-related variability of OH drivers, including CO, H_2O, and NO_2. These results provide new constraints on the atmospheric oxidative capacity and interannual variability of OH, necessary for understanding the chemistry of a myriad of species. This work also provides the path forward for a potential new way to constrain OH, and thus the methane lifetime, from space using the approximately 20 years of data from EOS satellites. Because most of the species necessary to constrain OH will also be retrieved from recent and upcoming geostationary satellites (e.g., GEMS and TEMPO), the results here could potentially provide a novel use for these missions.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.

Contributors: Daniel Anderson (NASA/GSFC, Code 614, UMBC), Bryan Duncan (NASA/GSFC, Code 614), A. Fiore (CU), C. Baublitz (CU), M. Follette-Cook (NASA/GSFC, Code 614, MSU), Julie Nicely (NASA/GSFC, Code 614, UMD), Glenn Wolfe (NASA/GSFC, Code 614)

Reference: Anderson et al., 2021: Spatial and temporal variability in the hydroxyl radical: understanding the role of large-scale climate features and their influence on OH through its dynamical and photochemical drivers. *Atmos. Chem. Phys.*, 21, 6481-6508. https://doi.org/10.5194/acp-21-6481-2021.

2.3.7. Observations of Lightning NO_x Production from GOES-R Post Launch Test Field Campaign Flights

Reactive nitrogen (NO_x) produced by lightning plays an important role in determining mid- and upper-tropospheric concentrations of the hydroxyl radical (OH), the atmosphere's cleanser; methane (CH_4), an especially potent greenhouse gas; and ozone (O_3), a greenhouse gas and pollutant. In this study, NO_x production per lightning flash was examined over the U.S. using GCAS NO_2 columns and ground-based (ENTLN) and satellite-based (GLM) observations of flashes. This analysis of observations during the GOES-R PLT field campaign provides a preview of the analysis that will be possible when continuous lightning detection from GLM instruments on GOES-16 and 17 is coupled with high spatial and temporal NO_2 columns from a geostationary instrument such as Tropospheric Emissions: Monitoring of Pollution (TEMPO).

Contributors: Dale Allen (NASA/GSFC, Code 614, UMD), Kenneth Pickering (NASA/GSFC, Code 614, Emeritus), Lok Lamsal (NASA/GSFC, Code 614, USRA), Douglas Mach, Mason Quick, Jeff Lapierre, Scott Janz, William Koshak, Matthew Kowalewski (NASA/GSFC, Code 614, USRA), Richard Blakeslee

Reference: Allen, D. J., K. E. Pickering, L. Lamsal, D. Mach, M. G. Quick, J. Lapierre, S. Janz, W. Koshak, M. Kowalewski and R. Blakesleem, 2021: Observations of Lightning NO_x production from GOES-R Post Launch Test Field Campaign Flights, *J. Geophys. Res.: Atmos.* 126(8). https://doi.org/10.1029/2020JD033769.

2.3.8. Australia's Black Summer Pyrocumulonimbus Super Outbreak Reveals Potential for Increasingly Extreme Stratospheric Smoke Events

The paper shows that two distinct phases of the Australian New Year Super Outbreak (ANYSO) pyroCb activity resulted in two of the three largest smoke particle injections into the lower stratosphere observed through March 2021, rivaling or exceeding the stratospheric impact from all volcanic eruptions observed during 2012-2020. The large stratospheric smoke plumes ensuing from ANYSO reached altitudes higher than smoke has ever been observed, encircled a portion of the Southern Hemisphere, altered dynamic circulation, and persisted for more than 15 months. Fewer than three years earlier, the Pacific Northwest Event (PNE) in Canada produced a persistent smoke plume that encircled a portion of the Northern Hemisphere. These regional pyroCb outbreaks represent a new class of stratospheric smoke plumes with the potential for significant climate feedbacks on seasonal and hemispheric scales. Large pyroCb outbreaks also serve as validation for nuclear winter theory, which is based on smoke from burning cities rising into the stratosphere and encircling the globe. The extreme scale of ANYSO therefore motivates a variety of future modeling work to understand the impact of stratospheric smoke plumes on surface cooling, stratospheric chemistry, and dynamic circulation. In addition, OMPS LPs AOD records showed that the highest levels seen during the last decade were observed during 2019-2020, with the Australian fires playing a significant role in reaching that milestone, with two of the four largest stratospheric plumes observed since 2012 therefore, originated from regional outbreaks of intense pyroCb activity.

Contributors: David A. Peterson, Michael D. Fromm, James R. Campbell, Edward J. Hyer, Christopher P. Camacho, George P. Kablick III, (Naval Research Laboratory) Ghassan Taha (NASA/GSFC, Code 614, MSU), Richard H. D. McRae (ACT Emergency Services Agency) Chris C. Schmidt (UWM), Matthew T. DeLand (NASA/GSFC, Code 614, SSAI)

References: Peterson, D. A., M. D. Fromm, R. H. D. McRae, J. R. Campbell, E. J. Hyer, G. Taha, C. P. Camacho, G. P. Kablick III, C. C. Schmidt and M. T. DeLand, 2021: Australia's Black Summer pyrocumulonimbus super outbreak reveals potential for increasingly extreme stratospheric smoke events. *npj Clim. Atmos. Sci.*, 4, 38. https://doi.org/10.1038/s41612-021-00192-9.

Taha, G., R. Loughman, T. Zhu, L. Thomason, J. Kar, L. Rieger and A. Bourassa, 2021: OMPS LP Version 2.0 multi-wavelength aerosol extinction coefficient retrieval algorithm. *Atmos. Meas. Tech.*, 14, 1015-1036. https://doi.org/10.5194/amt-14-1015-2021.

2.3.9. Measuring Atmospheric CO_2 Enhancements from the 2017 British Columbia Using a Lidar

https://esdresearch.nasa.gov/result/measuring-atmospheric-co2-enhancements-2017-british-columbia-using-lidar

Reference: Mao J., J. B. Abshire, S. R. Kawa, H.Riris, X. Sun, N. Andela and P. Kolbeck, 2021: Measuring Atmospheric CO_2 Enhancements from the 2017 British Columbia using a Lidar. *Geophys. Res. Lett.*, 48(16). https://doi.org/10.1029/2021GL093805.

2.3.10. The Long-term Transport and Radiative Impacts of the 2017 British Columbia Pyrocumulonimbus Smoke Aerosols in the Stratosphere

https://esdresearch.nasa.gov/result/long-term-transport-and-radiative-impacts-2017-british-columbia-pyrocumulonimbus-smoke

Reference: Das, S., P. R. Colarco, L. D. Oman, G. Taha and O. Torres, 2021: The Long-term Transport and Radiative Impacts of the 2017 British Columbia Pyrocumulonimbus Smoke Aerosols in the Stratosphere. *Atmos. Chem. Phys.*, 21, 12069-12090. https://doi.org/10.5194/acp-21-12069-2021.

2.3.11. Use of Multi-spectral Visible and Near-infrared Satellite Data for Timely Estimates of the Earth's Surface Reflectance in Cloudy Conditions: Part 2—Image Restoration with HICO Satellite Data in Overcast Conditions

https://esdresearch.nasa.gov/result/use-multi-spectral-visible-and-near-infrared-satellite-data-timely-estimates-earths-surface

Reference: Joiner, J., Z. Fasnacht, B.-C. Gao and W. Qin, 2021: Use of Hyper-Spectral Visible and Near-Infrared Satellite Data for Timely Estimates of the Earth's Surface Reflectance in Cloudy Conditions: Part 2—Image Restoration With HICO Satellite Data in Overcast Conditions. *Front. Remote Sens.*, 2(21). https://doi.org/10.3389/frsen.2021.721957.

2.3.12. CHAPS-D: Targeted Measurements from a Compact Imaging Spectrometer

https://esdresearch.nasa.gov/result/chaps-d-targeted-measurements-compact-imaging-spectrometer

Reference: Swartz, W. H., N. A. Krotkov, L. N. Lamsal, G. C. J. Otter, F. van Kempen, J. D. Boldt, M. F. Morgan, L. van der Laan, W. R. Zimbeck, S. M. Storck, Z. J. Post, S. J. Janz, M. G. Kowalewski, C. Li, J. P. Veefkind and P. F. Levelt, 2021: CHAPS: a sustainable approach to targeted air pollution observation from small satellites, in *Proc. SPIE* 11858, Sensors, Systems, and Next-Generation Satellites XXV, 1185817, doi:10.1117/12.2600175.

3. Major Activities

3.1. Missions

3.1.1. Future Mission Studies

3.1.1.1. AOS (Atmosphere Observing System)

The Atmosphere Observing System (AOS, https://aos.gsfc.nasa.gov) is part of the recently announced Earth System Observatory (ESO, https://science.nasa.gov/earth-science/earth-system-observatory), which arose from key observables identified by the 2017 NASA Earth Science Decadal Survey. ESO will provide key information related to understanding climate change, mitigating natural hazard, fighting forest fires, and improving real-time agricultural processes. AOS will address two of the five ESO areas of focus including:

Aerosols: Answering the critical question of how aerosols determine air quality and affect the global energy balance, a key source of uncertainty in predicting climate change.

Cloud, Convection, and Precipitation: Tackling one of the largest sources of uncertainty in future projections of climate change and targeting processes that influence the prediction of severe weather.

The AOS architecture includes up to 10 sensors, including Doppler radars, lidars, passive microwave radiometers, multi-angle polarimeters, shortwave and longwave spectrometers, and tandem stereo cameras, divided across two orbital planes, a polar sun-synchronous orbit and an inclined orbit. The observing system will also include a suborbital program to address science that can either be done better or only with suborbital measurement. AOS is currently in the mission concept phase (known as pre-Phase A) during which the team is finalizing mission requirements, examining potential international partnerships, prioritizing science capabilities, identifying and characterizing mission data products, and identifying and connecting with key applications communities.

For further information, please contact Scott Braun (NASA/GSFC, Code 612) (scott.a.braun@nasa.gov) or visit the AOS home page at https://aos.gsfc.nasa.gov.

3.1.1.2. 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 (NASA/GSFC, Code 612) is the Goddard project scientist. TROPICS launched a pathfinder satellite (the qualification unit, launched via ride share opportunity) in June 2021 and has produced valuable data (https://www.nasa.gov/feature/esnt/goddard/2021/nasa-s-tropics-pathfinder-satellite-produces-global-first-light-images-and-captures) in preparation for the full mission. The full constellation of six satellites will be launched by Astra Space, Inc. (https://astra.com/news/nasa-tropics-astras-first-earth-science-mission) in early-to-mid 2022. In the time prior to launch of the constellation, activities at Goddard 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 three ~550-km altitude, 30°-inclination orbital planes for at least one year.

For further information, please contact Scott Braun (NASA/GSFC, Code 612): scott.a.braun@nasa.gov.

3.1.1.3. TSIS-2

The Total and Spectral solar Irradiance Sensor-2 (TSIS-2) is a Cat3/Class D free-flyer mission, currently in formulation with the planned launch in 2024. Its main objective is to continue the collection of the key climate record of Total Solar Irradiance (TSI) and Solar Spectral Irradiance (SSI) that have been monitored for several decades from space. The total solar irradiance is the dominant energy source driving the Earth's climate and the most precise indicator of solar energy input to Earth's system. Measuring the incoming solar energy at different wavelength bands provides critical elements for understanding how the energy is absorbed by Earth's atmosphere and surface.

TSIS-2 is a remake of TSIS-1, which has two instruments: the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM), integrated into a single payload. The Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado, Boulder (CU) provided the TIM and SIM instruments. The TSIS-2 project is managed by GSFC with responsibilities including project science, management, system engineering and mission design, safety and mission assurance; spacecraft development, integration, and testing; launch support; mission operations, science operations, and ground data system; science data processing; and data product delivery and archive for public distribution and long-term data preservation.

NASA's Goddard Earth Science Data and Information Services Center (GES DISC) is the Distributed Active Archive Center (DAAC) for public distribution of TSIS-2 data and long-term science data archiving.

The TSIS-2 project scientist has overall management responsibility for the science elements of the project. The nominal mission lifetime is three years with potential two-year extension.

For further information please contact Dong Wu (NASA/GSFC, Code 613): dong.l.wu@nasa.gov.

3.1.2. Active Missions

3.1.2.1. Terra

Terra's 22-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. On 22 September 2021, an outstanding maneuver was performed by the Flight Operations Team at Goddard to successfully reboot Terra's solid-state recorder. Terra has been restored to the level of storage capability it had at launch! There are currently no known hardware limitations to the operation of Terra or any of its sensors, except for the shortwave infrared bands in the ASTER. 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.

Data from the Terra instruments were used in combination with other missions to show that the energy imbalance between that emitted by Earth and the amount of solar energy absorbed by Earth approximately doubled during the 14-year period from 2005 to 2019. Multiple federal and international agencies used Terra's land and atmospheric products for volcanic ash monitoring, weather forecasting, forest fire monitoring, carbon management, and global crop assessment. The mission's long-term record continued to be crucial to assess the impacts to air quality during the initial COVID-19 lockdowns and subsequent increases in transportation and industrial activities both in the United States and globally. Together, Terra's five instruments continued 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 2021 wildfires in the United States. Direct broadcast and near-real-time data products from Terra sensors were especially critical for predictions of local air quality and smoke transport as well as fire management. Terra is currently in extended operations. The 2020 Earth Science Senior Review endorsed the Terra mission for continued operations through 2023. The Terra Project fully expects the Terra platform and all five instruments to operate past 2026 allowing them to maintain their status as leaders in Earth science data production.

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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.

Recent scientific advances enabled by Aqua include long-term records of trace gases affecting air quality and climate (from AIRS), quantifying the substantial increase since 2000 in the global population exposed to floods (from MODIS) and testing how well state-of-the-art climate models represent observed changes in the Earth's radiation budget (from CERES). Furthermore, Aqua data and imagery monitored major environmental events around the world, from Hurricane Delta as it approached the U.S. Gulf Coast in early October 2020 to the volcanic emissions from the eruption of Cumbre Vieja on the Canary Island of La Palma in September 2021.

For further information, please contact Lazaros Oreopoulos (NASA/GSFC, Code 613): 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 short visible wavelengths. In 2020 and 2021, numerous researchers (as indicated by publications) have benefited from the long, stable OMI record in their studies of the impacts of the global pandemic on various air pollutants and their impacts on atmospheric chemistry and human health. Conversely, a number of researchers have used the OMI data, for example, to infer impacts of the pandemic on global economies (as air pollution is a proxy for fossil fuel use) and to infer the timing and effectiveness of lockdowns. One researcher found that OMI nitrogen dioxide data (NO_2) was useful as a proxy for the deceleration of the spread of COVID-19. OMI sulfur dioxide data continued to be used to monitor transient volcanic clouds for aviation avoidance and stratospheric aerosol studies. Observations from MLS continue to be used in a wide range of scientific studies. Most notably, they have been central to further discoveries concerning the impacts on the stratosphere of the catastrophic Australian bush fires at the turn of 2019/2020. MLS and other observations had already shown that multiple thunderstorms triggered by the fires injected distinct plumes of highly polluted air into the stratosphere, where they remained coherent for several months, rising to as high as 30 km altitude. Further examination of MLS observations has revealed that the subsequent dispersal of the smoke particles from these plumes throughout the southern mid-latitude lower stratosphere provoked a conversion of chlorine (largely originating from chlorofluorocarbons and other industrial chemicals) from benign forms into those that destroy stratospheric ozone. Such conversion is already well known to occur on the surfaces of cloud particles in the polar regions, giving rise to the Antarctic "ozone hole" each austral spring. Similar reactions are also known to take place on other types of particles, including those resulting from volcanic eruptions. However, none of the volcanic or other forest fire events in the 17-year MLS record to date have resulted in robustly detectable conversion of stratospheric chlorine into ozone-destroying forms on a hemisphere-wide scale. Nevertheless, the degree of chlorine conversion was smaller than that in typical polar winters, and consistent with that, no significant change in ozone was observed.

More information on Aura science highlights can be found at https://aura.gsfc.nasa.gov or contact Aura's Project Scientist, Bryan Duncan (NASA/GSFC, Code 614) (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. After a nine month hiatus due to the deterioration of its gyros in 2019, DSCOVR returned to full operation in March 2020. The spacecraft now relies only on its star tracker for attitude determination. DSCOVR has ample fuel and power generation capabilities to continue operating for at least through 2030. The DSCOVR NISTAR and EPIC Science Team Meeting was held virtually September 28-30, 2021. The presentations are available at https://avdc.gsfc.nasa.gov/pub/DSCOVR/Science_Team_Meetings/Science_Team_Meeting_Sept_2021. The meeting provided an opportunity to learn the status of EPIC and NISTAR, the status of recently released at the Atmospheric Science Data Center (ASDC) (https://asdc.larc.nasa.gov) improved L2 data products (ozone, sulfur dioxide, aerosols, clouds, vegetation, ocean surface photosynthetically available radiation (PAR) and sun glints), and the science results being achieved from the L1 point. The next STM will be held in the fall of 2022 (hopefully, in person). The special *Frontiers in Remote Sensing* issue, "DSCOVR EPIC/NISTAR: 5 years of Observing Earth from the first Lagrangian Point" has 22 submitted manuscripts. On December 2, 2021, out of them 16 papers have been published or accepted and six remain in review.

For further information, please contact Alexander Marshak (NASA/GSFC, Code 613): 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, Dr. Robert Levy (NASA/GSFC, Code 613) is the Deputy to Flight Project Scientist, Dr. Joel McCorkel (NASA/GSFC, Code 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 postlaunch 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 was 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-West/17 continues to degrade thermally, and so the already-heroic mitigation efforts have been expanded. 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 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. Due to backlogs at the launchpad (primarily COVID-driven), GOES-T is now scheduled to launch no earlier than March 1, 2022. Because of the later launch for GOES-T, it is likely that the Post-Launch-Testing (PLT) will be abbreviated (by then it will be GOES-18). Once GOES-18 is demonstrated to be nominal, the plan is to replace GOES-17 as GOES-West. The desire is that everything will check out before the fall 2022 'eclipse season', so GOES-18 would become GOES-West.

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 GeoXO (Geostationary and Extended Orbits). GeoXO is currently in pre-formulation to establish the science measurements and constellation to be implemented to meet NOAA's observational needs.

The GeoXO 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. Robert Levy (NASA/GSFC, Code 613) is now the Flight Project Scientist for GOES-R and Joel McCorkel (NASA/GSFC, Code 618) is now the new Project Scientist for GEO-XO.

The GOES-R series is an integral part of the Program of Record (PoR) for NASA's Decadal Survey (DS) missions such as the Aerosols—Cloud, Convection and Precipitation (A-CCP aka Atmospheric Observing System or AOS) mission. In other words, having access to dependable and accurate data and products from GOES-R is a requirement for meeting some of the A-CCP objectives. Other DS missions, such as Surface Biology and Geology (SBG) as well as other planned missions such as the Climate Absolute Radiance and Refractivity Observatory (CLARREO), also rely on GOES-R data availability and quality. Robert Levy has presented status of GOES-R mission and needs for products and collaboration at A-CCP and CLARREO science team meetings.

Robert Levy represented GOES-R and aerosol retrieval/products at international meetings such as AeroCom (https://aerocom.met.no/) and the Committee for Earth-Observation Satellites (CEOS) Atmospheric Composition—Virtual Constellation (AC-VC) discussions.

For further information, please contact Robert Levy (NASA/GSFC, Code 613): robert.c.levy@nasa.gov.

3.1.2.6. Suomi NPP

The Suomi National Polar-orbiting Partnership (NPP) satellite was launched on October 28, 2011. NPP's advanced visible, infrared, and microwave imagers and sounders are designed to improve the accuracy of climate observations and enhance weather forecasting capabilities for the nation's civil and military users of satellite data. 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 FY 2021, the NASA Suomi NPP team continued to add to the data records from Earth Observing System missions, enabling scientists to build multi-satellite, multidecadal (greater than 30 years) time series with high accuracy and long-term stability suitable for studies of Earth systems science. For example, using high resolution active fire-detection products from Visible Infrared Imaging Radiometer Suite (VIIRS), scientists found that fires across boreal forests in Alaska, U.S. and the Northwest Territories, Canada, are exhibiting overwintering. This behavior causes fires to smolder through the non-fire season and flare up in the subsequent spring. These conditions have become more frequent with climate change. In addition, total and vertical ozone measurements derived from Ozone Mapping and Profiler Suite (OMPS) show that the 2021 Antarctic ozone hole is larger and deeper than average ranking the 13^{th} largest in 43 years of satellite observations. The 2021 ozone depletion is driven by persistently cold temperatures and strong circumpolar winds in the Antarctic lower stratosphere.

To help monitor the impacts of the ongoing global pandemic in 2021, Suomi NPP products continued to contribute to the key socio-economic indicators in the tri-agency (ESA/NASA/JAXA) COVID-19 dashboard. For example, VIIRS aerosol, OMPS SO_2 and NO_2 products were used to help assess the impact of COVID-19 on air pollution. Cross-track Infrared Sounder (CrIS) measurements of tropospheric ozone also aided in evaluating model simulations of global tropospheric ozone responses to reduced NO_x emissions linked to the COVID-19 worldwide lockdowns. In addition, the VIIRS datasets continued to provide timely information during disaster events such as wildfires from California as well as other western states. OMPS SO_2 and aerosol index as well as CrIS SO_2 products also play an important role in early detection and tracking of the volcanic plumes during various volcanic eruptions in 2021.

For further information, please contact James Gleason (NASA/GSFC, Code 614): james.gleason@nasa.gov.

3.1.2.7. 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 2021, 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 2021, 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.

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). All the instruments and data 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 2027 and 2032. 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-Nadir and OMPS-Limb. The Libera Instrument was selected by NASA to fly on JPSS-3. Libera is focused on continuing the CERES Earth radiation budget data record. In 2021, all the JPSS-2 instruments were integrated on the JPSS-2 spacecraft. JPSS-2 environmental testing including thermal vacuum testing will be done in mid-2022, with a planned launch date of September 30, 2022.

For further information, please contact James Gleason (NASA/GSFC, Code 614): james.gleason@nasa.gov.

3.1.3.8. GPM

The Global Precipitation Measurement (GPM, htps://gpm.nasa.gov) 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 2021 including:

- Final preparation by algorithm teams for reprocessing of GPM products to Version 07 in late 2021 and early 2022.
- Organization of the PMM Science Team meeting in October 2021, held virtually due to COVID-19, to review recent science advancements, assess progress of GPM working groups, and review algorithm development and plans for the 2021-2022 reprocessing.
- Continuation of vigorous outreach and education efforts and 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 (NASA/GSFC, Code 612): scott.a.braun@nasa.gov, or visit the GPM home page at https://gpm.nasa.gov.

3.1.2.9. mini-LHR

Following the launch on 5 December 2019, MiniCarb traveled to the International Space Station and was set into orbit on 1 February 2020 via Northrop Grumman's Cygnus capsule which deployed MiniCarb with tipoff rotation of about 20° s−1 (significantly higher than the typical rate of 3° s−1 from prior CubeSats), from which the attitude control system was unable to recover resulting in a loss of power. In spite of this early failure, MiniCarb had many successes including rigorous environmental testing, successful deployment of its solar panels, and a successful test of the radio and communication through the Iridium network. This prior work and enticing cost (approximately $2 M for the satellite and $250 K for the payload) makes MiniCarb an ideal candidate for a low-cost and rapid rebuild as a single orbiter or constellation to globally observe key greenhouse gases.

Additional details of the design and fate of MiniCarb can be found at Meas. Sci. Technol. 33 (2022) 015902 (10pp). https://doi.org/10.1088/1361-6501/ac3679.

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		Deputy Project Scientist	Project
Bryan Duncan	Aura		Joanna Joiner	Aura
Steven Platnick	EOS		Lazaros Oreopoulos	AQUA
Scott Braun	GPM		Alexander Marshak	DSCOVR
James Gleason	JPSS		George Huffman	GPM
James Gleason	SNPP		Si-Chee Tsay	TERRA
Dong L. Wu	TSIS-1		Christina Hsu	SNPP
Dong L. Wu	TSIS-2		David Wolff	GPM GV
Scott Braun	TROPICS			
Robert Levy	GOES-R			

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
Anne Thompson	SO Sondes/SHADOZ	Launches were ongoing at 13 stations
Paul Newman/Thomas Hanisco	ISAF	Atom
Steven Platnick	eMAS	FIREX AQ
Stephan Kawa		CARAFE

Instrument Scientist/Manager/PI	Project/System	Recent Campaign
Ellsworth Welton	MPLNET	SEALS-sA, ORACLES
Si-Chee Tsay	XBADGER	Wallops Facility Operations
Si-Chee Tsay/David Wolff	ACHIEVE	Wallops Facility Operations
David Wolff	NPOL, D3R, ICE-POP	Wallops Facility Operations
Gerald Heymsfield	HIWRAP	SHOUT
Thomas McGee	TROPOZ, NDACC	KORUS-AQ
Robert Swap	Pandora	KORUS-AQ, OWLETS
Anne Thompson	SO Sondes/SHADOZ	Ascension Island Sondes
Paul Newman/Thomas Hanisco	ISAF	Atom
Steven Platnick	eMAS	ORACLES
Stephan Kawa		CARAFE
Vibart Stan Scott	AOS-ALICAT	
Edward Nowottnick	AOS-ALICAT	
Kerry Meyer	AOS Shortwave Spectrometer	
Dong L. Wu	SWIRP	ESTO/IIP
Dong L. Wu	Earth-IceCube	ESTO/InVEST
Antonia Gambacorta	PICs/HyMPI	ESTO/IIP

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

4. Field Campaigns

4.1. MPLNET

The Micro Pulse Lidar Network (MPLNET) released its Version 3 processing system and data set in November 2021. Version 3 (V3) was six years in development, and included support and deployment of the polarized Micro Pulse Lidar (MPL) and an expanded data suite including signal, cloud, aerosol, and PBL products. V3 also utilizes an entirely new data center with near-real-time data capability, enhanced data search, browsing, and online plotting, and numerous APIs for access to metadata and data resources. More information on MPLNET is available at https://mplnet.gsfc.nasa.gov.

New V3 data variables include polarized data such as volume and aerosol depolarization ratios, improved cloud detection (especially for thin daytime clouds), thin cloud optical depth, cloud fractions, cloud phase, improved night time aerosol retrievals using AERONET lunar aerosol optical depth (AOD), new mixed layer height and mixed layer AOD, and an expansive set of data quality flags and confidence ratings.

Due to COVID related delays, only a portion of the V3 data set from 2000-current is available. V3 reprocessing will continue through 2022 until the entire data set is finished.

MPLNET added several new sites in 2021: Houston, TX; OPAL (Eureka, CA); and Tazacorte, Canary Islands. MPLNET also supported the NASA TRACER-AQ field campaign with the new Houston site. Several sites are in planning phase: Halifax, CA; Amazon, Brazil; NASA Ames; Thule, Greenland; and Boulder, CO.

For further information please contact Ellsworth Welton (NASA/GSFC, Code 612): ellsworth.j.welton@nasa.gov.

