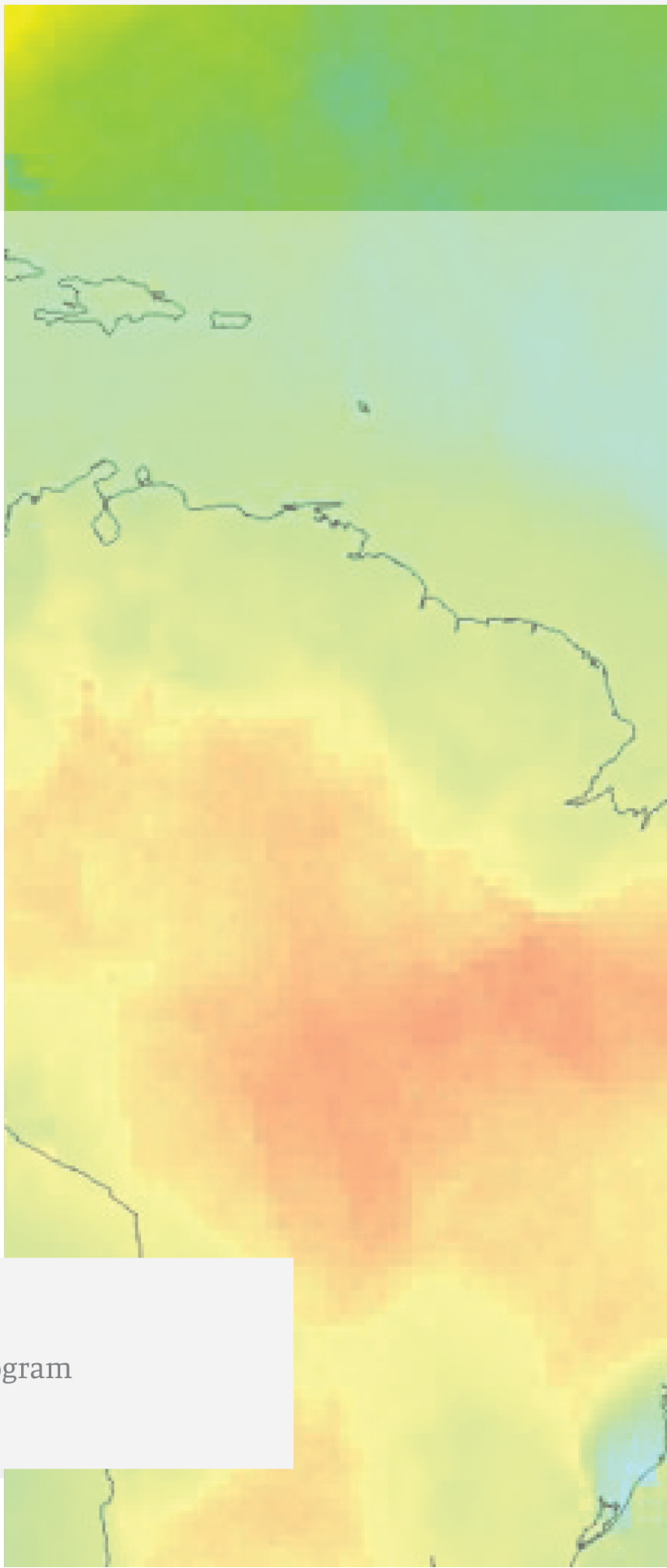
EARTH SCIENCE
APPLIED SCIENCES
HEALTH & AIR QUALITY



2022 ANNUAL SUMMARY

NASA Earth Science
Applied Sciences Program
Health & Air Quality

Health & Air Quality: 2022 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 focused in the following areas: Health and Air Quality, Disasters, Ecological Conservation, Agriculture, Wildland Fires, Climate Resilience, Water Resources, and Capacity Building.

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 2022

As the COVID-19 pandemic entered its third year in 2022, the HAQ team continued to support the agency's response to the pandemic through managing project augmentations, taking new opportunities for videoconference meetings with stakeholders and end-users across the world, and leading interagency and international groups. As the world began to open up once more, the HAQ team seized on the opportunity to again meet our colleagues in-person at venues across the nation and the world. While challenges persisted, the HAQ team persevered, successfully managing a diverse portfolio of projects and realizing 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 2022, 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 and led bi-weekly CoP meetings. The team showcased results across NASA platforms, including through web features, HAQ infographics, postcards, and videos. The third generation of the NASA Health and Air Quality Applied Sciences Team (HAQAST) continued work on five Tiger Teams launched in Summer 2021, while starting work on new Rapid Response projects. 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 2022. The HAQ program looks forward to upcoming activities and milestones, including new HAQAST Tiger Teams (to begin in Spring 2023), continued support for airborne field campaigns, as well as the support of, and applications planning for, relevant satellite missions (including the launch of TEMPO expected in April 2023).

III. Major Project 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) led 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 this tool in partnership with more than 19 public, private, and academic institutions in the Caribbean basin. **In May 2022, this project progressed to Application Readiness Level (ARL) 9 with the release of the Aerosol Monitoring Support Tool on the NOAA-sponsored Caribbean Coastal & Ocean Observing System (CARICOOS) platform.** The team worked to advance end-user training for sustained use of the web-based application, as well as finalized health education materials with the Puerto Rico Department of Health's Office of Public Health Preparedness & Response. These results were showcased in a NASA Applied Sciences web feature in October 2022 (Tracking Saharan Dust to Safeguard Public Health), including a NASA Video (An Early

Warning System Helps Puerto Rico Prepare for Saharan Dust). The project is scheduled for completion in January 2023.

Enhancing Cholera Risk Forecasts in Africa

Cholera is a waterborne disease transmitted by *Vibrio cholera*, causing an estimated 1.3 to 4 million annual cases of severe diarrhea and dehydration and 21,000 to 134,000 deaths worldwide. Due to case underreporting, cholera risk mapping is challenged with geographic variability across the African continent, which is recognized as having the largest cholera burden. Ben Zaitchik (Johns Hopkins University) led a team that partnered with the UN Global Task Force on Cholera Control (GTFCC) and Save the Children to develop a cholera forecasting tool to inform health authorities about cholera risk (1-3 months lead time) and support policy decisions to enhance cholera control. The team integrated LDAS, MODIS/VIIRS water quality and vegetation and land cover, and GEOS subseasonal to seasonal forecast data into a seasonal risk analysis for decision support. **In August 2022, this project progressed to ARL 8 with the the integration of the climatologic risk seasonality assessment (African Cholera Risk Early Warning System, ACREWS) into the GTFCC cholera dashboard.** These results were showcased in the *Lancet Global Health* article (The Seasonality of Cholera in Sub-Saharan Africa: A Statistical Modelling Study) in June 2022. The project was completed in August 2022.

