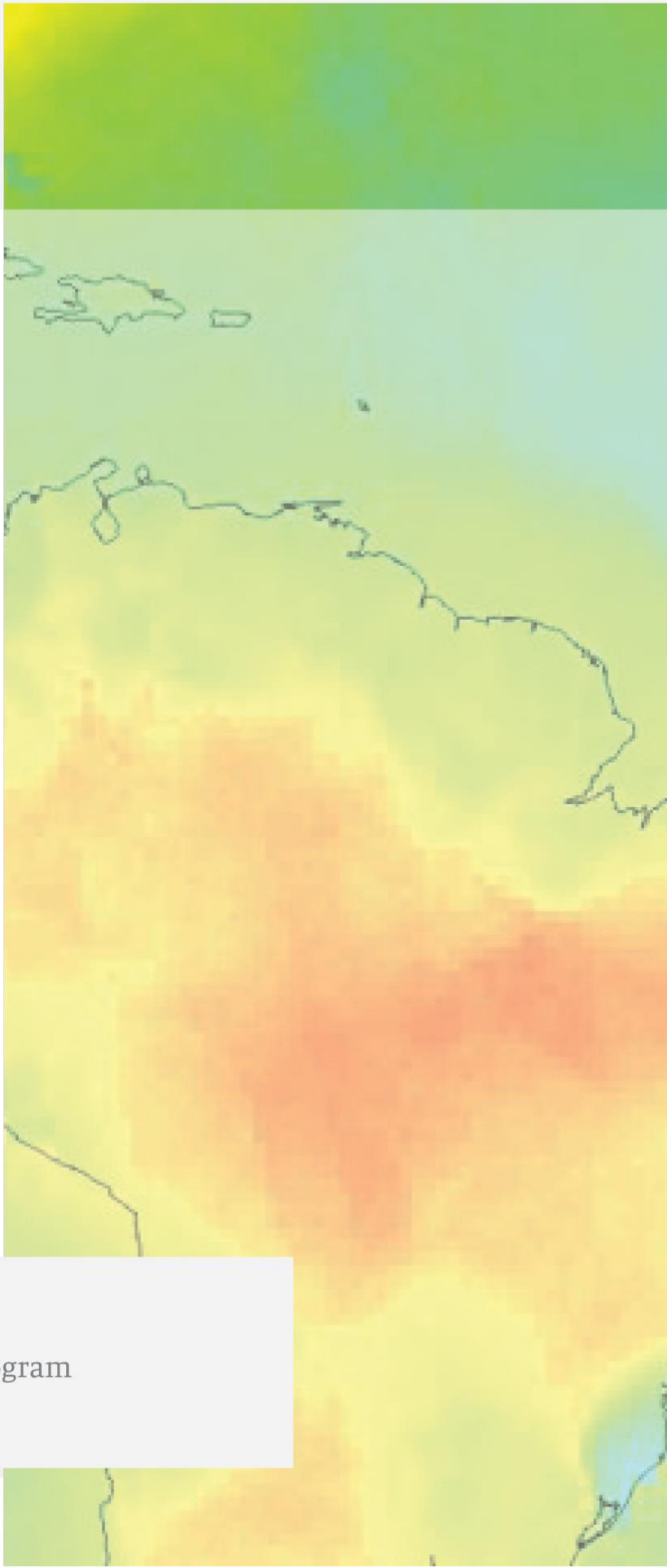
EARTH SCIENCE
APPLIED SCIENCES
HEALTH & AIR QUALITY



2021 ANNUAL SUMMARY

NASA Earth Science
Applied Sciences Program
Health & Air Quality

Health & Air Quality: 2021 Annual Summary

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I. Introduction

The Earth Science Division's (ESD) Applied Sciences Program promotes efforts to discover and demonstrate innovative and practical uses of Earth observations. The Program funds applied science research and applications projects to enable near-term uses of Earth observations, formulate new applications, integrate Earth observations and related products into practitioners' decision-making, and transfer the applications. The projects are carried out in partnership with public- and private-sector organizations to achieve sustained use and benefits from Earth observations.

The Applied Sciences Program's applications themes are currently focused on five of the eight Societal Benefit Areas of the Group on Earth Observations (GEO): Health and Air Quality, Disasters, Ecological Forecasting, Agriculture, and Water Resources.[1] The Program includes weather and climate-related influences and impacts within each of these themes.

The Health and Air Quality (HAQ) program area encourages the use of Earth observations in air quality management and public health, particularly involving environmental health and infectious diseases. The program also addresses the effects of climate change on air quality and public health to support managers and, ultimately, decision-makers of health-related issues.

II. Overview of 2021

As the COVID-19 pandemic entered its second year in 2021, the HAQ team continued to support the agency's response to the pandemic through project augmentations,

[1] The eight GEO SBAs are Agriculture, Ecosystems/Biodiversity, Disasters, Energy/Minerals, Health, Infrastructure/Transportation, Urban Development, and Water Resources.

taking new opportunities for videoconference meetings with stakeholders and end-users across the world, and leading interagency and international groups. Myriad challenges persisted, including slowdowns in project schedules and the reallocation of project budgets, the loss of human-to-human interactions and networking, and finding a balance between the pressures of work and life in a changed world. Through it all, the HAQ team persevered, successfully managing a diverse portfolio of projects and recognizing significant accomplishments.

Projects achieving significant milestones addressed public health issues such as air quality, infectious diseases, vector-borne diseases, and environmental health. Current projects in the portfolio met or exceeded expectations regarding technical performance. In addition, projects received media coverage or substantial praise from stakeholders on the value of the respective applied science applications.

The HAQ program supported online resources to disseminate important information and data covering health surveillance, the effects of global climate change on public health, and air quality management. In 2021, the program continued monthly HAQ newsletters that were circulated online and via mailing list. The program dynamically updated websites focusing on the GEO Health Community of Practice (CoP) and the GEO Earth Observations for Health (EO4HEALTH) Initiative, led bi-weekly CoP meetings, and showcased results across NASA web platforms, including new HAQ infographics. The third generation of the NASA Health and Air Quality Applied Sciences Team (HAQAST) was launched in February 2021 and selected five new Tiger Teams to begin work in Summer 2021. The HAQ program distributed applied research results and representatives led or participated in meetings across the health/air quality and Earth-science communities throughout the year, at both national and international levels.

The following report summarizes the challenges and many achievements that occurred during 2021. The HAQ program looks forward to upcoming activities and milestones, including new projects awarded through the Research Opportunities in Space and Earth Sciences (ROSES) 2021 solicitation, continued support for airborne field campaigns, as well as the support of, and applications planning for, relevant satellite missions.

III. Major Accomplishments

Many projects supported by the HAQ portfolio through the ROSES 2017 solicitation are reaching the end of their life cycle and, therefore, achieving final milestones. Some of the notable programmatic achievements this past year include:

Predicting the Impact of Saharan Dust Storms in the Caribbean
Saharan dust storms crossing the Atlantic Ocean naturally fertilize soil and coral reefs with phosphorus and other nutrients, but large dust plumes can adversely impact air

quality and human health. Pablo Méndez-Lázaro (University of Puerto Rico Medical Sciences Campus) is leading a team to track seasonal dust particles and develop an air quality forecasting tool that can inform policy decisions and educate the public on health risks related to dust storms. Since the start of this project in 2019, this team has incorporated MODIS, VIIRS, and GOES-16 aerosol optical depth measurements into developing an air quality forecasting tool in partnership with more than 19 public, private, and academic institutions in the Caribbean basin. **In August 2021, this project progressed to Application Readiness Level (ARL) 8 with the release of the Experimental Aerosol Monitoring Support Tool on the NOAA-sponsored Caribbean Coastal & Ocean Observing System (CARICOOS) platform.** The team is working to advance end-user training for sustained use of the web-based application as well as finalize health education materials with the Puerto Rico Department of Health's Office of Public Health Preparedness & Response. These results were showcased in a NASA web feature in April 2021(Saharan Dust Forecasts Minimize Health Risks in the Caribbean).