4.2. SHADOZ

The year 2021 saw a number of significant events and milestones in the Southern Hemisphere Additional Ozonesondes (SHADOZ; https://tropo.gsfc.nasa.gov/shadoz; see Figure 4.2.1) network. In June, Dr. Ryan Stauffer (NASA/GSFC, Code 614) assumed the PI role from Dr. Anne Thompson (NASA/GSFC, Emeritus), the founding PI who oversaw network operations for nearly 24 years, since its inception in 1998. Thompson remains involved in network activities via an appointment with UMBC JCET. In early October, SHADOZ-supported launches began at the Universidad San Francisco de Quito (USFQ; PI Dr. Maria Cazorla; data since 2014) and will continue monthly (see Figure 4.2.2). December also marked the reactivation of the USFQ San Cristóbal station, with ozonesonde launches there, and continuing twice per month, for the first time since January 2016. In addition, approvals for a new 10-year agreement with Instituto Nacional de Pesquisas Espaciais (INPE; Brazilian Space Agency) for the Natal, Brazil station are in progress.

An estimated total of 350 SHADOZ ozonesonde profiles were collected in 2021, bringing the grand total to over 9400 for the 24-year record of the network. The 2021 numbers represent almost a full recovery in data collection compared to 2020. To combat the travel and station visit disruption caused by the pandemic, the SHADOZ team (Stauffer, Thompson, and archiver/webmaster Debra Kollonige (NASA/GSFC, Code 614, SSAI)) organized four highly-successful regional virtual meetings in 2021 with station PIs, operators, and managers: (1) Southeast Asia; (2) Equatorial Americas; (3) Pacific; (4) African Region. The meetings enabled the SHADOZ team to present network, website, and data quality assurance updates, and stations presented overviews of their operations and data collection activities. This regional virtual meeting format will continue to serve as a valuable tool for station communication in the future.

The SHADOZ team are key members and contributors to international organizations and activities including NDACC (Stauffer Ozonesonde Working Group Co-Chair; Thompson completed Steering Committee Co-Chair role in September), the Tropospheric Ozone Assessment Report 2 (TOAR-II), and the Assessment of Standard Operating Procedures for Ozonesondes 2.0 (ASOPOS 2.0).

SHADOZ data and related activities remain a critical resource for the global ozone community, demonstrated by several major publications in 2021:

- Thompson et al., (2021): A landmark paper on SHADOZ regional and seasonal ozone trends provides the ozone community with highly-accurate ozone profile trends in the tropics to serve as a reference for satellite and model trends evaluations.
- Smit, Thompson, and ASOPOS 2.0, (2021), GAW Report No. 268: A new guidebook on ozonesonde measurement principles and best-practices was published to update the GAW Report No. 201 as a reference for the global ozonesonde network. In a related publication, Tarasick et al., (2021) reviews the current state of knowledge on ozonesonde techniques and data.
- Kollonige et al., (2021) was published in the May-June 2021 Edition of The Earth Observer and communicated several key updates on SHADOZ operations during the pandemic.
- Steinbrecht et al., (2021) used SHADOZ data in a study that identified a 7% decrease in Northern Hemisphere tropospheric ozone in mid-2020 owing to anthropogenic emissions decreases during the COVID-19 pandemic.
- Hubert et al., and Mettig et al., (2021) studies demonstrated that SHADOZ data remain heavily relied upon to validate new satellite ozone retrievals and products.

The results generated by the SHADOZ team were presented at numerous meetings and conferences including the 101st Annual AMS Meeting in January, the 11th Ozone Research Managers' Meeting in July, the NDACC Steering Committee Meeting in September, the Quadrennial Ozone Symposium in October, the SAGE-III/ISS Science Team Meeting in November, and the AGU Fall Meeting 2021 in December.

The future of the SHADOZ network is promising as it begins its 25th year of data collection, with the 2020 reactivation of the Watukosek station, the 2021 reactivation and continuation of the San Cristóbal and Quito stations, and eventual emergence from the pandemic.

For further information please contact Ryan Stauffer (NASA/GSFC, Code 614): ryan.m.stauffer@nasa.gov.

Select 2021 References:

Thompson, A. M., R. M. Stauffer, K. Wargan, et al., 2021: Regional and Seasonal Trends in Tropical Ozone from SHADOZ Profiles: Reference for Models and Satellite Products. *J. Geophys. Res.: Atmos.*, 126 (22): 10.1029/2021jd034691

Smit, H. G. J., A. M. Thompson, and the ASOPOS 2.0 Panel, 2021. Ozonesonde Measurement Principles and Best Operational Practices. WMO Global Atmosphere Watch Report Series, No. 268, World Meteorological Organization, Geneva. https://library.wmo.int/doc_num.php?explnum_id=10884

Tarasick, D. W., H. G. J. Smit, A. M. Thompson, et al., 2021: Improving ECC Ozonesonde Data Quality: Assessment of Current Methods and Outstanding Issues. *Earth Space Sci.*, 8 (3). 10.1029/2019ea000914.

Kollonige, D. E., A. M. Thompson, and R. M., Stauffer, 2021: NASA's SHADOZ Team Makes Advances in 2021 Despite the Pandemic. The Earth Observer, May-June 2021 Issue, 33 (3). https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/May%20-%20June%202021%20color%20508.pdf

Steinbrecht, W., D. Kubistin, C. Plass-Dülmer, et al., 2021: COVID-19 Crisis Reduces Free Tropospheric Ozone Across the Northern Hemisphere. *Geophy. Res. Lett.*, 48 (5). 10.1029/2020gl091987.

Hubert, D., K.-P. Heue, J.-C. Lambert, et al., 2021: TROPOMI tropospheric ozone column data: Geophysical assessment and comparison to ozonesondes, GOME-2B and OMI. *Atmos. Meas. Tech*., 14, 7405-7433. 10.5194/amt-2020-123.

Mettig, N., M. Weber, A. Rozanov, et al., 2021: Ozone profile retrieval from nadir TROPOMI measurements in the UV range. *Atmos. Meas. Tech.*, 14, 6057-6082. 10.5194/amt-14-6057-2021.

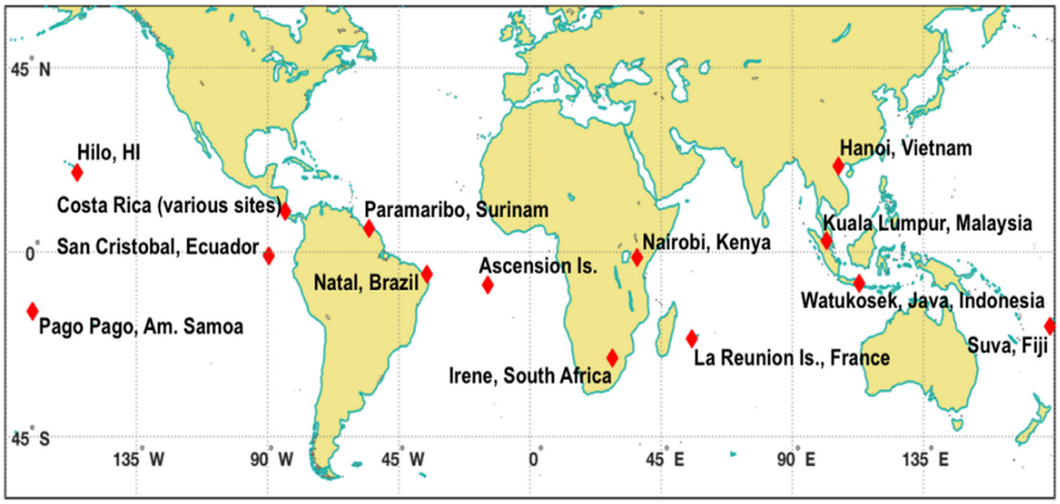

Figure 4.2.1: *Map of currently-operating SHADOZ stations. All stations shown have at least a 10-year record (https://tropo.gsfc.nasa.gov/shadoz/).*

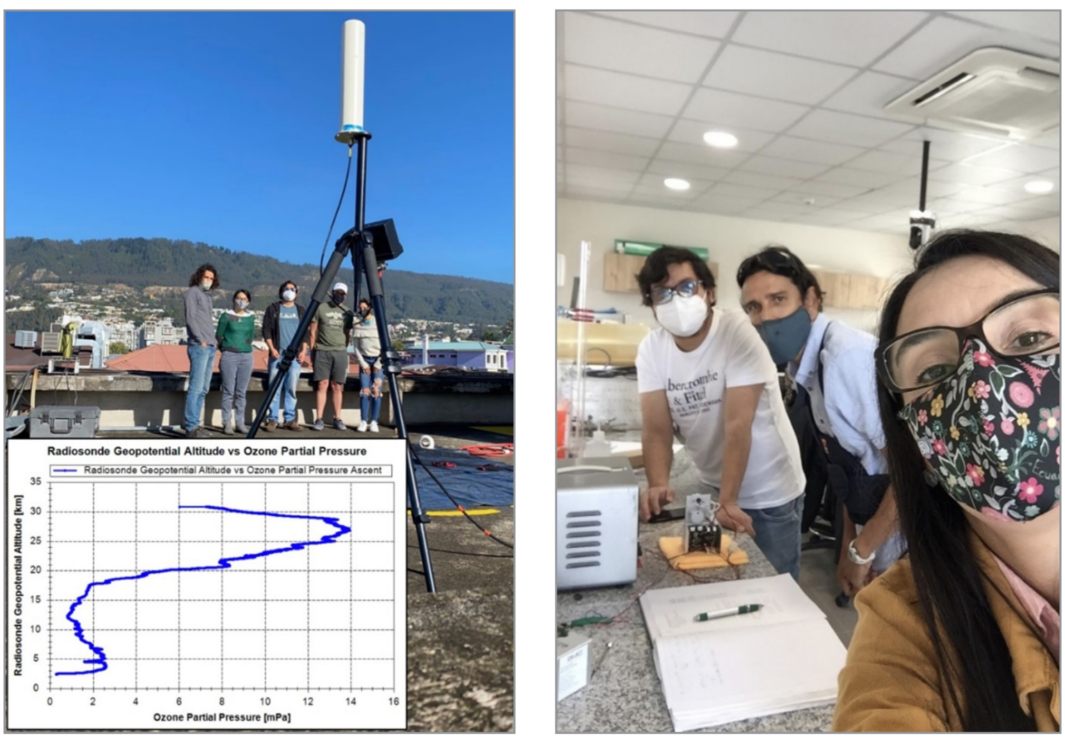

Figure 4.2.2: *(Left) The USFQ ozonesonde launch team after balloon release (ozonesonde antenna in foreground) in Quito, Ecuador on 1 October 2021. From left to right: Ariel Pila (San Cristóbal, Galapagos operations), María Cazorla (PI), Edgar Herrera (Quito operations), Diego Sandoval (USFQ student), and Isabela Saud (USFQ Dept. Environ. Eng.). The inset figure shows the ozonesonde ozone partial pressure profile from that flight. (Right) Ozonesonde training to prepare for San Cristóbal station reactivation. From left to right: Edgar Herrera, Ariel Pila, María Cazorla.*

4.3. eMAS/Oracles/FIREX-AQ

FIREX-AQ Level-1b data was updated (to version 3) to include a latitude and longitude dataset adjusted for the local topography. In addition, an effort was made to adjust some errant cloud top temperature data (a relatively small amount of warm cloud data that was too cold). But unfortunately adjusting that data skewed some data at the cold end, so the adjustment was not implemented. Following that work, a full Level-2 cloud and Level-2 aerosol datasets were processed and uploaded to the LAADS archive for distribution.

For further information please contact: G. Thomas Arnold (NASA/GSFC, Code 613): 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 Southeast 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; (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., small Unmanned Aircraft System (sUAS)—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, Fang, and Doi Angkhang Thailand, near the source regions of biomass-burning activities, including ~130 sUAS flights. Due to the continued COVID-19 pandemic, additional units of sUAS from international participants (e.g., Taiwan, Thailand, and Vietnam), planned to participate the spring IOPs 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 (NASA/GSFC, Code 613):
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 spectroradiometer and SMARTLabs (https://earth.gsfc.nasa.gov/climate/instruments/

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 is 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 continued COVID-19 pandemic, to deploy in setting like the Distributed Regional Aerosol Gridded Observation Networks (DRAGON) centered around the foothill supersite (Bidur, Nepal) to characterize the springtime 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 (NASA/GSFC, Code 613): 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 2021, the PGN supported 100 official instruments and an additional 40+ unofficial instruments.

Team Members: Tom Hanisco (NASA/GSFC, Code 614), Nader Abuhassan (JCET), Lena Shalaby (JCET), Alex Kotsakis (NPP), Farah Jawhar (JCET), Michael Gray (SSAI), Stephen Smith (SciGlob), Joe Robinson (JCET), and Alexander Cede (SciGlob).

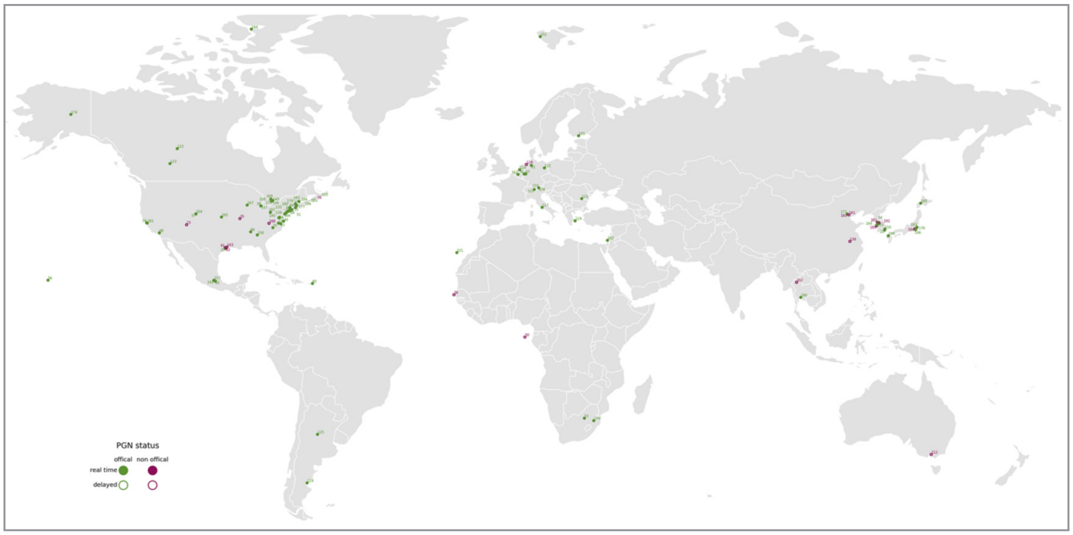

Figure 4.6.1: *Global distribution of the Pandora instruments in the PGN.*

Highlights from 2021:

- 2021 is marked by the COVID-19 partial closure and limited access. Lab calibrations at GSFC were allowed on a limited basis during the early part of the year. Full access in the second-half improved productivity, especially in calibrations. Operations of the network proceeded with minimal impact by working at home and remote locations.

- 43 instruments were added to the PGN during 2021, bringing the total to 100+.

- The Pandora group supported the TRACER-AQ campaign in Houston, TX with instruments at the University of Houston and at air quality monitoring sites at Aldine, Liberty and LaPorte.

- The Pandora group supported the GEMS Map of Air Pollution (GMAP II) 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).

- The PGN introduced new operational products based on sky viewing MAX-DOAS retrievals: NO_2 and HCHO profiles, tropospheric columns and boundary layer concentrations. New operational direct Sun SO_2 and HCHO products were added. These products join the standard direct Sun NO_2 and O_3 that were available in prior years. All new instruments produce the new products. Our goal in 2022 is to configure older instruments for the new retrieval.

Figure 4.6.2: *Left, instruments on the B33 roof are tested after laboratory calibrations. Instruments are sent to collaborators, for example Pan60 in Fajardo, Puerto Rico operated by PI Olga Mayol (right).*

Publications:

Bognar, K., R. Alwarda, K. Strong, M. P. Chipperfield, S. S. Dhomse, J. R. Drummond et al., 2021: Unprecedented spring 2020 ozone depletion in the context of 20 years of measurements at Eureka, Canada. *J. Geophys. Res.: Atmos.*, 126, e2020JD034365. https://doi.org/10.1029/2020JD034365

Spinei, E., M. Tiefengraber, M. Müller, M. Gebetsberger, A. Cede, L. Valin, J. Szykman, A. Whitehill, A. Kotsakis, F. Santos, N. Abuhasan, X. Zhao, V. Fioletov, S. C. Lee and R. Swap, 2021: Effect of polyoxymethylene (POM-H Delrin) off-gassing within the Pandora head sensor on direct-sun and multi-axis formaldehyde column measurements in 2016-2019. *Atmos. Meas. Tech.*, 14, 647-663. https://doi.org/10.5194/amt-14-647-2021.

Verhoelst, T., et al., 2021: 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.*, 14, 481-510. https://doi.org/10.5194/amt-14-481-2021.

For further information please contact Tom Hanisco: (NASA/GSFC, Code 614): thomas.hanisco@nasa.gov.

4.7. IWRAP 3D Winds: Next Generation of Mesoscale Weather Observing Platforms

With funding support from NOAA, Steve Guimond (NASA/GSFC, Code 612, UMBC) and NOAA colleagues (Zorana Jelenak, Paul Chang, and Joe Sapp) delivered a new, real-time airborne radar system for observing the three-dimensional (3D) hurricane boundary layer winds to the National Hurricane Center (NHC). Strong turbulence in the hurricane boundary layer is responsible for direct wind damage to infrastructure as well as enhancements to the overall storm surge, which have critical impacts on society when a hurricane approaches land. The refurbished Imaging Wind and Rain Airborne Profiler (IWRAP) radar can fully resolve the large turbulent eddies responsible for the impacts to society described above and provides a major advancement over previous airborne radars and in situ measurements. Co-PI Guimond was responsible for the scientific motivation and development of the real-time 3D winds algorithm that produces fast, accurate retrievals of the hurricane boundary layer winds. The new system was demonstrated in the 2021 Atlantic hurricane season with near real-time displays of the boundary layer wind structure in Hurricane Ida near landfall in Louisiana. The preliminary analysis showed peak windspeeds of ~ 170 mph in localized regions of the boundary layer, which appeared consistent with cursory wind gusts of 172 mph reported at Port Fourchon, LA.

For further information please contact: Steve Guimond (NASA/GSFC, Code 612, UMBC): stephen.guimond@nasa.gov.

4.8. CPEX-AW: Convective Processes Experiment—Aerosols & Winds Campaign Dates: August 18-September 10, 2021

CPEX-AW 2021 was a joint effort between NASA and the European Space Agency (ESA) focused on calibration and validation of ESA's Atmospheric Dynamics Mission-Aeolus (ADM-AEOLUS) Earth observation wind lidar satellite, specifically over St. Croix in the Caribbean Sea. ADM-AEOLUS launched in August 2018.

The primary focus of CPEX-AW was to observe tropical convection and its interaction with dust and the dry environment. Specific science objectives included:

- Better understanding interactions of convective cloud systems and tropospheric winds as part of the joint NASA-ESA Aeolus Cal/Val effort over the tropical Atlantic;
- Observing the vertical structure and variability of the marine boundary layer in relation to initiation and lifecycle of the convective cloud systems, convective processes (e.g., cold pools), and environmental conditions within and across the ITCZ;
- Investigating how the African easterly waves and dry air and dust associated with Sahara Air Layer control the convectively suppressed and active periods of the ITCZ;
- Investigating interactions of wind, aerosol, clouds, and precipitation and effects on long range dust transport and air quality over the western Atlantic.

For CPEX-AW, the NASA DC-8 aircraft payload included the High Altitude Lidar Observatory (HALO), Doppler Aerosol WiNd Lidar (DAWN), Airborne Third Generation Precipitation Radar (APR-3), the High Altitude MMIC Sounding Radiometer (HAMSR), and dropsondes.

Figure 4.8.1: *Photo Credit: Erin Czech, NASA ARC.*

Ed Nowottnick (NASA/GSFC, Code 612) and Pete Colarco (NASA/GSFC, Code 614) provided flight planning and forecasting support for the NASA CPEX-AW field campaign to target interactions between Saharan dust and convection in the Caribbean and tropical North Atlantic regions.

The CPEX-AW field campaign will resume in September 2022 and will be based out of Cabo Verde.

For further information please contact: Ed Nowottnick: (NASA/GSFC, Code 612): edward.p.nowottnick@nasa.gov.

Figure 4.8.2: *Photo Credit: Judy Alter, NASA ARC.*

4.9. MOOSE

Led by the Michigan Department of Environment, Great Lakes, and Energy, the Michigan-Ontario Ozone Source Experiment (MOOSE) is a multi-agency study aiming to assess strategies for lowering ozone pollution the border region of southeast Michigan and western Ontario. The 2021 component of this study included a suite of mobile laboratories, drones, and a suite of ground-based measurements observing trace gases with the goal of quantifying and characterizing emissions of ozone precursors in the region. To support this study from above, NASA's Earth Science Division's Research and Analysis Tropospheric Composition Program supported flights on NASA Langley Research Centers Gulfstream-III with two atmospheric composition instruments from GSFC: the GeoCAPE Airborne Simulator (Scott Janz, NASA/GSFC, Code 614 lead) and the Cloud Physics Lidar (Matt McGill, NASA/GSFC, Code 610 lead), and science led by Laura Judd from NASA Langley Research Center. This is the first time these instruments have flown on this platform, with the endurance to base flights from NASA Langley Research Center, transiting to the Detroit region each flight day and performing two sorties with a midday fuel in Battle Creek, Michigan before transiting back each flight day by late afternoon. The aircraft payload observes the spatial and temporal patterns of trace gases like nitrogen dioxide (NO_2), formaldehyde, and aerosols. These gases provide a high-resolution top-down view that will be used to evaluate chemical transport models, satellites, and provide characterization of column based measurements in comparison to surface based observations.

From June 5-24, 2021, 16 maps of data were collected over the study region during six flight days, with ozone air quality conditions ranging from clean to unhealthy for sensitive groups. The preliminary GCAS data shows that the highest NO_2 column densities are attributed to isolated point sources grouped in three main regions. Due to rainy and cloudy conditions the final week of the study in the MOOSE domain, one final flight on June 29, 2021, was dedicated to sampling an ozone event along the East Coast of the U.S. where the aircraft was able to map NYC/Long Island Sound, Baltimore/Washington, DC, and the Hopewell, Virginia area in a single flight. Total flight time for the mission accumulated to 54.7 hours over seven days.

For further information please contact: Scott Janz (NASA/GSFC, Code 614): scott.j.janz@nasa.gov.

4.10. TRACER-Air Quality (AQ)

Supported by NASA Earth Science Division's Research and Analysis and Applied Sciences programs, the TRACER-AQ mission leveraged activities associated with the Department of Energy's TRACER (TRacking Aerosol Convection ExpeRiment) by bringing air quality ground-based assets (e.g., TOLNET ozone lidars and Pandora Spectrometers) as well as outfitting the JSC Gulfstream-V (G-V) with an air quality remote sensing payload collecting data as proxy for the NASA Tropospheric Emission:

Monitoring of Pollution (TEMPO) mission over the Houston, Texas region. TEMPO will be the first geostationary air quality satellite mission sampling multiple times daily over greater North America after launch in late 2022.

The G-V payload included the GeoCAPE Airborne Simulator (GCAS) and High Spectral Resolution Lidar (HSRL)-2 installed in both nadir ports of the aircraft for the first time. From September 1-27, these instruments were flown on 11 science flights amounting to 89.2 hours and over 38,000 miles traveled to map air quality repeatedly over the Houston, Texas region. The endurance of the G-V is optimal for all-day repeated sampling of air quality over a targeted area to capture the diurnal evolution of emissions and how they interact meteorologically and chemically impacting air quality. Research flight times ranged from 5 to 9.6 hours in duration.

During the first 10 science flights, this payload collected 27 maps of the spatial distribution of ozone precursors (NO_2 + HCHO), and vertical distribution of ozone and aerosol characteristics over the Houston, Texas region in collaboration with the Texas Commission on Environmental Quality; the 11^{th} science flight took place over the Gulf of Mexico in collaboration with the Bureau of Ocean Energy Management to collect data over offshore platforms for emissions sampling. Flights were episodic due to the requirements of cloud-free skies throughout most daylight hours. The first two flights were flown at first opportunity on September 1 and 3, which were cleaner conditions challenged by sporadic multi-cell convective storms that often occur over the area. However, the bulk of science flights were during two multi-day air quality events (each four days in length) from September 8-11 and 23-26, with a mid-month break due to the influence of Hurricane Nicholas and its remnants impacting cloud cover over Houston. This is the first time that NO_2 and HCHO observations from GCAS have been collected coincidently with ozone measurements from HSRL2-DIAL, creating the most comprehensive TEMPO-proxy dataset to date.

In continuance of preceding Houston air quality studies (the last one being DISCOVER-AQ in 2013) and in preparation for the upcoming TEMPO mission, the TRACER-AQ mission goals include researching connections between ozone photochemistry and meteorology in Houston, Texas, with a focus over the adjacent waterbodies over which the aircraft was able to sample in these regions unmonitored by surface networks and infrequently by boat. The multi-perspective observations collected from ground and airborne instruments provide a comprehensive dataset for evaluating air quality models as well as the utility of satellite based remote sensing through validation of Sentinel-5P TROPOMI and proxy-datasets for TEMPO. These datasets are also being used to update findings about pollution inequality within the city which disproportionately impacts low-income communities of color.

Highlights include, but are not limited to, top-down views of spatial patterns of NO_2, ozone, and HCHO from morning through afternoon including observing emissions from ships and industry in the Houston Ship Channel and the greater Houston area, capturing high ozone observations from multiple perspectives over the water in Galveston Bay and the Gulf of Mexico, and preliminary modeling efforts linking the physics and chemistry to observed datasets in the region.

TRACER-AQ science team members are from NASA LaRC, NASA GSFC, University of Houston, Baylor University, St. Edwards University, TCEQ, Virginia Tech, University of Virginia, the DOE TRACER team.

For further information please contact John Sullivan (NASA/GSFC, Code 614): john.t.sullivan@nasa.gov.

4.11. NDACC

Three lidar systems are maintained and deployed through NASA GSFC to support the Network for the Detection of Atmospheric Composition Change (NDACC). The Aerosol and Temperature Lidar (AT) has been operating for over 20 years and can retrieve quantities of aerosol, elastic, vibrational, and rotational Raman temperature, and water vapor (Raman DIAL). The Stratospheric Ozone Lidar Trailer Experiment (STROZ-LITE) has been operating since 1988 and can retrieve quantities of ozone, aerosol, elastic and vibrational Raman temperature, water vapor (Raman DIAL). The Tropospheric Ozone Lidar (TROPOZ) has been producing tropospheric ozone profiles since 2014 for various NDACC and NASA field campaigns. During FY21, these lidars have been back at GSFC during the COVID period to perform several hardware and laser upgrades. During September 2021, the TROPOZ was deployed to Houston, TX to support the TRACER-AQ study.

For further information please contact John Sullivan (NASA/GSFC, Code 614): john.t.sullivan@nasa.gov.

4.12. IMPACTS

Northeast 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 a 5-year program with three intensive winter field campaigns during 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 aircrafts. 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 snowstorm. The airborne measurements were supplemented with ground-based measurements from rawinsondes launched from IMPACTS-funded mobile sounding systems and 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. The original 2021 field campaign was moved to 2022 because of COVID, so no new data was collected in 2021. The 2022 flights are in progress, at the time of this report, and they are going extremely well with aircraft sampling a number of snow systems including a strong nor'easter, and under COVID constraints.