Improving Health Hazard Mitigation Planning and Response

Unexpected hazardous events, like hurricanes and flooding, can lead to adverse health effects and economic impacts in vulnerable communities, and highlight the need for improved policy decisions that enhance community resilience. Using Hurricane Harvey as a case study, Julia Gohlke (Virginia Polytechnic Institute & State University) led a team to enhance syndromic surveillance with flood-based Earth observations to better inform health authorities about health risks related to flooding. The team used MODIS, VIIRS, NLDAS, IMERG, and Copernicus Sentinel-1 data to provide more accurate estimates of spatial relationships between flooding and public health needs to enhance current hazard mitigation planning and emergency response measures in vulnerable communities. **In June 2022, this project progressed to ARL 7 with the integration of environmental exposure estimates and synthetic population modeling to enhance the CDC/ATSDR Social Vulnerability Index (SVI).** These results were highlighted in *Health and Place* (Estimating Changes in Emergency Department Visits associated with Floods caused by Tropical Storm Imelda using Satellite Observations and Syndromic Surveillance) in March 2022 and *International Journal of Disaster Risk Reduction* (Flooding and Emergency Department Visits: Effect Modification by the CDC/ATSDR Social Vulnerability Index) in June 2022. The project was completed in September 2022.

Tackling Air Quality Challenges in the Great Lakes

Along the shoreline of Lake Michigan, poor air quality days are often associated with the formation of a lake breeze bringing emissions from upwind urban areas of Chicago and Milwaukee. However, simulating the scale of these dynamics influencing air pollution is a challenge. A project led by Jason Otkin from the University of Wisconsin-Madison has been supporting the Lake Michigan Air Directors Consortium (LADCO) and Wisconsin Department of Natural Resources (WDNR) through development, verification, and delivery of a satellite-constrained meteorological modeling platform based on the WRF model, plus some additional tools, to conduct air quality assessment modeling for ozone in the Lake Michigan region. **In April 2022, this project achieved ARL 8 as LADCO has now implemented its updated Earth observation constrained air quality regulatory modeling platform.** These transferred capabilities include NASA SPoRT LIS soil moisture and satellite derived sea surface temperature data to improve the meteorology of LADCO's air quality simulations. The simulations using this observation-optimized platform are supporting ozone and regional haze state implementation plans for the six LADCO member states (MN, WI, IL, IN, MI, OH). The successes of this project were highlighted through web featues on nasa.gov and NASA Earth Observatory in July 2022. It is anticipated that the results of this project will also have utility in other parts of the country with complex meteorology related to air quality issues.

Cloud and lightning impacts on ozone simulations

To improve the accuracy of the Decision Support Tools (DSTs) used by health and air quality managers to meet the health effect standards set by the Clean Air Act, Arastoo Pour Biazar, from the University of Alabama in Huntsville, led a team to incorporate NASA/NOAA satellite observations in WRF-CMAQ (Weather Research and Forecasting-Community Multiscale Air Quality Modeling System), a common and key DST for ozone State Implementation Plans (SIPs). Stakeholders (EPA, LADCO, CARB, TCEQ, GAEPD) will use the improved DST to develop and evaluate emissions control strategies under the SIPs for attainment of the National Ambient Air Quality Standards (NAAQS). **In 2022, this project concluded at ARL 7 by improving cloud simulations and lightning emissions with satellite data in WRF-CMAQ.** These improved tools now estimate lightning nitrogen oxide emissions and its impact on ozone, which have direct implications on air quality and climate. Tools and training have been shared with partner agencies to support future air quality demonstrations required by the Clean Air Act.

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 January 2022, this project reached an ARL 9 as these datasets have been integrated into Climate Action Plans in Accra, Addis Ababa, Buenos Aires, Guadalajara, Lima, and Johannesburg.** Led by this team, on January 5, 2022, *The Lancet Planetary Health* published two articles on childhood asthma and urban health burdens. These companion papers highlight long-term trends in NO_2 and PM2.5 pollution and attributed them to pediatric asthma and broader disease burdens, respectively, from 2000-2019 in over 13,000 cities globally. In August 2022, the Health Effects Institute published the first State of Global Air – Cities report based on this team's datasets estimates in 13,000 cities.

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 June 2022, the project advanced to ARL 8, after the successful integration of the ArboMAP system into the operational activities of the Louisiana state health department.** Additionally, the team is testing ArboMAP with data from Oklahoma and Michigan in partnership with the Southern Nazarene University and Michigan Department of Health and Human Services, respectively. ArboMAP results were highlighted in *Environmental Health Perspectives* (Integrated Forecasts Based on Public Health Surveillance and Meteorological Data Predict West Nile Virus in a High-Risk Region of North America) in August 2022. The project was completed in December 2022.

IV. Health and Air Quality Applied Sciences Team

The third generation of the NASA Health and Air Quality Applied Sciences Team (HAQAST) continues 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 HAQAST initiative has continued to advance high-impact applied research, collaborate as a group, and engage with external health and air quality partners. In 2022, HAQAST continued the first round of Tiger Teams, advanced the first-ever round of Rapid Response projects, and launched the review process for a strong set of second-round Tiger Team proposals to begin in Spring 2023. Ongoing Tiger Team and Rapid Response projects are discussed in sections IV.A and IV.B, below.

In 2022, HAQAST launched the HAQAST Ambassadors program, to strengthen and showcase connections between NASA and the user community. This effort creates a stakeholder venue for feedback, discussion, and regular communication for deeper, more sustained involvement with HAQAST activities. There are currently 16 ambassadors, representing federal, state, non-profit, and private-sector health and air quality organizations (Figure 1).

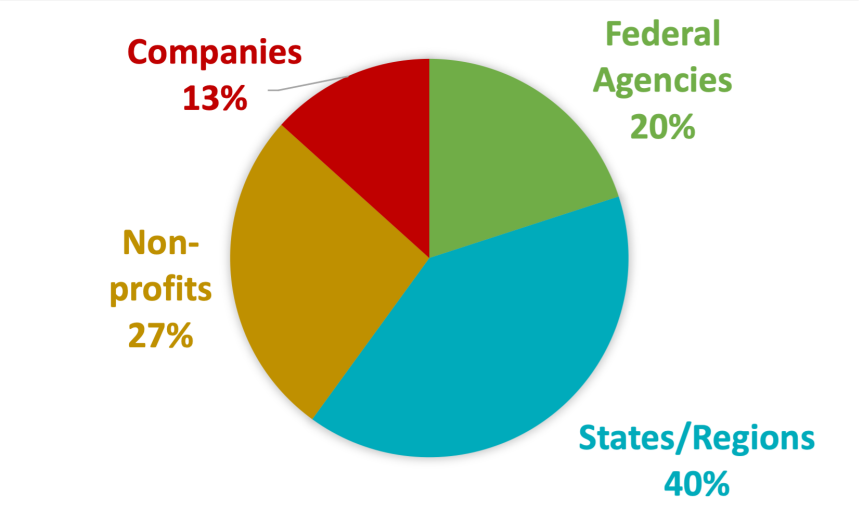

Fig. 1: HAQAST Ambassador organization affiliation.