Dust Storms in the Southwest United States

The occurrence of dust storms in the Southwestern U.S. has doubled between the 1990s and the 2000s, which has increased the incidence of Valley fever infections, highway accidents, and crop and property damage. Daniel Tong (George Mason University) and his team have used MODIS and Landsat data to provide more accurate estimates of dust and nitrogen oxide (NOx) emissions for air quality management, public health surveillance, and highway safety in the Southwestern U.S. **In November 2021, the project jumped to ARL 9, when the NOAA/National Weather Service adopted the updated FENGSHA (an English analog of the Mandarin term for wind-blown dust) dust emission module and the MODIS/VIIRS Bidirectional Reflectance Distribution Functions (BRDF) and albedo-based dust source map into operational forecasts for their Community Multiscale Air Quality (CMAQ) and Global Ensemble Forecast-Aerosols (GEFS)-Aerosol models. This information has been integrated into the National Air Quality Forecast Capability (NAQFC) system, and these new capabilities have shown measurable improvement of real-time National Weather Service (NWS) operational dust forecasts.** Project results were showcased through the following media:

- NASA web feature (Dust Storms and Valley Fever in the American West) in May
- NASA Applied Sciences' web feature (Dust Storms, Valley Fever... and Cake Pans) in May
- World Meteorological Organization (WMO) Airborne Dust Bulletin in July
- Arizona Center for Investigative Reporting report in September (Scientists Work to Unravel Fungus Ecology as Valley Fever Expands throughout West)

Notably, Daniel Tong was elected the new global chair of the Steering Committee of the WMO's Sand & Dust Storm-Warning Advisory System Program in October 2021.

Urban Planning with Earth Observations

To meet the needs of the U.S. and international organizations to quantitatively assess air pollution health impacts and mitigation benefits in cities, Susan Anenberg (George Washington University) and her team are integrating satellite data into climate action planning tools for assessing air quality and health co-benefits of greenhouse gas mitigation. **The C40 Cities' Climate Action Planning Pathways tool and the Stockholm Environment Institute's Urban LEAP-IBC tool now include satellite-derived Fine Particulate Matter (PM2.5) estimates created from merged MODIS, MISR, and SeaWIFs AOD data adjusted to estimate surface PM2.5 using CALIPSO climatology. In 2021, the data available in LEAP-IBC also expanded to include ozone. In May, the project achieved ARL 8 through the release of Climate Action Plans for Buenos Aires and Johannesburg, which include data from the satellite-derived PM2.5 dataset.** Future expansions include Accra, Addis Ababa, Guadalajara, and Lima. This team also increased data accessibility through the creation of a website that houses temporal trends in PM2.5, ozone, and nitrogen dioxide and their associated health burdens in over 13,000 cities worldwide: https://share.streamlit.io/nigel1998/urbanaq/master/UrbanAQ.py. The team also strives to communicate the inequality in air pollution exposure, such as PM2.5 burdens on lower income communities and people of color in Washington, DC, which was highlighted in November: https://earthobservatory.nasa.gov/images/149047/an-extra-air-pollution-burden.

Assessing Risk of Mosquito-borne Outbreaks

Mosquito-borne diseases cause significant morbidity and mortality across the U.S. and world, and climate variability can impact the global emergence of mosquitoes and disease transmission. Two HAQ projects, led by Michael Wimberly (University of Oklahoma) and Assaf Anyamba (NASA Goddard Space Flight Center (GSFC)/ Universities Space Research Association (USRA)), support the integration of NASA Earth observation data to enhance public health surveillance programs related to mosquito-borne disease transmission. Both projects made notable progress in 2021.

Arbovirus Monitoring and Prediction System

In the U.S., the Northern Great Plains is a high-risk geographic region for West Nile virus (WNV) transmission, with the highest incidence in South Dakota. Starting in 2018, Michael Wimberly (University of Oklahoma) and his team developed and integrated the WNV early warning system in South Dakota (Arbovirus Monitoring and Prediction (ArboMAP) system, ArboMAP), with open access GitHub, into the South Dakota Department of Health operational WNV surveillance activities. This system was driven by mosquito infection data, historical human case data, and environmental monitoring data from NASA's North American Land Data Assimilation System and Soil Moisture Active Passive (SMAP) satellites. The success of this project led to a new task to scale and integrate the system in additional states. **In September 2021, the project**

advanced to ARL 7, after the successful integration of the ArboMAP system into the operational environments of the Louisiana and Oklahoma state health departments. They are also testing ArboMAP with data from Michigan in partnership with the Michigan Department of Health and Human Services. Notably, Michael Wimberly contributed to a collaborative article (Satellite Observations and Malaria: New Opportunities for Research and Applications), published in *Trends in Parasitology* in June 2021.

Tracking Chikungunya with the CHIKRisk App

The transmission of the chikungunya virus is prevalent in Africa, Southeast Asia, the Indian subcontinent, and the Pacific Region. Assaf Anyamba (NASA GSFC/USRA) and his team have integrated data from IMERG, GLDAS, MODIS, and from the Socioeconomic Data and Applications Center (SEDAC) in a machine learning framework to prepare global maps of chikungunya risk and predict outbreaks up to three months in advance. **In April, the project progressed to ARL 8 with the updated release of the CHIKRisk App. This tool is operational to project partners – Department of Defense (DoD) Armed Forces Health Surveillance Branch/Division, the Pan American Health Organization, and the World Health Organization – to support the DoD Data-to-Decision Initiative for Force Health Protection and monthly public health advisories for other partners.** These results were showcased in a NASA Applied Sciences' web feature in June 2021 (Tracking Mosquitoes from Space? NASA Does That) and NASA Hyperwall Talks (Climate Variability and Disease Outbreaks) at the U.S. Center Glasgow 2021 UN Climate Conference in November 2021.

Response to the COVID-19 Global Pandemic

Driven by the pandemic caused by COVID-19, several researchers supported by the HAQ program have made achievements to better understand connections between the global pandemic and our environment. Below we highlight two of these research teams:

Inconsistent Effects of Social Distancing on Air Quality in Global Cities

Susan Anenberg, Dan Goldberg, and Gaige Kerr (George Washington University) led a one-year project titled, *Inconsistent Effects of Social Distancing on Air Quality in Global Cities: Lessons for Protecting Near-Term Public Health and Designing Longer-Term Urban Transportation Policies*. In 2021, this team published six manuscripts, presented in dozens of forums, and communicated their findings through the media. A few notable achievements include highlighting environmental disparities that persisted through COVID-19 lockdowns (https://www.pnas.org/content/118/30/e2022409118 & https://cpb-us-e1.wpmucdn.com/blogs.gwu.edu/dist/3/1552/files/2021/10/Anenberg_EM.pdf), utilizing TROPOMI products in partnership with NOAA to better understand the impact of the "new normal" on emissions (https://doi.org/10.1029/2021JD034797), and communicating the power of satellite data to inform policy on air pollution and environmental justice to Congressional and White House staff.

Monitoring the Meteorological and Air Quality Factors Affecting the COVID-19 Pandemic
Ben Zaitchik (Johns Hopkins University) was tasked to investigate whether environmental factors affect the spread of COVID-19. His team is using GPM, SMAP, LDAS, and MERRA-2 data to examine climatic and hydrometeorological factors in temporal and spatial variability that may influence COVID-19 transmission. His team has refined the COVID-19 case record database, which assigns data to a consistent geographical hierarchy aligned with hydrometeorological variables, and completed the COVID-19 risk analyses for Brazil, the United States, and selected South and Central American countries. This project was highlighted in the NASA Earth Observatory web feature (Does COVID-19 Have Seasons? An Update with Ben Zaitchik) in March 2021. Ben Zaitchik has also served as co-chair of the WMO COVID-19 Task Team, where he has contributed to the preparation of the First Report of the WMO COVID-19 Task Team: Review on Meteorological and Air Quality Factors affecting the COVID-19 Pandemic in April 2021 and the coordination of a series of Virtual COVID-19 Roundtables in June and September 2021.

IV. Health and Air Quality Applied Sciences Team

In 2021, the third generation of the NASA Health and Air Quality Applied Sciences Team (HAQAST) (http://haqast.org) launched, continuing the mission of linking NASA's satellites and data products to public stakeholders in the air quality and public health communities. Led by Tracey Holloway (University of Wisconsin-Madison), the 2021-2025 HAQAST initiative includes 14 members and over 70 co-investigators, post-docs, students, and collaborators. The first year of the new HAQAST initiative was focused on building team rapport with investigators and stakeholders, including the start of a new set of Tiger Teams.

