EARTH SCIENCE
APPLIED SCIENCES

2020 ANNUAL SUMMARY

HEALTH & AIR QUALITY

NASA Earth Science
Applied Sciences Program

Health & Air Quality: 2020 Annual Summary

Table of Contents

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 (SBAs) 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) Applications program 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 2020

Perseverance is a key word at NASA, in fact, it is the name of the newest rover to explore the surface of Mars. That word also exemplified the work of the HAQ team in 2020. As the COVID-19 pandemic exploded across the globe in early 2020, the HAQ team pivoted to mandatory telework and a suspension of all in-person meetings. Immediately, the team swung into action, supporting the agency's response to the pandemic through augmenting projects with COVID-19 related tasks, taking new opportunities for expanded videoconference meetings with stakeholders and end-users across the world, and leading interagency and international groups. Myriad challenges were faced, including slowdowns in project schedules and the reallocation of project budgets, the loss of human-to-human interactions and networking, and finding a new 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.

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

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 Applications program continued to support 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 2020, the program continued monthly HAQ newsletters that were circulated online and via mailing list. The program expanded a website focusing on the GEO Health Community of Practice and the GEO Earth Observations for Health (EO4HEALTH) Initiative and showcased results across NASA web platforms. The applications program distributed applied research results and representatives led or participated in meetings across the health/air quality and Earth-science communities, at both the national and international levels.

The following report summarizes the challenges and many achievements that occurred during 2020. The HAQ Applications program looks forward to upcoming activities and milestones, including future solicitations, continued support for airborne field campaigns, as well as the support of, and applications planning for, relevant satellite missions.

III. Major Accomplishments

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 serve as a natural fertilizer for plants, but these large dust plumes can adversely impact air quality and human health. Pablo Méndez-Lázaro (U. of Puerto Rico Medical Sciences Campus) is leading a team to develop a forecasting tool for dust transport in the Caribbean that incorporates information from satellite-based Earth observations. In June 2020, the team used this prototype tool to issue three days of advance public notice of one of the most extreme Saharan dust events on record. This work was highlighted in more than 70 news reports and articles in English and Spanish (CBS News, National Geographic, *New York Times*, Noticias Telemundo, Univision New York). These results were showcased in a NASA Earth Observatory feature in June 2020 (A Dust Plume to Remember) and NASA web features in July 2020 (NASA Helps Puerto Rico Prepare for Saharan Dust Impacts and La NASA Ayudó a Puerto Rico a Prepararse para los Impactos del Polvo Sahariano) and November 2020 (Pablo Méndez-Lázaro: Braving the Storms for Puerto Ricans' Health). 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 19 public, private, and academic institutions in the Caribbean basin. This team has developed three working groups – Resilience, Public Health, and Well Being; Atmospheric Forcing and Air Quality; and Decision Support Tool: Computation and Visualization – to help characterize the distribution pattern and variability of African Dust in annual events and quantify the impact on respiratory diseases using Earth observation and public health data.

Dust Storms in the Southwest United States

- The occurrence of dust storms in the Southwestern USA 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 U.) and his team have used MODIS (aerosol optical depth, NDVI, Black-sky albedo observations) 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 USA. The team collaborates with an array of local, regional, and national end-users and partners in transportation, health, and air quality agencies. In November 2020, the project jumped to ARL 8 when the National Weather Service National Air Quality Forecast Capability (NAQFC) system evaluated and approved the dust and NOx emission data for operational forecasts by the National Weather Service (NWS). These new forecasts demonstrated remarkably better performance, when compared to the previous version without this emission update. When Tong attended the World Meteorological Organization (WMO)'s Sand & Dust Storm-Warning Advisory System annual meeting, he was invited to lead an effort to develop a global dust database for long-term trend analysis to monitor desertification based on datasets developed in his NASA-funded projects. The WMO also nominated him to a panel to design a global version of the DustWatch App and invited his projects' results to be part of a Dust Summer School to train students and stakeholders. These activities were highlighted in a NASA Applied Sciences' web feature in April 2020 (NASA Contributes to National Public Health Week), a Science Friday article in April 2020 (A Fever in the Dust), and an EOS article in December 2020 (Saving Lives by Predicting Dust Storms)

Helping States Attain Ozone Air Quality Standards

- To meet the requirements for the Clean Air Act, regions that are non-compliant with the National Ambient Air Quality Standards for key trace gases like ozone and PM must demonstrate plans for reaching attainment. Two ROSES 2017 HAQ projects, led by Jason Otkin (U. of Wisconsin-Madison) and Arastoo Pour-Biazar (U. of Alabama in Huntsville), support the integration of NASA Earth observational datasets into common decision support tools (chemical transport models) used for implementation planning for attaining NAAQS for ozone. Both projects made notable progress in 2020.