HAQAST outreach activities continued to reach a wide audience through regular e-newsletters (sent to a mailing list of over 1,200 subscribers), Twitter (@NASA_HAQAST currently has more than 4,800 followers), and LinkedIn. Over the past year, HAQAST's applied research investigators have been interviewed or quoted in many outlets, including NBC News, Axios, *Forbes*, *Chicago Sun Times*, Pew, *The Hill*, Nature News, *Scientific American*, and Healthline. The work of HAQAST investigators has also

appeared in policy-relevant outlets such as the Health Effect Institute's *"Air Quality and Health in Cities: A State of the Global Air Report"*, and the *Lancet Countdown Report and U.S. Brief*.

The HAQAST website continues to be a valuable resource for relevant NASA data and tools. The website logged 13,340 users in 2022, an increase of 29 percent over 2021. The most popular pages were the ones relating to HAQAST meetings (~12,600 page views), Tiger Teams (~2,000 page views), NASA tools (~1,700 page views), and the principal investigators' (PIs) biographies (~1,400 page views).

HAQAST has continued to build on its reputation of hosting meetings that are friendly, intellectually fulfilling, and publicly useful venues for disseminating the latest and greatest applied air quality and environmental health research, as well as providing 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, along with lessons-learned about on-line and hybrid meetings during the pandemic.

In January 2022, HAQAST held an online meeting, HAQAST Update22. This two-day meeting leveraged parallel panels to meet audience interests, with 12 sessions featuring HAQAST PIs and stakeholders. HAQAST Update22 attracted 373 registrants, with 301 unique attendees during the meeting, and ~100 views of the recording made available after the meeting (Figure 2).

In June 2022, HAQAST returned to a hybrid format, meeting in Houston, Texas, with HAQAST PI host Qian Xiao. This two-day meeting built on the success of Update22, and also leveraged two crossover panels with the concurrent TEMPO Early Adopters Meeting. This meeting attracted more than the 261 registrants, with 55 people attending in-person and 240 online, and an additional 186 views of the recordings. This meeting also featured the launch of our HAQAST Ambassadors program with an informal breakfast panel, in which attending Ambassadors shared their enthusiasm for NASA applied science efforts and their motivation for engaging in HAQAST.

In October 2022, HAQAST Wisconsin built on the popular parallel-session format of other 2022 HAQAST meetings, offering multiple breakout rooms and ample opportunity for discussion to build collaborations and engagement. Held at the Pyle Center on the campus of the University of Wisconsin-Madison, with host HAQAST Team Lead Tracey Holloway, this meeting had 350 registrants, with approximately 95 in-person and 182 online, and an additional 158 views of the recordings by the end of 2022. This meeting leveraged a crossover panel with the National Association of Clean Air Agencies. Due

to the extremely positive reception to the HAQAST Wisconsin logo, designed by student Alex Pavelic, this design will serve as the basis for future HAQAST meetings.

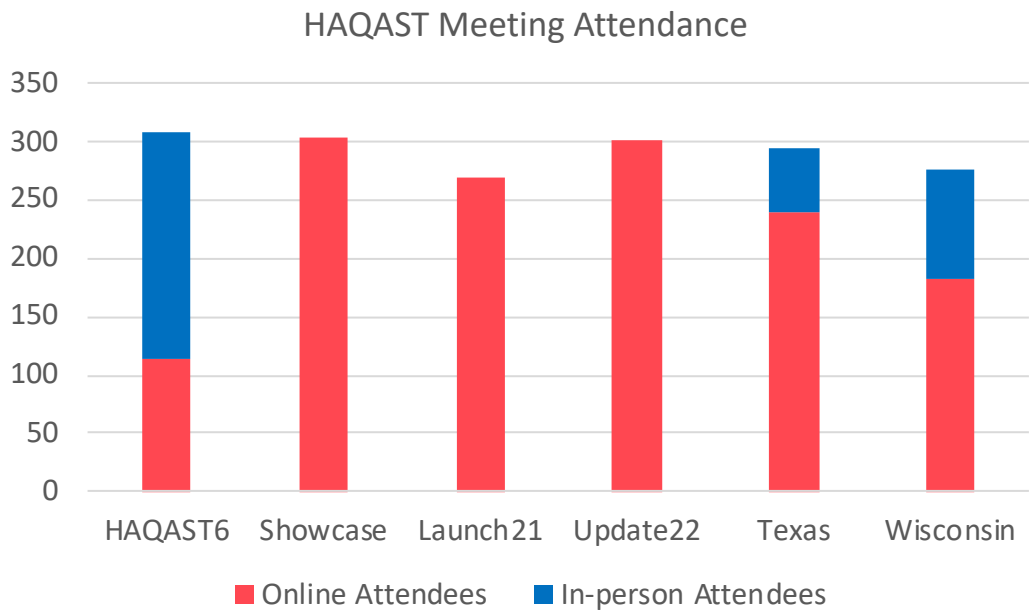

Fig. 2: Total HAQAST estimated meeting attendance [both remote (red) and in-person (blue)], of the last six meetings (HAQAST6 in 2019, and Showcase 2020 from the last generation of HAQAST), with Launch21 from 2021 and the last three meetings in 2022.