For further information please contact: Gerry Heymsfield, (NASA/GSFC, Code 612): gerald.heymsfield@nasa.gov, and John Yorks, (NASA/GSFC, Code 612): john.yorks@nasa.gov.

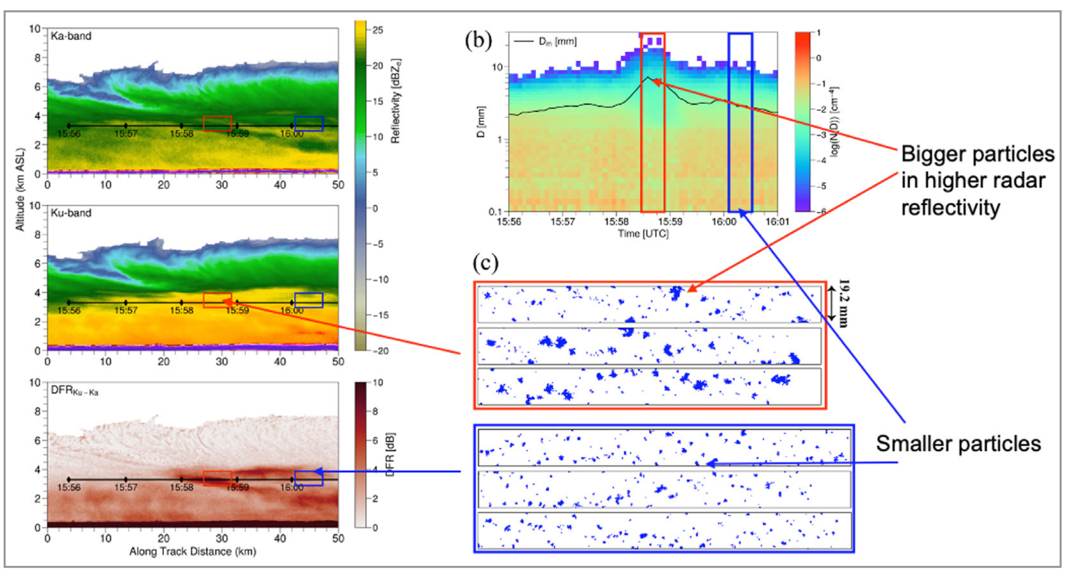

Figure 4.12.1: *Data collected during 7 February 2020 flight that an excellent snow case in Central New York state. Image from EXRAD radar reflectivity data (upper left) and images from ice particle measurements from coordinated P-3 flight legs (dashed lines) in EXRAD image.*

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

The Code 610 web development team currently supports 43 project sites, 19 for AT and 24 for HBG. Most of these sites are supported using Drupal, a content management system that provides a common platform with a modern look-and-feel and mobile-responsive web pages. Many of these sites are hosted on https://earth.gsfc.nasa.gov, a consolidated portal for detailed project information related to campaigns, instruments, and selected data products.

5.1. New Websites / Major Rebuilds

- *LIS:* Completed complete rebuild in Drupal 9 and deployed to the public. 508-Compliance testing performed using SortSite.

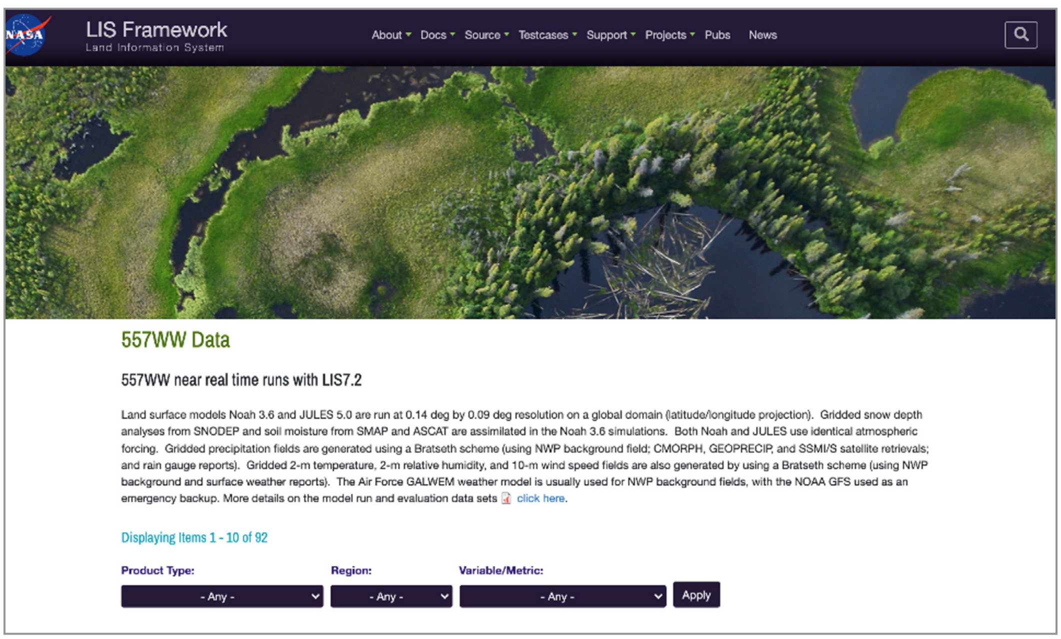

Figure 5.1.1: *LIS Framework Website.*

- *Sun Climate:* Full website rebuild in progress.
- *MCST:* Full website rebuild in progress.
- *PUMAS:* Completed upgrade to Drupal 9 and deployed to the public. 508-Compliance testing performed using SortSite.

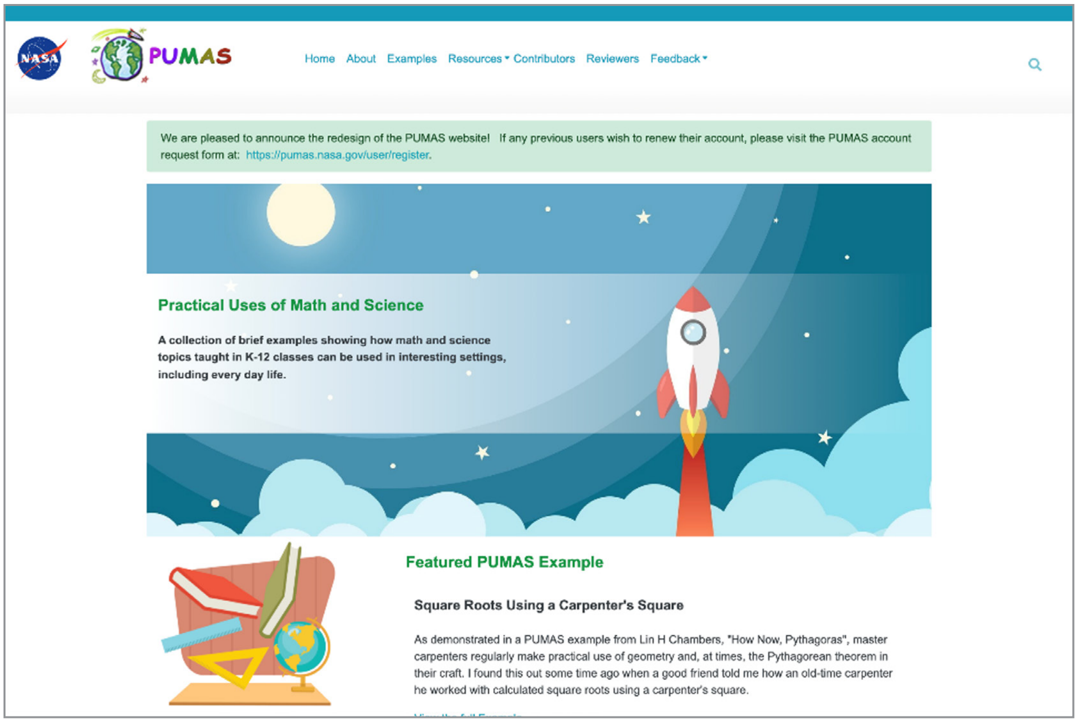

Figure 5.1.2: *PUMAS Website.*

5.2. New Development

- *Consolidated to the 614 Atmosphere Chemistry website on https://earth.gsfc.nas.govSED Consolidation:* Coordinated with Lara Clemence and 610 management to identify and categorize shared or redundant organizational content and migrate, consolidate, link and/or redirect as identified.
- *Beautiful Earth:* Consolidated to the 615 cryosphere site on Earth.
- *CIRC:* Consolidated to the 613 climate site on Earth.
- *Cloud Modeling:* Consolidated to the 612 mesoscale site on Earth.
- *GMI:* Consolidated to the 612 mesoscale site on Earth.
- *ICESat-4 Polar Radar Altimetry:* Coordinated with Jeremy Harbeck to assist consolidation to the 615 cryosphere site on Earth.
- *SMART Labs:* Consolidated to the 613 climate site on Earth.
- *THOR:* Consolidated to the 613 climate site on Earth.
- *Mini-LHR and MiniCarb.*

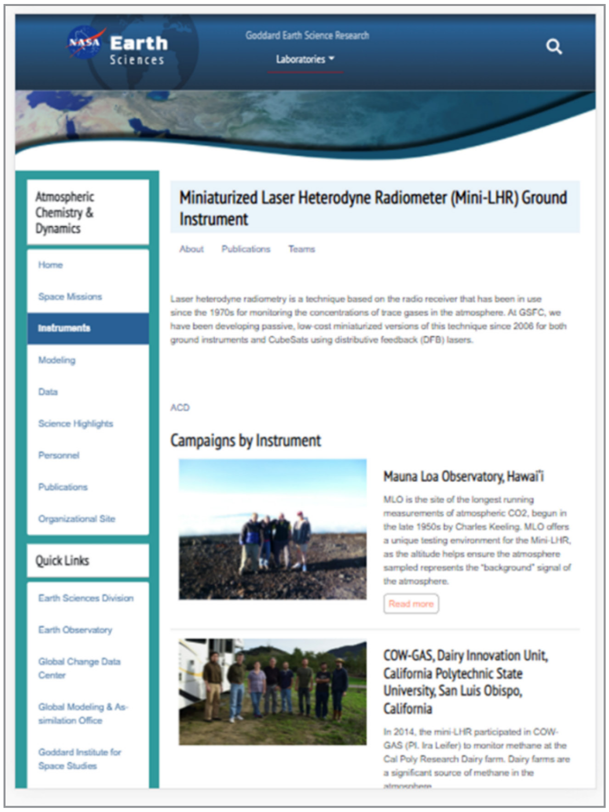

Figure 5.2.1: *Mini-LHR Website.*

5.3. Drupal 9 Upgrades

All Drupal 8 websites maintained by this team were updated to Drupal 9 in advance of the November 2021 end-of-life data for this version of Drupal. This update brings nine more labs/project sites up to date in Drupal and demonstrates the benefit of consolidating project web pages using a widely used and supported CMS.

- *Earth Science Projects:* Upgraded from Drupal 8.
- *LDAS:* Upgraded from Drupal 8.

5.4. New Features

- *EPIC:* New daily UV aerosol product.
- *LIS and LDAS:* NCCS media tools for modeling data products
- *Air Quality:* Updated NO_2 datasets for world cities and for US cities.
- *MCST:* Custom Citations module for Drupal 9 to manage scholarly citations.

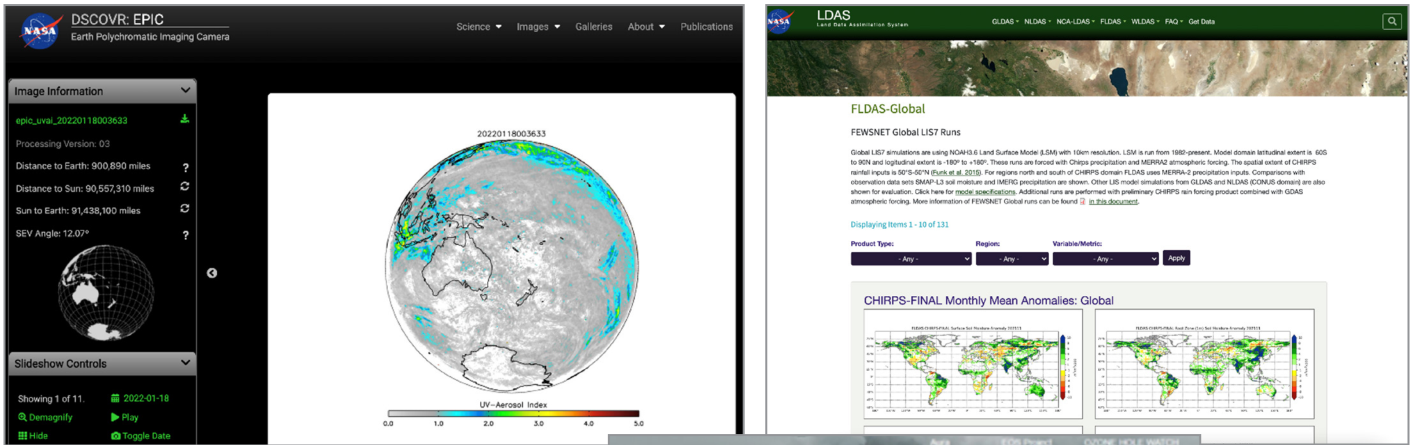

Figure 5.4.1: *Websites with new features: EPIC (top left), LDAS (top right) and Air Quality (bottom).*

5.5. Security Work/Server Migrations

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.

5.6. Decommissioned or Consolidated

Server Rebuilds and Migrations:

- 610AT Web Servers (Ganeti Cluster)
- 612 Meso Servers
- 613 EPIC Web Server
- 615 ICESat-2 Web Servers
- 617 Spider Web Server

- *Launchpad Integration:* Completed new integrations for Earth science projects, LDAS and LIS. Tested and implemented a solution for integrating Drupal 8 and Drupal 9 websites and deployed on all Drupal 8 and Drupal 9 websites. Coordinated on a possible workaround for setting up new integrations in the sandbox for Launchpad. Updated SimpleSAMLphp to v1.19.3. Worked with SAs to verify PHP OPcache installed correctly across servers.

- *CISA Web Scanning:* Received detailed scan results from the CISA web application scanning initiative from DHS. The GLAMR website was volunteered to be a testcase for this activity. Analyzed scan results, documented findings, identified false positives and provided feedback on both the specific findings and the overall usefulness of the activity.

- *DHS Web Scanning:* Received a notice from SOC that a DHS scan flagged a problem with an alias on the Sun Climate website related to a mismatched TLS certificate. Coordinated with System Administrators and removed the unneeded alias to resolve.

- *SOC Investigation:* Responded to a vulnerability finding from SOC on the EPIC website in conjunction with Tom Northcutt (NASA/GSFC, Code 610/ADNET). Documented all actions taken and provided timely reporting and remediation. Subsequently performed a minor version update to the Laravel Framework, refreshed database credentials, and generated a new application key.

- *SOC Investigation:* Performed an investigation of the PUMAS website feedback form for SOC-20211122-1184014 reported by an unknown third party. Researched possible leads related to the return IP being from Microsoft Azure. In certain circumstances, Microsoft IP addresses were exposed to a Burp Collaborator scan. Coordinated with Jasaun Neff (NASA/GSFC, Code 606/ADNET) to investigate. After further testing and evaluation, the issue was declared a false positive caused by Microsoft Outlook's Safelinks scanning activity. Provided a response timeline with preliminary findings for the investigation report.

5.7. Data Calls

- *HQ Web Modernization:* Attended several HQ Web Modernization Town Hall meetings and provided feedback to management as requested.

- *SMD Web Modernization:* Documented foreseen impacts to GSFC 610 labs should the proposed SMD Web Modernization effort go forward as currently stated, per request. Provided guidance and supporting information to 610 management on request. Responded to several rounds of data calls to provide responses for all websites managed by this task. Coordinated with key PIs whose websites were identified as in scope to be consolidated to SMD in this effort to come up with responses. Made data exports of key information from AART to be input into the spreadsheet. Added the Agency need/justification from a previous such data call for each website where new responses were not provided.

- *OATS Action 1744—Web Modernization/Web Cleanup:* Responded to an action item related to Web Modernization. Websites with low visitation rates were targeted for removal unless responses and justifications were provided. Coordinated with Responsible NASA Officials and key points of contact to update justifications for websites on the list which we've been instructed to keep. Answered questions about the action item and offered to help other lab members with responses. Received several requests for assistance consolidating older websites into the corresponding lab sites on https://earth.gsfc.nasa.gov to help meet this effort. Coordinated with system administrators in cases where duplicate and/or unused aliases could be retired. Provided formal responses to Emily Wilson (NASA/GSFC, Code 610) per request.

5.8. Maintenance, Planned Work, Consolidations, and Continuous Improvement

- *Drupal:* Performed 1,328 updates, including core version upgrades, security updates, bug fixes, and library/dependency updates.
- *WordPress:* Applied 42 upgrades to cores, plugins, and themes.
- *Repositories:* Made 700 commits and performed 127 code reviews on pull requests.
- *Service Desk:* Responded to 491 help desk issues and/or ad hoc tickets.
- *PHP Upgrades:* Upgraded to PHP 7.4 on all web servers.
- *MySQL / MariaDb Upgrades:* Required upgrades performed on all web servers.
- *Bamboo Automation:* Modified Bamboo plans for Drupal 9. New Bamboo integrations for 612 Meso Server, 613 EPIC Server, and 617 Spider Server.
- *EPIC:* Performed software upgrades for the Laravel Framework and its backend dependencies. Switched to using Yarn for frontend dependency management Upgraded D3, jQuery and Smartmenus to the newest versions. Separated jQuery code from D3 code in order to prevent conflicts between the two libraries. Refactored all D3 code for generating orthographic maps of displayed land masses, due backwards compatibility issues. Debugged ongoing SELinux problems and SFTP/SSH scripting issues preventing project personnel from delivering the new image product to the website.
- *Jira:* Restructured the backlog to reorganize items. Added rough estimates to help with long-term estimations. Created 14 new epics (projects) for each remaining Drupal-7 and legacy website rebuild currently planned. Added initial placeholder issues to each rebuild. Performed cleanup on the Jira Roadmaps to better display projected timelines.

- *Drupal 7 Rebuilds:* ICESat-2, Air Quality, Snow.nasa.gov, Dark Target, Atmosphere Imager, NU-WRF, GLAMR
- *Legacy Website Rebuilds:* G-LiHT, HAR, Aerocenter, MODIS and VIIRS Snow Ice
- *Website Consolidations:* I3RC, Deep Blue, ECOSAR, AESMIR
- *Continuous Improvement:* Created a Drupal 9 Site Launch checklist for reference on future deployments. *Team members:* Susannah Pearce, Nathan Perrin, Rashida Holland (NASA/GSFC, Code 613, GST).

For further information, please contact Ernest Pittarelli (NASA/GSFC, Code 619, SSAI): 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
Distinguished Public Service Medal	John Blaisdell (610)	For Exceptional Public Service in Support of Critical NASA Earth Remote Sensing Research
Exceptional Scientific Achievement Medal	Dong Wu (613)	For scientific and technological leaps that have paved the way for improved space-based observations of ice clouds
Exceptional Scientific Achievement Medal	Alexey Lyapustin (613)	For exceptional innovation in extracting maximum geophysical information content from widely available measurements of space-based imaging spectroradiometers
Exceptional Scientific Achievement Medal	Christina Hsu (613)	For exceptional achievement in creating space-based, multi-decadal and high-quality aerosol records for use in climate and air quality research
Exceptional Scientific Achievement Medal	Pete Colarco (614)	For exceptional use of Goddard's Chemistry-Climate Modeling infrastructure for characterizing observing systems for aerosol and climate studies

6.2. Robert H. Goddard Awards

Atmospheric Research team members received the following individual awards.

Robert H. Goddard Award	Recipient	Citation
Sciences	Main Chin (614)	For outstanding scientific leadership in global scale modelling of atmospheric aerosols processes in combination with observational constrains from space-based observations
Sciences	Tamas Varnai (613/UMBC)	For outstanding scientific achievements in unveiling through satellite remote sensing the nature of Earth scenes containing heterogeneous mixtures of clouds, aerosols, and surfaces
Customer Service	Shana Mattoo (613)	For outstanding customer service to Goddard's aerosol enterprise, sustained over four decades through developing and implementing algorithms for global aerosol remote sensing
New Opportunities Captured	Earth Science Decadal Mission ACCP Architecture Study Team, 612 (Scott Braun)	For outstanding science and mission architecture development leading to two new GSFC-led projects studying the Atmosphere with multiple breakthrough technologies

6.3. External Awards and Recognition

Anne Thompson was elected to the prestigious American Academy of Arts and Sciences. This is a wonderful recognition and acknowledgement of Thompson's outstanding career. "Founded in 1780, the American Academy of Arts and Sciences honors excellence and convenes leaders from every field of human endeavor to examine new ideas, address issues of importance to the nation and the world, and work together, as expressed in our charter, "to cultivate every art and science which may tend to advance the interest, honor, dignity, and happiness of a free, independent, and virtuous people." Our studies have helped set the direction of research and analysis in science and technology policy, global security and international affairs, social policy, education, and the humanities." Thompson joins Claire Parkinson and John Mather as current GSFC members of the Academy. Also elected this year was GSFC and Earth Sciences Division alumni Marshall Shepherd, currently at the University of Georgia. You can find the list of new members at: https://www.amacad.org/news/2021-member-announcement.

Congratulations to authors S. Munchak (NASA/GSFC, Code 612), S. Ringerud (NASA/GSFC, Code 612, UMD), L. Brucker (NASA/GSFC, Code 615, USRA), Y. You, I. de Gelis, and C. Prigent for the article "An active–passive microwave land surface database from GPM". It was selected as the winner of the IEEE Geoscience and Remote Sensing Society 2020 Transactions Prize Paper Award. The award presentation was scheduled for IGARSS 2021 in Brussels, Belgium.

Dr. Paul A. Newman (NASA/GSFC, Code 610), Chief Scientist for Earth sciences was awarded the Cleveland Abbe Award for Distinguished Service to the Atmospheric and Related Sciences, by the American Meteorological Society. The Cleveland Abbe Award for Distinguished Service to the Atmospheric and Related Sciences by an Individual is presented on the basis of activities that have materially contributed to the progress of the atmospheric and related sciences or to the application of the atmospheric and related sciences to general, social, economic, or humanitarian welfare. Newman's award citation reads "For sustained leadership and service to science resulting in strengthened policy development for the Montreal Protocol, including contributions to the Kigali Amendment."

Mariel Friberg and William Gregory Blumberg (NASA/GSFC, Code 613, NPP), postdoctoral fellows of the Climate and Radiation Laboratory, are members of NGAPS which received the 1st SED Diversity, Inclusion and Equity Award.

Chris Kidd (NASA/GSFC, Code 612, UMD) has accepted his nomination to sit on the National Academies Committee on Radio Frequencies (CORF). This committee, sponsored by the National Science Foundation and NASA, considers the needs for radio frequency requirements and interference protection for scientific and engineering research, coordinates the views of the U.S. scientists, and acts as a channel for representing the interests of U.S. scientists.

Erin Delaria (NASA/GSFC, Code 614, UMD) recently won a prestigious NASA Postdoctoral Program (NPP) fellowship. She will work with Glenn Wolfe (NASA/GSFC, Code 614), Thomas Hanisco (NASA/GSFC, Code 614), Jason St. Clair (NASA/GSFC, Code 614, UMBC), and other GSFC scientists to develop new in situ instrumentation and data/model synthesis techniques to improve our understanding of the atmosphere-biosphere exchange of nitrogen dioxide (NO_2), a key pollutant observed by space-based remote sensors.

On October 3, SBUV-MOD team P.K. Bhartia (NASA/GSFC, Code 610, Emeritus), Stacey Frith (NASA/GSFC, Code 614, SSAI), Natalya Kramarova (NASA/GSFC, Code 614), Gordon Labow (NASA/GSFC, Code 614, SSAI), Richard McPeters (NASA/GSFC, Code 614), and Richard Stolarski (NASA/GSFC, Code 614, Emeritus) received the 2021 Farman Award during the 2021 Quadrennial Ozone Symposium "In recognition of their teamwork to produce high-quality and state-of-the-art total ozone record from space."

Alexei Lyapustin (NASA/GSFC, Code 613) was selected as a 2021 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/2021.

Joanna Joiner (NASA/GSFC, Code 614) and Alexei Lyapustin (NASA/GSFC, Code 613), were among eight Code 610 Directorate scientists selected as 2021 Highly Cited Researchers by Clarivate (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.

On December 9, Sarah Ringerud (NASA/GSFC, Code 612, UMD) was awarded “ESSIC Best Paper of the Year for 2021” at the 2021 ESSIC Holiday party for her publication “Applications of dynamic land surface information for passive microwave precipitation retrieval”, S. Ringerud (NASA/GSFC, Code 612, UMD), C Peters-Lidard (NASA/GSFC, Code 610), S. J. Munchak (NASA/GSFC, Code 612), and Y. You (UMD), 2021, *J. Atmos. Tech.*, 38(2), 167-180, doi:10.1175/JTECH-D-20-0048.1. This work describes a hybrid Optimal Estimation-Bayesian precipitation retrieval for passive microwave sensors over land surfaces. Results show the retrieval improves false alarms as compared to operational Bayesian algorithms and can accurately detect the presence of snow cover, which is crucial for passive microwave retrievals.

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.

William Nordberg Award Recipients	Year	William Nordberg Award Recipients	Year
Joanne Simpson	1994	Wei-Kuo Tao	2008
Mark Schoeberl	1998	Paul Newman	2011
William K. M. Lau	1999	Anne Douglass	2013
Yoram J. Kaufman	2000	Anne Thompson	2018
Michael D. King	2001	Ralph Kahn	2019
P. K. Bhartia	2003	Joanna Joiner	2020
Robert Adler	2007		

6.5. American Meteorological Society

6.5.1. Special Awards

Two Code 610 colleagues will be honored by the American Meteorological Society (AMS) at the 2022 AMS Annual Meeting. Mian Chin (NASA/GSFC, Code 614) and Gerald Heymsfield (NASA/GSFC, Code 612) have each been named a Fellow of the American Meteorological Society (AMS).

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.*

6.5.3. Fellows

According the AMS, those eligible for election to Fellow shall have made outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period of years. The nomination to Fellow is open to Members. New Fellows are elected each year by the AMS Council (the Society's principal governing body) at its fall meeting from a slate submitted by the Fellows Committee of not more than two-tenths of 1 percent of all AMS Members. Fellows shall have made outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period of years."

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

Congratulations to Mian Chin (NASA/GSFC, Code 614) for her selection as a 2021 AGU Fellow. This announcement follows closely on Mian's selection as a 2022 AMS Fellow. Mian is having a banner year.

Mian Chin

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.

Chin was one of three NASA scientists awarded fellowship status for 2021. AGU noted that they have made outstanding achievements and contributions by pushing the frontiers of our science forward. They have also embodied AGU's shared vision of a thriving, sustainable, and equitable future for all powered by discovery, innovation, and action. Equally important is that they conducted themselves with integrity, respect, diversity, and collaboration while creating deep engagement in education and outreach. Since 1962, AGU has elected fewer than 0.1% of members to join this prestigious group of individuals.