Tiger Teams are a unique feature of HAQAST. They are short-term, high-impact collaborative efforts between HAQAST members and public stakeholders to identify and solve critical problems using NASA data and products. The five Tiger Teams launched in the summer of 2021 were chosen from nine proposals that underwent a competitive review process by stakeholders from end-user organizations. All five Tiger Teams meet regularly with stakeholders to develop deliverables. Current Tiger Teams include:

1. Satellite Data for Environmental Justice, led by Susan Anenberg (George Washington University) and Qian Xiao (University of Texas Health Science Center at Houston)
    - This project will enhance the ability for stakeholders to map metrics supporting environmental health and equity, including supporting community

engagement and policy initiatives.

2. Enabling Stakeholder Access and Utilization of Data Products for Health and Air Quality Applications (First Steps), led by Kevin Cromar (New York University)
    - This project will deliver thorough documentation of products, case studies to highlight data for health and air quality applications, and a homepage to serve as a simple one-stop shop for all these resources.

3. Communicating the Uncertainties of Satellite-based NOx Emissions for Urban Planning, led by Dan Goldberg (George Washington University)
    - This project will quantify uncertainties using sensitivity analyses and engage stakeholders to help researchers prioritize aspects of estimating NOx emissions that are most impactful for decision-making.

4. Enabling U.S. Environmental Protection Agency (EPA) to Ingest High-Frequency Satellite Air Quality Data into the AirNow System, led by Pawan Gupta (USRA)
    - This project initiates a new collaboration between HAQAST members, NOAA, and U.S. EPA to develop a value added hourly and daily $PM_{2.5}$ dataset covering the continental U.S. region and integrate it into the AirNow system.

5. Fused Earth Observations to Quantify Health Impacts from Agricultural Fires, led by Sheryl Magzamen (Colorado State University) and Amber Soja (National Institute of Aerospace (NIA))
    - This project leverages expertise among HAQAST members to quantify smoke from sugarcane residue burning in the southeastern U.S., and will serve as a best practice for conducting exposure assessment using a fusion approach for other agricultural burning practices across the U.S.

HAQAST communication outreach continued to focus on media and public engagement, reaching a wide audience through regular e-newsletters (sent to a mailing list of over 1,000 subscribers) and Twitter (@NASA _HAQAST currently has more than 4,500 followers). Over the past year, HAQAST's applied research investigators have been interviewed in many outlets, including the Associated Press*, India Times, National Geographic, Washington Post*, and *Wisconsin Public Radio.* The work of HAQAST investigators has also appeared in policy-relevant outlets such as the *World Meteorological Association Airborne Dust Bulletin*, the *Lancet Countdown Report and U.S. Brief*, and the *Nelson Institute Brief*.

The HAQAST website continues to be a valuable resource for relevant NASA data and tools. The website logged 10,337 users in 2021, an increase of 8 percent over 2020. The most popular pages were the ones relating to HAQAST meetings (~6,000 page views), NASA tools (~1,700 page views), principal investigators' (PIs) biographies (~1,700 page views), and Tiger Teams (1,700 page views).

This new generation of applied researchers has continued to build on the reputation of HAQAST conferences as friendly, intellectually fulfilling, and publicly useful venues for disseminating the latest and greatest applied air quality and environmental health research, as well as a valuable opportunity for researcher/public stakeholder networking. The approach to HAQAST meetings is shaped on the highly successful experience from the 2016-2020 HAQAST effort. Meeting activities in 2021 were impacted by restrictions related to the COVID-19 pandemic. The 2021 meetings focused on engaging new investigators and collaborators in a virtual format to launch activities and build a cohesive team.

In early 2021, HAQAST hosted Launch21, an online meeting centered on introducing the new team and generating new ideas for the formation of Tiger Teams. This one-day meeting had seven sessions with HAQAST PIs and stakeholders, including breakouts on each of the topics to brainstorm and record new ideas. HAQAST Launch21 attracted 327 registrants, with 269 unique attendees during the meeting, and ~100 views of the recording made available after the meeting. Each breakout topic at the meeting was further engaged by separate discussion groups throughout the spring, which ultimately led to the creation of Tiger Team proposals (See Fig. 1).

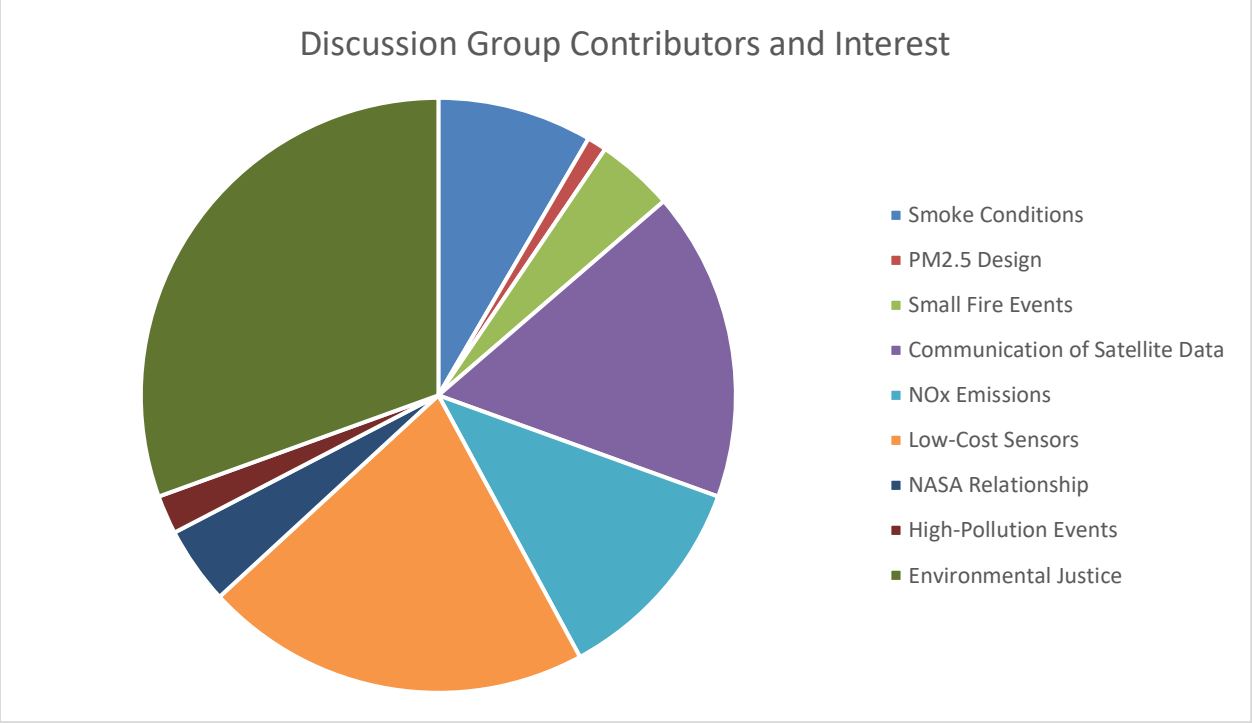

Fig. 1: Proportion of Spring 2021 attendees participating in Tiger Team discussion groups.

By leveraging prior HAQAST partners and an online format, the new team began with a splash, hosting nearly 10 times more attendees for Lauch21 relative to the first meeting of the 2016-2020 HAQAST. These experiences have demonstrated the audience demand for remote options as well as all-virtual webinars. (see Fig. 2).