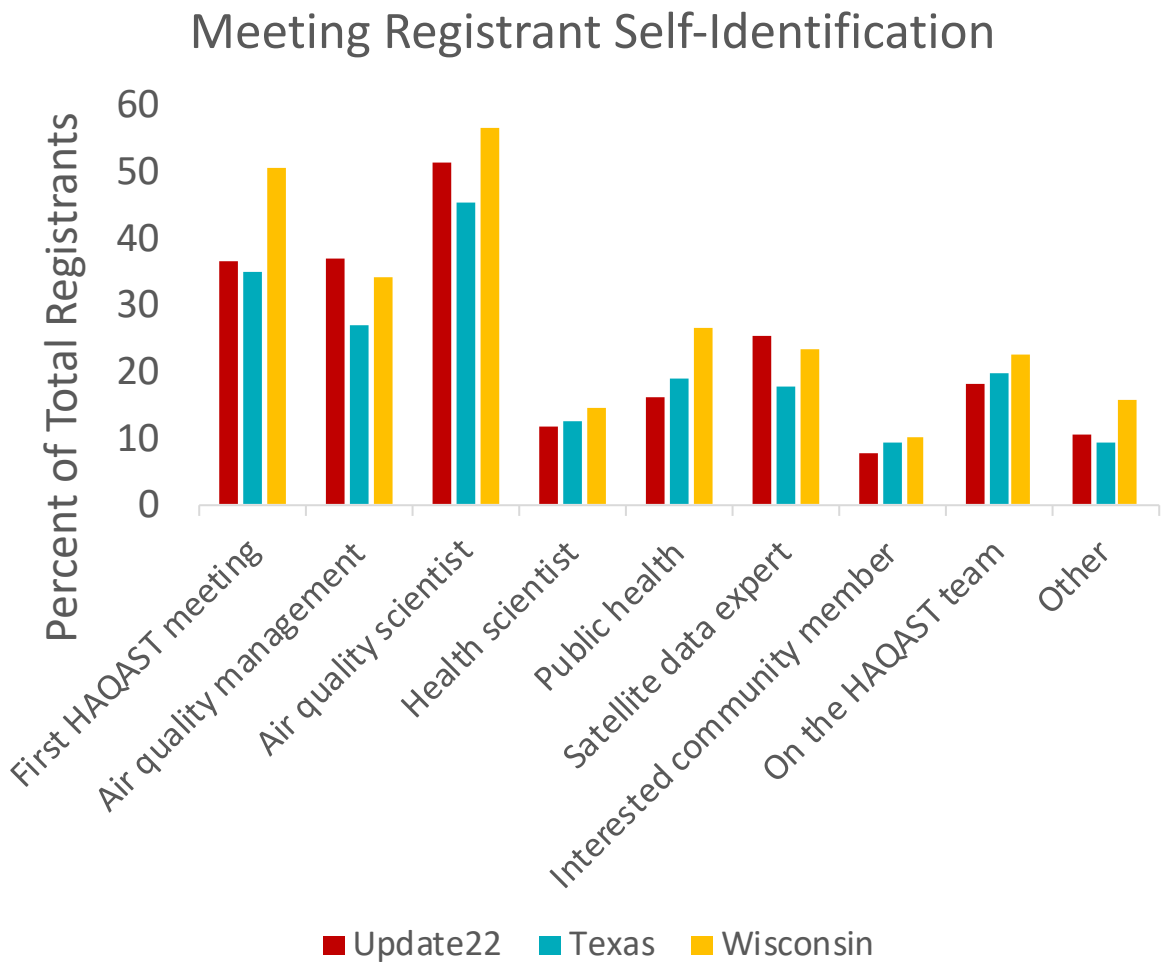

Fig. 3: Meeting registrant self-identification for the HAQAST 2022 meetings. Registrants can select multiple categories.

There was an increase in first-time HAQAST meeting attendees during HAQAST Wisconsin, as well as growing increases in health scientists/public health affiliates based on meeting registration information during the 2022 meetings (Figure 2). All public presentations from HAQAST conferences can be found at the Past Meetings tab of the HAQAST website. A video introducing the HAQAST team can also be found on the website.

HAQAST members' applied research culminated in the publication of 30 peer-reviewed articles in 2022, with more in queue as the research publication cycle catches up with the backlog of submitted manuscripts.

IV.A 2021-2023 HAQAST 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 met regularly with stakeholders to develop deliverables, with the teams planning to conclude in early 2023.

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 is enhancing the ability for stakeholders to map metrics supporting environmental health and equity, including supporting community engagement and policy initiatives. This team developed a webpage to share their work and resources.

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 is delivering 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. This team has developed a prototype.

3. Communicating the Uncertainties of Satellite-based NOx Emissions for Urban Planning, led by Dan Goldberg (George Washington University)
    - This project is quantifing uncertainties using sensitivity analyses and engaging stakeholders to help researchers prioritize aspects of estimating NOx emissions that are most impactful for decision-making. This team developed a step-by-step video tutorial for using TROPOMI NO2 data.

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 the U.S. EPA to develop a value added hourly and daily $PM_{2.5}$ dataset covering the continental U.S. and integrating it into the AirNow system. This team published updates in the Air and Waste Management Association's EM *Plus Quarterly* publication.

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 serves as a best practice for conducting exposure assessment using a fusion approach for other agricultural burning practices across the U.S. This team presented preliminary results at HAQAST meetings and the American Geophysical Union fall meeting.

IV.B 2022-2023 HAQAST Rapid Response Projects

The Rapid Response projects were a new initiative launched this year, designed to target health and air quality that require urgent attention, with a shorter term focus than a Tiger Team. The current Rapid Response Teams include:

1. Collaborating with the New Mexico Department of Health to Respond to Wildfires and Extreme Heat, led by Chris Uejio (Florida State University)
    - Amidst the largest two wildfires in New Mexico's history, this team is collaborating with the New Mexico Department of Heath to improve accessibility of air quality measures and to understand adverse health effects of heat and PM2.5 exposure.

2. Distribution and Pollution: Investigating the Influence of Warehouse-related Transportation Activities on NO2 and PM2.5 Using Satellites, Models, and Monitors, led by Susan Anenberg (George Washington University), Yang Liu (Emory University), and Ted Russell (Georgia Tech)
    - With a rise in the construction and prevalence of warehouses near metropolitan areas, this team seeks to explore approaches for tracking air pollution from warehouse-related transportation activities. They are collaborating with the Environmental Defense Fund, the International Council on Clean Transportation, the Lake Michigan Air Directors Consortium (LADCO), and the South Coast Air Quality Management District (SCAQMD) to complete an analysis, simulation, and sensor to satellite comparison.

3. HAQAST Ambassador Stakeholder Engagement Rapid Response, led by Tracey Holloway and Jenny Bratburd (University of Wisconsin)
    - This team seeks to support the newly developed HAQAST Ambassadors program. A major focus is the creation of an online user forum to provide

expert advice to users of all levels of expertise. This will serve as a resource for stakeholder questions, and a portal for increasing use of satellite data.

4. Incorporating Remote Sensing Derived Estimates of Wildland Fires into the American Thoracic Society "Health of the Air" Annual Report, led by Kevin Cromar (New York University) and Daniel Tong (George Mason University)
   - This team analyzes wildfire health impacts to be included in the American Thoracic Society (ATS) annual report and promotes county level communication related to air quality. The ATS report is widely used by air quality managers and policymakers to understand the health impacts of air pollution.

5. Responding to the Need of Smoke Forecasts in Alaska: A Data Fusion Approach with Advanced Deep Learning Algorithms, led by Jingqiu Mao (University of Alaska-Fairbanks), Pawan Gupta (NASA GSFC), and Steve Moran (BreezoMeter, Inc.)
   - In response to air pollution from massive wildfires in Alaska in 2022, this team is mobilizing to integrate machine learning with low-cost ground sensors, satellite data, and air quality models. This air quality data will be shared through different platforms including mobile apps to provide access to the general public.