In fall 2020, Jason Otkin (PI), Brad Pierce (U. of Wisconsin-Madison), and their team successfully integrated components of their satellite-constrained meteorological modeling platform into the Lake Michigan Air Directors Consortium's (LADCO) process for regional haze and ozone air quality planning, achieving an ARL 6. Like many other urban-coastal regions, the impact of lake/land-breeze circulations on near-surface ozone is challenging to simulate in models. Two years into the project, GLSEA SST observations and NASA SPoRT LIS datasets with incorporated soil moisture data from SMAP are now utilized at LADCO. Zac Adelman (LADCO, Executive Director) stated, "Following the Lake Michigan Ozone Study (LMOS) field campaign in 2017, LADCO and its state partners in the region needed guidance on how to assimilate the information collected during the campaign into air quality management decisions." LMOS observations have been key for demonstrating the improved accuracy of this new modeling platform. Future components to the modeling framework that are currently being tested include bias correction of CMAQ clouds using GOES-16 CLAVR-x cloud retrievals, S-NPP VIIRS green vegetation fraction, and downscaling NOx emissions using S-NPP nightlights for CMAQ.

Arastoo Pour Biazar (U. of Alabama in Huntsville) and his team reached an ARL 5 in November 2020 by demonstrating a prototype system for GOES cloud assimilation into the WRF-CMAQ tool, which is used by their partners at the US EPA, LADCO, CARB, TCEQ, and GaEPD. Overall, this application project plans to integrate surface temperature, insolation, cloud, and lightning products from MODIS, VIIRS, and GOES into their partners' modeling frameworks to improve key physical factors required for accurate air quality simulations, such as boundary-layer development, cloud simulations, and lightning-generated NOx.

Urban Planning with Earth Observations

- A project led by Susan Anenberg (George Washington U.) progressed to ARL 7 in May 2020 with the updated release of the Long-range Energy Alternatives Planning-Integrated Benefits Calculator (LEAP-IBC) by their project partner Stockholm Environment Institute (SEI), which can be used to estimate the impact of air quality policy changes to health-related outcomes (e.g., avoided deaths) at an urban spatial scale (previously national). This tool uses input from GEOS-Chem to estimate the impact of emissions on populated weighted PM2.5 exposure, which are then scaled to match observations from remote sensing measurements (merged MODIS, MISR, and SeaWIFs AOD adjusted to estimate surface PM2.5 using CALIPSO climatology). So far, this urban-scale LEAP-IPC has been demonstrated by SEI in Accra, Ghana, working with Ghana EPA, to explore health benefits of public transportation design options in Accra. By the end of this project, this urban scale tool will be demonstrated in two additional cities (Santiago, Chile, and another city to be determined).

Assessing Risk of Mosquito-borne Outbreaks

- Mosquito-borne diseases cause significant morbidity and mortality across the United States and world. Two HAQ projects, led by Michael Wimberly (U. of Oklahoma) and William Pan (Duke U.), support the integration of NASA Earth observational datasets to enhance public health surveillance programs related to mosquito-borne disease transmission. These projects received project augmentations to expand their scope and made notable progress in 2020. These projects were highlighted on a NASA web feature in July 2020 (NASA Contributes to National Mosquito Control Awareness Week 2020).