Chin is a physical scientist in the Atmospheric Chemistry and Dynamics Laboratory. She leads a research team to simulate global and regional aerosols and trace gases and analyze data from satellite, aircraft, and surface sites. She joined NASA Goddard in 2003, concentrating on atmospheric model development and satellite data analysis. Her current research includes aerosol-cloud-chemistry-climate interactions, regional and global air quality, transport of aerosols and trace gases, aerosol impacts on global energy balance, and modeling and analysis of data from satellite, ground-based, and airborne observations. Chin and her Goddard group developed one of the first global aerosol computer models, called the GOCART model.

Union Fellows	Year	Union Fellows	Year
David Atlas	1972	Michael D. King	2006
Joanne Simpson	1994	William K.-M. Lau	2007
Mark R. Schoeberl	1995	Anne R. Douglass	2007
Richard S. Stolarski	1996	Paul Newman	2010
David A. Randall	2002	Warren Wiscombe	2013
Anne M. Thompson	2003	Lorraine Remer	2015
Marvin A. Geller	2004	Ralph Kahn	2020
Gerald R. North	2004	Mian Chin	2021
Eugenia Kalnay	2005		

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

On January 6, Dorian Janney (NASA/GSFC, Code 612, ADNET) was the invited presenter for the Climate Change Research Initiative Education (CCRI) Ambassadors group. The CCRI event was hosted by Matthew Pearce (NASA/GSFC, Code 160) and Rosalba Giarratano (NASA/GSFC, Code 160). Janney shared information on the science and technology behind the Global Precipitation Measurement mission and focused on how to access and analyze IMERG data. She also shared many educational resources which have been designed to show the real-world applications of NASA's Earth observation data. There were 19 formal educators present during this hour-long virtual presentation.

On January 10, Dorian Janney presented to 108 participants during a virtual orientation and introduction to the upcoming classes being offered through the Osher Lifelong Learning Institute at the University of Hawaii at Manoa. She offered a virtual class which focused on the GLOBE Observer app and four tools, and included guest presentations from several NASA SMEs during the spring.

On January 12, Brian Campbell (NASA/GSFC, 610.W/GST) gave a virtual presentation entitled "All About the NASA ICESat-2 Mission: Lasers from space measuring ice, trees, oceans, and how students, educators, and citizen scientists can get involved through NASA and the GLOBE Program" to 85 elementary through high school students and eight educators from Anne Arundel County, Maryland. The presentation highlighted the first two and a half years of the ICESat-2 Mission observations and how participants can take tree height observations using a hand-held clinometer and the NASA GLOBE Observer App's trees tool for citizen science. The educators and their students plan to join the Trees Around the GLOBE Student Research Campaign to further their knowledge and participate in student learning and research.

On January 19, Brian Campbell, Dorian Janney, Christopher Shuman (NASA/GSFC, Code 615, UMBC), Peter Falcon (JPL), and Peder Nelson (OSU) planned and implemented the twenty-ninth Trees Around the GLOBE Student Research Campaign virtual webinar entitled, "Getting Started with your Trees Around the GLOBE Student Research Projects: An open forum webinar with a student presentation from Malta, educators, and the Trees Campaign core team" that was attended live by 46 GLOBE participants from thirteen countries: Argentina, Brazil, Colombia, Croatia, India, Italy, Netherlands, Kenya, Pakistan, Philippines, Republic of Korea, Switzerland, and the United States. During the webinar, students from the St. Michael School in Malta presented about how they have begun their research projects related to trees. The webinar also focused on some specific research questions that students, using data and online tools, can explore and answer as part of their student research projects. A discussion on the DeSoto National Forest, story maps, comparing GLOBE and NASA satellite data, and selecting of online tools were also featured.

On January 21, Brian Campbell continued working with two high school student groups from the Netherlands on their NASA SMAP soil moisture, story mapping research projects for the NASA GLOBE Program, entitled "Project Soil Drought" and "Soil Drought in the Netherlands" (http://bit.ly/39YJJVY). The students will be submitting their research projects to the NASA GLOBE Program's 2021 International Virtual Science Symposium (IVSS), where students can share their research, earn virtual badges, get feedback from a team of STEM professionals, and discuss their research with other students and the GLOBE community.

From February 3-6, Dorian Janney attended the Maryland Organization of Environmental and Outdoor Educators (MAEOE) conference and led the following presentations: "NASA Day Focus" featured a virtual NASA booth staffed in real-time by Dorian Janney and Brian Campbell throughout the conference. Janney and Campbell met in separate zoom rooms to share NASA Earth Science mission resources, GLOBE Program resources, and answer questions.

Dorian Janney, Brian Campbell, Todd Toth (NASA/GSFC, Code 160, ADNET) and Genevieve Escande de Messieres (NASA/GSFC, Code 618, SSAI) served on the virtual lunch-time panel. They shared information about various NASA Earth observing missions and resources, how and why NASA missions study Earth, and how participants can help NASA scientists with environmental observations through the GLOBE Program as well as information about NASA's Earth to Sky Program. There were 79 participants who attended this panel.

During "NASA Earth Science and You," Janney shared information about the Global Precipitation Measurement (GPM) mission as well as other NASA Earth observing missions. She showed participants how to access several NASA Earth Science websites and gave examples of the educational and outreach resources participants could find on these sites.

On February 5, Janney gave a virtual presentation to members of the Africa GLOBE "Science Squad", providing administrators with information on NASA's Earth science missions, the GLOBE and GLOBE Observer programs, and helped them learn how to use the GLOBE Observer app and four tools with their groups throughout Africa.

On February 5, Janney presented to a class for the Osher Lifelong Learning Institute (OLLI) through the University of Hawaii at Manoa's OLLI program. She gave an overview of the GLOBE Observer app, as well as information about NASA's Earth observing missions.

On February 8, Brian Campbell was featured in a new NASA video from My NASA Data. The video, entitled, "Breaking Down the Big Questions at NASA," was created for students wanting to do student research projects, who often get tangled up in the onset of their research with problems like "What questions can I answer?" and "How do I answer such a huge scientific question?" The video discusses how to answer large research questions by starting with a series of smaller, exploratory questions that can serve as a guide to student research and to help answer the larger, seemingly difficult research questions. The video can be viewed at: https://go.nasa.gov/3aMrR11.

On February 9, Dorian Janney, met with the GLOBE Education Work Group to work on deciding how to determine the GLOBE performance measurement metrics.

On February 12, Dorian Janney organized and presented a 90-minute class for the Osher Lifelong Learning Institute (OLLI) through the University of Hawaii at Manoa's OLLI program. She showed the participants how to use the GLOBE Observer app "Clouds" tool.

On February 18, Dorian Janney helped to organize and participate in the GLOBE Mission Mosquito monthly webinar. She showed the participants how to use Story Maps to develop their International Virtual Science Symposium presentations.

On February 19, Dorian Janney organized and presented a 90-minute class for the Osher Lifelong Learning Institute (OLLI) through the University of Hawaii at Manoa's OLLI program. She showed participants how to use the GLOBE Observer app "Land Cover" tool.

On February 19, Brian Campbell created a video for use at the virtual NASA Wallops exhibit booth of the Junior Achievement Inspire Program's 2021 event. The video focused on the science of NASA and the why there is a continuing need for future STEM professionals. The JA Inspire virtual event will have over 6,000 middle and high student participants from across the Delmarva Peninsula.

On February 26, Dorian Janney organized and presented a 90-minute class for the Osher Lifelong Learning Institute (OLLI) through the University of Hawaii at Manoa's OLLI program. Brian Campbell was the guest presenter, and shared information about the ICESat-2 mission and showed participants how to use the GLOBE Observer app "Tree Height" tool. Janney led the class and showed the participants their GLOBE data over the past week.

On February 26, Dorian Janney organized and presented to a group of graduate students at the University of Coimbra, Portugal. Dr. Vasco Mantas has been using IMERG data from the Global Precipitation Measurement (GPM) mission with these students during their semester course. Andrea Portier (NASA/GSFC, Code 612, SSAI) presented on the GPM mission and applications, and Janney showed them where to access a variety of NASA-developed resources and training opportunities.

On March 4, Jie Gong (NASA/GSFC, Code 613, USRA) had discussions with students and presented a seminar at Colorado State University entitled "Polarization Difference —the scientific story behind one variable and its practical applications".

On March 5, Dorian Janney (NASA/GSFC, Code 612, ADNET) organized and taught a class to "lifelong learners" who are taking the six-week OSHER Lifelong Learning Institute GLOBE course through the University of Hawaii. She focused on showing them how NASA Earth observation data are being used by researchers and decision-makers to predict, monitor, and respond to mosquito-transmitted disease. They focused on the Global Precipitation Measurement (GPM) mission and learned how to access GPM's IMERG data to see how much precipitation was observed falling in their location. They also learned how to use the GLOBE Observer "Mosquito Habitat Mapper" tool.

On March 9, Brian Campbell, Dorian Janney, Dr. Christopher Shuman (NASA/GSFC, Code 615, UMBC), Peter Falcon (JPL), and Peder Nelson (OSU) planned and implemented the thirty-first Trees Around the GLOBE Student Research Campaign virtual webinar entitled, "Finalizing and Submitting your Trees Around the GLOBE Student Research Campaign Projects: Final project discussions with campaign team and participants, including student tree research projects in the Philippines." The webinar was attended by eighty-one participants from sixteen countries.

On March 12, Dorian Janney organized and taught a class to "lifelong learners" who are taking the six-week OSHER Lifelong Learning Institute GLOBE course through the University of Hawaii. During this final class session, she shared new data from the Global Precipitation Measurement (GPM) mission which depicted the heavy rains that fell on Hawaii during the week of March 8th. The GPM Science team at GSFC helped to assemble these data and offered comparison data between NASA's IMERG data and NOAA's gauge data for several locations around Hawaii.

On March 29, Lazaros Oreopoulos (NASA/GSFC, Code 613) was invited to present a Virtual AOS Departmental Seminar at McGill University entitled "A Somewhat Detailed Overview of Cloud Impacts on the Earth's Radiation Budget."

Robert Levy (NASA/GSFC, Code 613) participated as a member of the virtual examining committee to evaluate the dissertation proposal for Mr. Taylor "Kai" Wilmot, at the University of Utah. His academic advisor is Dr. Gannet Hallar. Among other modeling and surface-based datasets, he will be using NASA's satellite data products to quantify the role of wildfire smoke to air quality trends in cities of the Western United States.

From March 30-April 6, NASA ARSET completed an introductory online training titled "Introduction to Population Grids and their Integration with Remote Sensing Data for Sustainable Development and Disaster Management". This two-part training series, developed and presented by members of the POPGRID Data Collaborative, focused on the different global population grids and their application to a range of topics related to development planning and monitoring of the SDGs (e.g., environment, hazards, and access to resources). Attendees were exposed to the latest data and methods used to produce global grids, how the grids incorporate remote sensing inputs, and how population grids can be used in conjunction with other types of data. Brock Blevins (NASA/GSFC, Code 614, SSAI) hosted the training with guest speakers Robert Chen (SEDAC), Charles Huyck (ImageCat), Stefan Leyk (UC Boulder), Greg Yetman (CIESIN), Linda Pistolesi (CIESIN), James Gibson (CIESIN), and Susana Adamo (CIESIN). Ana Prados, Selwyn Hudson-Odoi, David Barbato (NASA/GSFC, Code 614, UMBC) and Jonathan O'Brien (NASA/GSFC, Code 614,SSAI) supported the training. In attendance were 1,038 participants from 111 countries and 35 U.S. states. Approximately 500 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/arset-introduction-population-grids-and-their-integration-remote

On April 6, Brian Campbell co-presented, with fellow NASA Earth Science Education Collaborative (NESEC) colleagues, Marile Colon Robles (NASA/LaRC) and Dr. Russanne Low (Institute for Global Environmental Strategies), at the 2021 American Philosophical Society's "The Promise and Pitfalls of Citizen Science Symposium." The presentation featured a discussion on the NASA GLOBE Observer App for citizen science, highlighting the comparison of the space-based and ground-based observations, focusing on the four protocol observations (clouds, mosquito habitats, land cover, and trees) and the lessons learned in citizen science during the current COVID-19 pandemic. There were fifty-three participants.

On April 13, Dorian Janney gave a two-hour presentation to share the GLOBE Program and NASA Earth science missions which correlate to the GLOBE Observer tools to 27 graduate students who are enrolled in the Norte Dame Environmental Education course.

On April 14, Dorian Janney gave an hour-long presentation to the Solar System Ambassadors and Museum Informal Education Alliance to share information about the Global Precipitation Measurement (GPM) mission and introduce them to several new applications resources. There were 36 adult participants from all over the United States in attendance.

On May 18, Dorian Janney met with the GLOBE Education Work Group to develop a procedure for educational resource submission for the GLOBE Implementation Office.

On May 19, Dorian Janney was a guest speaker for the joint NOAA/Chesapeake Bay Foundation monthly educator webinar. She shared information on the GLOBE Program and shared information on how to download and use the four tools in the GLOBE Observer app. There were 35 formal and informal educators attending this virtual event in person.

On May 24, Olivia Clifton (NASA/GSFC, Code 611, USRA) was featured as a panelist for the AGU Atmospheric Sciences Section Early Career Committee webinar series which focused in working on U.S. research institutions. New intern Katheryn Pech of University of Alabama–Huntsville is a rising senior in Atmospheric Sciences and is working under the mentorship of Ali Tokay (NASA/GSFC, Code 612, UMBC).

On May 25, the Applied Remote Sensing Training (ARSET) program completed its longest (six part) bilingual series, titled Satellite Observations and Tools for Fire Risk, Detection, and Analysis. It covered the use of Earth observations pre-fire (fire types, conditions, & fire danger), during-fire (thermal anomalies and smoke mapping), and post-fire (burned area, landscape changes, & regrowth). The content spanned air quality, disasters, and land applications. The course instructors were Melanie Follette-Cook (NASA/GSFC, Code 614, MSU), Pawan Gupta, Amita Mehta (NASA/GSFC, Code 612, UMBC), Erika Podest, Sean McCartney (NASA/GSFC, Code 610, SSAI), Juan Torres-Pérez, Zach Bengtsson, Robert Field (NASA/GSFC, Code 611, CU), and Ana Prados (NASA/GSFC, Code 614, UMBC); and guest presenters Elijah Orland (NASA/GSFC, Code 617, USRA) and Blanca Rios. Brock Blevins (NASA/GSFC, Code 614, SSAI), Selwyn Hudson-Odoi (NASA/GSFC, Code 612, UMBC), David Barbato (NASA/GSFC, Code 614, UMBC) and Jonathan O'Brien (NASA/GSFC, Code 614, SSAI) supported the training. In attendance were 2,544 participants from 110 countries and 47 U.S. states. Approximately 1,200 unique organizations were represented. You can learn more about the training in English at:

https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-observations-and-tools-fire-risk-detection-and, or in Spanish at: https://appliedsciences.nasa.gov/join-mission/training/spanish/arset-observaciones-de-satelites-y-herramientas-para-el-riesgo.

On March 23, Dorian Janney wrote and published the feature story: "Building Connections: How NASA Data Empowers End Users, From Ecologists to Resource Analysts". The article was published on the Global Precipitation Measurement website and can be viewed at: https://gpm.nasa.gov/applications/building-connections-how-nasa-data-empowers-end-users-ecologists-resource-analysts

On March 29, Dorian Janney reviewed and reported back on three Green School applications for the Maryland Green Schools to support the work being done by The Maryland Association for Environmental and Outdoor Education (MAEOE).

On April 2, Dorian Janney judged five GLOBE Program International Virtual Science Symposium projects, and developed the two user profiles which are included in this applications package. This applications package was released by NASA social media platforms as a part of the Women's History Month celebration. Twitter: https://twitter.com/NASAEarth/status/1376614235757633537; Facebook: https://www.facebook.com/nasaearth/posts/10159621628262139.

On May 5, Dorian Janney gave a presentation to support the Arlington Public Schools' B-WET MWEE training, which was hosted by Eco-Schools USA and the GLOBE Program. She shared information on the Global Precipitation Measurement (GPM) mission and shared how GPM data and data from other Earth-observing satellites are being used to help predict, monitor, and respond to mosquito-transmitted disease. She then showed participants how to use the GLOBE Program Mosquito Habitat Mapper tool. There were 21 adults who attended this training session.

On May 25, Dorian Janney assisted with and presented during the "Trees Around the GLOBE" half-day workshop. There were over 50 participants from all around the world attending this virtual event.

On June 1, Dorian Janney wrote and delivered a monthly newsletter to the 21 members of the GLOBE OLLI course to share the total GLOBE Observer observations they had submitted for each of the four tools and to update them on various GLOBE and NASA news.

On June 1, Dorian Janney wrote and submitted an article entitled "Measuring Freshwater from Space" to the National Earth Science Teachers Association (NESTA) for possible inclusion in the fall issue of "The Earth Scientist". The article focuses on the Global Precipitation Measurement (GPM) mission and shares recently developed education and outreach resources which share information on the ways in which GPM and other NASA Earth observation data are being used for real-world applications.

On June 3, Brian Campbell gave a virtual talk to two high school geometry classes at Parkside High School and James M. Bennett High School, both in Salisbury, Maryland. Campbell discussed the importance of taking tree height observations from the ground and space and talked about the mathematics involved with using a hand-held clinometer and the NASA GLOBE Observer Trees Tool for Citizen Science.

On June 10, Dorian Janney, Brian Campbell, Kristen Weaver (NASA/GSFC, Code 612, SSAI) and colleagues at the NASA Langley Research Center presented at the 1st Congreso Latinoamericano de Ciencia Ciudadana (First Latin American Congress of Citizen Science). Janney presented on the NASA GLOBE Observer Mosquito Habitat Mapper and GLOBE Mission Mosquito. Brian presented on the NASA GLOBE Observer Trees and Land Cover Tools as well as ICESat-2, GEDI, and Landsat. Weaver presented on the NASA GLOBE Observer Eclipse observations.

On June 10, Dorian Janney helped to organize and run the monthly GLOBE Mission Mosquito webinar. This webinar focused on the work being done with tribal communities in Norman, OK to share information and resources related to the Mosquito Habitat Mapper protocol.

On June 16, Chris Kidd (NASA/GSFC, Code 612, UMD) gave an enriching talk on the topic of Climate Change to year seven pupils at the John Hanson Community School in Andover, UK.

On June 14, Brian Campbell gave a virtual 2021 Career Day Event talk to eighty-two people, students (seventy-seven) and educators (five), at the Wicomico County Middle School in Salisbury, Maryland in Wicomico County. Campbell's presentation, "20 Years in my Job as a NASA Senior Earth Science Specialist" focused on the Earth Science outreach, communication, and education work he does as part of the NASA Science Mission Directorate's Earth Science Division and STEM. Campbell also gave a call-out for students to become the next generation of STEM professionals to help us continue to answer the continually growing set of science questions.

On June 30, Alexander Marshak (NASA/GSFC, Code 613) gave a virtual presentation entitled "DSCOVR/NISTAR: Some Science Results," at the University of Colorado Libera weekly team meeting. https://lasp.colorado.edu/home/libera/

On July 7, Dorian Janney helped to organize and participate in the Montgomery County Public School Science Resource Teacher training. Dalia Kirschbaum (NASA/GSFC, Code 617) gave the keynote presentation on climate change and climate modeling. Janney prepared a resource packet to accompany this talk to ensure all teachers had ready access to related NASA resources. https://arcg.is/1bW8OS0

On July 8, Dorian Janney was an invited panelist for the Smithsonian's National Museum of Natural History's YES summer interns. She answered questions about her career and how she became employed at NASA, and provided information about the Global Precipitation Measurement (GPM) mission and showed students how to use the GLOBE Observer app. There were 30 students from traditionally underserved communities as well as 10 adult mentors.

On July 12-16, multiple members of the GLOBE Observer team attended and presented at the virtual GLOBE Annual Meeting.

- July 12, Holli Kohl (NASA/GSFC, Code 610, SSAI) and Kristen Weaver (NASA/GSFC, Code 612, SSAI) gave a brief overview of the GLOBE Observer app as part of the protocol introduction session

- Brian Campbell and Holli Kohl co-presented a NASA GLOBE Observer Land Cover and Trees training session.

- Dorian Janney gave a presentation with other members of the Education Working Group during the Working Group Report Outs and moderated one of the evening networking sessions titled "COVID-19 and Teaching Virtually".

- July 12, Trena Ferrell (NASA/GSFC, Code 610) co-hosted the D and I evening network event.

- July 13, Dorian Janney gave a lightning talk presentation titled "Who Uses NASA's Earth Observation data? STEM Career Deep Dive" and co-presented an experienced protocol training focused on surface temperature and the mosquito habitat mapper and later facilitated the networking session which focused on climate change.

- July 14, Kristen Weaver presented about the GLOBE Teams capability.

- July 14, Dorian Janney, Brian Campbell, Holli Kohl and Kristen Weaver were part of a presentation titled "Out of School Opportunities to Welcome New Learners to GLOBE."

- July 15, Brian Campbell gave a report-out on "3 Years of the Trees Around the GLOBE Student Research Campaign: Transitioning Between Data Collection and Data Literacy"

- Heather Mortimer (NASA/GSFC, Code 610/SSAI) presented a workshop on "Digital Accessibility."

- Dorian Janney facilitated the "Protocol Reflections" networking session.

- Virtual posters were presented by Brian Campbell, "Comparing GLOBE Tree Height Data to NASA ICESat-2 Data," and Holli Kohl, "GLOBE Observer and a Changing GLOBE: An Invitation for Community Input for 2021-2025."

- Heather Mortimer presented a workshop on Digital Accessibility

- July 13, Dorian Janney gave a virtual presentation entitled "Who Uses NASA's Earth Observation data? STEM Career Deep Dive" to the participants at the annual GLOBE meeting. She focused on sharing resources developed by GPM's Outreach team, which focus on how IMERG data are being used for real-world applications. https://youtu.be/ljJf_fmDKfo

- July 14, Dorian Janney was part of a virtual presentation entitled "Out of School Opportunities to Welcome New Learners to GLOBE" during the annual GLOBE meeting.

- July 14, Dorian Janney co-presented an experienced virtual protocol training focused on surface temperature and the mosquito habitat mapper at the annual GLOBE meeting.

On July 28, Dorian Janney met with teachers and administrators from NASA's Climate Change Resource Institute (CCRI) to share the latest Global Precipitation Measurement (GPM) mission's outreach climate modeling products as well as other GPM applications products.

On August 3, Dorian Janney gave a virtual presentation to 36 formal and informal educators who were taking a joint NOAA-Chesapeake Bay Program summer course offered by Maryland's Department of Education. She shared information about the Global Precipitation Measurement (GPM) mission as well as several GPM education and outreach resources and gave them information on the GLOBE Program.

On August 5, Dorian Janney worked virtually with five National Park interpreters who are involved in NASA's Earth-to-Sky Program. She helped them plan for an upcoming three-day workshop and shared several education and outreach resources which have been developed by the Global Precipitation Measurement (GPM) Outreach team. She also gave them information on the GLOBE Program and the GLOBE Observer app.

On August 10, Dorian Janney participated and presented during the monthly "Trees Around the GLOBE" webinar. She showed the 29 participants from around the world how to access and analyze IMERG data from the Global Precipitation Measurement (GPM) and shared many relevant GPM-developed education and outreach resources with them.

On August 20, Dorian Janney organized and presented during the Solar System Ambassador and Museum and Informal Education Alliance webinar which focused on climate change and climate modeling. She shared many education and outreach resources which have been developed by the Global Precipitation Measurement Outreach team and showed participants how to access and analyze IMERG data. There were 24 adult participants from around the United States attending this virtual presentation.

On August 10, Brian Campbell, Dorian Janney, and the Trees Around the GLOBE Student Research Campaign Core Team planned and implemented the thirty-sixth Trees Around the GLOBE Student Research webinar workshop entitled, "At Ease with the Trees: Preparing for Student Investigations and Research Projects with the Trees Around the GLOBE Student Research Campaign Team, Session II." During this special webinar, participants were able to work directly, via breakout discussions, with the Trees Around the GLOBE Student Research Campaign team members to focus on several specific research topics for future student projects. These included: "Land Cover and Land Cover Change for Student Research," GLOBE Tree Height Comparisons with ICESat-2 and GEDI" "GPM Precipitation Data and How it Affects Trees," and "What Can We Do to Support Your Plans for Student Research?" There were 31 unique participants from Argentina, Croatia, Greece, India, Ireland, Kenya, Nigeria, Switzerland, and the United States.

On August 26, Dorian Janney presented a poster entitled "Water for Wheaties? Education/Outreach Resources" during the AmeriGEO Week 2021 meeting. This poster shared the education and outreach resources which were developed by the Global Precipitation Measurement Mission's Outreach team which focus on applications for food security using NASA's Earth observing data.

On September 29, Dorian Janney presented on the Global Precipitation Measurement (GPM) mission for the NASA EPDC STEM Engagement and Educator Professional Development Collaborative "Explore Earth - Our Climate Is Changing and NASA Is on Top of It" webinar. She and Andrea Portier shared new resources to help explain the differences between climate and weather, explored how the data collected by GPM and other NASA Earth observing missions informs the use and development of climate modeling. They also provided information about the GPM mission and describe how data from this mission is being used to improve life around the world with an emphasis on the many education and outreach resources which have been developed to share this information with others.

On October 5, Dorian Janney wrote a blog entitled "Exploring Engineering Solutions for a Changing Climate with NASA's Global Precipitation Measurement mission" for The GLOBE Program website. This blog was shared through several channels, including The Space Foundation's Teacher Liaisons and Solar System Ambassadors. https://bit.ly/3uKCzyP

On September 21, Brian Campbell, Dorian Janney, and the Trees Around the GLOBE Student Research Campaign Core Team planned and implemented the thirty-seventh Trees Around the GLOBE Student Research webinar workshop entitled, "Celebrating Land Cover and Tree Height Observations from the Ground and Space with the Launch of the Landsat 9 Satellite: Celebrating the First Three Years of the Trees Around the GLOBE Student Research Campaign by Taking a Deeper Dive into the Landsat, ICESat-2, GEDI, GPM, and ECOSTRESS Missions." During the 2-hour webinar, there were 31 unique participants from 10 countries: Argentina, Bulgaria, Colombia, Croatia, Greece, India, Pakistan, Switzerland, United States, and Uruguay.

On October 5-7, Brian Campbell participated and presented at the NASA GLOBE Program's 2021 Virtual Europe and Eurasia Regional Meeting. Over 200 participants, from 20+ countries, registered for the meeting. During the meeting, Campbell announced the continuation of the Trees Around the GLOBE Student Research Campaign for a fourth year. The campaign, which commenced on September 1, 2018, in correlation with the launch of the ICESat-2 spacecraft, focuses on tree height, land cover, greenings, and the carbon cycle. As part of the campaign, there have been over 85,000 observations from students, educators, and citizen scientists. Year 4 will focus on collaborative efforts among the GLOBE campaigns (European Phenology Campaign, GLOBE Mission Mosquito, and the Urban Heat Island Effect–Surface Temperature Field Campaign) and where the campaign measurements and observations can overlap and provide participants with an amazing, cross-campaigns, robust dataset.

On October 8, Brian Campbell participated in the GLOBE Asia-Pacific Regional Coordination Office webinar, "GLOBE Scientist Story with Yashraj Patil: An Expedition to the Himalayas." Attending were fifty-five educators and scientists and fifty students from India, Nepal, Philippines, Republic of Korea, Taiwan Partnership, Thailand, Vietnam, and the United States. Brian Campbell and Dorian Janney have worked with and mentored Yashraj over the last six months focusing on what NASA GLOBE Program environmental measurement protocols would be best to implement during the expedition and how to turn his expedition research results into an ArcGIS StoryMap. You can see the 2021 Himalayan Expedition StoryMap at https://bit.ly/3ukNRcA.