V. Assessment

Challenges and opportunities presented themselves in 2022, as the world endured a third year of the COVID-19 pandemic. However, as severe cases and deaths began to wane, NASA personnel returned to the office part-time and meetings began to assume a hybrid format. The HAQ team continued an expansion of interactions with global stakeholders through a variety of platforms; challenges included the balance of work and life pressures, as the number of emails, meetings, and tasks were overwhelming at times. Overall, the HAQ team performed superbly throughout the year, while managing costing and schedule impacts to many projects in the portfolio.

The HAQ portfolio exceeded technical performance expectations in 2022, with several projects reaching top-tier ARLs of 7 to 9.

The portfolio made significant progress on reducing the balance of uncosted funds in 2022. 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, by the end of 2022, only two percent of FY20 funds remained uncosted, and

24 percent of FY21 funds remained uncosted. Both of these figures are considered a low burden of uncosted funds. Additionally, a few 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 2022 due to the pandemic, significant results were accomplished in all areas. Schedule and costing issues will continue to be monitored and mitigated in 2023.

VI. Project Portfolio

At the end of 2022, the HAQ portfolio included 17 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, four projects had an ARL of 1-3; seven projects had ARLs of 4-6; and six projects had achieved an ARL of 7-9. A total of 41 percent of active projects increased at least one ARL from December 2021 to December 2022. Four additional ROSES 2017 projects completed prior to December 2022, with three achieving an ARL 7 and one achieving ARL 9.

VII. Program Management

The 2022 NASA HAQ Annual Team Meeting was held virtually on September 19 and 22, 2022. 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 of the Center for Disease Control's (CDC's) Environmental Health Tracking Section provided the keynote partner address. Additionally, Aries Keck (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 and beyond.

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. Ten awards from this solicitation were announced in March 2022. Selections and project abstracts can be located here. .

John Haynes serves as program manager for HAQ at NASA Headquarters. 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 six major conferences in 2022. Below is a brief synopsis of their contributions.

At the **102nd AMS Annual Meeting in January (virtual),** the HAQ team organized two sessions titled, *Advancing Awareness of Environmental Threats to Human Health through the Integration of NASA Earth Observations*, with 10 scientific talks and more than 50 attendees. Notably, one session was selected as the Presidential Session on Health Security. John Haynes participated on the panel titled, *Exploring the Evolution of Frameworks in Climate Risk Tools and Applications*, and Laura Judd served on the panel entitled, *Clouds, Aerosol, and Air Quality in the Coastal Urban Environment: Interagency Field Campaigns in the Houston, Texas, Region during 2021–22*. The HAQ program also presented the poster entitled, *Promoting One Health Networks to Examine Ecosystem Risks to Human Health*.

At the **AMCA Annual Conference in March (Jacksonville, FL)**, Helena Chapman led a symposium titled, *Enhancing US and Global Mosquito Surveillance with NASA Satellite Data*, with over 50 attendees. John Haynes and NASA-funded researchers highlighted projects that use satellite data to forecast risk of WNV in the United States and malaria in Peru and Myanmar as well as enhance a global health management information system to support malaria control in low- and middle-income countries. Helena also presented the talk titled, *Incorporating NASA Satellite Data in Vector Control and Public Health Activities*, in the Disease and Vector Studies session.

At the **ATS International Conference in May (San Francisco, CA)**, the HAQ team convened a session titled, *Integrating NASA Satellite Data in Cross-cutting Applications in Respiratory Health*. This session highlighted the NASA HAQ program, HAQAST team, and two NASA projects on using satellite data to examine respiratory health risks from transportation-related air pollution and Saharan dust plumes. The HAQ program also supported the *Meet the Expert: Mapping Health and Exposure: GIS to Impress* session.

For the **A&WMA 115th Annual Conference and Exhibition in June (San Francisco, CA)**, the HAQ team organized a session titled, *Satellite Perspectives on Environmental*

Justice. Attended by approximately 40 participants, this session included five panelists who described examples of integrating satellite and ground-based data for use in stakeholders' decision-making activities related to quantifying environmental inequalities associated with artificial lights at night and air pollution, such as the HAQAST Tiger Team on Environmental Justice and EPA EJScreen. Laura Judd also presented on how column formaldehyde data can inform on ozone air quality using examples from field campaigns, which is being explored as a pathway for decision support applications related to ozone monitoring.

APHA Annual Meeting & Expo in November (Boston, MA): The HAQ team convened the *How Satellite Data Support Public Health Data Science* symposium, as part of the Applied Public Health Statistics section. Attended by an estimated 35 attendees, this session included five panelists who described the integration of satellite Earth observations into public health tools related to particulates, enteric diseases, malaria, and cholera. Also, Helena Chapman presented the talk titled, *The Power of NASA Data and Visualizations*, as part of the Public Health Education and Health Promotion section, with over 50 attendees.

As always, the HAQ team had a large presence at the **American Geophysical Union (AGU) Fall Meeting in December (Chicago, IL)** which included an organized session titled, *Decision Support Applications for Public Health Surveillance*. The session had 60 attendees engaged in seven scientific talks and 11 posters. The HAQ program presented the poster titled, *Innovative Earth Science Applications to Support Public Health Surveillance*. Helena Chapman also co-organized two GeoHealth sessions. Additionally, John Haynes presented the NASA Hyperwall talk titled, *Accelerating Air Quality Solutions through Earth Observations*, at the NASA exhibit booth.

Invited Presentations

In the hybrid world of 2022, invited presentations were frequent contributions among the HAQ team. Below is a description of the top 20 meetings where the HAQ team was invited to present in chronological order:

In January 2022, Laura Judd served as a panelist for the *The Air You Breathe* webinar, supported by the **AMS**, which highlighted Houston air quality and NASA-led TRACER-AQ activities.

In February 2022, Helena Chapman presented the talk titled, *GEO Health Community of Practice: Using Earth Observation Data to Inform Health Decision-making*, as a virtual panelist for the *One Health Meets Social Sciences w*ebinar, as part of the **One Health Commission's Social Sciences Initiative**.

In May 2022, John Haynes presented an invited talk titled, *Monitoring Environmental Risks Using Earth Observations*, to 45 attendees of the **Dust Alliance of North America (DANA) Webinar**. Laura Judd participated on the *Roundtable Discussion on the Future of Satellite Remote Sensing of Air Quality in Health Applications*, as part of the **Health Applications for Satellite-Derived Air Quality: Opportunities and Potential Pitfalls workshops**, organized by the Health Effects Institute. Also, Helena Chapman gave the keynote talk titled, *Bridging Scientific Communities to Enhance Public Health Surveillance and Promote One Health Collaborations*, for the **University of Guelph's One Health and Development Symposium**.