  In the United States, the Northern Great Plains is a high-risk geographic region for West Nile Virus (WNV) transmission. Of the 50 states, South Dakota has a long-term record of the highest reported incidence of West Nile Virus (WNV), including WNV neuroinvasive disease. Michael Wimberly (U. of Oklahoma) and his team successfully developed the WNV early-warning system in South Dakota (Arbovirus Monitoring and Prediction (ArboMAP) system) with open access GitHub, driven by a combination of mosquito infection data and environmental monitoring data from NASA's North American Land Data Assimilation System (NLDAS) and Soil Moisture Active Passive (SMAP) satellites, which are calibrated with historical human case data. ArboMAP was successfully integrated into South Dakota Department of Health operational WNV surveillance activities in 2018 and 2019. In 2020, as the Deep South is another high-risk region for WNV, the team expanded WNV weekly seasonal forecasting to Louisiana, as well as the states of Michigan and Oklahoma. The forecasts predicted low rates of WNV risk across these states, and initial reports of human cases from 2020 indicated that these predictions were generally accurate. Preliminary findings also demonstrate a delayed increase in WNV cases following severe storms in Louisiana. After the initial implementation of ArboMAP on these state Departments of Health systems, the team has continued to identify new key collaborators, provided virtual training to staff, and assisted teams with generating weekly WNV reports.

  In the Amazonian region of South America, the countries of Colombia, Peru, Ecuador, and Venezuela have experienced a resurgence in malaria, attributed to challenges like climate change and the expansion of mosquito habitats. To inform malaria control policies, William Pan (Duke U.) and his team developed a Malaria Early Warning System for Peru, which is capable of forecasting malaria outbreaks up to 12 weeks in advance (90% sensitivity). His team integrated multi-layered data from NASA's Land Data Assimilation System (LDAS), human population density, and weekly malaria surveillance to forecast both the incidence of malaria and probabilities of an outbreak (as defined by the local Ministries of Health). In 2020, the team has developed strong government and academic partnerships in Peru (Peruvian Centers for Disease Control; Climate

and Infectious Disease Laboratory at the U. Peruana Cayetano Heredia) and Ecuador (Ecuadorian Ministry of Health; U. San Francisco de Quito) to train and implement the system locally. Functionally, the project has achieved ARL 7 as the team is awaiting confirmation from both governments on their willingness to adopt and integrate the system into their current surveillance programs. With travel restrictions and collaborators reassigned to COVID-19 response efforts, scheduled training programs have been cancelled, with virtual options being explored. The project is scheduled for completion in July 2021.

Response to the COVID-19 Global Pandemic

- Driven by the global pandemic caused by COVID-19, NASA ESD took advantage of this unprecedented natural experiment by supporting projects solicited through the ROSES Rapid Response and Novel Research (RRNES) program element addressing environmental, economic, and societal impacts due to the virus. Of the 20 selected projects, two currently supported HAQ researchers were selected to further their research in connection to COVID-19:

  Susan Anenberg (George Washington U.) was selected to lead a one-year project entitled, *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*. To date, her team has presented this research at a number of conferences and webinars and have published the manuscript, Disentangling the Impact of the COVID-19 Lockdowns on Urban NO2 From Natural Variability. This project was highlighted in a NASA web feature in May 2020 (NASA Funds Four Research Projects on COVID-19 Impacts).

  Pablo Méndez-Lázaro (U. of Puerto Rico Medical Sciences Campus) was selected to lead a one-year project entitled, *Study of Imminent Interactions Between SARS-CoV-2 (COVID-19), Air Quality Due to Saharan Dust and Urban Aerosols, and Social-Environmental Factors in Puerto Rico in Summer 2020: Proxies of Health Risks in Small Island States in the Caribbean Region*. The team aims to determine if seasonal African dust, which crosses the Caribbean basin annually between May and August, will have significant impacts on susceptibility and disease severity associated with COVID-19 infection. This project was highlighted in a NASA web feature in September 2020 (Rapid-Response Applied Sciences Research on COVID-19's Environmental Connections).

  The HAQ Applications program further expanded a project led by Ben Zaitchik (Johns Hopkins U.) with a project augmentation 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 generated a COVID-19 case record database that assigns data to a consistent geographical hierarchy aligned with hydrometeorological variables. This project was highlighted in the NASA Earth Observatory web feature (Could COVID-19 Have Seasons? Searching for Signals in Earth Data) and a NASA web feature in July 2020 (Ben Zaitchik: Working from the Couch and Tracking Coronavirus (COVID-19).