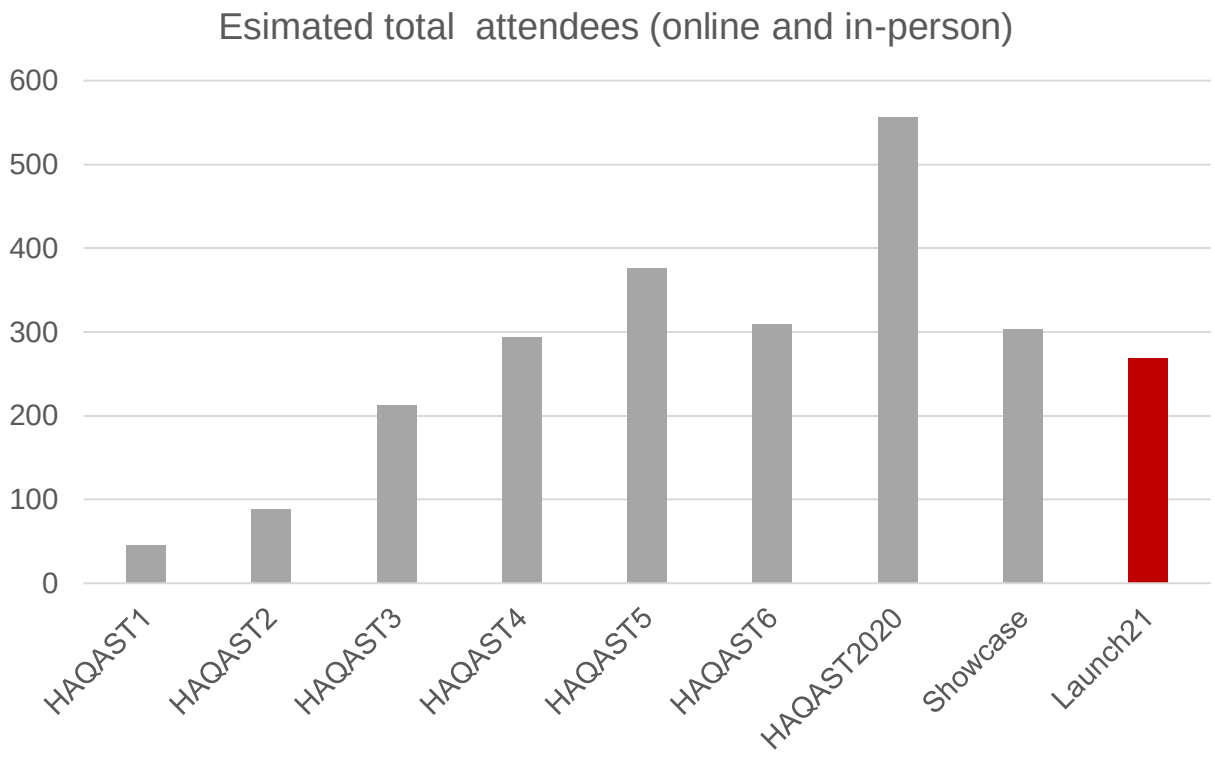

Fig. 2: Total HAQAST estimated meeting attendance (both remote, in-person, and virtual), 2016–2021. Meetings from 2016-2020 in gray, first meeting of third generation HAQAST in red.

In October 2021, HAQAST held a series of three internal online meetings aimed at giving team members more opportunities to engage with each other, sharing strategies about working with stakeholders and discovering future opportunities, and fostering team-wide collaboration. These meetings included HAQAST investigators, Tiger Team leads, active stakeholders, and research team members, for a total of ~60 participants.

All public presentations from HAQAST conferences can be found at the Past Meetings tab of the HAQAST website. A video introducing the newest HAQAST team can also be found on the website.

HAQAST members' applied research culminated in the publication of more than 30 peer-reviewed articles in 2021, with more in queue as the research publication cycle catches up with the backlog of submitted manuscripts.

V. Assessment

Challenges and opportunities presented themselves in 2021, as the world endured a second year of the COVID-19 pandemic. As new waves of COVID-19 cases swept across the nation and the world, NASA continued mandatory telework, and the HAQ team relied on an entirely virtual workplace. Opportunities included an expansion of interactions with global stakeholders through a variety of virtual platforms; challenges included a loss of human-to-human connections and networking. The loss of in-person discussions was particularly felt in HAQAST, scientific and end user conferences, and peer-review panels. Also, the balance of work and life pressures was a foremost concern, as the number of emails, videoconferences, and tasks were overwhelming at times. However, with the arrival of vaccines and the resumption of some in-person conferences by late 2021, a brighter future could be glimpsed. The HAQ team performed superbly throughout the year, while managing costing and schedule impacts to many projects in the portfolio.

Overall, the HAQ portfolio exceeded technical performance expectations in 2021, with several projects reaching top-tier ARLs of 7 to 9.

The portfolio made significant progress on reducing the balance of uncosted funds in 2021. Associates worked diligently with PIs to uncover issues at their institutions. Many times, such discrepancies appeared to result from “invoice lag” between NASA and the institutions, with costed funds not showing on NASA accounts until long after invoices had been submitted by grantees. The COVID-19 pandemic only exacerbated this issue. However, FY19 uncosted funds were down ~81 percent from December 2020 to December 2021; FY20 uncosted funds were down ~74 percent over the same period. Additionally, several projects reallocated budgets due to COVID-19 impacts, but these were at no additional cost to the government

Overall, while some projects in the HAQ portfolio managed schedule disruptions in 2021 due to the pandemic, significant results were accomplished in all areas. Schedule and costing issues will continue to be monitored and mitigated in 2022, with hopes for an easing of the pandemic and its impacts.

VI. Project Portfolio

At the end of 2021, the HAQ portfolio included 18 active projects along with the activities of the 14-member HAQAST. The portfolio met or exceeded expectations on technical performance. By the end of the year, zero projects had an ARL of 1-3; six projects had ARLs of 4-6; and twelve projects had achieved an ARL of 7-9. A total of 83 percent of projects increased at least one ARL from December 2020 to December 2021, and 22 percent increased by two or more ARLs over the same period.

VII. Program Management

The 2021 NASA Health and Air Quality Applications Annual Team Meeting was held virtually on October 12 and 20, 2021. PIs presented information about each project in the portfolio including milestones achieved over the past year, plans for the coming year, ARL estimates, budgets, and any risks/opportunities foreseen. Angel Werner and Nicholas Skaff of the Center for Disease Control's (CDC's) Environmental Health Tracking Section provided the keynote partner address. Additionally, Aries Keck, of NASA Applied Sciences Communications, provided information on more effective outreach to participants. John Haynes facilitated a virtual town hall discussion on future goals, partnerships, and opportunities. This open platform offered an opportunity for researchers to describe priorities, express concerns, and identify specific challenges faced during the COVID-19 pandemic. The Team Meeting ended with a celebration of the career of Sue Estes, senior associate program manager for HAQ, as she entered retirement. Additionally, a web feature was published on Sue's prolific and outstanding contributions to NASA: https://appliedsciences.nasa.gov/our-impact/people/celebrating-sue-health-and-air-quality-colleague-retires-applied-sciences.

The NASA ROSES 2021 Program Element A.37, "Earth Science Applications: Health and Air Quality," solicitation was issued in February 2021. The HAQ program received a total of 68 proposals in response. A virtual peer review panel in November 2021 evaluated all received proposals in terms of their intrinsic merit, relevance and responsiveness to HAQ goals and program element objectives, and realism of cost. Awards from this solicitation are expected to be announced in March 2022.

John Haynes serves as program manager for HAQ at NASA Headquarters. In addition to Sue Estes, the HAQ program team includes Helena Chapman (NASA Headquarters/Booz Allen Hamilton) and Laura Judd (NASA Langley Research Center (LaRC)) as associate program managers.

VIII. Community Leadership

Conference Presence

The HAQ team presented at nine major conferences in 2021. Below is a brief synopsis of their contributions.

At the **101st AMS Annual Meeting in January (virtual),** the HAQ team organized a session titled, "Integrating NASA Satellite Data to Strengthen Environmental Health Applications: Approaches to Informing Health Decision-Making and Enhancing Public Engagement," with nine scientific talks and more than 40 attendees. The HAQ program

also presented the poster entitled, *Using NASA Satellite Data to Expand Environmental Health Networks: Emphasis on the One Health Concept*.

At the **AMCA Annual Conference in March (virtual)**, Helena Chapman led a symposium titled, "NASA Earth Observations for Improved Vector-borne Disease Surveillance," with over 130 virtual attendees. Researchers described examples of integrating satellite with ground-based data to enhance mosquito-borne disease surveillance (particularly dengue, zika, West Nile virus, and malaria) and risk characterization (ArboMAP, DHIS2, VectorSurv). She also presented the talk titled, *Using Satellite Data to Enhance One Health Networks in Vector Control*, in the "Disease and Vector Studies" session.

Helena Chapman presented a poster at the **ASPPH Annual Meeting (virtual)** entitled, *Promoting Innovative Scientific Approaches to Build One Health Networks*, encouraging multidisciplinary collaborations that integrate diverse scientific data and approaches that can foster community partnerships (e.g., GEO Health CoP), strengthen public education, and ultimately protect population health.

At the **ATS International Conference in May (virtual)**, the HAQ team convened a session titled, "Using NASA's Earth Observation Data for Applications in Respiratory Health." This session highlighted three NASA projects incorporating satellite data to examine health effects of urban ambient pollution and dust storms for community health assessments and public health surveillance.