In July, Helena Chapman presented an overview of the HAQ program and selected projects to 10 interns of the **NASA ESD's High School Senior Experience**. Additionally, Helena Chapman presented the talk titled, *Publishing the Sciences,* to approximately 30 interns of the **NASA ESD's Seminar Series** – targeted to undergraduate and graduate students in the Summer Internship Experience. John Haynes was a panelist on the *Climate-driven Zoonotic Risk Workshop* session, hosted in Washington, DC, by **Sandia National Laboratories.**

In September 2022, John Haynes and Helena Chapman gave a lecture to 10 students about *Spatialization and Dynamics of Vector-borne Diseases: Advances in Remote Sensing*, as part of the *Interdisciplinary Seminars in Global Infectious Diseases* course at **Georgetown University**. Also, John Haynes presented the talk titled, *Utilizing Earth Observations to Inform Health and Air Quality Management Decisions*, and Helena Chapman gave the talk titled, *Using Earth Observations to Enhance Public Health Surveillance*, to 20 physicians of the **Uniformed Services University of Health Sciences' Journal Club of Occupational and Environmental Medicine and Preventive Medicine residency programs**. Additionally, Helena Chapman was an invited panelist for the **NASA-AMCA webinar** titled, *Satellite Data Applications and Advancements in Vector Control Initiatives*, in Spanish, with over 60 attendees from six countries.

In November 2022, Laura Judd presented an overview of the HAQ program for the 2022 **ICESat-2 Atmospheric Applications Focus Session**. Also, Helena Chapman presented the talk titled, *NASA Health and Air Quality Applications,* during the **US Food and Drug Administration (FDA)'s Center for Veterinary Medicine One Health Day Virtual conference**, along with panelists from the National Park Service, National Wildlife Foundation, National Institutes of Health, and World Bank. Additionally, Helena Chapman served as a panel (in Spanish) on the *Geography and Health: The Power of GIS in Landscape Analysis* webinar, as part of the Esri Chile's World GIS Day activities.

In December 2022, Helena Chapman shared congratulatory words (in Spanish) to 100 girls graduating from the **NASA/Houston program's NASA Ella es Astronauta program** in Colombia.

Throughout the year, the HAQ program had six invited webinars in the educational sector. John Haynes, Helena Chapman, and Laura Judd introduced the HAQ program to:

- University of Alabama in Huntsville's Department of Atmospheric and Earth Science
- Morehouse School of Medicine
- Princeton University's Freshman Seminars
- Illinois High School
- Texas Southern University's Leadership, Education, and Advancements in Undergraduate Research Pathways (TU-LEAP) STEM Grand Rounds
- Universidad Catolica del Cibao's School of Health Sciences (Dominican Republic)

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.

From January to October 2022, the NASA Applied Sciences Program supported seven seminars of the **AOS Applications**, which highlighted how NASA AOS aerosol products may be leveraged to inform decision-making activities in air quality, health, and disaster applications. The **AOS Community Assessment Report (CAR)** was published in April 2022. This living document provides an overview of key stakeholder communities and their needs relevant to AOS in terms of their current use and potential application of data products for decision making. AOS looks forward to entering phase A in January 2023.

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 in Huntsville) co-hosted the *Air Quality Monitoring with New-Generation Satellites* session at AMS and presented on air quality management applications using TEMPO data at the A&WMA's Measurements Conference. He also organized two Early Adopters workshops in 2022. In June 2022, the TEMPO Science

team hosted a three-day virtual science team meeting meeting, with over 290 participants, focused on the TEMPO mission status, product development updates, validation planning, intensive field campaigns set for summer 2023, and joint sessions with NASA HAQAST and stakeholders on air quality, health, and environmental justice applications of TEMPO.

In October 2022, a TEMPO mission overview was provided as part of the recent **ARSET** training on Accessing and Analyzing Air Quality Data from Geostationary Satellites, with over 700 participants. In November 2022, the TEMPO Mission and Early Adopters Program were represented at the Stakeholder Summit hosted by the NASA Short-term Prediction Research and Transition (SPoRT) Center. A TEMPO Mission overview was presented at the event, followed by a TEMPO air quality breakout session with approximately 25 participants including representatives from local and state air quality agencies. TEMPO was also represented at the NASA Volcanic Ash Advisory Center (VAAC) Workshop in November, where VAACs discussed the critical role that TEMPO trace gas and aerosol products could play in monitoring volcanic eruptions.

From January to June 2022, Abbey Nastan (Jet Propulsion Laboratory) and Aaron Naeger, the deputy program application leads for MAIA and TEMPO, led the NASA Airathon crowdsourcing competition, in collaboration with the U.S. Department of State, U.S. Environmental Protection Agency, and crowdsourcing platforms DrivenData and HeroX. More than 1,000 participants used remote sensing data and other geospatial data sources to develop models for estimating daily levels of PM2.5 and NO2 across three urban areas (Los Angeles, CA; Delhi, India; Taipei, Taiwan).

In May 2022, the NASA Applied Sciences Program supported the Air Quality and Applied Atmospheric Sciences Focus Sessions of the **NASA PACE Applications**. This event focused on future uses of PACE satellite data products to support research and applied sciences in the context of air quality and atmospheric sciences. John Haynes served as a panelist and provided an overview of the HAQ program. In September 2022, the 2022 PACE Applications Workshop was held, focusing on future uses of PACE satellite data products and applications to benefit society and support decision-making in the context of water resources, air quality and health, climate, disasters, and ecological forecasting. Abbey Nastan and Aaron Naeger participated in the session panel on mission synergies, which sparked a productive discussion of cross-mission needs.

In May 2022, Abbey Nastan (Jet Propulsion Laboratory) presented an overview on MAIA at the **European Geosciences Union (EGU) General Assembly** in Vienna,

Austria. In June 2022, she highlighted MAIA and plans for Targets of Opportunity at the NASA Volcanic Ash Advisory Center (VAAC) workshop as well as MAIA's targets in Asia at the ISEE-AWPC/ISES-AC joint conference. She also described these MAIA updates at the Western States Air Resources Council in August 2022, and at the HAQAST Wisconsin meeting in October 2022.

In August 2022, the MAIA and TEMPO Applications Programs hosted a joint **MAIA-TEMPO Environmental Justice Workshop**. More than 190 participants attended the workshop, including representatives from 20 EJ advocacy organizations, epidemiologists, environmental health researchers, and air quality managers. Presenters described NASA's HAQ program, current initiatives in equity and EJ, updates on MAIA and TEMPO projects, and MAIA and TEMPO data products and capabilities in the EJ context. The event featured a panel session where CleanAIRE NC, Ute Mountain Ute Tribe, and California Communities Against Toxics described their organization's EJ activities and use of air quality data.