On October 11, Kristen Weaver, Brian Campbell, and Peter Falcon (JPL) presented at the virtual 2021 GLOBE Program Slovenia Kick-off Event. Their joint talk, "GLOBE Observer and Connections to NASA" focused on the NASA GLOBE Observer, NASA science connections, GLOBE measurement campaigns, and the use of GLOBE data for professional science publications. During the event, there were 75 participants (from Slovenia, Czech Republic, Croatia, and the United States) and an additional number of students from multiple schools across Slovenia. Slovenia recently joined the GLOBE Program, bringing the number of GLOBE-participating countries to 126.

On October 12-14, Brian Campbell participated in the virtual 2021 GLOBE Program's North American Regional Meeting (NARM). During the event's GLOBE Exchange Session, Campbell presented a video he pre-recorded, showcasing the partnerships involved with the Trees Around the GLOBE Student Research Campaign and the active participation of students, educators, researchers, and citizen scientists from 58 GLOBE countries.

On October 15, Dorian Janney published an article entitled "Monitoring Freshwater Resources from Space" for NESTA's The Earth Scientist peer-reviewed quarterly journal. This article focuses on the GPM mission and explains how being able to know when, where, and how much precipitation is falling to Earth enables many decision-makers to have vital data to respond to the needs of living things and to help respond to the challenges of both climate change and human population growth. In this article, teachers can find a variety of NASA-created education and outreach resources to help them share the science, technology, and real-world applications behind GPM; one of NASA's preeminent Earth-observing satellite missions. https://nestanet.org/TES.public.

On October 26, Brian Campbell participated in a live interview with students as part of the Propel Charter School Career Connections Program in Pittsburgh, Pennsylvania. Hosted by the Carnegie Science Center, over 200 elementary school students participated by asking questions about NASA careers, NASA Earth Science, and the need for future STEM professionals. Campbell covered many Earth-observing missions like ICESat-2, GPM, SMAP, Landsat, GEDI, and ECOSTRESS and the GLOBE Program. Campbell will be following up with individual classrooms, virtually, during the 2021-2022 school year.

On October 26 and 28, Holli Kohl and Kristen Weaver co-presented with Marilé Colon Robles (LaRC) about the GLOBE Observer, the app of The GLOBE Program, and the NASA GLOBE CLOUD GAZE project on the Zooniverse platform at two Accenture virtual employee engagement question and answer sessions. Registration for each session was close to 100 attendees.

On October 28, Dorian Janney gave a virtual presentation entitled "NASA at Your Table" to support the Maryland STEMFEST activities. She shared information from the recent NASA campaign and gave a deeper dive into the use of data from the Global Precipitation Measurement mission for these applications. https://youtu.be/p-OvyhZtcrc

On October 29, Dorian Janney was an invited presenter for the virtual meeting of the Massachusetts Association for School Superintendent GS21 committee. She shared information about NASA's Earth Science missions and gave a deep dive into the ways that data from the Global Precipitation Measurement mission are used in real-world applications. She also gave information about the GLOBE Program's field campaigns.

On November 16, Dorian Janney gave a virtual presentation to 26 high school students and teachers to describe the science and technology behind the Global Precipitation Measurement (GPM) mission and share ways that participants can use data from this and other NASA Earth science missions to support International Virtual Science Symposium (IVSS) projects.

On November 17, Dorian Janney worked with the GLOBE Education Work Group to make final decisions about how to share the plans for the GLOBE Mentor Teacher applications with the larger GLOBE community.

On December 1, Brian Campbell participated in the Fall 2021 GLOBE Program's European Phenology Campaign Webinar, entitled "Our Autumn with Trees." The webinar highlighted the campaign's virtual tree magazine, Tree Reporters' Challenge, and student presentations of Fall Green-Down Activities. The webinar was led by the GLOBE Europe and Eurasia Coordination Office in the Czech Republic.

On December 7, Brian Campbell and his Trees Around the GLOBE Student Research Campaign Team planned and implemented the fortieth Trees Around the GLOBE Student Research webinar workshop entitled, "Looking at the Land Cover and Tree Canopy of the GLOBE Africa Region and the critical need for GLOBE data observations in the Africa Region. Region Focus: Africa." This campaign webinar began a two-month focus on the GLOBE Africa Region. Beginning with a recorded discussion with GLOBE Africa Regional Coordinator, Mr. Mark Brettenny, the webinar focused on the importance of taking land cover and tree height observations across Africa, with a focus on data literacy. They then took a close look at the Global Land Cover Viewer and the Global Forest Canopy Height online tool looking at current and past land cover and tree height data in the Africa Region. Following the use of these online tools, the campaign highlighted some useful content from the NASA Eyes on Earth online tool and had a discussion on the importance of taking multiple observations of land cover and tree height.

On December 8, Brian Campbell presented virtually to educators as part of an Arlington County Public Schools professional development workshop. Campbell presented "Let's Talk GLOBE Trees: The Trees Around the GLOBE Student Research Campaign, NASA GLOBE Observer Trees Tool, and NASA Missions." Arlington County Public School teachers will adapt the material for use in their science classrooms and become a larger part of the GLOBE community.

On December 7, Dorian Janney gave a virtual presentation during the GEO Health Community of Practice Annual Meeting. Her flash talk focused on the work being done by the Food Security and Safety working group over the past year and highlighted their plans for the upcoming year. This talk can be seen at: http://www.geohealthcop.org/workshops/annualmeeting2021-day1

On December 7, Dorian Janney gave a virtual presentation for the Arlington County, VA professional development for teachers. Her presentation was entitled "What's the Buzz? From Satellites to Smart Phones." She shared how NASA Earth observations are being used to predict, monitor, and respond to mosquito-transmitted disease and how the public can help with these efforts by using the GLOBE Observer app, emphasis on potential mosquito breeding habitats and how to use this tool with MWEE activities. https://bit.ly/3daUt5C.

On December 10, Dorian Janney met with Cassy Tefft de Muñoz, Director of Educational Outreach at Michigan Technological University, and several other members of her department to share the recent Global Precipitation Measurement (GPM) mission's "Who's Using GPM Data" STEM education resources. They expressed interest in using her work and projects in a video to share with high school students as a part of their STEM series, GPM Data STEM education resources.

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 2021 among the various laboratories.

Table 7.3.1: Climate and Radiation

2021 Climate and Radiation Laboratory Seminar Series Coordinators: W. Reed Espinosa and Jie Gong (UMBC)

Date	Speaker	Title
January 6	Florian Tornow Columbia University NASA Goddard Institute for Space Studies	On Aerosol-mediated Cloud Transitions in Cold Air Outbreaks as Informed by ACTIVATE
January 27	Elizabeth Barnes Department of Atmospheric Science Colorado State University	Viewing Climate Signals through an AI Lense
February 3	Olga Mayol Department of Environmental Science University of Puerto Rico – Rio Piedras	My journey as an aerosol scientist exploring the tropics: from the Amazon to "Godzilla"
February 17	Christine Chiu Department of Atmospheric Science Colorado State University	Pushing the Boundary of Cloud Retrieval for Process-level Understanding

Date	Speaker	Title
March 3	Grégory Cesana Columbia University NASA Goddard Institute for Space Studies	Observational Constraint on Low-cloud Feedbacks Suggest Moderate Climate Sensitivity
March 17	Hanii Takahashi University of California, Los Angeles NASA Jet Propulsion Laboratory	Detection and Tracking of Tropical Convective Storms based on Globally Gridded Precipitation Measurements: Algorithm and Survey over the Tropics
April 7	Adeyemi Adebiyi University of California, Los Angeles	How Much Solar Radiation does Atmospheric Mineral Dust Absorb, and How Much Do Climate Models Simulate?
April 21	Shaocheng Xie Lawrence Livermore National Laboratory	Toward Improving the Representation of Diurnal Cycle of Precipitation in Climate Models
May 5	Adam B. Milstein MIT Lincoln Laboratory	Computational Imaging in Infrared Remote Sensing of the Atmosphere
May 19	Feiqin Xie Texas A&M University – Corpus Christi	Planetary Boundary Layer Observations from GNSS Radio Occultation, and the Synergy of Satellite Lidar with Passive Infrared and Microwave Imagers
June 2	Feng Xu The University of Oklahoma	Polarimetric Aerosol and Cloud Remote Sensing Inversion – AirMSPI Practice and Beyond
June 16	Meloë Kacenelenbogen NASA Ames Research Center	Identifying Chemical Aerosol Signatures using Optical Suborbital Observations: How much can optical properties tell us about composition?
July 7	Willem Marais The University of Wisconsin-Madison	Leveraging spatial textures, through machine learning, to identify aerosols and distinct cloud types from multispectral observations
July 21	Snorre Stamnes, Eduard V. Chemyakin and Adam Bell NASA Langley Research Center Polarimetry Group	New Developments in Polarimetric and Lidar Remote Sensing
September 15	Jianwu Wang Department of Information Systems University of Maryland, Baltimore County	Developing Passive Satellite Cloud Remote Sensing Algorithms using Collocated Observations, Numerical Simulation and Deep Learning
October 6	Seth Seidel The University of California, Davis	The Lightness of Water Vapor, Clouds, and Tropical Climate

Date	Speaker	Title
October 20	Armin Sorooshian University of Arizona	Smoke, Ships, Dust, Salt, and Other Features Interacting with Clouds: Findings from Recent Field Campaigns
November 3	Richard Moore NASA Langley Research Center	Aerosol Effects on Clouds in the Remote Atmosphere: From the North Atlantic Ocean Surface to Cruising Altitudes of the Upper Troposphere
November 17	Dr. George Tselioudis NASA Goddard Institute for Space Studies	A New ISCCP Weather State Dataset, its Use in CMIP6 Model Evaluation, and Some Recent Weather State Trends
December 1	Antonia Gambacorta Climate & Radiation Laboratory NASA Goddard Space Flight Center	Advances in Hyperspectral Microwave Sounding: What new science can we do?

Table 7.3.2: Atmospheric Chemistry and Dynamics

Date	Speaker	Title
January 28	Joanna Joiner (30 min)	New MODIS-based gross primary production product
February 4	Susan Strahan (20 min) Luke Oman (20 min)	Observed asymmetry in stratospheric transport trends from 1994-2018 Addressing a Large Seasonal Bias in Modeled High Latitude Lower Tropospheric Ozone
February 11	Dan Anderson (20 min) Melanie Cook (20 min)	OH-Themed Presentations – Part 1 The Relationship between the Spatiotemporal Variability of OH, its Photochemical Drivers, and Large-Scale Climate Features A Global Survey of OH Sensitivity Using Models to Prioritize Observations to Constrain OH Variability
February 18	Jianping Mao (40 min)	The Goddard CO_2 Sounder Lidar: measuring CO_2 enhancements from wildfires and resolving CO_2 gradients
February 25	Glenn Wolfe (60 min)	NTERFACE: An EVS mission concept to transform our understanding of agricultural nitrogen
March 4	Arlene Fiore, Colleen Baublitz, Dan Westervelt (Columbia U.) (60 min)	OH-Themed Presentations – Part 2
March 11	John Sullivan, Alex Kotsakis, Luke Valin (EPA) (60 min)	Ground-based AQ campaign results
March 18	Ed Nowottnick, Pete Colarco, Melanie Follette-Cook, Bryan Duncan (60 min)	A-CCP-Themed Presentations

Date	Speaker	Title
March 25	Paul Newman (60 min)	Understanding the stratosphere to troposphere transition layer using water and ozone observations
April 1	Erin Delaria	Atmosphere-biosphere exchange of NO_x
April 8	Anne Thompson & Ryan Stauffer (45 mins)	Ozonesonde Quality Assurance Updates
April 22	Glenn Wolfe	Photochemical Evolution of the 2013 CA Rim Fire
May 6	Qing Liang	The impact of Typhoon on the UT/LS chemical composition
May 13	Zhining Tao, Dongchul Kim	NASA Unified Weather & Research Forcasting Model (NU-WRF) Development and Application
May 20	Matt McGill	Listening session
May 27	Olga Tweedy	Response of the Upper-Level Monsoon Anticyclones and Ozone to Abrupt CO_2 Changes
June 3	Giorgio Doglioni – University of Trento, Italy Sampa Das	Theme: British Columbia 2017 pyroCb event
June 10	Omar Torres (25 min) Mian Chin (25 min)	Theme: British Columbia 2017 pyroCb event (cont.) Temporal evolution of the stratospheric aerosol loads from the 2017 and 2020 pyroCb events Not BC 2017 Theme UTLS aerosol and Asian summer monsoon
June 17	Ana Prados (15-20 min)	ARSET Update
June 24	Zach Fasnacht & Joanna Joiner	Can we see through clouds and aerosol using multi-spectral data?
July 1	Mian Chin	UTLS aerosol and Asian summer monsoon
July 8	Lok Lamsal (25 min)	Theme: Aura: 17 y since launch Next-generation NO_2 Earth Science Data Record from OMI/Aura and other UV/Vis sensors
July 15	Aura-themed presentations (research, algorithm development, synergy with other missions, validation, etc.)	Aura: 17 y since launch Ruth Lieberman (675: "some upper atmosphere perspectives gained by combining Aura and Heliophysics mission data")
July 22	Ruth Lieberman (675)	Theme: Aura: 17 y since launch Some upper atmosphere perspectives gained by combining Aura and Heliophysics mission data
July 22	Mark Schoeberl/STC	SAGE III/ISS Cirrus, Subvisible Cirrus and Aerosols

Date	Speaker	Title
July 29	Can Li (~30 min) Niko Fedkin (UMD; ~15-20 min)	Theme: Aura: 17 y since launch Recent progress on satellite SO_2 retrievals New machine learning based volcanic SO_2 height retrievals and potential applications
September 2	PK Bhartia (30 min)	Development of mesospheric ozone profile dataset from OMPS LP
September 9	Dave Haffner Zain Jerath	Tropospheric aerosol profile observations using OMPS LP data Theme: British Columbia 2017 pyroCb event (cont.) Temporal evolution of the stratospheric aerosol loads from the 2017 and 2020 pyroCb events
September 16	Bryan Duncan	The Aura Mission: Looking Forward
September 23	Fei Liu (30 min)	A new method for inferring city emissions and lifetimes of nitrogen oxides from high-resolution nitrogen dioxide observations: A model study
October 7	Zhifeng Yang (UMBC; now at Howard U.)	Assimilating Ozone Lidar Profile and AirNow Surface Ozone Observations over the eastern U.S. during a Canadian Wildfire Smoke Intrusion Event using WRF-Chem/DART
October 21	Natalya Kramarova Jerry Ziemke	Evaluation of EPIC Version 3 total ozone columns: comparisons with ground-based and satellite measurements A new tropospheric ozone data product from DSCOVR EPIC
October 28	Pete Colarco	An Update on the Chemistry-Climate Modeling Group Activities, Accomplishments and Plans
November 4	Mark Schoeberl (30 minutes)	The RROCI Mission - MODIS on the Cheap'
November 18	Anne Thompson (20-25 min) Ryan Stauffer	Regional and Seasonal Trends in Tropical Ozone from SHADOZ Profiles: Reference for Models and Satellite Products
December 2	John Sullivan, A.Kotsakis, S. Janz, R. Stauffer	NASA TRACER-AQ Campaign Overview: Understanding Pollution Transport in Houston, TX
December 9	Huisheng Bian	The response of the Amazon ecosystem to the photosynthetically active radiation fields: Integrating impacts of biomass burning aerosol and clouds in the NASA GEOS Earth System Model

Aerosol, Cloud, and Precipitation research are among the nine cross-cutting themes of the Earth Sciences Division at NASA's Goddard Space Flight Center. The AeroCenter-Cloud Precipitation Center (AeroCenter-CPC) 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, clouds, and precipitation. AeroCenter interests include aerosol effects on radiative transfer, clouds and precipitation, climate, the biosphere, the role of aerosols in air quality and human health, and the atmospheric correction of aerosol blurring of satellite imagery of the ground. CPC topics include 1) cloud-precipitation processes and interactions with surface processes, aerosols, mesoscale dynamics, and large scale circulations, 2) remote sensing, radiative transfer, and scattering theory of cloud and precipitation particles, 3) cloud microphysics and convection measurements and parameterizations, and 4) satellite missions and field campaigns associated with cloud and precipitation processes. We hold weekly discussion-based, interactive seminars, with aerosol-related topics on the 1st and 3rd weeks of the month, and cloud/precipitation-related topics on the 2nd and 4th weeks. In the 2021 season, AeroCenter-CPC hosted 19 seminars, and the current AeroCenter-CPC member list holds 356 members. More information on AeroCenter-CPC activities can be found at https://aerocenter.gsfc.nasa.gov/.

Table 7.3.3: AeroCenter—Cloud Precipitation Center Seminars

Seminar series coordinators: David Giles (NASA/GSFC, Code 618, SSAI), Jasper Lewis (NASA/GSFC, Code 612, UMBC), Melanie Follette-Cook (NASA/GSFC, Code 612), and Yingxi Shi (AeroCenter Seminars); Toshihisa Matsui (NASA/GSFC, Code 612, UMD), and Kerry Meyer (CPC Seminars)

Date	Speaker	Title
February 9	Xia Li University of Utah	Effects of Wintertime Arctic Sea Ice Leads on Low-level Clouds
February 23	Jie Gong Universities Space Research Association, Code 613	The first global 883 GHz cloud ice survey: IceCube Level 1 data calibration, processing and analysis
March 2	Randall Martin Washington University in St. Louis	Perspectives on the Global Distribution of Fine Particulate Matter
March 9	Youtong Zheng University of Maryland	To couple or not to couple? New insights into the cloud-topped boundary layer
March 30	Jun Wang University of Iowa	Satellite remote sensing of aerosol vertical distribution: A critical review and future directions
April 20	Mian Chin Code 614	Monitoring air quality from geostationary satellite: Perspectives from modeling and ground-based measurements to understand the AOD-PM2.5 relationship at sub-daily time scales

Date	Speaker	Title
April 27	Erica Dolinar Navy Research Laboratory	Novel Parameterization of Ice Cloud Effective Size from Collocated CALIOP-IIR and CloudSat Retrievals
May 4	Rob Levy Code 613	Aerosols and Clouds in the Advanced Imager Era
May 18	Alexei Lyapustin Code 613	Retrieval of Spectral Aerosol Absorption over Land using EPIC UV-Vis Observations and beyond
June 1	Yunqian Zhu University of Colorado Boulder	The Impact of Volcanic Eruptions on Stratospheric Chemistry and Aerosols
June 8	Colten Peterson University of Michigan	Synergy of Far-Infrared and Mid-Infrared Radiances for Polar Cloud Phase Determination, Part I: Ice Thermodynamic Phase
July 13	Peter Colarco/Ed Nowottnick Code 614	Diving a bit into the weeds of how we treat the dust particle size distribution in models (you've been warned)
September 28	David Peterson Navy Research Laboratory	Australia's Black Summer Pyrocumulonimbus Super Outbreak Reveals Potential for Increasingly Extreme Stratospheric Smoke Events
October 5	Scott Rudlosky National Oceanic and Atmospheric Administration	Geostationary Lightning Mapper Observations and Applications
October 12	Adele Igel University of California Davis	Invigoration or Enervation of Convective Clouds by Aerosols?
November 2	Qianqian Song University of Maryland Baltimore County	Deriving Size-Resolved Dust Direct Radiative Effect Efficiency from a Satellite-based Decadal Dust Optical Thickness Climatology
November 16	Ed Hyer Navy Research Laboratory	Normalizing fire observations across sensors using FRP distributions
November 23	Stephen Guimond University of Maryland Baltimore County, Code 612	The Energetics of Hurricane Intensification
December 7	Meng Gao Science Systems and Applications, Inc., Code 616	Accelerating multi-angle polarimetric aerosol and ocean color retrievals for NASA's PACE mission through deep learning

Please note: Due to overlapping interests and membership, the committee members for AeroCenter and CPC have decided to merge these two seminar series.

7.4. Outreach

7.4.1. Introduction

Science plays an important role in people's 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 outreach activities to communicate the importance and benefits of NASA's Earth Science research through engagement with local, regional, and national organizations and institutions. Target audiences may include policy makers, resource managers, teachers, students, citizens, and particular professional groups. The Earth Observatory's site shares the images, stories, and discoveries that emerge from NASA research about the environment. 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 (EO). The group works with scientists and staff from across NASA's Earth Science Division as well as affiliated institutions and organizations. Imagery from the EO regularly appear in the popular media, science magazines, textbooks, and blogs. Since its founding in 1999, the EO 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 nearly 80,000 images, including those produced for the Earth Observatory website.

In 2021, 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 2021 include:

- The EO website experienced its busiest year in its 22-year history, serving on average over 910,000 visitors and 1.9 million pageviews per month during 2021.

- In 2021, the EO hosted two iterations of its "Tournament Earth—Astronaut Photography Edition" and "The Landsat Games." Tournament Earth provides visitors with an opportunity to vote on their favorite images from a curated collection and in 2021 over 1 million readers voted. The majority of those votes came during the "Astronaut Photography Edition"—a collaboration between the EO and the JSC Crew Earth Observations Facility team—which featured a winning photo of Lake Van, Turkey.

- The EO continued to provide coverage of natural and manmade events through its Natural Events section, particularly emphasizing the summer wildfire and hurricane seasons in the Northern Hemisphere.

- Four new issues of EO Kids were published, featuring stories and imagery from the EO and written for audiences aged 9 to 14.

- EO staff also participated at ESD and SMD strategic efforts, including the ESD Strategic Communications Working Group and the NASA and SMD Web Modernization teams.

For additional information please contact Kevin Ward (NASA/GSFC, Code 613, SSAI): kevin.a.ward@nasa.gov.

7.4.3 Outreach

On January 14, NASA and NOAA climate experts released their annual assessment of global temperatures over the last year. Due to requests for information from news outlets all over the world, virtual interview opportunities with participating scientists were made available on January 15. Alfonso Delgado-Bonal (NASA/GSFC, Code 613, USRA) conducted one newspaper, two radio, and four television news interviews for Spanish-language media outlets. https://svs.gsfc.nasa.gov/13791.

On February 4, Dorian Janney gave a 90-minute virtual workshop entitled "What's the Buzz? From satellites and smart phones – working together to reduce the threat of mosquito-transmitted disease". During this presentation, she shared information about the Global Precipitation Measurement (GPM) mission and explained how data from this mission as well as several other NASA Earth observing satellites are used to predict, monitor, and respond to mosquito-transmitted disease. She also shared information about the GLOBE Observer "Mosquito Habitat Mapper" tool and the GLOBE "Mission Mosquito" field campaign.

On May 24-28, Santiago Gassó (NASA/GSFC, Code 613, UMD) was an invited panelist and gave a talk entitled "Dust Alerts and Social Media, a perspective from run-of-the-mill scientists" at the Dust Storm session of the NSF-AGU sponsored online workshop Bringing Land, Ocean, Atmosphere and Ionosphere.

On June 14, Dorian Janney assisted and presented during the monthly "Trees Around the GLOBE" webinar. There were 37 participants from several countries who participated in this event.

On June 28, Kristen Weaver presented about GLOBE Observer and NASA citizen science generally as part of a webinar for the Prince William Conservation Alliance.

On June 30, Kristen Weaver and Brian Campbell (610.W/GST) gave presentations at the 2021 Slovenia International Conference for Outdoor Learning Didactics: ICT and Outdoor Learning, sponsored by the Republic of Slovenia and the European Union. Kristen gave a presentation/training on the NASA GLOBE Observer Clouds Tool and served on a panel for "New and Future Technologies and Their Possible Impact on Outdoor Learning." Campbell presented on the NASA GLOBE Observer Trees Tool and the ICESat-2 Mission.

On June 30, Kristen Weaver connected virtually with summer camp participants as a subject matter expert, part of the GLOBE Goes to Camp efforts organized by the NASA GLOBE Clouds team at NASA Langley.

NASA ARSET completed an introductory-level, online training titled NASA Earth Observations for Energy Management. This four-part training was conducted in collaboration with Battelle and introduced NASA Earth observations and tools that can be used for energy management applications, specifically through the NASA POWER project's web services and tools. Natasha Sadoff, Amy Leibrand, Meredith Fritz, Paul Stackhouse, and Bradley Macpherson delivered the training. Ana Prados (NASA/GSFC, Code 614, UMBC), Brock Blevins (NASA/GSFC, Code 614, SSAI), Selwyn Hudson-Odoi (NASA/GSFC, Code 614,UMBC), David Barbato (NASA/GSFC, Code 614, UMBC), and Jonathan O'Brien (NASA/GSFC, Code 614, SSAI) supported the training. In attendance were 851 participants from 96 countries and 31 U.S. states. Approximately 400 unique organizations were represented. You can learn more about the training and access the materials at: https://appliedsciences.nasa.gov/join-mission/training/english/nasa-earth-observations-energy-management

On August 20, Dorian Janney developed three StoryMaps to accompany and support the NASA At Your Table campaign. These StoryMaps show the ways in which data from the Global Precipitation data are used to support crop monitoring, drought, and food security. These resources can be viewed here: https://gpm.nasa.gov/education/interactive/nasa-your-table

On August 23, Dorian Janney presented a poster entitled "What's the Buzz? From Satellites to Your Cell Phone" during the AmeriGEO Week 2021 meeting. This poster shared information on how NASA Earth observations are used to predict, monitor, and respond to mosquito-transmitted disease around the world, and highlighted the Global Precipitation Measurement mission's "Disease Initiative" as well as sharing the GLOBE Program "Mosquito Habitat Mapper" tool.

On August 24, Dorian Janney assisted with the development of the "Climate Modeling Applications Package" which is being released through various NASA social media channels. Most of the related resources included in this package can be found here: https://arcg.is/ajC9u1.

On August 26, Dorian Janney presented a poster entitled "Water for Wheaties? Education/Outreach Resources" during the AmeriGEO Week 2021 meeting. This poster shared the education and outreach resources which were developed by the Global Precipitation Measurement Mission's Outreach team which focus on applications for food security using NASA's Earth observing data.

On August 26, Dorian Janney presented a poster entitled "GEO Health CoP Food Security and Safety Small Work Group" during the AmeriGEO Week 2021 meeting. This poster shared the work being done by this work group and invited potential shareholders to become involved in upcoming efforts.

On September 7, Dorian Janney gave a flash talk entitled "What's the Buzz? From Satellites to Your Cell Phone" to the participants on the GEO Health Infectious Diseases telecon. Her presentation focused on the Global Precipitation Measurement (GPM) mission's "Disease Initiative" effort and introduced the GLOBE Observer "Mosquito Habitat Mapper" tool.

On September 9, Dorian Janney organized and presented during the monthly GLOBE Mission Mosquito webinar. She explained how IMERG data from the Global Precipitation Measurement (GPM) mission and other NASA Earth observations are being used to help predict, monitor, and respond to mosquito-transmitted disease and demonstrated how to access and analyze IMERG data using Giovanni.