For the **A&WMA 114th Annual Conference and Exhibition in June (virtual)**, the HAQ team organized a session titled, "Innovative Uses of Earth Observations within NASA Health and Air Quality Applied Sciences Team (HAQAST)." Attended by approximately 80 participants, this session included five panelists describing examples from the newest version of HAQAST for integrating satellite- and ground-based data for use in stakeholder activities related to air quality management. Helena Chapman also gave a presentation entitled, *Promoting Environmental Resiliency through One Health Collaborations during the COVID-19 Pandemic*, in the "COVID-19: Effects, Control and Management" session.

APHA Annual Meeting & Expo in October (virtual): The HAQ team convened the "Using NASA Satellite Data to Enhance Global Health Surveillance and Decision-Making: A One Health Approach" symposium which included five presentations described the integration of satellite Earth observations into public health tools related to particulates, dust, chikungunya, and cholera. Also, Helena Chapman presented the talk, *Key Community Collaborations to Examine the Health Impacts of Changing Global Ecosystems*.

As the first hybrid meeting since the onset of COVID-19, the HAQ team organized a panel for the **A&WMA's Visibility Conference (Bryce Canyon City, UT)** titled, "NASA

Earth Science Capabilities for Investigating Aerosol Impacts." Five panelists presented to ~ 30 attendees on the use of NASA Earth observations to better understand aerosol impacts in relation to wildfires, air quality, and health.

Helena Chapman presented at the **National Conference of Science, Technology and Innovation (CONACIETI 2021) in October (virtual)**. Her talk was entitled, *Applications in Earth and Health Sciences: Focus on One Health*, where she promoted the use of Earth observations to bridge Earth and health science communities.

As always, the HAQ team had a large presence at the **American Geophysical Union (AGU) Fall Meeting in December (New Orleans, LA)** which included an organized session titled, "Connecting Global Ecosystems to Human Health: Enhanced Decision Support Applications Using NASA Satellite Data." The session had 70 attendees engaged in seven scientific talks and five posters. Helena Chapman also co-organized an oral session, "Applying a One Health Framework to Climate Change and Health: Soil and Water Quality, Sustainable Food Systems, Biodiversity, and Animal and Human Health" and Laura Judd organized the "Advances in a Global Observing System for Air Quality" session. Additionally, Helena Chapman served as an invited panelist on the "Science and Society Student Career Panel," and Laura Judd presented preliminary outcomes of the Tracking Aerosol Convection Interactions Experiment – Air Quality (TRACER-AQ) campaign during a town hall titled, "Clouds, Aerosol, and Air Quality in the Coastal Urban Environment: Interagency Field Campaigns in the Houston, Texas, Region 2021-2022."

Invited Presentations

In the mostly virtual world of 2021, invited presentations were quite regular among the HAQ team. Below is a description of the top 15 meetings where the HAQ team was invited to present in chronological order:

In January, John Haynes and Helena Chapman were invited to give lectures for the *Global Health and Infectious Diseases* course of the **National Institutes of Health's (NIH's) Foundation for Advanced Education in the Sciences**.

In February, John Haynes and Juli Trtanj (NOAA) were invited presenters to the monthly **CDC Zoonoses & One Health Updates (ZOHU) webinar**. Their talk, *NASA and NOAA Earth Observations for Health and Air Quality Applications*, was attended by over 500 participants and focused on applications of satellite data in relation to the COVID-19 pandemic.

Also, in February, John Haynes presented, *A Day in the Life of a Program Manager for Health and Air Quality at NASA*, to 30 students at the **University of Oklahoma's AMS Student Chapter** and **National Weather Association**.

In March 2021, Helena Chapman presented the topic, *Exploring an Innovative Health Career: From Mosquitoes to Satellites*, in Spanish, to 40 participants in **Women Power Week**, which was hosted by the University of Chile, the University of Concepción, and the University of Santiago de Chile.

Helena Chapman presented, *Health and Air Quality Applications for One Health,* during the **US Food and Drug Administration (FDA)'s One Health Virtual Symposium in April**. Other panelists represented the CDC, USDA, University of California-Davis, and the Global Virome Project.

April and May proved to be busy, with seven invited webinars in the educational sector. John Haynes, Helena Chapman, and Laura Judd introduced the HAQ program to:

- George Washington University's Milken Institute School of Public Health
- Tuskegee University's Public Health Program
- Howard University's School of Public Health
- University of Florida's College of Public Health and Health Professions
- Ohio State University's Veterinary Public Health Club
- Cornell University's Veterinary One Health Association
- SKEMClub of Don Bosco Technical High School (Costa Rica)

In June 2021, John Haynes presented, *Using NASA Earth Observation Satellites to Enhance Health and Air Quality Applications*, in the "Geospatial Technologies and Human Health" session, of the **National Institute of Environmental Health Sciences (NIEHS) Workshop** on "Integrating Multiscale Geospatial Environmental Data Into Large Population Health Studies."

Also, in June 2021, John Haynes presented to the **U.S. Department of State Bureau of Educational and Cultural Affairs' International Visitor Leadership Program** about the role of NASA and the importance of partnerships between agencies and sectors. This was followed on by additional presentations from John Haynes and Helena Chapman to the same group in August about innovative applications of NASA Earth observations to examine ecosystem risks that influence the global spread of infectious diseases and the One Health concept.

In August 2021, John Haynes presented a talk as part of the **NASA GSFC Air Quality and Health Group** monthly meeting.

Also, in August 2021, Helena Chapman presented the talk, *Publishing the Sciences,* to approximately 32 interns of the **NASA ESD's Seminar Series** – targeted to undergraduate students in the Summer Internship Experience.

In September, John Haynes and Helena Chapman gave a lecture to 15 students about, *Spatialization and Dynamics of COVID-19 and other Infectious and Vector-borne*

Diseases: Advances in Remote Sensing, as part of the *Interdisciplinary Seminars in Global Infectious Diseases* course at **Georgetown University**.

Also, in September, Helena Chapman presented, *Using Earth Observations to Enhance Public Health Surveillance*, to 30 physicians of the **Uniformed Services University of Health Sciences' Journal Club of Occupational and Environmental Medicine and Preventive Medicine residency programs**.

In September, John Haynes was invited to speak at a **Breezometer** webinar, *Environmental Reporting in the Era of Climate Change: Expert Opinions.*

In October, as part of the **Harris County Public Health**'s One Health Conference 2021, Helena Chapman presented the talk, *Building One Health Networks within the Earth and Health Science Communities*, as part of the "Operationalizing One Health" virtual panel.

In November, three invited NASA Hyperwall Presentations at the **U.S. Center Glasgow 2021 UN Climate Conference** highlighted work done by HAQ-supported individuals:

- Assaf Anyamba (University of Maryland, Baltimore County/NASA GSFC): Climate Variability and Disease Outbreaks
- Amber Soja (NIA/NASA LaRC): Connections Between Fire, Weather, and Climate
- Laura Judd (NASA LaRC): Revealing Urban Pollution Patterns

Mission Applications

The HAQ team continues to support and participate in workshops related to integrating future NASA mission data with stakeholders and end user partners. Below are our larger contributions to Atmosphere Observing System (AOS) (formerly Aerosol, Cloud, Convection and Precipitation (ACCP)), Tropospheric Emissions: Monitoring of Pollution (TEMPO), Multi-Angle Imager for Aerosols (MAIA), Plankton, Aerosol, Clouds, ocean Ecosystem (PACE), and Airborne Science.

In March, the NASA Applied Sciences Program supported the **NASA ACCP Air Quality Workshop** focused on current applications and future opportunities of ACCP observations to support air quality and disaster applications. This three half-day virtual meeting provided an opportunity for over 160 virtual representatives from federal and state operational agencies, private companies, and boundary organizations to discuss how NASA ACCP aerosol products could be better leveraged to inform decision-making activities.

Throughout the year, there were engagements with the **TEMPO team and TEMPO Early Adopters**. Aaron Naeger (Deputy Program Applications lead for TEMPO**,** University of Alabama Huntsville) organized two Early Adopters workshops in 2021. The first was the Pre-launch TEMPO Data User Tutorial in April 2021, which provided an

overview and specifications of the first major release of pre-launch proxy TEMPO data products for the Early Adopter community. In November, Aaron Naeger organized a second Data Tutorial for the TEMPO mission. These tutorials included over 170 participants from U.S. state and local air quality agencies, federal agencies, academic institutions, and international organizations who attended to learn updates on the TEMPO pre-launch proxy data (nitrogen dioxide, formaldehyde, ozone, aerosol products), application examples, and intended data uses. Aaron Naeger also led the "Revolutionary Air-Pollution Applications from Future TEMPO Observations" article in the *Bulletin of the American Meteorological Society* magazine.