Honors and Recognition

Helena Chapman received the **Bronze President's Volunteer Service Award** in May 2022, for her community service at the Smithsonian Museum of Natural History and Smithsonian Associates. Helena Chapman also received the **Quintiliano Jáquez of Leadership Commitment Award** (Premio Quintiliano Jáquez al Liderazgo Comprometido) in October 2022, as part of the X Conference on Citizen Leadership Commitment, issued by the Iberoamerican University, in Santo Domingo, Dominican Republic (*Listín Diario* newspaper). This award recognized her commitment to leading community health and medical education activities within the Dominican Republic.

Media Highlights

As in past years, the HAQ team continues 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 (NASA Applied Sciences web feature)
- Air Quality Awareness Week (Twitter)
- National Mosquito Control Awareness Week in June (NASA Earth Facebook and NASA Earth Twitter)
- International Day of Clean Air for blue skies in September (NASA Earth Facebook, NASA Earth Twitter1, NASA Earth Twitter2 and NASA Atmosphere Twitter
- One Health Day in November (One Health Day event page)

- HAQ Handouts (Updated informational handouts on NASA Resources and One Health)

Helena Chapman and Laura Judd authored the article titled, Adding Satellite Data to Health Curricula, which was published in the *Clinical Teacher* in January 2022. Laura Judd also co-authored the article titled, *A Succession of Cloud, Precipitation, Aerosol, and Air Quality Field Experiments in the Coastal Urban Environment*, which was published in the *Bulletin of the American Meteorological Society* in February 2022. Helena Chapman also co-authored the article titled, Integrating One Health Topics to Enhance Health Workers' Leadership in Health Promotion Activities, which was published in *Global Health Promotion* in October 2022.

Other Highlights

During **NASA Earth Science Applications Week 2022**, John Haynes provided an overview of HAQ activities and achievements. Ben Zaitchik (Johns Hopkins University) shared updates on his research to inform understanding, monitoring and prediction of gastrointestional disease burden estimates and distribution of health resources across three continents. Pawan Gupta (University of Alabama in Huntsville) provided an overview on recent ARSET HAQ trainings, and Aaron Naeger (University of Alabama in Huntsville) described the TEMPO mission and relevant updates leading to the launch. Jenny Bratburd (University of Wisconsin-Madison) gave an update on HAQAST and the upcoming NASA HAQAST Wisconsin meeting.

Throughout 2022, the program continued its active participation in the **U.S. Global Change Research Program (USGCRP) Climate Change and Human Health Working Group (CCHHG)**, **CDC's One Health Federal Interagency COVID-19 Coordination Group, and the Interagency Council for Advancing Meteorological Services Committee of Services and its sub-committee on Atmospheric Composition**.

IX. International Activities

In 2022, 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 August 2022, more than 1,100 participants (including 100 in-person) attended hybrid sessions of the AmeriGEO Week 2022 online and in Asuncion, Paraguay. Using the theme, *Human Migration in Focus: Earth Observations for Resilience and Equitable Development*, the symposium aimed to identify synergies and priorities using Earth observation data that can strengthen regional collaborations across AmeriGEO's five thematic priorities. The "Bridging Earth and Health Science Communities in Environmental Health: Focus on Vector-borne Diseases, Extreme Heat, and Air Quality" session – facilitated by John Haynes, Juli Trtanj (NOAA), and Helena Chapman – focused on emerging global health challenges of malaria control, wildfires, urban heat, and climate change as leading priorities for the upcoming decade. The team supported a session of eight poster presentations. Notably, this event was the first in-person public engagement of the AmeriGEO Health thematic community. As an AmeriGEO side event, Helena Chapman and Ricardo Quiroga (NASA) provided formal presentations (in Spanish) on using Earth observations for disaster preparedness and public health applications to more than 100 students and faculty at the Universidad del Pacífico (UP) and the Universidad de la Integración de las Américas (UNIDA) in Asuncion, Paraguay.

In November 2022, GEO Week 2022 was held online and in Accra, Ghana, and aimed to highlight initiatives from GEO members, participating organizations, and associates in a series of live discussions and interactive content related to the *Global Action for Local Impact* theme. The EO4Health team co-convened the *Earth Observation and Health: Early Warning Systems and Beyond!* side event, in collaboration with the European Commission and GEO DRR-WG. The event highlighted how Earth observations can offer valuable insight for health decision-making, including the GEO Work Programme 2023-2025 and the Road to GEO Post 2025. Also, GEO Health CoP members participated as panelists in two AfriGEO Symposium sessions on cholera forecasting (Antar Jutla, University of Florida) and air quality forecasting (Katherine Emma Knowland, NASA GSFC/Morgan State University).

In December, the GEO Work Programme 2023-2025: Summary Document was released, which provided notable items and updates to the GEO Work Programme activities, with information on the EO4Health work plan on pages 26-28. This summary document supports the EO4Health Implementation Plan for 2023-2025 with details about the EO4Health activities and projects.

GEO Health and Environment Community of Practice (CoP)

Under the leadership of chair John Haynes, the GEO Health 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 2022, the GEO Health CoP held biweekly teleconferences to provide program and project updates, to share knowledge on emerging environmental risks, 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, as part of the GEO Work Programme 2023-2025. A synthesis of monthly themes is shared below:

- **January 2022**: Ann Stapleton (USDA National Institute of Food and Agriculture) described an AI-related potential pilot project around meta-data using knowledge graphs, and Kathryn Berger (Development Seed) shared previous Agrimetrics work producing models to solve global agri-food challenges.
- **February 2022**: Nale Mudau (South African National Space Agency) and Phoebe Oduor (Regional Centre for Mapping of Resources for Development) shared current activities and priorities of the AfriGEO region. Anna Stewart-Ibarra (Inter-American Institute for Global Change Research) moderated the discussion to identify synergies for AfriGEO collaborations.
- **February-March 2022:** The CoP Small Work Groups leads – Heat (Ben Zaitchik, Johns Hopkins University; Cascade Tuholske, Columbia University's Earth Institute); Infectious Diseases (Antar Jutla, University of Florida); Food Security and Safety (Dorian Janney, NASA GSFC); and Health Care Infrastructure (John Balbus, NIEHS; Andreas Skouloudis, iSteep.org) – highlighted upcoming priorities and workstream activities.
- **March-April 2022**: The EO4Health, GEO Health CoP, and AfriGEO coordinated the two-day Special Edition: AfriGEO Webinar to showcase ongoing Earth science applications addressing emerging health challenges across Africa. With over 110 attendees, 18 flash talks highlighted air quality and heat topics (Day 1) and vector-borne diseases, water-related pathogens, and environmental health concerns (Day 2). Panelists represented institutions in Kenya, Netherlands, Puerto Rico, Spain, Uganda, United Kingdom, USA, and Zimbabwe.
- **April 2022**: Chandana Unnithan (UN COPUOS STSC Space and Global Health Work Group) described a technology intervention that addressed the opioid crisis during the COVID-19 pandemic.
- **May 2022**: Krzysztof Knop (Wrocław University, Poland) discussed his work on modeling the spread of avian influenza using geolocation data and machine learning techniques.
- **June 2022**: Alex Schmid (LocationHealth, Switzerland) highlighted LocationHealth, a GeoHealth startup that delivers spatial health information for real estate and travel. Kamal Ramsingh (ZA SPACE, South Africa) shared ongoing public-private partnerships to stimulate the development of small, medium, and micro-sized enterprises in the EO and Space Tech. Juli Trtanj