On August 26, Brian Campbell gave a three-hour secondary science teacher professional development workshop at the James M. Bennett High School. Sixteen secondary science teachers and one county science supervisor, from three Wicomico County High Schools (Wicomico High School, James M. Bennett High School, Parkside High School), attended the workshop. The workshop focused on NASA Earth Science, Laser altimetry with ICESat-2 and GEDI, the GLOBE Program and the NASA GLOBE Observer Trees Tool. Teachers were trained on how to take tree height observations using a hand-held clinometer and the NASA GLOBE Observer Trees Tool, compare their ground-based tree height observations with those from ICESat-2 through Open Altimetry, and how to estimate the amount of carbon dioxide a tree can take in, based on its tree height and tree circumference (converted to tree diameter). The Wicomico County Science Supervisor will be instrumental in adopting the GLOBE Program into the county science curriculum.

On August 30, Dorian Janney and Brian Campbell worked with GLOBE Program India scientist and engineer, Yashraj Patil, to align his 2021 Himalayan Expedition research with a suite of GLOBE Program environmental measurement protocols. Yashraj spent several weeks in Ladakh, India taking observations of land cover, cloud cover, salinity, pH in areas such as the Saboo Cloudburst Site, Indus-Yarlung Suture Zone, Tso Kar Ramsar Site, and the Puga Geothermal System Site. Through this research, Yashraj compared his data on the ground to data from missions like Landsat, CloudSat, and Meteosat-8 and is creating an ArcGIS Story Map about his research that will be released in the near future.

On September 21, Chris Kidd (NASA/GSFC, Code 612, UMD) gave a virtual talk entitled “Meteorology and Climate Change” to King Edward VI High School for Girls, Birmingham (UK).

Ryan Kramer (NASA/GSFC, Code 613, UMBC) wrote an article for the French popular science magazine *La Recherche* about how satellite measurements of Earth’s energy budget are used to understand present-day climate change. The article described his recent *Geophysical Research Letters* paper “Observational Evidence of Increasing Global Radiative Forcing”.

On September 21, Dorian Janney gave two flash talks during the Special Edition of the GEO Health Community of Practice (http://www.geohealthcop.org/workshops/2021/9/21/telecon-sep2021). The first talk focused on the Global Precipitation Measurement (GPM) mission and shared the many education and outreach materials which have been developed to highlight the application s of GPM data. The second talk focused on the GEO Health Community of Practice Food Security and Safety work group efforts.

On September 21, Dorian Janney presented during the monthly “Trees Around the GLOBE” webinar. She presented an overview of the Global Precipitation Measurement (GPM) mission and showed participants where to find the education and outreach resources on the “Precipitation Education” website.

On October 28, Dorian Janney gave a virtual presentation entitled “NASA at Your Table” to support the Maryland STEMFEST activities. She shared information from the recent NASA campaign and gave a deeper dive into the use of data from the Global Precipitation Measurement mission for these applications.

Scott Braun (NASA/GSFC, Code 612) was featured in a podcast for The Weather Company’s Weather Geeks podcast series (https://podcasts.apple.com/us/podcast/getting-a-grip-on-the-tropics/id1373312240?i=1000540595657). He was interviewed by former NASA meteorologist Marshall Shepherd and discussed his career and how NASA airborne (GRIP, HS3) and spaceborne missions (TRMM, GPM, TROPICS, AOS) contribute to our understanding and improved prediction of hurricanes.

On November 16, Susan Strahan (NASA/GSFC, Code 614, USRA) was interviewed on the topic of the ozone layer for the documentary series "Our Changing Earth" produced by Wildbear Entertainment Production Company. The documentary will be distributed internationally.

OMPS/NPP PCA SO_2 product—PI, Can Li (NASA/GSFC, Code 614, UMD)—was among the top 5 product files downloaded from GES DISC during the last five years. Other MEaSUREs ozone, aerosol, SO_2 and NO_2 products were among the top 20 product files downloaded from GES DISC.

On March 1, Scott Braun (NASA/GSFC, Code 612) gave a presentation as part of the University of Maryland's ESSIC Seminar Series. The topic was "NASA Space-based Precipitation Measurements of Tropical Cyclones: Past, Present, and Future." Braun described research contributions from TRMM, applications highlights associated with GPM, planned science and activities with the upcoming TROPICS EV-I mission, and the current status of the NASA Decadal Survey Aerosols, Clouds, Convection, and Precipitation (ACCP) study for a future observing system.

The Earth Observatory Group (NASA/GSFC, Code 613, SSAI) held their annual competition, Tournament Earth 2021, to vote for favorite images focused on astronaut photography. The EO team partnered with astronauts and staff with the ISS Crew Earth Observations Facility and the Earth Science and Remote Sensing Unit at Johnson Space Center to select 32 of the best photographs captured by astronauts aboard the ISS. Vote for your favorites at https://earthobservatory.nasa.gov/tournament-earth.

On March 15, Ralph Kahn (NASA/GSFC, Code 613) and Lauren Zamora (NASA/GSFC, Code 613, UMD) presented a tutorial on "Wildfire smoke, desert dust, volcanic ash, urban and industrial pollution: What we are learning about airborne particles from space-based remote sensing" at the Nordic Society for Aerosol Research (NOSA) 2021 Symposium.

Ryan Kramer (NASA/GSFC, Code 613, UMBC) was interviewed by FOX for a story reported through FOX-affiliated TV stations about his recent study "Observational Evidence of Increasing Global Radiative Forcing" with Lazaros Oreopoulos (NASA/GSFC, Code 613) and collaborators (https://www.fox5dc.com/news/nasa-finds-direct-evidence-that-humans-are-causing-climate-change). The study has been reported on by other media outlets nationally and internationally, including CBS News (https://www.cbsnews.com/news/climate-change-human-cause-nasa-study-carbon-emissions/).

On April 10, Ralph Kahn was quoted in an Earth Observatory highlights of the month article about tracking La Soufrière plumes with MISR. https://earthobservatory.nasa.gov/images/148190/tracking-la-soufrieres-plume.

With multiple storms offshore and smoke streaming over the United States, the Earth Observatory Group (NASA/GSFC, Code 613, SSAI) is reporting on natural events as they happen and soliciting input from scientists like Charles Helms (NASA/GSFC, Code 610, USRA) to help explain these events. https://earthobservatory.nasa.gov/images/148725/storms-churn-around-north-america.

On April 16, Jackson Tan (NASA/GSFC, Code 613, USRA) gave a seminar at the Department of Atmospheric Science at Texas A&M University–Corpus Christi entitled "20 Years of Global Precipitation Measurement with IMERG V06".

On April 19, Tianle Yuan (NASA/GSFC, Code 613, UMBC) and Hongbin Yu (NASA/GSFC, Code 613) were interviewed by NASA's Earth Science News team who produced a story entitled "Earth Day Connections: NASA study Predicts Less Saharan Dust in Future Winds," The article is based on research from two studies dealing with African dust variability in general and the Godzilla dust storm, respectively. A feature video accompanying the story highlights multiple NASA instruments and data. https://www.nasa.gov/feature/esnt/2021/nasa-study-predicts-less-saharan-dust-in-future-winds.

The Earth Observatory Group concluded its annual Choose-Your-Favorite-Image event —Tournament Earth—focusing on photographs of Earth captured by astronauts aboard the ISS. Over 930,000 voters selected their favorite images, whittling the contestants from 32 down to a single winner: a photo shot by astronaut Kate Rubins in September 2016, showing part of one of the largest alkaline lakes in the world, Lake Van, Turkey. https://go.nasa.gov/3tL5vpb

On April 22, for NASA's Earth Day Campaign, Alfonso Delgado-Bonal (NASA/GSFC, Code 613, UMD) conducted 8 interviews for international, national, and statewide Spanish-language media outlets. https://svs.gsfc.nasa.gov/13833.

Ryan Kramer, Aprille Ericsson (NASA/GSFC, Code 550) and Janelle Wellons appeared on the educational webcast "All Things Aviation & Aerospace" on Earth Day to discuss their jobs and provide advice for pursuing a career in earth science and engineering.

On May 5, Dorian Janney and Andrea Portier gave an hour-long presentation to open the 2021 COSI Science Festival, Ohio's largest annual science event. They presented information on freshwater on Earth, the science, technology, and applications behind the Global Precipitation Measurement mission, and introduced GPM's most recent Applications Package resources. https://youtu.be/RiNyibbnNnA

On May 25-28, Joe Munchak (NASA/GSFC, Code 612) gave a presentation at the invitation only 2nd ESA EarthCARE Validation Workshop. The presentation was titled "Perspectives on Ground Validation from the NASA/JAXA Global Precipitation Measurement Mission."

On June 1, Dorian Janney wrote and delivered a monthly newsletter to the 21 members of the GLOBE OLLI course to share the total GLOBE Observer observations they have submitted for each of the four tools and to update them on various GLOBE and NASA news.

A profile of Ryan Kramer was featured in an "Early Career Scientist Spotlight" article: https://science.gsfc.nasa.gov/600/ECSS/Ryan-Kramer.html.

On August 11, Scott Braun (NASA/GSFC, Code 612) was interviewed for The Weather Channel's Weather Geeks podcast by Marshall Shepherd to talk about hurricanes and how NASA studies them. The interview covered his educational background and early career, background on hurricane related processes, and key NASA measurements of hurricanes from the TRMM, GPM, and upcoming TROPICS missions, the GRIP and HS3 airborne campaigns, and a look forward to the Atmosphere Observing System (formerly ACCP) currently under study. The interview is expected to be available before the end of August.

On August 20, the Earth Observatory Group (NASA/GSFC, Code 613, SSAI) reported on the Greenland Ice Sheet's intense and widespread melting this summer (https://earthobservatory.nasa.gov/images/148720/rain-and-warmth-trigger-more-melting-in-greenland) with the help of Lauren Andrews (NASA/GSFC, Code 610.1) and Christopher Shuman (NASA/GSFC, Code 615, UMBC) entitled: "Earth Observatory: Rain and Warmth Trigger More Melting in Greenland" (IOTD August 20). This popular, generally accessible story covers the recent late-summer weather system that caused extensive melting on the Greenland Ice Sheet. Because of modeling predictions prior to the weather event, EO was alerted and then able to move quickly on this story. Lauren Andrews, Kathryn Hansen (NASA/GSFC, Code 613, SSAI), Lauren Dauphin (NASA/GSFC, Code 613, SSAI), and Christopher Shuman (NASA/GSFC, Code 615, UMBC).

The Earth Observatory Group produced a preliminary report on the effects of Hurricane Ida over Louisiana as seen by multiple NASA satellites and models, including GMAO's GEOS-5. Scott Braun provided context and interpretation of the event. https://earthobservatory.nasa.gov/images/148767/hurricane-ida-batters-louisiana.

The Lake Mead reservoir is at its lowest levels since the 1930s. A recent Earth Observatory story uses satellite imagery from the past 20 years to illustrate the changes to this vital basin. https://earthobservatory.nasa.gov/images/148758/lake-mead-drops-to-a-record-low.

A profile of Mariel D. Friberg (NASA/GSFC, Code 613, NPP) was featured in an "Early Career Scientist Spotlight" article. https://science.gsfc.nasa.gov/600/ECSS/Mariel-Friberg.html.

On September 16, Cynthia Hall (NASA/GSFC, Code 613, SSAI) co-hosted a workshop for 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 https://earthdata.gov’s new Data Pathfinders and Data Toolkits to help new and expert data users more intuitively access NASA data, information about Alaska Satellite Facility Distributed Active Archive Center’s (ASF DAAC) new on-demand interferometric SAR workflow, and a tutorial from the Applied Sciences SERVIR program on monitoring land use change and estimating forest stand height using SAR data.

The October Goddard Applied Sciences highlight was “Earth Observations Support Surveillance and Elimination of Vector-borne Diseases,” a collaborative effort with Mariel D. Friberg-Aponte (NASA/GSFC, Code 613, UMD) and external stakeholders in Panama, Costa Rica, and Japan.

Santiago Gassó (NASA/GSFC, Code 613, UMD) was interviewed by a researcher from the BBC Natural History Unit to provide background about dust storms and dust activity in Argentina for an upcoming film on wildlife and natural phenomena in the region.

Stephen Lang (NASA/GSFC, Code 612, SSAI) wrote an article using IMERG to examine precipitation patterns for the 2021 monsoon in India. The article was shared to web and social media by Jacob Reed (NASA/GSFC, Code 617, Telophase) (https://gpm.nasa.gov/applications/summer-monsoon-season-ends-india, https://twitter.com/NASAAtmosphere/status/1458192808670543877, https://www.facebook.com/NASAAtmosphere/posts/248093810677853).

The Earth Observatory Group reported on new research showing that neighborhoods in Washington, DC, with more people of color are exposed to more air pollution and have higher rates of disease. Adam Voiland (NASA/GSFC, Code 613, SSAI) and Kevin Ward (NASA/GSFC, Code 613, SSAI) from Earth Observatory Group: “Like many cities in the eastern United States, Washington, DC has seen major improvements in air quality in recent decades. While cleaner air has yielded significant health benefits, those benefits have not accrued evenly.” https://earthobservatory.nasa.gov/images/149047/an-extra-air-pollution-burden.

On November 23-24, George J. Huffman (NASA/GSFC, Code 612) moderated two sessions in Workshop 2 of the Improving Urban Water Management in Western and Central Asia Workshop Serial (2021-2024), organized by UNESCO components ICWRGC, RCUWM, [virtual]. These sessions included 11 participating countries, stretching from Egypt to Bangladesh.

The first observation of smoke from forest fires reaching the North Pole was highlighted in the November issue of Harper's Magazine from a satellite image posted by Santiago Gassó (NASA/GSFC, Code 613, UMD) on Twitter. Harper's Magazine is a general interest monthly published since 1860.

November 23, Mariel D. Friberg (NASA/GSFC, Code 613, UMD) was featured in a "Conversations with Goddard" article titled "Mariel Friberg Uses Satellite Data to Study Wildfires. https://www.nasa.gov/feature/goddard/2021/mariel-friberg-uses-satellite-data-to-study-wildfires.

8. Atmospheric Sciences in the News

The following pages contain links to press releases that describe some of the laboratory's activities during 2021:

NASA's Globe Program Celebrates 25 Years
https://www.nasa.gov/feature/esnt/2021/nasa-s-globe-program-celebrates-25-years

Direct observations confirm that humans are throwing Earth's energy budget off balance
https://phys.org/news/2021-03-humans-earth-energy.html

NASA study predicts less Saharan dust in future winds
https://phys.org/news/2021-04-nasa-saharan-future.html

As record heat scorches western Russia and central Canada, climate alarm bells ring
https://www.washingtonpost.com/weather/2021/05/20/record-heat-russia-canada-climate-change/

Pathfinder satellite paves way for constellation of tropical-storm observers
https://phys.org/news/2021-07-pathfinder-satellite-paves-constellation-tropical-storm.html

Direct Observations Confirm That Humans Are Throwing Earth's Energy Budget off Balance
https://climate.nasa.gov/news/3072/direct-observations-confirm-that-humans-are-throwing-earths-energy-budget-off-balance/

Pathfinder Satellite Paves Way for Constellation of Tropical-storm Observers
https://www.nasa.gov/feature/esnt/2021/pathfinder-satellite-paves-way-for-constellation-of-tropical-storm-observers

NASA-Funded Network Tracks the Recent Rise and Fall of Ozone-Depleting Pollutants
https://climate.nasa.gov/news/3065/nasa-funded-network-tracks-the-recent-rise-and-fall-of-ozone-depleting-pollutants/

NASA, LAPAN Launch Ozonesonde From Indonesian Site for 1st Time in 8 Years
https://www.nasa.gov/feature/goddard/2021/nasa-and-lapan-launch-ozonesonde-from-indonesian-site-for-the-first-time-in-eight-years

NASA-funded Network Tracks the Recent Rise and Fall of Ozone Depleting Pollutants
https://www.nasa.gov/feature/goddard/2021/nasa-funded-network-tracks-the-recent-rise-and-fall-of-ozone-depleting-pollutants

Direct Observations Confirm that Humans are Throwing Earth's Energy Budget off Balance
https://www.nasa.gov/feature/goddard/2021/direct-observations-confirm-that-humans-are-throwing-earth-s-energy-budget-off-balance

2021 Antarctic Ozone Hole 13th-Largest, Will Persist into November
https://www.nasa.gov/feature/goddard/2021/2021-antarctic-ozone-hole-13th-largest-will-persist-into-november

NASA Study Examines Houston-area Air Quality Issues
https://www.nasa.gov/feature/langley/nasa-study-examines-houston-area-air-quality-issues

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

Ahn, C., O. Torres, H. Jethva, R. Tiruchirapalli, and L. Huang. 2021. "Evaluation of Aerosol Properties Observed by DSCOVR/EPIC Instrument From the Earth-Sun Lagrange 1 Orbit." *J. Geophys. Res.: Atmos.*, 126 (12): [10.1029/2020jd033651]

Allen, D. J., K. E. Pickering, L. Lamsal, D. M. Mach, M. G. Quick, J. Lapierre, S. Janz, W. Koshak, M. Kowalewski, and R. Blakeslee. 2021. "Observations of Lightning NO_x Production From GOES-R Post Launch Test Field Campaign Flights." *J. Geophys. Res.: Atmos.,* 126 (8): [10.1029/2020jd033769]

Anderson, D. C., B. N. Duncan, A. M. Fiore, C. B. Baublitz, M. B. Follette-Cook, J. M. Nicely, and G. M. Wolfe. 2021. "Spatial and temporal variability in the hydroxyl (OH) radical: understanding the role of large-scale climate features and their influence on OH through its dynamical and photochemical drivers." *Atmos. Chem. Phys.*, 21 (8): 6481-6508 [10.5194/acp-21-6481-2021]

Anstey, J. A., T. P. Banyard, N. Butchart, L. Coy, P. A. Newman, S. Osprey, and C. J. Wright. 2021: "Prospect of Increased Disruption to the QBO in a Changing Climate." Geophys. Res. Lett., 48 (15): [10.1029/2021gl093058]

Bian, H., E. Lee, R. D. Koster, D. Barahona, M. Chin, P. R. Colarco, A. Darmenov, S. Mahanama, M. Manyin, P. Norris, J. Shilling, H. Yu, and F. Zeng. 2021. "The response of the Amazon ecosystem to the photosynthetically active radiation fields: integrating impacts of biomass burning aerosol and clouds in the NASA GEOS Earth system model." *Atmos. Chem. Phys.*, 21 (18): 14177-14197 [10.5194/acp-21-14177-2021]

Bian, Q., S. Kreidenweis, J. C. Chiu, S. D. Miller, X. Xu, J. Wang, R. Kahn, J. A. Limbacher, L. A. Remer, and R. C. Levy. 2021. "Constraining aerosol phase function using dual-view geostationary satellites." *J. Geophys. Res.: Atmos.*, 126 [10.1029/2021jd035209]

Bilal, M., A. Mhawish, J. E. Nichol, Z. Qiu, M. Nazeer, M. A. Ali, G. de Leeuw, R. C. Levy, Y. Wang, Y. Chen, L. Wang, Y. Shi, M. P. Bleiweiss, U. Mazhar, L. Atique, and S. Ke. 2021. "Air pollution scenario over Pakistan: Characterization and ranking of extremely polluted cities using long-term concentrations of aerosols and trace gases." *Remote Sens. Environ.*, 264 112617 [10.1016/j.rse.2021.112617]

Bolvin, D. T., G. J. Huffman, E. J. Nelkin, and J. Tan. 2021. "Comparison of Monthly IMERG Precipitation Estimates with PACRAIN Atoll Observations." *J. Hydrometeorol.*, 22 (7): 1745-1753 [10.1175/jhm-d-20-0202.1]

Breen, K. H., D. Barahona, T. Yuan, H. Bian, and S. C. James. 2021. "Effect of volcanic emissions on clouds during the 2008 and 2018 Kilauea degassing events." *Atmos. Chem. Phys.,* 21 (10): 7749-7771 [10.5194/acp-21-7749-2021]

Buchholz, R. R., H. M. Worden, M. Park, G. Francis, M. N. Deeter, D. P. Edwards, L. K. Emmons, B. Gaubert, J. Gille, S. Martínez-Alonso, W. Tang, R. Kumar, J. R. Drummond, C. Clerbaux, M. George, P.-F. Coheur, D. Hurtmans, K. W. Bowman, M. Luo, V. H. Payne, J. R. Worden, M. Chin, R. C. Levy, J. Warner, Z. Wei, and S. S. Kulawik. 2021. "Air pollution trends measured from Terra: CO and AOD over industrial, fire-prone, and background regions." *Remote Sens. Environ.*, 256, 112275 [10.1016/j.rse.2020.112275]

Byrne, B., J. Liu, M. Lee, Y. Yin, K. W. Bowman, K. Miyazaki, A. J. Norton, J. Joiner, D. F. Pollard, D. W. Griffith, V. A. Velazco, N. M. Deutscher, N. B. Jones, and C. Paton-Walsh. 2021. "The Carbon Cycle of Southeast Australia During 2019-2020: Drought, Fires, and Subsequent Recovery." *AGU Adv.*, 2 (4): [10.1029/2021av000469]

Campbell, B. A. 2021. "ICESat-2 and the Trees Around the GLOBE student research campaign: Looking at Earth's tree height, one tree at a time." *Acta Astronautica*, 182 203-207 [10.1016/j.actaastro.2021.02.002]

Cawse-Nicholson, K., P. A. Townsend, D. Schimel, A. M. Assiri, P. L. Blake, M. F. Buongiorno, P. Campbell, N. Carmon, K. A. Casey, R. E. Correa-Pabón, K. M. Dahlin, H. Dashti, P. E. Dennison, H. Dierssen, A. Erickson, J. B. Fisher, R. Frouin, C. K. Gatebe, H. Gholizadeh, M. Gierach, N. F. Glenn, J. A. Goodman, D. M. Griffith, L. Guild, C. R. Hakkenberg, E. J. Hochberg, T. R. Holmes, C. Hu, G. Hulley, K. F. Huemmrich, R. M. Kudela, R. F. Kokaly, C. M. Lee, R. Martin, C. E. Miller, W. J. Moses, F. E. Muller-Karger, J. D. Ortiz, D. B. Otis, N. Pahlevan, T. H. Painter, R. Pavlick, B. Poulter, Y. Qi, V. J. Realmuto, D. Roberts, M. E. Schaepman, F. D. Schneider, F. M. Schwandner, S. P. Serbin, A. N. Shiklomanov, E. N. Stavros, D. R. Thompson, J. L. Torres-Perez, K. R. Turpie, M. Tzortziou, S. Ustin, Q. Yu, Y. Yusup, and Q. Zhang. 2021. "NASA's surface biology and geology designated observable: A perspective on surface imaging algorithms." *Remote Sens. Environ.*, 257, 112349 [10.1016/j.rse.2021.112349]

Chaves, L. F., and M. D. Friberg. 2021. "Aedes albopictus and Aedes flavopictus (Diptera: Culicidae) pre-imaginal abundance patterns are associated with different environmental factors along an altitudinal gradient." *Curr. Res. Insect Sci.*, 1 100001 [10.1016/j.cris.2020.100001]

Chen, H., S. Schmidt, M. D. King, G. Wind, A. Bucholtz, E. A. Reid, M. Segal-Rozenhaimer, W. L. Smith, P. C. Taylor, S. Kato, and P. Pilewskie. 2021. "The effect of low-level thin arctic clouds on shortwave irradiance: evaluation of estimates from spaceborne passive imagery with aircraft observations." *Atmos. Meas. Tech.*, 14 (4): 2673-2697 [10.5194/amt-14-2673-2021]

Chen, T., Z. Li, R. A. Kahn, C. Zhao, D. Rosenfeld, J. Guo, W. Han, and D. Chen. 2021. "Potential impact of aerosols on convective clouds revealed by Himawari-8 observations over different terrain types in eastern China." *Atmos. Chem. Phys.*, 21 (8): 6199-6220 [10.5194/acp-21-6199-2021]

Chen, X., J. Wang, X. Xu, M. Zhou, H. Zhang, L. Castro Garcia, P. R. Colarco, S. J. Janz, J. Yorks, M. McGill, J. S. Reid, M. de Graaf, and S. Kondragunta. 2021. "First retrieval of absorbing aerosol height over dark target using TROPOMI oxygen B band: Algorithm development and application for surface particulate matter estimates." *Remote Sens. Environ.*, 265 112674 [10.1016/j.rse.2021.112674]

Cho, C., J. M. Clair, J. Liao, G. M. Wolfe, S. Jeong, D. I. Kang, J. Choi, M.-H. Shin, J. Park, J.-H. Park, A. Fried, A. Weinheimer, D. R. Blake, G. S. Diskin, K. Ullmann, S. R. Hall, W. H. Brune, T. F. Hanisco, and K.-E. Min. 2021. "Evolution of formaldehyde (HCHO) in a plume originating from a petrochemical industry and its volatile organic compounds (VOCs) emission rate estimation." *Elementa: Sci. Anthropocene*, 9 (1): [10.1525/elementa.2021.00015]

Cho, N., J. Tan, and L. Oreopoulos. 2021. "Classifying planetary cloudiness with an updated set of MODIS Cloud Regimes." *J. Appl. Meteorol. Climatol.,* [10.1175/jamc-d-20-0247.1]

Choi, M., S. P. Sander, R. J. Spurr, T. J. Pongetti, G. van Harten, B. J. Drouin, D. J. Diner, D. Crisp, A. Eldering, O. V. Kalashnikova, J. H. Jiang, J. J. Hyon, and D. Fu. 2021. "Aerosol profiling using radiometric and polarimetric spectral measurements in the O_2 near infrared bands: Estimation of information content and measurement uncertainties." *Remote Sens. Environ.*, 253 112179 [10.1016/j.rse.2020.112179]

Das, S., P. R. Colarco, L. D. Oman, G. Taha, and O. Torres. 2021. "The long-term transport and radiative impacts of the 2017 British Columbia pyrocumulonimbus smoke aerosols in the stratosphere." *Atmos. Chem. Phys.*, 21 (15): 12069-12090 [10.5194/acp-21-12069-2021]

DeLang, M. N., J. S. Becker, K.-L. Chang, M. L. Serre, O. R. Cooper, M. G. Schultz, S. Schröder, X. Lu, L. Zhang, M. Deushi, B. Josse, C. A. Keller, J.-F. Lamarque, M. Lin, J. Liu, V. Marécal, S. A. Strode, K. Sudo, S. Tilmes, L. Zhang, S. E. Cleland, E. L. Collins, M. Brauer, and J. J. West. 2021. "Mapping Yearly Fine Resolution Global Surface Ozone through the Bayesian Maximum Entropy Data Fusion of Observations and Model Output for 1990-2017." *Environmental Science and Technology acs.est.0c07742* [10.1021/acs.est.0c07742]

DeLeon, C. M., J. Heath, W. R. Espinosa, D. Wu, and M. Kupinski. 2021. “UV linear stokes imaging of optically thin clouds.” *Polariz. Sci. Remote Sens. X,* 11833, 1-7 [10.1117/12.2595161]

Delgado-Bonal, A., A. Marshak, Y. Yang, and L. Oreopoulos. 2021. “Global daytime variability of clouds from DSCOVR/EPIC observations.” *Geophys. Res. Lett.*, 48 [10.1029/2020gl091511]

deSouza, P. N., P. A. Oriama, P. P. Pedersen, S. Horstmann, L. Gordillo-Dagallier, C. Christensen, C. O. Franck, R. Ayah, R. Kahn, J. Klopp, K. Messier, and P. L. Kinney. 2021. “Spatial variation of fine particulate matter levels in Nairobi before and during the COVID-19 curfew: Implications for environmental justice.” *Environ. Res. Comm.*, 3. [10.1088/2515-7620/ac1214]