In May, the article, TEMPO Air Pollution Sensor Treks Toward Satellite Integration, by Joe Atkinson (NASA LaRC), was published on the NASA website highlighting the progress of the TEMPO instrument's integration onto its hosted ride to space.

In June, the NASA TEMPO Science Team held their annual science team meeting virtually. The Early Adopters program was highlighted. Slides from this meeting are publicly available here.

Abbey Nastan (deputy program applications lead for **MAIA,** Jet Propulsion Laboratory (JPL)) coordinated MAIA's third annual Early Adopters Workshop in September 2021. This featured recent project updates about MAIA simulated data, which will help Early Adopters prepare for MAIA data before launch. The MAIA team provided guided tutorials, as well as a Jupyter notebook and user guide, to facilitate Early Adopter's use of the simulated data. More than 140 people (including 80 in-person participants) attended the Early Adopters workshop.

In September, the NASA Applied Sciences Program supported the 2021 NASA **PACE Applications Workshop**. This event focused on future uses of PACE satellite data, products, and applications to support decision-making in water resources, air quality and health, climate, disasters, and ecological forecasting.

Also, in September 2021, NASA partnered with the Department of Energy TRACER, Texas Commission on Environmental Quality, the Bureau of Ocean Energy Management, and several academic institutions to collect enhanced air quality measurements over the Houston/Gulf of Mexico region for the TRACER-AQ field campaign. A high-level description can be found in the NASA article, NASA Study Examines Houston-area Air Quality Issues.

Honors and Recognition

As part of the 2021 NASA Agency Honor Awards, Helena Chapman received the NASA Early Career Achievement Medal. These awards are NASA's most prestigious and are presented to individuals and teams who have distinguished themselves by making outstanding contributions to the Agency's mission. Helena's medal was awarded for outstanding early career service to NASA and society in advancing innovative and

practical uses of Earth science observations for improving public health decision-making.

Also in 2021, Helena Chapman received the 40 Gators Under 40 Award by the University of Florida. This award recognized University of Florida graduates who are contributing significantly to their communities and professions.

To honor Women's History Month in March, WTKR news (CBS; Norfolk, VA) promoted STEM careers by highlighting Laura Judd's career path in the news report and article entitled, To Mars and Back: Meet the Women Helping NASA Langley Break Barriers in Science.

Media Highlights

As in past years, the HAQ team aims to recognize work ongoing in their portfolio during dedicated weeks and days each quarter in the public health and air quality sectors:

- National Public Health Week in April: https://appliedsciences.nasa.gov/our-impact/story/building-connections-national-public-health-week
- National Mosquito Control Awareness Week in June: https://appliedsciences.nasa.gov/our-impact/news/tracking-mosquitoes-space-nasa-does
- International Day of Clean Air for blue skies in September: https://appliedsciences.nasa.gov/our-impact/story/supporting-healthy-air-healthy-planet-texas-and-beyond
- One Health Day in November: https://appliedsciences.nasa.gov/our-impact/news/connecting-human-animal-and-environmental-health-nasas-role-one-health-day-2021
- HAQ Infographics – a series of six new infographics highlighting different activities of the portfolio: https://appliedsciences.nasa.gov/what-we-do/health-air-quality (scroll to bottom of page)

Additionally, in September, The *EM* magazine of the Air & Waste Management Association launched a special issue with the theme, *New Insights in Air Quality Monitoring Using Satellite Data*. This issue highlighted five articles with contributions from people supported by the HAQ program, including HAQAST.

Other Highlights

During **NASA Earth Science Applications Week 2021**, PIs supported by the HAQ program – Julia Gohlke (Virginia Tech) and Assaf Anyamba (NASA GSFC/USRA) – presented their HAQ projects and participated in the group discussion. Tracey Holloway (University of Wisconsin-Madison) and the HAQAST team also created a This is HAQAST video to promote the new HAQAST membership.

Throughout 2021, the program continued its active participation in the **U.S. Global Change Research Program (USGCRP) Climate Change and Human Health Working Group (CCHHG)** and **CDC's One Health Federal Interagency COVID-19 Coordination Group in 2021**. Laura Judd served as co-lead of the CCHHG Research Workstream with U.S. Environmental Protection Agency (EPA) colleagues, Rona Birnbaum and Caitlin Gould. In November 2021, this workstream completed a compendium of federally funded research related to climate change and human health.

IX. International Activities

In 2021, the HAQ management team continued its active leadership and contribution to GEO, including the monthly U.S. GEO and Americas Caucus meetings. They have provided regular updates on the GEO Health CoP, the EO4Health Initiative, and related applied research projects. Below are some highlights within each activity.

Group on Earth Observations (GEO)
In June 2021, the NASA HAQ program participated in the GEO Virtual Symposium 2021. The Sustainable Partnerships for Health Decision-making and One Health Collaborations session – facilitated by John Haynes, Juli Trtanj (NOAA), and Helena Chapman – showcased three sustainable partnerships that have leveraged scientific expertise by incorporating innovative data and technology to understand impacts and support preparedness and response related to pressing global health issues, including the ongoing COVID-19 pandemic. Also, John Haynes presented on EO4Health in the "Generalizing the Concept of the Essential Variables" session. This virtual symposium encouraged multidisciplinary collaborations that connect experts, promote the use of innovative approaches, and align agendas to meet the Sustainable Development Goals.

In August 2021, more than 700 participants attended virtual sessions of the AmeriGEO Week 2021. Using the theme, *Advancing Collaboration and Data Integration for Decision Support*, the symposium aimed to identify synergies and priorities using Earth observation data that can strengthen regional collaborations. The "Using Earth Observations for Public Health Surveillance" session – facilitated by John Haynes, Juli Trtanj (NOAA), and Helena Chapman – focused on emerging global health challenges as a leading priority in the upcoming decade. Notably, this event was the first public engagement of the AmeriGEO Health thematic community, with more than 120 attendees.

In November 2021, GEO Week 2021 was held virtually and aimed to highlight initiatives from GEO members, participating organizations, and associates in a series of live discussions and interactive content. The EO4Health Initiative team contributed a brief overview of activities during the AmeriGEO side event. The GEO 2021 Highlights Report provided notable items and updates to the GEO Work Programme activities,

including GEO's efforts to strengthen youth engagement, support climate change action, and highlight the community's response to COVID-19. More information on EO4Health activities and projects can be found on pages 34-36.

GEO Health and Environment Community of Practice

Under the leadership of chair John Haynes, the GEO Health and Environment CoP continued its mission as a global network of governments, organizations, and observers that seeks to use environmental observations to improve health decision-making at the international, regional, country, and district levels.

From January to November 2021, the GEO Health CoP held biweekly teleconferences to provide program and project updates, share knowledge for COVID-19 response, offer Small Work Group updates, and coordinate the next steps of the GEO Health CoP work plan. This work plan supports GEO efforts and advances development of the EO4Health Initiative. A synthesis of monthly themes is shared below:

- **January 2021**: Bryan Duncan (NASA GSFC) presented on CityAQ, a pilot project that provided optimized air quality forecasts to city health and air quality managers
- **February 2021**: The Central American Technological University team introduced the COVID-19 and Dengue Observatory in Honduras, which offers epidemiologic and geospatial data to help coordinate prevention and mitigation strategies to enhance infectious disease and disaster management in Honduras. William Pan (Duke University) described the successful development of a malaria early warning system that produces 12-week forecasts of outbreaks in the Amazon region.
- **March 2021**: Vineet Khanna (Veterans Affairs Medical Center) discussed lung cancer screening with pollution as a factor. Pawan Gupta (NASA Marshall Space Flight Center (MSFC)/USRA) described air quality forecasting with NASA SERVIR in Thailand. Pablo Méndez-Lázaro (University of Puerto Rico Medical Sciences Campus) shared an update of the air quality forecasting tool on seasonal Saharan dust storm events in the Caribbean. Marjan Van Meerloo (European Commission) discussed the European Innovation Council's Horizon Prize on Early Warning for Epidemics Prize, to offer support for scalable, reliable and cost-effective early warning system prototypes to forecast and monitor vector-borne diseases. Ben Zaitchik (Johns Hopkins University) presented harmonized Earth observation datasets with COVID-19 cases.
- **April 2021**: Aaron Naeger (University of Alabama in Huntsville) described the TEMPO Mission and Early Adopters Program, and Abigail Nastan (JPL) and John Haynes highlighted the MAIA Mission and Early Adopters Program.
- **May 2021**: Tabassum Insaf (NY Department of Health) discussed heat mitigation efforts in New York, Christian Braneon (Goddard Institute for Space

Studies) described mapping urban heat islands and using global climate models and remote sensing datasets in resiliency planning, Hunter Jones (NOAA) highlighted NOAA's NIHHIS community-led summer campaigns. Assaf Anyamba (NASA GSFC/USRA) described the development of global risk maps of chikungunya with the CHIKRisk App.