IV. Health and Air Quality Applied Sciences Team

In 2020, the NASA Health and Air Quality Applied Sciences Team (HAQAST) (http://haqast.org), led by Tracey Holloway (U. of Wisconsin-Madison), concluded its mission of linking NASA's satellites and data products to public stakeholders in the air quality and public health communities. HAQAST officially concluded in August 2020, and a solicitation for a new HAQAST team was released in February 2020, which will begin work in early 2021. This final year of HAQAST was focused on finishing applied research activities and distributing final deliverables to stakeholders, as well as setting the stage for the successful launch of the next version of HAQAST.

The four current Tiger Teams, launched in the summer of 2018, were chosen from eight proposals that underwent a competitive review process by stakeholders from end-user organizations. All four Tiger Teams met regularly with stakeholders and transferred their final deliverables to their stakeholder partners. Current Tiger Teams include:

1. *Satellite-Evaluated and Satellite-Informed O_3 Distributions for Estimating U.S. Background O_3*, led by Jessica Neu (NASA Jet Propulsion Laboratory [JPL]).

    - The delivery of a variety of O_3 boundary conditions, in the most popular file formats identified by air-quality stakeholders, for use in modelling O_3 transport from other countries into the U.S.

2. *Supporting the Use of Satellite Data in Regional Haze Planning*, led by Arlene Fiore (Columbia University/Lamont Doherty Earth Observatory).

    - A series of technical guidance documents, aimed at regional air-quality managers, and intended to help them evaluate regional haze in their planning. These documents are archived at https://airquality.gsfc.nasa.gov/hazevisibility-planning.

3. *Using Satellite Remote Sensing to Derive Global Climate and Air Pollution Indicators*, led by Susan Anenberg (George Washington University).

- A series of presentations, informational webinars, visualizations, data, and technical guidance documents, all concerning the derivation of global climate and air pollution indicators from satellite data.

4. *Air Quality and Health Burden of 2017 California Wildfires*, led by Susan O'Neill (U.S. Forest Service).

    - The completion of a fire emissions inventory, air quality modeling for smoke, a health impact analysis of California's 2017 wildfire season, and a series of training videos, all aimed at fire managers in the U.S. Many of these final deliverables are at or near operational status, and are available here: https://sites.google.com/firenet.gov/wfaqrp-airfire/projects/haqast/2017NorthernCAWildfiresTT?authuser=0.

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 966 subscribers) and Twitter (@NASA _HAQAST currently has more than 4,200 followers). Over the past four years, HAQAST's applied research has been profiled in *US News & World Report*; *Europapress* (Spain); the award-winning documentary film, *Dust*; a number of NASA stories and web features; and many other popular media outlets.

The HAQAST website continues to be a "one-stop shop" for relevant NASA data and tools. The website logged 9,580 users in 2020, an increase of 20 percent over 2019. The most popular pages were the ones relating to HAQAST meetings (~7,000 page views), NASA tools (~1,200 page views), Principal Investigators' biographies (~1,000 page views), and Tiger Teams (750 page views).

HAQAST hosted meetings every six months from its inception in 2016 through summer 2020, with a focus on progress review and stakeholder engagement. HAQAST conferences have gained the reputation 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.

In 2020, HAQAST changed its format, shifting away from meetings to draw in new audiences and collaborators, and towards meetings that offered a summation of HAQAST's work. Notably, the winter meeting, HAQAST2020, was a series of 14 one-hour webinars that stretched from mid-February to mid-March 2020. The webinars were either hands-on workshops (for example, PI Arlene Fiore and her team member Xiaomeng Jin gave a tutorial on using Giovanni to plot tropospheric NO_2), or engaged discussions of best practices (for example, PI Mark Zondlo shared tips and tricks for working with satellite NH_3 measurements). A highlight of the series was a collaboration between HAQAST members Tracey Holloway and Yang Liu and Will Barrett, the

Director of the American Lung Association's Advocacy and Clean Air Program. HAQAST2020 attendance exceeded expectations, with 557 unique registrants signing up for a total of 4,048 sessions (each registrant signed up for an average of 7.3 sessions). Attendees were primarily local to the US, including a number of registrants from tribal communities, but the audience also extended across the world, to Europe, Asia, India, and South America.