Dubovik, O., D. Fuertes, P. Litvinov, A. Lopatin, T. Lapyonok, I. Doubovik, F. Xu, F. Ducos, C. Chen, B. Torres, Y. Derimian, L. Li, M. Herreras-Giralda, M. Herrera, Y. Karol, C. Matar, G. L. Schuster, R. Espinosa, A. Puthukkudy, Z. Li, J. Fischer, R. Preusker, J. Cuesta, A. Kreuter, A. Cede, M. Aspetsberger, D. Marth, L. Bindreiter, A. Hangler, V. Lanzinger, C. Holter, and C. Federspiel. 2021. “A Comprehensive Description of Multi-Term LSM for Applying Multiple a Priori Constraints in Problems of Atmospheric Remote Sens.: GRASP Algorithm, Concept, and Applications.” *Front. Remote Sens.*, 2 [10.3389/frsen.2021.706851]

Duncan, B. N., C. A. Malings, K. E. Knowland, D. C. Anderson, A. I. Prados, C. A. Keller, K. R. Cromar, S. Pawson, and H. Ensz. 2021. “Augmenting the Standard Operating Procedures of Health and Air Quality Stakeholders With NASA Resources.” *GeoHealth*, 5 (9): [10.1029/2021gh000451]

Falah, S., A. Mhawish, M. Sorek-Hamer, A. I. Lyapustin, I. Kloog, T. Banerjee, F. Kizel, and D. M. Broday. 2021. “Impact of environmental attributes on the uncertainty in MAIAC/MODIS AOD retrievals: A comparative analysis.” *Atmos. Environ.*, 262 118659 [10.1016/j.atmosenv.2021.118659]

Fernandez, R. P., J. A. Barrera, A. I. López-Noreña, D. E. Kinnison, J. Nicely, R. J. Salawitch, P. A. Wales, B. M. Toselli, S. Tilmes, J. Lamarque, C. A. Cuevas, and A. Saiz-Lopez. 2021. “Intercomparison Between Surrogate, Explicit, and Full Treatments of VSL Bromine Chemistry Within the CAM-Chem Chemistry-Climate Model.” *Geophys. Res. Lett.*, 48 (4): [10.1029/2020gl091125]

Fleming, E. L., Q. Liang, L. D. Oman, P. A. Newman, F. Li, and M. M. Hurwitz. 2021. “Stratospheric impacts of continuing CFC-11 emissions simulated in a chemistry-climate model.” *J. Geophys. Res.: Atmos.*, [10.1029/2020jd033656]

Flower, V. J., and R. A. Kahn. 2021. “Twenty years of NASA-EOS multi-sensor satellite observations at Kīlauea volcano (2000-2019).” *J. Volcanol. Geotherm. Res.*, 415, 107247 [10.1016/j.jvolgeores.2021.107247]

Fromm, M. D., G. P. Kablick, D. A. Peterson, R. A. Kahn, V. J. Flower, and C. J. Seftor. 2021. “Quantifying the source term and uniqueness of the 12 August 2017 Pacific Northwest pyroCb event.” *J. Geophys. Res.: Atmos.*, 126 (e2021JD034928): [10.1029/2021jd034928]

Funk, C. C., P. Peterson, G. J. Huffman, M. F. Landsfeld, C. Peters-Lidard, F. Davenport, S. Shukla, S. Peterson, D. H. Pedreros, A. C. Ruane, C. Mutter, W. Turner, L. Harrison, A. Sonnier, J. Way-Henthorne, and G. J. Husak. 2021. “Introducing and evaluating the Climate Hazards center IMErg with Stations (CHIMES)—Timely station-enhanced Integrated Multi-satellitE Retrievals for Global Precipitation Measurement.” *Bull. Am. Meteorol. Soc.,* 1-52 [10.1175/bams-d-20-0245.1]

Gatebe, C. K., H. Jethva, R. Gautam, R. Poudyal, and T. Várnai. 2021. “A new measurement approach for validating satellite-based above-cloud aerosol optical depth.” *Atmos. Meas. Tech.*, 14 (2): 1405-1423 [10.5194/amt-14-1405-2021]

Geogdzhayev, I. V., A. Marshak, and M. Alexandrov. 2021. “Calibration of the DSCOVR EPIC Visible and NIR Channels using Multiple LEO Radiometers.” *Front. Remote Sens.*, 2 [10.3389/frsen.2021.671933]

Gong, J., D. L. Wu, and P. Eriksson. 2021. “The first global 883 GHz cloud ice survey: IceCube Level 1 data calibration, processing and analysis.” *Earth Sys. Sci. Data,* 13, 5369-5387 [10.5194/essd-13-5369-2021]

Gorkavyi, N., N. Krotkov, C. Li, L. Lait, P. Colarco, S. Carn, M. DeLand, P. Newman, M. Schoeberl, G. Taha, O. Torres, A. Vasilkov, and J. Joiner. 2021. “Tracking aerosols and SO_2 clouds from the Raikoke eruption: 3D view from satellite observations.” *Atmos. Meas. Tech.*, 14 (12): 7545-7563 [10.5194/amt-14-7545-2021]

Gorkavyi, N., S. Carn, M. DeLand, Y. Knyazikhin, N. Krotkov, A. Marshak, R. Myneni, and A. Vasilkov. 2021. “Earth Imaging From the Surface of the Moon With a DSCOVR/EPIC-Type Camera.” *Front. Remote Sens.*, 2 [10.3389/frsen.2021.724074]

Gorkavyi, N., Z. Fasnacht, D. Haffner, S. Marchenko, J. Joiner, and A. Vasilkov. 2021. “Detection of anomalies in the UV–vis reflectances from the Ozone Monitoring Instrument.” *Atmos. Meas. Tech.*, 14 (2): 961-974 [10.5194/amt-14-961-2021]

Guanter, L., C. Bacour, A. Schneider, I. Aben, T. A. van Kempen, F. Maignan, C. Retscher, P. Köhler, C. Frankenberg, J. Joiner, and Y. Zhang. 2021. "The TROPOSIF global sun-induced fluorescence dataset from the Sentinel-5P TROPOMI mission." *Earth Sys. Sci. Data*, 13 (11): 5423-5440 [10.5194/essd-13-5423-2021]

Guilloteau, C., E. Foufoula-Georgiou, P. Kirstetter, J. Tan, and G. J. Huffman. 2021. "How well do multi-satellite products capture the space-time dynamics of precipitation? Part I: five products assessed via a wavenumber-frequency decomposition." *J. Hydrometeorol.*, 22, 2805-2823 [10.1175/JHM-D-21-0075.1]

Guo, H., C. M. Flynn, M. J. Prather, S. A. Strode, S. D. Steenrod, L. Emmons, F. Lacey, J.-F. Lamarque, A. M. Fiore, G. Correa, L. T. Murray, G. M. Wolfe, J. M. St. Clair, M. Kim, J. Crounse, G. Diskin, J. DiGangi, B. C. Daube, R. Commane, K. McKain, J. Peischl, T. B. Ryerson, C. Thompson, T. F. Hanisco, D. Blake, N. J. Blake, E. C. Apel, R. S. Hornbrook, J. W. Elkins, E. J. Hintsa, F. L. Moore, and S. Wofsy. 2021. "Heterogeneity and chemical reactivity of the remote troposphere defined by aircraft measurements." *Atmos. Chem. Phys.,* 21 (18): 13729-13746 [10.5194/acp-21-13729-2021]

Hammer, M. S., A. van Donkelaar, R. V. Martin, E. E. McDuffie, A. Lyapustin, A. M. Sayer, N. C. Hsu, R. C. Levy, M. J. Garay, O. V. Kalashnikova, and R. A. Kahn. 2021. "Effects of COVID-19 lockdowns on fine particulate matter concentrations." *Sci. Adv.*, 7 (26): eabg7670 [10.1126/sciadv.abg7670]

Han, M., and S. A. Braun. 2021. "Understanding the Global Three-dimensional Distribution of Precipitation Mean Particle Size with the Global Precipitation Measurement Mission." *J. Clim.*, 34 9775-9796 [10.1175/jcli-d-21-0134.1]

He, H., R. J. Kramer, and B. J. Soden. 2021. "Evaluating Observational Constraints on Intermodel Spread in Cloud, Temperature and Humidity Feedbacks." *Geophys. Res. Lett.*, 48. [10.1029/2020gl092309]

Herzfeld, U., A. Hayes, S. Palm, D. Hancock, M. Vaughan, and K. Barbieri. 2021. "Detection and Height Measurement of Tenuous Clouds and Blowing Snow in ICESat-2 ATLAS Data." *Geophys. Res. Lett.,* 48 (17): [10.1029/2021gl093473]

Holloway, T., D. Miller, S. Anenberg, M. Diao, B. Duncan, A. M. Fiore, D. K. Henze, J. Hess, P. L. Kinney, Y. Liu, J. L. Neu, S. M. O'Neill, M. T. Odman, R. B. Pierce, A. G. Russell, D. Tong, J. J. West, and M. A. Zondlo. 2021. "Satellite Monitoring for Air Quality and Health." *Annual Review of Biomedical Data Science.* 4 (1): 417-447 [10.1146/annurev-biodatasci-110920-093120]

Huff, A. K., S. Kondragunta, H. Zhang, I. Laszlo, M. Zhou, V. Caicedo, R. Delgado, and R. Levy. 2021. "Tracking Smoke from a Prescribed Fire and its Impacts on Local Air Quality using Temporally Resolved GOES-16 ABI Aerosol Optical Depth (AOD)." *J. Atmos. Oceanic Tech.,* 38, 963-976 [10.1175/jtech-d-20-0162.1]

Jin, D., L. Oreopoulos, D. Lee, J. Tan, and N. Cho. 2021. "Cloud-Precipitation Hybrid Regimes and their Projection onto IMERG Precipitation Data." *J. Appl. Meteorol. Climatol.,* 60 (6): 733-748 [10.1175/jamc-d-20-0253.1]

Joiner, J., Z. Fasnacht, B.-C. Gao, and W. Qin. 2021. "Use of Hyper-Spectral Visible and Near-Infrared Satellite Data for Timely Estimates of the Earth's Surface Reflectance in Cloudy Conditions: Part 2- Image Restoration With HICO Satellite Data in Overcast Conditions." *Front. Remote Sens.*, 2, 21 [10.3389/frsen.2021.721957]

Jordan, C. E., R. M. Stauffer, B. T. Lamb, M. Novak, A. Mannino, E. C. Crosbie, G. L. Schuster, R. H. Moore, C. H. Hudgins, K. L. Thornhill, E. L. Winstead, B. E. Anderson, R. F. Martin, M. A. Shook, L. D. Ziemba, A. J. Beyersdorf, C. E. Robinson, C. A. Corr, and M. A. Tzortziou. 2021. "New In Situ Aerosol Hyperspectral Optical Measurements over 300-700 nm, Part 2: Extinction, Total Absorption, Water- and Methanol-soluble Absorption observed during the KORUS-OC cruise." *Atmos. Meas. Tech.,* 14, 715–736 [10.5194/amt-2020-318]

Kedem, B., R. M. Stauffer, X. Zhang, and S. Pyne. 2021. "On the Probabilities of Environmental Extremes." *Int. J. Stat. Med. Res.,* 10, 72-84 [10.6000/1929-6029.2021.10.07]

Keller, C. A., K. E. Knowland, B. N. Duncan, J. Liu, D. C. Anderson, S. Das, R. A. Lucchesi, E. W. Lundgren, J. M. Nicely, E. Nielsen, L. E. Ott, E. Saunders, S. A. Strode, P. A. Wales, D. J. Jacob, and S. Pawson. 2021. "Description of the NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0." *J. Adv. Model. Earth Sys.,* 13 (4): [10.1029/2020ms002413]

Kidd, C., E. Graham, T. Smyth, and M. Gill. 2021. "Assessing the Impact of Light/Shallow Precipitation Retrievals from Satellite-Based Observations Using Surface Radar and Micro Rain Radar Observations." *Remote Sens.,* 13 (9): 1708 [10.3390/rs13091708]

Kidd, C., G. Huffman, V. Maggioni, P. Chambon, and R. Oki. 2021. "The Global Satellite Precipitation Constellation: Current Status and Future Requirements." *Bull. Am. Meteorol. Soc.*, 102 (10): E1844-E1861 [10.1175/bams-d-20-0299.1]

Kidd, C., T. Matsui, and S. Ringerud. 2021. "Precipitation Retrievals from Passive Microwave Cross-Track Sensors: The Precipitation Retrieval and Profiling Scheme." *Remote Sens.,* 13 (5): 947 [10.3390/rs13050947]

Kim, D., M. Chin, C. A. Cruz, D. Tong, and H. Yu. 2021. "Spring Dust in Western North America and Its Interannual Variability—Understanding the Role of Local and Transported Dust." *J. Geophys. Res.: Atmos.*, 126 (22): [10.1029/2021jd035383]

Kloss, C., G. Berthet, P. Sellitto, F. Ploeger, G. Taha, M. Tidiga, M. Eremenko, A. Bossolasco, F. Jégou, J.-B. Renard, and B. Legras. 2021. "Stratospheric aerosol layer perturbation caused by the 2019 Raikoke and Ulawun eruptions and their radiative forcing." *Atmos. Chem. Phys.,* 21 (1): 535-560 [10.5194/acp-21-535-2021]

Knobelspiesse, K., A. Ibrahim, B. Franz, S. Bailey, R. Levy, Z. Ahmad, J. Gales, M. Gao, M. Garay, S. Anderson, and O. Kalashnikova. 2021. "Analysis of simultaneous aerosol and ocean glint retrieval using multi-angle observations." *Atmos. Meas. Tech.*, 14 3233-3252 [10.5194/amt-14-3233-2021]

Kok, J. F., A. A. Adebiyi, S. Albani, Y. Balkanski, R. Checa-Garcia, M. Chin, P. R. Colarco, D. S. Hamilton, Y. Huang, A. Ito, M. Klose, D. M. Leung, L. Li, N. M. Mahowald, R. L. Miller, V. Obiso, C. Pérez García-Pando, A. Rocha-Lima, J. S. Wan, and C. A. Whicker. 2021. "Improved representation of the global dust cycle using observational constraints on dust properties and abundance." *Atmos. Chem. Phys.*, 21 (10): 8127-8167 [10.5194/acp-21-8127-2021]

Kok, J. F., A. A. Adebiyi, S. Albani, Y. Balkanski, R. Checa-Garcia, M. Chin, P. R. Colarco, D. S. Hamilton, Y. Huang, A. Ito, M. Klose, L. Li, N. M. Mahowald, R. L. Miller, V. Obiso, C. Pérez García-Pando, A. Rocha-Lima, and J. S. Wan. 2021. "Contribution of the world's main dust source regions to the global cycle of desert dust." Atmos. Chem. Phys. 21 (10): 8169-8193 [10.5194/acp-21-8169-2021]

Korkin, S., A. Sayer, A. Ibrahim, and A. Lyapustin. 2021. "A practical guide to writing a radiative transfer code." *Comput. Phys. Commun.*, 271, 108198 [10.1016/j.cpc.2021.108198]

Koster, R. D., Q. Liu, R. H. Reichle, and G. J. Huffman. 2021. "Improved Estimates of Pentad Precipitation Through the Merging of Independent Precipitation Data Sets." *Water Resour. Res.*, 57 (12): e2021WR030330 [10.1029/2021wr030330]

Kostinski, A., A. Marshak, and T. Várnai. 2021. "Deep Space Observations of Terrestrial Glitter." *Earth Space Sci.*, 8 (2): 2020EA001521 [10.1029/2020ea001521]

Kramarova, N. A., J. R. Ziemke, L.-K. Huang, J. R. Herman, K. Wargan, C. J. Seftor, G. J. Labow, and L. D. Oman. 2021. "Evaluation of Version 3 Total and Tropospheric Ozone Columns From Earth Polychromatic Imaging Camera on Deep Space Climate Observatory for Studying Regional Scale Ozone Variations." *Front. Remote Sens.*, 2 [10.3389/frsen.2021.734071]

Kramer, R. J., H. He, B. J. Soden, L. Oreopoulos, G. Myhre, P. M. Forster, and C. J. Smith. 2021. "Observational evidence of increasing global radiative forcing." *Geophys. Res. Lett.*, 48 (7): e2020GL091585 [10.1029/2020gl091585]

Krotkov, N., V. Realmuto, C. Li, C. Seftor, J. Li, K. Brentzel, M. Stuefer, J. Cable, C. Dierking, J. Delamere, D. Schneider, J. Tamminen, S. Hassinen, T. Ryyppö, J. Murray, S. Carn, J. Osiensky, N. Eckstein, G. Layne, and J. Kirkendall. 2021. "Day-Night Monitoring of Volcanic SO_2 and Ash Clouds for Aviation Avoidance at Northern Polar Latitudes." *Remote Sens.,* 13 (19): 4003 [10.3390/rs13194003]

Lagomasino, D., T. Fatoyinbo, E. Castañeda-Moya, B. D. Cook, P. M. Montesano, C. S. Neigh, L. A. Corp, L. E. Ott, S. Chavez, and D. C. Morton. 2021. "Storm surge and ponding explain mangrove dieback in southwest Florida following Hurricane Irma." *Nature Comm.*, 12 (1): 4003 [10.1038/s41467-021-24253-y]

Lamsal, L. N., N. A. Krotkov, A. Vasilkov, S. V. Martchenko, W. Qin, E.-S. Yang, Z. Fasnacht, J. Joiner, S. Choi, D. Haffner, W. H. Swartz, B. Fisher, and E. Bucsela. 2021. "Ozone Monitoring Instrument (OMI) Aura nitrogen dioxide standard product version 4.0 with improved surface and cloud treatments." *Atmos. Meas. Tech.*, 14, 455-479 [10.5194/amt-14-455-2021]

Li, J., Y. Wang, R. Zhang, C. Smeltzer, A. Weinheimer, J. Herman, K. F. Boersma, E. A. Celarier, R. W. Long, J. J. Szykman, R. Delgado, A. M. Thompson, T. N. Knepp, L. N. Lamsal, S. J. Janz, M. G. Kowalewski, X. Liu, and C. R. Nowlan. 2021. "Comprehensive evaluations of diurnal NO_2 measurements during DISCOVER-AQ 2011: effects of resolution-dependent representation of NO_x emissions." *Atmos. Chem. Phys.,* 21 (14): 11133-11160 [10.5194/acp-21-11133-2021]

Lim, Y.-K., D. L. Wu, K.-M. Kim, and J. N. Lee. 2021. "An investigation on seasonal and diurnal cycles of TOA shortwave radiations from DSCOVR/EPIC, CERES, MERRA-2, and ERA5." *Remote Sens.,* 13 (21): 4595 [10.3390/rs13224595]

Liu, J., L. Baskaran, K. Bowman, D. Schimel, A. A. Bloom, N. C. Parazoo, T. Oda, D. Carroll, D. Menemenlis, J. Joiner, R. Commane, B. Daube, L. V. Gatti, K. McKain, J. Miller, B. B. Stephens, C. Sweeney, and S. Wofsy. 2021. "Carbon Monitoring System Flux Net Biosphere Exchange 2020 (CMS-Flux NBE 2020)." *Earth Sys. Sci. Data*, 13 (2): 299-330 [10.5194/essd-13-299-2021]

Loría-Salazar, S. M., A. M. Sayer, J. Barnes, J. Huang, C. Flynn, N. Lareau, J. Lee, A. Lyapustin, J. Redemann, E. J. Welton, J. L. Wilkins, and H. A. Holmes. 2021. "Evaluation of Novel NASA Moderate Resolution Imaging Spectroradiometer and Visible Infrared Imaging Radiometer Suite Aerosol Products and Assessment of Smoke Height Boundary Layer Ratio During Extreme Smoke Events in the Western USA." *J. Geophys. Res.: Atmos.,* 126 (11): [10.1029/2020jd034180]

Lu, X., Y. Hu, Y. Yang, M. Vaughan, S. Palm, C. Trepte, A. Omar, P. Lucker, and R. Baize. 2021. "Enabling value added scientific applications of ICESat-2 data with effective removal of afterpulses." *Earth Space Sci.*, [10.1029/2021ea001729]

Lu, Z., J. Wang, X. Xu, X. Chen, S. Kondragunta, O. Torres, E. M. Wilcox, and J. Zeng. 2021. "Hourly Mapping of the Layer Height of Thick Smoke Plumes Over the Western U.S. in 2020 Severe Fire Season." *Front. Remote Sens.*, 2 [10.3389/frsen.2021.766628]

Lyapustin, A., S. Go, S. Korkin, Y. Wang, O. Torres, H. Jethva, and A. Marshak. 2021. "Retrievals of Aerosol Optical Depth and Spectral Absorption From DSCOVR EPIC." *Front. Remote Sens.*, 2 [10.3389/frsen.2021.645794]

Lyapustin, A., Y. Wang, S. Go, M. Choi, S. Korkin, D. Huang, Y. Knyazikhin, K. Blank, and A. Marshak. 2021. "Atmospheric Correction of DSCOVR EPIC: Version 2 MAIAC Algorithm." *Front. Remote Sens.*, 2 [10.3389/frsen.2021.748362]

Madhavan, S., J. Sun, and X. Xiong. 2021. "Sensor calibration impacts on dust detection based on MODIS and VIIRS thermal emissive bands." *Adv. Space Res.*, 67 (10): 3059-3071 [10.1016/j.asr.2021.02.035]

Manney, G. L., M. L. Santee, Z. D. Lawrence, K. Wargan, and M. J. Schwartz. 2021. "A Moments View of Climatology and Variability of the Asian Summer Monsoon Anticyclone." *J. Clim*., 1-69 [10.1175/jcli-d-20-0729.1]

Mao, J., J. B. Abshire, S. R. Kawa, H. Riris, X. Sun, N. Andela, and P. T. Kolbeck. 2021. "Measuring Atmospheric CO_2 Enhancements From the 2017 British Columbia Wildfires Using a Lidar." *Geophys. Res. Lett.*, 48 (16): [10.1029/2021gl093805]

Mao, J., T. Zhao, C. A. Keller, X. Wang, P. J. McFarland, J. M. Jenkins, and W. H. Brune. 2021. "Global Impact of Lightning-Produced Oxidants." *Geophys. Res. Lett.*, 48 (21): [10.1029/2021gl095740]

Marais, E. A., J. F. Roberts, R. G. Ryan, H. Eskes, K. F. Boersma, S. Choi, J. Joiner, N. Abuhassan, A. Redondas, M. Grutter, A. Cede, L. Gomez, and M. Navarro-Comas. 2021. "New observations of NO_2 in the upper troposphere from TROPOMI." *Atmos. Meas. Tech*., 14 (3): 2389-2408 [10.5194/amt-14-2389-2021]

Marinescu, P. J., S. C. van den Heever, M. Heikenfeld, A. I. Barrett, C. Barthlott, C. Hoose, J. Fan, A. M. Fridlind, T. Matsui, A. K. Miltenberger, P. Stier, B. Vie, B. A. White, and Y. Zhang. 2021. "Impacts of Varying Concentrations of Cloud Condensation Nuclei On Deep Convective Cloud Updrafts—A Multimodel Assessment." *J. Atmos. Sci.,* [10.1175/jas-d-20-0200.1]

Marshak, A., A. Ackerman, A. Da Silva, T. Eck, B. Holben, R. Kahn, R. Kleidman, K. Knobelspiesse, R. C. Levy, A. Lyapustin, L. Oreopoulos, L. Remer, O. Torres, T. Varnai, G. Wen, and J. Yorks. 2021. "Aerosol properties in cloudy environments from Remote Sens. observations: a review of the current state of knowledge." *Bull. Am. Meteorol. Soc.,* 1-57 [10.1175/bams-d-20-0225.1]

Marshak, A., A. Delgado-Bonal, and Y. Knyazikhin. 2021. "Effect of Scattering Angle on Earth Reflectance." *Front. Remote Sens.,* 2 [10.3389/frsen.2021.719610]

McFarlane, C., P. K. Isevulambire, R. S. Lumbuenamo, A. M. Ndinga, R. Dhammapala, X. Jin, V. F. McNeill, C. Malings, R. Subramanian, and D. M. Westervelt. 2021. "First Measurements of Ambient PM2.5 in Kinshasa, Democratic Republic of Congo and Brazzaville, Republic of Congo Using Field-calibrated Low-cost Sensors." *Aerosol Air Qual. Res.,* 21 [10.4209/aaqr.200619]

McGarry, J. F., C. C. Carabajal, J. L. Saba, A. R. Reese, S. T. Holland, S. P. Palm, J. A. Swinski, J. E. Golder, and P. M. Liiva. 2021. "ICESat-2/ATLAS Onboard Flight Science Receiver Algorithms: Purpose, Process, and Performance." *Earth Space Sci.*, 8 (e2020EA001235): [10.1029/2020ea001235]

Mettig, N., M. Weber, A. Rozanov, C. Arosio, J. P. Burrows, P. Veefkind, A. M. Thompson, R. Querel, T. Leblanc, S. Godin-Beekmann, R. Kivi, and M. B. Tully. 2021. "Ozone profile retrieval from nadir TROPOMI measurements in the UV range." *Atmos. Meas. Tech.*, 14 (9): 6057-6082 [0.5194/amt-14-6057-2021]

Milani, L., and N. B. Wood. 2021. "Biases in CloudSat Falling Snow Estimates Resulting from Daylight-Only Operations." *Remote Sens.*, 13 (11): 2041 [10.3390/rs13112041]

Milani, L., M. S. Kulie, D. Casella, P. E. Kirstetter, G. Panegrossi, V. Petkovic, S. E. Ringerud, J.-F. Rysman, P. Sanò, N.-Y. Wang, Y. You, and G. Skofronick-Jackson. 2021. "Extreme Lake-Effect Snow from a GPM Microwave Imager Perspective: Observational Analysis and Precipitation Retrieval Evaluation." *J. Atmos. Oceanic Tech.,* 38 (2): 293-311 [10.1175/jtech-d-20-0064.1]

Miller, R. L., G. A. Schmidt, L. Nazarenko, S. E. Bauer, M. Kelley, R. Ruedy, G. L. Russell, A. Ackerman, I. Aleinov, M. Bauer, R. Bleck, V. Canuto, G. Cesana, Y. Cheng, T. L. Clune, B. Cook, C. A. Cruz, A. D. Del Genio, G. S. Elsaesser, G. Faluvegi, N. Y. Kiang, D. Kim, A. A. Lacis, A. Leboissetier, A. N. LeGrande, K. K. Lo, J. Marshall, E. E. Matthews, S. McDermid, K. Mezuman, L. T. Murray, V. Oinas, C. Orbe, C. P. García-Pando, J. P. Perlwitz, M. J. Puma, D. Rind, A. Romanou, D. T. Shindell, S. Sun, N. Tausnev, K. Tsigaridis, G. Tselioudis, E. Weng, J. Wu, and M. Yao. 2021. "CMIP6 Historical Simulations (1850-2014) with GISS-E2.1." *J. Adv. Model. Earth Sys.,* 13 e2019MS002034 [10.1029/2019ms002034]