- **June 2021**: Haris Kontoes (National Observatory of Athens) introduced the EuroGEO Action Group's Early Warning System for Mosquito-borne Diseases (EYWA). Victoria Gammino (MITRE) described vector habitat detection efforts to combat onchocerciasis. Anna Stewart-Ibarra (Inter-American Institute (IAI) for Global Change Research, IAI) introduced IAI and highlighted selected projects, and Liana Anderson (CEMADEN, Brazil) discussed the IAI-project of wildfire early warning systems in the Amazon region (MAP-FIRE).
- **July 2021**: Cascade Tuholske (Columbia University's Earth Institute) described a new daily urban extreme heat dataset (Global High Resolution Daily Urban Extreme Heat Exposure, UEH-Daily).
- **August 2021**: Natasha Sadoff (NASA GSFC/SSAI) provided an overview of the NASA PACE mission.
- **September 2021**: The *Special Edition: The Americas* teleconferences offered 21 flash talks on infectious diseases, public health infrastructure, capacity building, and community-based applications in the Western Hemisphere.
- **October 2021:** Myles Harris (University College London (UCL)) described the UCL Institute for Risk and Disaster Reduction Space Health Risks Research Group.
- **November 2021:** Thilanka Munasinghe and Ethan Joseph (Rensselaer Polytechnic Institute (RPI)) and Assaf Anyamba (NASA GSFC/USRA) described the RPI-NASA Student Engagement collaboration and *IEEE Xplore* publication (Scraping Unstructured Data to Explore the Relationship between Rainfall Anomalies and Vector-Borne Disease Outbreaks). Amin Dezfuli (NASA GSFC) introduced his research on examining large-scale climatic phenomena affecting migratory birds to North America. Sophia Liu (United States Geological Survey) discussed operationalizing open science and innovation through crowdsourcing, citizen science, and prize competitions.
- In **December 2021**, the GEO Health CoP and the AGU partnered to hold the GEO Health CoP Meeting at AGU Virtual Fall Meeting 2020. A full agenda of and highlights from this meeting can be found here: Day 1 and Day 2.

To showcase the effort of the GEO Health CoP, Helena Chapman prepared a brief article, "Junior Doctors Lead a Global Call to Action to Promote Multidisciplinary Collaborations," for the World Medical Association's *Junior Doctors Network Newsletter* (October Issue 2021).

Throughout 2021, Small Work Groups within the GEO Health CoP continued to serve as essential networking tools for CoP members. The leads of these five groups are as follows:

1. Heat (Ben Zaitchik, John Hopkins University; Cascade Tuholske, Columbia University's Earth Institute)
2. Infectious Diseases (Antar Jutla, University of Florida)
3. Air Quality, Wildfires, and Respiratory Health (Eric Klos, DailyBreath; Pawan Gupta, NASA MSFC/USRA)
4. Food Security and Safety (Dorian Janney, NASA GSFC/GPM)
5. Health Care Infrastructure (John Balbus, NIH/NIEHS; Andreas Skouloudis, iSteep.org)

Each group leverages the expertise of CoP members to provide scientific and technical information on selected health-related topics for specific project tasks, projects, and activities. The leadership team continued to promote opportunities for CoP members to contribute to the Small Work Groups through a weekly listserv distribution list.

The GEO Health CoP continued to support the COVID-19 Earth Observation Dashboard, a tri-agency collaboration among NASA, the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA). This web platform leveraged the expertise of three partner agencies to investigate how social distancing measures and regional shelter-in-place guidelines have affected Earth's air, land, and water. This platform expanded the integration of relevant Earth observation data to include more than 150 economic, agriculture, air, water, and health indicators. Notably, in June 2021, these agencies hosted the Earth Observation Dashboard Hackathon (NASA, ESA, JAXA Host Hackathon to Study COVID-19's Environmental Effects).

In April 2021, John Haynes and Juli Trtanj (NOAA) presented an overview of the GEO Health CoP and EO4Health Initiative at the U.S. GEO Briefing to U.S. Embassies in the Americas Region, with 85 total participants from 64 embassies in 15 countries. A similar briefing was held in December for U.S. Embassies in Africa. Also, Helena Chapman highlighted current activities of the GEO Health CoP and EO4Health at the Panama Forum on Earth Observation for Social Benefit (in Spanish) in April.

In June 2021, several GEO Health CoP members, who formed part of the WMO COVID-19 Task Team, collaborated with the WMO/WHO Integrated Health Services Study Group to coordinate a series of virtual roundtable events focusing on sharing experiences to promote actionable meteorologically-informed decision-making during the COVID-19 pandemic. The first (Compound Climate Hazards and COVID-19) and second (COVID-19 Seasonality: Current Understanding and Relevance to Decision-making) roundtables were held in June and September 2021, respectively.

EO4Health Initiative

The NASA Applied Sciences Program issued a solicitation to support the GEO Work Programme in 2016. This solicitation included a section targeting the EO4Health Initiative. Awards from this solicitation were announced in October 2017. In 2021, the following key accomplishments were noted for these projects:

- A project led by Antarpreet Jutla (University of Florida) has integrated satellite data systems into the weekly time step for the epidemic and endemic models of cholera for Africa. The team has collaborated with the United Kingdom Foreign, Commonwealth and Development Office (UK-FCDO), United Nations Children's Emergency Fund (UNICEF), United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), and Red Cross Climate Center. In 2021, the team conducted weekly assessments of cholera risk in Yemen, Ethiopia, and Sudan, which have been integrated into health decision-making processes of project partners. Situational assessments were conducted in additional African nations. The team released the Vibrio Prediction Hub, including a cholera risk map viewer, and the team is working on the development of an Android App prototype to inform cholera risk reduction in this geographic region. The team is developing training sessions with UNOCHA and UNICEF for sustained use of the web-based application. More information on this project can be found on the NASA Applied Sciences webpage.

- A project led by Tatiana Loboda (University of Maryland, College Park) has merged Earth observations of environmental conditions with population exposure and vulnerability status to assemble and execute the full-scale model of the Myanmar Malaria Early Warning System (MMEWS). The team has collaborated with Duke Global Health Institute in Myanmar. In 2021, the team implemented the Malaria Burden Potential model of the MMEWS at spatial (240m country-wide with localized zoom in at 30m) and temporal (8-day) resolutions and completed historical runs (2016-2020) to compare with available reports of malaria prevalence across Myanmar. To date, model coding was optimized to enable in-country operations with locally available computing resources, and the team established the alternative web-based system delivery platform using the WebGIS platform. International travel restrictions, team reassignments to COVID-19 response efforts, and political instability in Myanmar resulted in the inability to implement training activities, as well as limited communication with Myanmar government officials and collaborators. More information on this project can be found on the NASA Applied Sciences webpage.

- A project led by Jack Malone (Louisiana State University) has used NASA satellite data (*e.g.*, ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) and SMAP), geographic information systems, and ecological niche modeling to develop geospatial models and risk maps on visceral leishmaniasis for Sao Paulo and Bahia states (Brazil). The team has

collaborated with Sao Paulo State University, Adolfo Lutz Institute, Federal University of Bahía, University of Antioquia, and Federal University of Uberlandia. In 2021, models assimilating SMAP soil moisture and VIIRS land surface temperature data enhanced models calculated from the classical WorldClim Version 2 to assess the risk of visceral leishmaniasis and guide control program interventions at the community level in Brazil. Preliminary results using ECOSTRESS data (land surface temperature, evapotranspiration, evaporative stress index, potential evapotranspiration) produced 70m/30m resolution maps of sand fly distribution in Feira de Santana, Bahia, recognized as an area of intense visceral leishmaniasis transmission. The team is developing a one-week course module and a second manual to train and implement operational results on visceral leishmaniasis and *Aedes*-borne diseases at the state level (1km) and municipality health unit level (70m/30m). More information on this project can be found on the NASA Applied Sciences webpage.