(NOAA) and the Heat Small Work Group offered a debrief on the National Integrated Heat Health Information System (NIHHIS) National Meeting and shared ongoing activities of the Heat Small Work Group.

- **July 2022**: Michael Wimberly and Dawn Nekorchuk (University of Oklahoma) presented an update on the Arbovirus Mapping and Prediction (ArboMAP) to Forecast Mosquito-Borne Disease Outbreaks. Thilanka Munasinghe and Jon Harris (Rensselaer Polytechnic Institute) and Assaf Anyamba (NASA GSFC/USRA) described the second RPI-NASA Student Engagement collaboration (Predicting Crimean Congo Hemorrhagic Fever Outbreaks using Temporal Climate Data).
- **August 2022**: The EO4Health team moderated an open discussion about AmeriGEO Week 2022.
- **September 2022**: The *Special Edition: The Americas Webinar* offered 13 flash talks on environmental health, infectious diseases, and data integration applications in the Western hemisphere.
- **November 2022:** The EO4Health team moderated an open discussion about the AfriGEO Symposium, GEO Week 2022, and GEO efforts to explore heat-health topics. Thilanka Munasinghe and Ajeet Parmar (Rensselaer Polytechnic Institute) and Assaf Anyamba (ORNL) described the third RPI-NASA Student Engagement collaboration (2021 Monthly Rice Production in Chinese Coastal Provinces).

In July 2022, the Managing Health Risks with Earth Observations article was published on the GEO blog, highlighting the recent launch of the *Earth Observation, Public Health and One Health: Activities, Challenges and Opportunities* textbook. This textbook was edited by Stéphanie Brazeau and Nicholas Ogden (Public Health Agency of Canada, Canada), with contributions and support from Guy Aubé (Canadian Space Agency) and other international experts.

In December 2022, the GEO Health CoP held the CoP Annual Meeting 2022, which provided that provided an opportunity for 80 members to describe ongoing research applications using Earth observations to enhance health decision-making and priority focus areas that advance GEO Health CoP goals and Work Group activities. At AGU2022, the GEO Health CoP held two networking receptions, where 30 members connected in-person and shared ongoing work.

Throughout 2022, 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, formerly Columbia University's Earth Institute, currently Montana State University)

2. Infectious Diseases (Antar Jutla, University of Florida)
3. Air Quality, Wildfires, and Respiratory Health (Eric Klos, DailyBreath; Pawan Gupta, formerly NASA MSFC/USR, currently NASA GSFCA)
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 has continued to support the Earth Observing Dashboard, a tri-agency collaboration (2020-2024) among NASA, the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA). This web platform leveraged the expertise of the three partner agencies to better understand the impact of human activity on the changing Earth's air, land, and water ecosystems on seven themes (atmosphere, oceans, biomass, cryosphere, agriculture, COVID-19, economy).

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 2022, the following key accomplishments were noted for two 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 prototype phase of the modeling algorithm is available for almost all the countries of the world, and the request can be made by contacting the research team. 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 2022, the team conducted weekly assessments of cholera risk (four weeks in advance) in Yemen, Ethiopia, and Sudan, which have been integrated into health decision-making processes of project partners. Situational assessments were also conducted in Ukraine, Ghana, Pakistan, Bangladesh, Congo, and Ethiopia. The team released the Vibrio Prediction Hub, including a cholera risk map viewer, and the team will continue to work with project partners through their ROSES 2021 project, by developing capacity building activities to engage end-users for sustained use of the web-based application as well as confirming an anticipatory

decision-making framework for potential interventions. Project results were highlighted in *GeoHealth* (Predictive Intelligence for Cholera in Ukraine?) in September 2022. More information on this project can be found on the NASA Applied Sciences webpage. The project is scheduled for completion in May 2023.

- A project led by Jack Malone (Louisiana State University and A&M College) has used NASA satellite data (*e.g.*, ECOSTRESS and SMAP), geographic information systems, and ecological niche modeling to develop risk maps to illustrate visceral leishmaniasis and Aedes-borne arbovirus potential spread to guide control program interventions in the Americas. 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 2022, the team continued working with project partners to investigate the impact of temperature and potential evapotranspiration in disease transmission, and finalize the one-week course module content of 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). Project results were highlighted in *Geospatial Health* (Use of Soil Moisture Active Passive Satellite Data and WorldClim 2.0 Data to Predict the Potential Distribution of Visceral Leishmaniasis and its Vector Lutzomyia longipalpis in Sao Paulo and Bahia States, Brazil) in June 2022. More information on this project can be found on the NASA Applied Sciences webpage. The project is scheduled for completion in April 2023.

X. Looking Ahead

During 2023 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, as well as field and Earth Venture (EV) campaigns, including the Synergistic TEMPO Air Quality Science Study (STAQS) campaign in 2023. The program looks forward to final results in 2023 from the first round of HAQAST Tiger Teams and Rapid Response projects, with the launch of new Tiger Teams in Spring 2023.

In 2023, HAQ program personnel plan to participate in relevant sessions of the AMS Annual Meeting, the AMCA Annual Meeting, the ATS International Conference, 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 2023, a continued emphasis will be placed on outreach to minority serving institutions and underrepresented communities.

The program will enhance engagement with the private sector in 2023, particularly exploring activities with philanthropic foundations such as the Bill and Melinda Gates Foundation and the Rockefeller Foundation.

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, part of the Earth System Observatory, which is expected to enter phase A in January 2023, 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 (including simulated data files) for the upcoming TEMPO Earth Venture mission (launch expected in April 2023) and the MAIA Earth Venture mission (launch expected NET late 2024).

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

B. Contacts in the NASA Applied Sciences Program - HAQ Program Area

Program Manager:
John Haynes
jhaynes@nasa.gov

Associate Program Managers:
Helena Chapman
helena.chapman@nasa.gov

Laura Judd
laura.m.judd@nasa.gov