Mohrmann, J., R. Wood, T. Yuan, H. Song, R. Eastman, and L. Oreopoulos. 2021. "Identifying meteorological influences on marine low-cloud mesoscale morphology using satellite classifications." *Atmos. Chem. Phys.,* 21 (12): 9629-9642 [10.5194/acp-21-9629-2021]

Morison, J., D. W. Hancock, S. Dickinson, J. W. Robbins, L. Roberts, R. Kwok, S. P. Palm, B. Smith, M. F. Jasinski, B. Plant, and T. . 2021. "Algorithm Theoretical Basis Document (ATBD) for Ocean Surface Height, Release 4." NASA Goddard Space Flight Center [Full Text]

Nault, B. A., D. S. Jo, B. C. McDonald, P. Campuzano-Jost, D. A. Day, W. Hu, J. C. Schroder, J. Allan, D. R. Blake, M. R. Canagaratna, H. Coe, M. M. Coggon, P. F. DeCarlo, G. S. Diskin, R. Dunmore, F. Flocke, A. Fried, J. B. Gilman, G. Gkatzelis, J. F. Hamilton, T. F. Hanisco, P. L. Hayes, D. K. Henze, A. Hodzic, J. Hopkins, M. Hu, L. G. Huey, B. T. Jobson, W. C. Kuster, A. Lewis, M. Li, J. Liao, M. O. Nawaz, I. B. Pollack, J. Peischl, B. Rappenglück, C. E. Reeves, D. Richter, J. M. Roberts, T. B. Ryerson, M. Shao, J. M. Sommers, J. Walega, C. Warneke, P. Weibring, G. M. Wolfe, D. E. Young, B. Yuan, Q. Zhang, J. A. de Gouw, and J. L. Jimenez. 2021. "Secondary organic aerosols from anthropogenic volatile organic compounds contribute substantially to air pollution mortality." *Atmos. Chem. Phys.,* 21 (14): 11201-11224 [10.5194/acp-21-11201-2021]

Nault, B. A., P. Campuzano-Jost, D. A. Day, D. S. Jo, J. C. Schroder, H. M. Allen, R. Bahreini, H. Bian, D. R. Blake, M. Chin, S. L. Clegg, P. R. Colarco, J. D. Crounse, M. J. Cubison, P. F. DeCarlo, J. E. Dibb, G. S. Diskin, A. Hodzic, W. Hu, J. M. Katich, M. J. Kim, J. K. Kodros, A. Kupc, F. D. Lopez-Hilfiker, E. A. Marais, A. M. Middlebrook, J. Andrew Neuman, J. B. Nowak, B. B. Palm, F. Paulot, J. R. Pierce, G. P. Schill, E. Scheuer, J. A. Thornton, K. Tsigaridis, P. O. Wennberg, C. J. Williamson, and J. L. Jimenez. 2021. "Chemical transport models often underestimate inorganic aerosol acidity in remote regions of the atmosphere." *Comm. Earth Environ.*, 2 (1): 93 [10.1038/s43247-021-00164-0]

Neelam, M., R. Bindlish, P. E. O'Neill, G. J. Huffman, R. Reichle, S. Chan, and A. Colliander. 2021. "Evaluation of GEOS Precipitation Flagging for SMAP Soil Moisture Retrieval Accuracy." *J. Hydrometeorol.,* 22, 1317-1332 [10.1175/jhm-d-20-0038.1]

Neto, R. M., C. A. Santos, R. M. da Silva, C. A. dos Santos, Z. Liu, and N. W. Quinn. 2021. "Geospatial cluster analysis of the state, duration and severity of drought over Paraíba State, northeastern Brazil." *Sci. Total Environ.*, 149492 [10.1016/j.scitotenv.2021.149492]

Novak, G. A., C. H. Fite, C. D. Holmes, P. R. Veres, J. A. Neuman, I. Faloona, J. A. Thornton, G. M. Wolfe, M. P. Vermeuel, C. M. Jernigan, J. Peischl, T. B. Ryerson, C. R. Thompson, I. Bourgeois, C. Warneke, G. I. Gkatzelis, M. M. Coggon, K. Sekimoto, T. P. Bui, J. Dean-Day, G. S. Diskin, J. P. DiGangi, J. B. Nowak, R. H. Moore, E. B. Wiggins, E. L. Winstead, C. Robinson, K. L. Thornhill, K. J. Sanchez, S. R. Hall, K. Ullmann, M. Dollner, B. Weinzierl, D. R. Blake, and T. H. Bertram. 2021. "Rapid cloud removal of dimethyl sulfide oxidation products limits SO_2 and cloud condensation nuclei production in the marine atmosphere." *Proc. Natl. Acad. Sci.*, 118 (42): e2110472118 [10.1073/pnas.2110472118]

O'Neill, M. E., L. Orf, G. M. Heymsfield, and K. Halbert. 2021. "Hydraulic jump dynamics above supercell thunderstorms." *Science*, 373 (6560): 1248-1251 [10.1126/science.abh3857]

Orbe, C., D. W. Waugh, S. Montzka, E. J. Dlugokencky, S. Strahan, S. D. Steenrod, S. Strode, J. W. Elkins, B. Hall, C. Sweeney, E. J. Hintsa, F. L. Moore, and E. Penafiel. 2021. "Tropospheric Age-of-Air: Influence of SF6 Emissions on Recent Surface Trends and Model Biases." *J. Geophys. Res.: Atmos.,* 126 (19): [10.1029/2021jd035451]

Padulles, R., E. Cardellach, F. J. Turk, C. O. Ao, M. de la Torre Juarez, J. Gong, and D. L. Wu. 2021. "Sensing Horizontally Oriented Frozen Particles With Polarimetric Radio Occultations Aboard PAZ: Validation Using GMI Coincident Observations and Cloudsat a Priori Information." *IEEE Trans. Geosci. Remote Sens.*, 1-13 [10.1109/tgrs.2021.3065119]

Palm, S. P., P. Selmer, J. Yorks, S. Nicholls, and E. Nowottnick. 2021. "Planetary Boundary Layer Height Estimates From ICESat-2 and CATS Backscatter Measurements." *Front. Remote Sens.,* 2 [10.3389/frsen.2021.716951]

Palm, S. P., Y. Yang, U. Herzfeld, D. Hancock, A. Hayes, P. Selmer, W. Hart, and D. Hlavka. 2021. "ICESat-2 Atmospheric Channel Description, Data Processing and First Results." *Earth Space Sci.*, 8 (8): [10.1029/2020ea001470]

Park, S., L. M. Western, T. Saito, A. L. Redington, S. Henne, X. Fang, R. G. Prinn, A. J. Manning, S. A. Montzka, P. J. Fraser, A. L. Ganesan, C. M. Harth, J. Kim, P. B. Krummel, Q. Liang, J. Mühle, S. O'Doherty, H. Park, M.-K. Park, S. Reimann, P. K. Salameh, R. F. Weiss, and M. Rigby. 2021. "A decline in emissions of CFC-11 and related chemicals from eastern China." *Nature*, 590 (7846): 433-437 [10.1038/s41586-021-03277-w]

Peterson, D. A., M. D. Fromm, R. H. McRae, J. R. Campbell, E. J. Hyer, G. Taha, C. P. Camacho, G. P. Kablick, C. C. Schmidt, and M. T. DeLand. 2021. "Australia's Black Summer pyrocumulonimbus super outbreak reveals potential for increasingly extreme stratospheric smoke events." npj *Clim. Atmos. Sci.*, 4 (1): 38 [10.1038/s41612-021-00192-9]

Prados, A., E. Podest, D. G. Barbato, A. Carleton-Hug, B. Blevins, S. Hudson-Odoi, A. Mehta, and C. K. Ovando Crespo. 2021. "Best Practices In Multilanguage Satellite Remote Sens. Training: Case Studies In Spanish-Speaking Countries [Education]." *IEEE Geosci. Remote Sens. Magazine,* 9 (2): 105-111 [10.1109/mgrs.2021.3060777]

Rajagopal, M., E. Zipser, G. Huffman, J. Russell, and J. Tan. 2021. "Comparisons of IMERG Version 06 Precipitation At and Between Passive Microwave Overpasses in the Tropics." *J. Hydrometeorol.*, 22 (8): 2117-2130 [10.1175/jhm-d-20-0226.1]

Redemann, J., R. Wood, P. Zuidema, S. J. Doherty, B. Luna, S. E. LeBlanc, M. S. Diamond, Y. Shinozuka, I. Y. Chang, R. Ueyama, L. Pfister, J.-M. Ryoo, A. N. Dobracki, A. M. da Silva, K. M. Longo, M. S. Kacenelenbogen, C. J. Flynn, K. Pistone, N. M. Knox, S. J. Piketh, J. M. Haywood, P. Formenti, M. Mallet, P. Stier, A. S. Ackerman, S. E. Bauer, A. M. Fridlind, G. R. Carmichael, P. E. Saide, G. A. Ferrada, S. G. Howell, S. Freitag, B. Cairns, B. N. Holben, K. D. Knobelspiesse, S. Tanelli, T. S. L'Ecuyer, A. M. Dzambo, O. O. Sy, G. M. McFarquhar, M. R. Poellot, S. Gupta, J. R. O'Brien, A. Nenes, M. E. Kacarab, J. P. Wong, J. D. Small-Griswold, K. L. Thornhill, D. Noone, J. R. Podolske, K. S. Schmidt, P. Pilewskie, H. Chen, S. P. Cochrane, A. J. Sedlacek, T. J. Lang, E. Stith, M. Segal-Rozenhaimer, R. A. Ferrare, S. P. Burton, C. A. Hostetler, D. J. Diner, S. E. Platnick, J. S. Myers, K. G. Meyer, D. A. Spangenberg, H. Maring, and L. Gao. 2021. "An overview of the ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) project: aerosol-cloud-radiation interactions in the Southeast Atlantic basin." *Atmos. Chem. Phys.*, [10.5194/acp-21-1507-2021]

Sand, M., B. H. Samset, G. Myhre, J. Glíß, S. E. Bauer, H. Bian, M. Chin, R. Checa-Garcia, P. Ginoux, Z. Kipling, A. Kirkevåg, H. Kokkola, P. Le Sager, M. T. Lund, H. Matsui, T. van Noije, D. J. Olivié, S. Remy, M. Schulz, P. Stier, C. W. Stjern, T. Takemura, K. Tsigaridis, S. G. Tsyro, and D. Watson-Parris. 2021. "Aerosol absorption in global models from AeroCom phase III." *Atmos. Chem. Phys.*, 21 (20): 15929-15947 [10.5194/acp-21-15929-2021]

Schoeberl, M., E. Jensen, T. Wang, G. Taha, R. Ueyama, Y. Wang, M. DeLand, and A. Dessler. 2021. "Cloud and Aerosol Distributions From SAGE III/ISS Observations." *J. Geophys. Res.: Atmos.*, 126 (23): [10.1029/2021jd035550]

Schultz, C. J., S. S. Harkema, D. M. Mach, M. Bateman, T. J. Lang, G. M. Heymsfield, M. L. McLinden, L. Li, M. Poellot, and K. Sand. 2021. "Remote Sens. of Electric Fields Observed Within Winter Precipitation During the 2020 Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) Field Campaign." *J. Geophys. Res.: Atmos.*, 126 (16): [10.1029/2021jd034704]

Schutgens, N., O. Dubovik, O. Hasekamp, O. Torres, H. Jethva, P. J. Leonard, P. Litvinov, J. Redemann, Y. Shinozuka, G. de Leeuw, S. Kinne, T. Popp, M. Schulz, and P. Stier. 2021. "AEROCOM and AEROSAT AAOD and SSA study—Part 1: Evaluation and intercomparison of satellite measurements." *Atmos. Chem. Phys.*, 21 (9): 6895-6917 [10.5194/acp-21-6895-2021]

Shi, Y. R., R. C. Levy, L. Yang, L. A. Remer, S. Mattoo, and O. Dubovik. 2021. "A Dark Target research aerosol algorithm for MODIS observations over eastern China: increasing coverage while maintaining accuracy at high aerosol loading." *Atmos. Meas. Tech.*, 14 (5): 3449-3468 [10.5194/amt-14-3449-2021]

Spinei, E., M. Tiefengraber, M. Müller, M. Gebetsberger, A. Cede, L. Valin, J. Szykman, A. Whitehill, A. Kotsakis, F. Santos, N. Abbuhasan, X. Zhao, V. Fioletov, S. C. Lee, and R. Swap. 2021. "Effect of Polyoxymethylene (POM-H Delrin) offgassing within Pandora head sensor on direct sun and multi-axis formaldehyde column measurements in 20160-2019." *Atmos. Meas. Tech.*, 14 647-663 [10.5194/amt-14-647-2021]

Sroka, S., and S. R. Guimond. 2021. "Organized Kinetic Energy Backscatter in the Hurricane Boundary Layer from Radar Measurements." *J. Fluid Mech.*, 924 A21 [10.1017/jfm.2021.632]

Steinbrecht, W., D. Kubistin, C. Plass-Dülmer, J. Davies, D. W. Tarasick, P. V. Gathen, H. Deckelmann, N. Jepsen, R. Kivi, N. Lyall, M. Palm, J. Notholt, B. Kois, P. Oelsner, M. Allaart, A. Piters, M. Gill, R. Van Malderen, A. W. Delcloo, R. Sussmann, E. Mahieu, C. Servais, G. Romanens, R. Stübi, G. Ancellet, S. Godin-Beekmann, S. Yamanouchi, K. Strong, B. Johnson, P. Cullis, I. Petropavlovskikh, J. W. Hannigan, J. Hernandez, A. Diaz Rodriguez, T. Nakano, F. Chouza, T. Leblanc, C. Torres, O. Garcia, A. N. Röhling, M. Schneider, T. Blumenstock, M. Tully, C. Paton-Walsh, N. Jones, R. Querel, S. Strahan, R. M. Stauffer, A. M. Thompson, A. Inness, R. Engelen, K. Chang, and O. R. Cooper. 2021. "COVID-19 Crisis Reduces Free Tropospheric Ozone Across the Northern Hemisphere." *Geophys. Res. Lett.*, 48 (5): [10.1029/2020gl091987]

Su, J., M. P. McCormick, M. S. Johnson, J. T. Sullivan, M. J. Newchurch, T. A. Berkoff, S. Kuang, and G. P. Gronoff. 2021. "Tropospheric NO_2; measurements using a three-wavelength optical parametric oscillator differential absorption lidar." *Atmos. Meas. Tech.*, 14 (6): 4069-4082 [10.5194/amt-14-4069-2021]

Sun, X., J. B. Abshire, A. Ramanathan, S. R. Kawa, and J. Mao. 2021. "Retrieval algorithm for the column CO_2 mixing ratio from pulsed multi-wavelength lidar measurements." *Atmos. Meas. Tech.*, 14 (5): 3909-3922 [10.5194/amt-14-3909-2021]

Swartz, W. H., N. Krotkov, L. Lamsal, G. Otter, F. van Kempen, J. Boldt, F. Morgan, L. van der Laan, W. Zimbeck, S. Storck, Z. Post, S. Janz, M. Kowalewski, C. Li, P. Veefkind, and P. Levelt. 2021. "CHAPS: a sustainable approach to targeted air pollution observation from small satellites." *Sensors, Systems, and Next-Generation Satellites XXV* [10.1117/12.2600175]

Takbiri, Z., L. Milani, C. Guilloteau, and E. Foufoula-Georgiou. 2021. "Quantitative Investigation of Radiometric Interactions between Snowfall, Snow Cover, and Cloud Liquid Water over Land." *Remote Sens.*, 13 (13): 2641 [10.3390/rs13132641]

Tan, I., G. Sotiropoulou, P. C. Taylor, L. Zamora, and M. Wendisch. 2021. "A Review of the Factors Influencing Arctic Mixed-Phase Clouds: Progress and Outlook." *Cloud Physics and Dynamics: Showers and Shade from Earth's Atmosphere* [10.1002/essoar.10508308.1]

Tan, J., G. J. Huffman, D. T. Bolvin, E. J. Nelkin, and M. Rajagopal. 2021. "SHARPEN: A Scheme to Restore the Distribution of Averaged Precipitation Fields." *J. Hydrometeorol.,* 22 (8): 2105-2116 [10.1175/jhm-d-20-0225.1]

Tan, J., N. Cho, L. Oreopoulos, and P. Kirstetter. 2021. "Evaluation of GPROF V05 Precipitation Retrievals under Different Cloud Regimes." *J. Hydrometeorol.,* [10.1175/jhm-d-21-0154.1]

Tarasick, D. W., H. G. Smit, A. M. Thompson, G. A. Morris, J. C. Witte, J. Davies, T. Nakano, R. Van Malderen, R. M. Stauffer, B. J. Johnson, R. Stübi, S. J. Oltmans, and H. Vömel. 2021. "Improving ECC Ozonesonde Data Quality: Assessment of Current Methods and Outstanding Issues." *Earth Space Sci.*, 8 (3): [10.1029/2019ea000914]

Theys, N., V. Fioletov, C. Li, I. De Smedt, C. Lerot, C. McLinden, N. Krotkov, D. Griffin, L. Clarisse, P. Hedelt, D. Loyola, T. Wagner, V. Kumar, A. Innes, R. Ribas, F. Hendrick, J. Vlietinck, H. Brenot, and M. Van Roozendael. 2021. "A sulfur dioxide Covariance-Based Retrieval Algorithm (COBRA): application to TROPOMI reveals new emission sources." *Atmos. Chem. Phys.*, 21 (22): 16727-16744 [10.5194/acp-21-16727-2021]

Thompson, A. M., R. M. Stauffer, K. Wargan, J. C. Witte, D. E. Kollonige, and J. R. Ziemke. 2021. “Regional and Seasonal Trends in Tropical Ozone From SHADOZ Profiles: Reference for Models and Satellite Products.” *J. Geophys. Res.: Atmos.*, 126 (22): [10.1029/2021jd034691]

Turk, F. J., S. E. Ringerud, A. Camplani, D. Casella, R. J. Chase, A. Ebtehaj, J. Gong, M. Kulie, G. Liu, L. Milani, G. Panegrossi, R. Padullés, J.-F. Rysman, P. Sanò, S. Vahedizade, and N. B. Wood. 2021. “Applications of a CloudSat-TRMM and CloudSat-GPM Satellite Coincidence Dataset.” *Remote Sens.*, 13 (12): 2264 [10.3390/rs13122264]

Valero, F. P., A. Marshak, and P. Minnis. 2021. “Lagrange Point Missions: The Key to next Generation Integrated Earth Observations. DSCOVR Innovation.” *Front. Remote Sens.,* 2 [10.3389/frsen.2021.745938]

Van Donkelaar, A., M. S. Hammer, L. Bindle, M. Brauer, J. R. Brook, M. J. Garay, N. C. Hsu, O. V. Kalashnikova, R. A. Kahn, C. Lee, R. C. Levy, A. Lyapustin, A. M. Sayer, and R. V. Martin. 2021. “Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty.” *Environ. Sci. Technol.*, [10.1021/acs.est.1c05309]

Várnai, T., and A. Marshak. 2021. “Analysis of Near-Cloud Changes in Atmospheric Aerosols Using Satellite Observations and Global Model Simulations.” *Remote Sens.,* 13 (6): 1151 [10.3390/rs13061151]

Vasilkov, A., N. Krotkov, E.-S. Yang, L. Lamsal, J. Joiner, P. Castellanos, Z. Fasnacht, and R. Spurr. 2021. “Explicit and consistent aerosol correction for visible wavelength satellite cloud and nitrogen dioxide retrievals based on optical properties from a global aerosol analysis.” *Atmos. Meas. Tech.*, 14 (4): 2857-2871 [10.5194/amt-14-2857-2021]

Wang, G., and J. Moisan. 2021. “Remote Sens. of Phytoplankton Pigments.” In L. Pereira, & A. M. Gonçalves (Eds.), Plankton Communities. IntechOpen. [10.5772/intechopen.95381]

Wang, J., M. Wang, J. Kim, J. Joiner, N. Zeng, F. Jiang, H. Wang, W. He, M. Wu, T. Chen, W. Ju, and J. M. Chen. 2021. “Modulation of Land Photosynthesis by the Indian Ocean Dipole: Satellite-Based Observations and CMIP6 Future Projections.” *Earth's Future*, 9 (4): [10.1029/2020ef001942]

Wang, J., W. A. Petersen, and D. B. Wolff. 2021. “Validation of Satellite-Based Precipitation Products from TRMM to GPM.” *Remote Sens.*, 13 (9): 1745 [10.3390/rs13091745]

Wang, T., D. L. Wu, J. Gong, and C. Wang. 2021. “Long-term observations of upper-tropospheric cloud ice from the MLS.” J. *Geophys. Res.: Atmos.* [10.1029/2020jd034058]

Weir, B., L. E. Ott, G. J. Collatz, S. R. Kawa, B. Poulter, A. Chatterjee, T. Oda, and S. Pawson. 2021. "Bias-correcting carbon fluxes derived from land-surface satellite data for retrospective and near-real-time assimilation systems." *Atmos. Chem. Phys.*, 21 9609-9628 [10.5194/acp-21-9609-2021]

Wen, G., and A. Marshak. 2021. "Precipitable Water Vapor Variation in the Clear-Cloud Transition Zone From the ARM Shortwave Spectrometer." *IEEE Geosci. Remote Sens. Lett.*, 1-5 [10.1109/lgrs.2021.3064334]

Werner, F., N. J. Livesey, M. J. Schwartz, W. G. Read, M. L. Santee, and G. Wind. 2021. "Improved cloud detection for the Aura Microwave Limb Sounder (MLS): training an artificial neural network on colocated MLS and Aqua MODIS data." *Atmos. Meas. Tech.,* 14 (12): 7749-7773 [10.5194/amt-14-7749-2021]

Wilson, E. L., V. J. Riot, A. J. DiGregorio, G. Ramu, P. Cleveland, L. M. Simms, D. Carter, B. Bruner, J. Young, and G. Villanueva. 2021. "MiniCarb: a passive, occultation-viewing, 6U CubeSat for observations of CO_2, CH_4, and H_2O." *Meas. Sci. Technol.*, 33 (1): 015902 [10.1088/1361-6501/ac3679]

Wu, D. L., D. E. Jennings, K.-K. Choi, M. D. Jhabvala, J. A. Limbacher, T. Flatley, K.-M. Kim, A. T. La, R. J. Salawitch, L. D. Oman, J. Gong, T. R. Holmes, D. C. Morton, T. Hewagama, and R. J. Swap. 2021. "Compact Thermal Imager (CTI) for Atmospheric Remote Sensing." *Remote Sens.,* 13 (22): 4578 [10.3390/rs13224578]

Yorks, J. E., P. A. Selmer, A. Kupchock, E. P. Nowottnick, K. E. Christian, D. Rusinek, N. Dacic, and M. J. McGill. 2021. "Aerosol and Cloud Detection Using Machine Learning Algorithms and Space-Based Lidar Data." *Atmos.,* 12 (5): 606 [10.3390/atmos12050606]

You, Y., C. Peters-Lidard, S. J. Munchak, J. Tan, S. Braun, S. Ringerud, W. Blackwell, J. X. Yang, E. Nelkin, and J. Dong. 2021. "Improving Cross-track Scanning Radiometers' Precipitation Retrieval over Ocean by Morphing." *J. Hydrometeorol.,* 22 (9): 2393-2406 [10.1175/jhm-d-21-0038.1]

Young, P. J., A. B. Harper, C. Huntingford, N. D. Paul, O. Morgenstern, P. A. Newman, L. D. Oman, S. Madronich, and R. R. Garcia. 2021. "The Montreal Protocol protects the terrestrial carbon sink." *Nature*, 596 (7872): 384-388 [10.1038/s41586-021-03737-3]

Yu, H., Q. Tan, L. Zhou, Y. Zhou, H. Bian, M. Chin, C. L. Ryder, R. C. Levy, Y. Pradhan, Y. Shi, Q. Song, Z. Zhang, P. R. Colarco, D. Kim, L. A. Remer, T. Yuan, O. Mayol-Bracero, and B. N. Holben. 2021. "Observation and modeling of the historic "Godzilla" African dust intrusion into the Caribbean Basin and the southern US in June 2020." *Atmos. Chem. Phys.,* 21 (16): 12359-12383 [10.5194/acp-21-12359-2021]

Yu, Y., O. V. Kalashnikova, M. J. Garay, H. Lee, M. Choi, G. S. Okin, J. E. Yorks, J. R. Campbell, and J. Marquis. 2021. "A global analysis of diurnal variability in dust and dust mixture using CATS observations." *Atmos. Chem. Phys.*, 21 (3): 1427-1447 [10.5194/acp-21-1427-2021]

Zamora, R. A., B. F. Zaitchik, M. Rodell, A. Getirana, S. Kumar, K. Arsenault, and E. Gutmann. 2021. "Contribution of Meteorological Downscaling to Skill and Precision of Seasonal Drought Forecasts." *J. Hydrometeorol.,* [10.1175/jhm-d-20-0259.1]

Zeng, X., J. Gong, X. Li, and D. L. Wu. 2021. "Modeling the Radiative Effect on Microphysics in Cirrus Clouds against Satellite Observations." *J. Geophys. Res.: Atmos.*, [10.1029/2020jd033923]

Zhang, J., R. J. Spurr, J. S. Reid, P. Xian, P. R. Colarco, J. R. Campbell, E. J. Hyer, and N. L. Baker. 2021. "Development of an Ozone Monitoring Instrument (OMI) aerosol index (AI) data assimilation scheme for aerosol modeling over bright surfaces – a step toward direct radiance assimilation in the UV spectrum." *Geosci. Model Dev.*, 14 (1): 27-42 [10.5194/gmd-14-27-2021]

Zhang, L. N., S. Solomon, K. A. Stone, J. D. Shanklin, J. D. Eveson, S. Colwell, J. P. Burrows, M. Weber, P. F. Levelt, N. A. Kramarova, and D. P. Haffner. 2021. "On the use of satellite observations to fill gaps in the Halley station total ozone record." *Atmos. Chem. Phys.,* 21 (12): 9829-9838 [10.5194/acp-21-9829-2021]

Zheng, J., Z. Zhang, A. Garnier, H. Yu, Q. Song, C. Wang, P. Dubuisson, and C. Di Biagio. 2021. "The thermal infrared optical depth of mineral dust retrieved from integrated CALIOP and IIR observations." *Remote Sens. Environ.*, 270 112841 [10.1016/j.rse.2021.112841]

Zhou, M., J. Wang, X. Chen, X. Xu, P. R. Colarco, S. D. Miller, J. S. Reid, S. Kondragunta, D. M. Giles, and B. Holben. 2021. "Nighttime smoke aerosol optical depth over U.S. rural areas: First retrieval from VIIRS moonlight observations." *Remote Sens. Environ.,* 267, 112717 [10.1016/j.rse.2021.112717]

Zhou, Y., Y. Yang, P.-W. Zhai, and M. Gao. 2021. "Cloud Detection Over Sunglint Regions With Observations From the Earth Polychromatic Imaging Camera." *Front. Remote Sens.,* 2 [10.3389/frsen.2021.690010]

Ziemke, J. R., G. J. Labow, N. A. Kramarova, R. D. McPeters, P. K. Bhartia, L. D. Oman, S. M. Frith, and D. P. Haffner. 2021. "A global ozone profile climatology for satellite retrieval algorithms based on Aura MLS measurements and the MERRA-2 GMI simulation." *Atmos. Meas. Tech.*, 14 (10): 6407-6418 [10.5194/amt-14-6407-2021]