- A project led by Ben Zaitchik (Johns Hopkins University) integrated climatological, hydrological, ecological, and human behavioral data to develop statistical models of high-impact gastrointestinal infectious diseases, at global gastrointestinal disease study sites. The team has collaborated with Brigham Young University. In 2021, the team completed multi-pathogen modeling analyses, implemented an optimized Bayesian predictive modeling approach, and finalized the online visualization tool for shigella infection (Shigella Risk Assessment Tool). With supplementary funding through the NASA Rapid Response and Novel Research in the Earth Sciences program of ROSES 2020, the team refined the COVID-19 risk analyses for Brazil, United States, and selected South and Central American countries for subsequent public dissemination using GitHub. More information on this project can be found on the NASA Applied Sciences webpage.

X. Looking Ahead

2022 will be a year of continued challenges due to the COVID-19 pandemic; however, the wide availability of vaccines and the resumption of some in-person meetings in late 2021 gives hope for more face-to-face interactions. During 2022 and beyond, the HAQ program will continue to support the agency's response to the pandemic, while looking for new and innovative opportunities in the health and air quality communities. The program will expand and grow its relationship with current and future relevant NASA missions and designated observables, as well as field and Earth Venture (EV) campaigns, including the State and Tribal Air Quality System (STAQS) air quality campaign in 2023. The program looks forward to results in 2022 from the first round of HAQAST Tiger Teams. Additionally, new awards from the ROSES 2021 HAQ solicitation are expected to be announced in March 2022.

In 2022, HAQ program personnel plan to participate in relevant sessions of the AMS Annual Meeting, the AMCA Annual Meeting, the ATS Annual Meeting, the A&WMA Annual Meeting, the APHA Annual Meeting, and the AGU Fall Meeting.

The program will continue to engage schools of public health at various venues throughout the year to inform students and faculty of NASA Earth science capabilities and discuss opportunities for future collaborations. In 2022, a continued emphasis will be placed on outreach to minority serving institutions and underrepresented communities.

The program will keep abreast of studies and opportunities related to Program of Record missions (*e.g*., PACE) and Designated Observables outlined in the *Decadal Survey for Earth Science and Applications from Space*, of the National Academies of Sciences, Engineering and Medicine, released in January 2018. The Decadal Survey identified Aerosols (A) and Clouds, Convection and Precipitation (CCP) as high priority Designated Observables to be addressed, which are particularly relevant to this program. These Designated Observables have been brought together under the AOS mission, which is expected to enter phase A in 2022, with additional applications workshops planned to engage the community and solicit mission input and feedback. Additionally, the program is active in applications planning and early adopter activities for the upcoming TEMPO Earth Venture mission (launch expected in January 2023) and the MAIA Earth Venture mission (launch expected NET late 2023).

The program will continue to examine “grand challenges” to the community—particularly those outlined in the Decadal Survey—in collaboration with the NASA Earth Science Research and Analysis Program. For example, obtaining accurate ground-level aerosol and constituent measurements from remotely-sensed columnar values are a critical challenge. While progress has been made in this area, thanks to investments in algorithm development and targeted field campaigns, large discrepancies remain. Satellite observations for air quality will be increasingly vital. The launch of TEMPO in 2023, along with its Korean (Geostationary Environment Monitoring Spectrometer [GEMS]) and European (Copernicus-Sentinel-4) constellation partners, will allow unprecedented high temporal and spatial resolution measurements of tropospheric ozone, aerosols, and their precursors to create a revolutionary dataset that will help address these challenges.

The HAQ program has established strong relationships with federal, state, local, and international partners to identify unique applications of NASA satellite observations and realize their operational use. These applications provide critical components for integration with various forecasts, models, and decision support systems. This will continue to be the case with the launch of upcoming NASA satellite missions. NASA’s participation in health and air quality applications research and the related transition to operations of results with EPA, NOAA, CDC, and others fills a significant niche in

national capabilities and is a vital component of both current and future domestic and international programs and plans.

XI. Appendix

A. Abbreviations and Acronyms

A&WMA: Air and Waste Management Association
A-CCP: Aerosols and Clouds, Convection and Precipitation
ACCP: Aerosol, Cloud, Convection and Precipitation
AGU: American Geophysical Union
AMCA: American Mosquito Control Association
AMS: American Meteorological Society
AOS: Atmosphere Observing System
APHA: American Public Health Association
AQE: Air Quality Explorer (AQE)
ARL: Application Readiness Level
ARSET: Applied Remote Sensing Training program
ASDC: Atmospheric Science Data Center
ASPPH: Association of Schools & Programs of Public Health
ATS: American Thoracic Society
AVES: American Veterinary Epidemiology Society
CCHHG: Climate Change and Human Health Working Group
CCP: Clouds, Convection and Precipitation
CDC: Centers for Disease Control and Prevention
CONIDA: Comisión Nacional de Investigación y Desarrollo Aeroespacial
CoP: Community of Practice
D-MOSS: Dengue MOdel forecasting Satellite-based System
DOD: Department of Defense
DOH: Department of Health
ECOSTRESS: ECOsystem Spaceborne Thermal Radiometer Experiment
EO4HEALTH: Earth Observations for Health
EPA: Environmental Protection Agency
EPHTN: Environmental Public Health Tracking Network
ESA: European Space Agency
ESD: Earth Science Division
EPA: Environmental Protection Agency
EV: Earth Venture
FDA: Food and Drug Administration

GEDI: Global Ecosystem Dynamics Investigation
GEMS: Geostationary Environment Monitoring Spectrometer
GEO: Group on Earth Observations
GHHIN: Global Heat Health Information Network
GISTDA: Geo-Informatics and Space Technology Development Agency
GLOBE: Global Learning and Observation to Benefit the Environment
GOES: Geostationary Operational Environmental Satellite
GSFC: Goddard Space Flight Center
HAB: Harmful Algal Bloom
HAQ: Health and Air Quality
HAQAST: Health and Air Quality Applied Sciences Team
IAI: Inter-American Institute
ICES: International Center for Earth Simulation
ISU: International Space University
JAXA: Japan Aerospace Exploration Agency
JPL: Jet Propulsion Laboratory
LaRC: Langley Research Center
MAIA: Multi-Angle Imager for Aerosols
MODIS: Moderate Resolution Imaging Spectroradiometer
MPH: Masters of Public Health
MSFC: Marshall Space Flight Center
NASA: National Aeronautics and Space Administration
NCAR: National Center for Atmospheric Research
NIA: National Institute of Aerospace
NIEHS: National Institute of Environmental Health Sciences
NIH: National Institutes of Health
NIHHIS: National Integrated Heat Health Information System
NOAA: National Oceanic and Atmospheric Administration
NRC: National Research Council
PACE: Plankton, Aerosol, Clouds, ocean Ecosystem
PI: Principal Investigator
PM: Particulate Matter
$PM_{2.5}$: Fine Particulate Matter
RedCLARA: Latin American Cooperation of Advanced Networks
ROSES: Research Opportunities in Space and Earth Sciences
RPI: Rensselaer Polytechnic Institute
RSIG: Remote Sensing Information Gateway
S5P: Copernicus Sentinel-5 Precursor
SDDOH: South Dakota Department of Health
SICA: Sistema de la Integración Centroamericana
SMAP: Soil Moisture Active Passive
STEMM: Science, Technology, Engineering, Mathematics, and Medicine
TCEQ: Texas Commission on Environmental Quality
TEMPO: Tropospheric Emissions: Monitoring of Pollution

TRACER: Tracking Aerosol Convection Interactions Experiment
TROPOMI: TROPOspheric Monitoring Instrument
UK-DFID: United Kingdom Department for International Development
UN: United Nations
UNICEF: United Nations Children's Fund
UNOOSA: United Nations Office for Outer Space Affairs
USDA: U.S. Department of Agriculture
USGCRP: U.S. Global Change Research Program
USRA: Universities Space Research Association
UV: Ultraviolet
VIIRS: Visible Infrared Imaging Radiometer Suite
VL: Visceral Leishmaniasis
WESTAR: Western States Air Resources Council
WMO: World Meteorological Organization
WNV: West Nile Virus
WRAP: Western Regional Air Partnership

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