As with every HAQAST conference, a post-conference survey was sent to HAQAST2020 attendees and received 105 responses. A total of 99% of attendees recommended further webinar series and, overall, attendees were extremely pleased with the ease of communication, audio and visual quality, and the overall experience. Attendees who had experiences with the in-person HAQAST meetings were asked to compare the quality of virtual to in-person, and the virtual meetings compared favorably with ease of attendance; however, in-person meetings were noted as far better for networking. The full results can be seen in Figure 1 below.

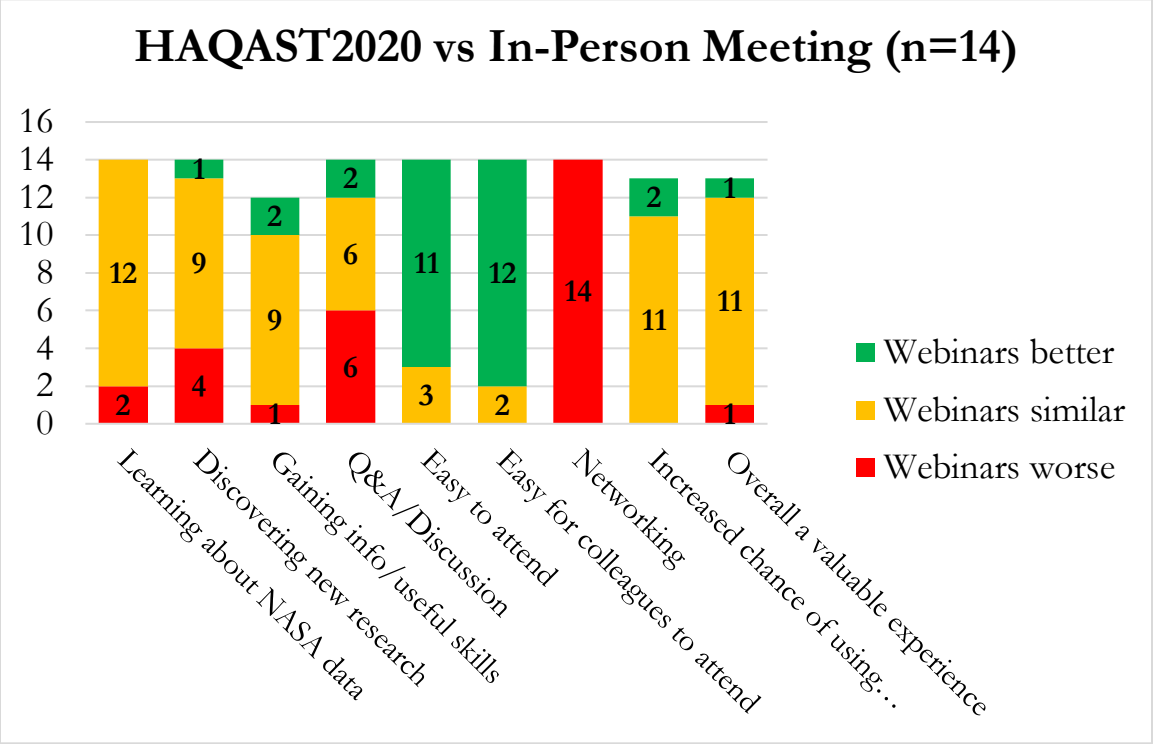

Figure 1: HAQAST2020 audience response comparing the virtual HAQAST2020 webinars to the in-person HAQAST meetings.

The initial plan for the final HAQAST meeting—the Showcase—was to hold the event in-person at NASA Headquarters. Unfortunately, the COVID-19 pandemic derailed

those plans, so HAQAST harnessed the experience of running virtual webinars to pivot to a virtual Showcase, which was held from July 21-22, 2020. An innovative format was devised for this final meeting: each day would feature four 1-hour panels. The panels were organized around themes that cut across the team's expertise and success—a general overview, working with $PM_{2.5}$, using tools for smoke and fire, working with public stakeholders, integrating NASA data in global health applications, quantifying uncertain emission sources, using high-resolution data for community-level analyses, and examining global background O_3. The beginning of every panel featured a brief approximately 3-minute film—a highlight reel to set the tone for the rest of the panel, which as devoted to panelists' concluding HAQAST thoughts and a wide-ranging, open Q&A. A total of 303 registrants from across the US and the world attended. Glowing reports were received from participants, along with an increase in activity on Twitter as viewers followed along.

All slides, presentations, pictures, films, and posters from both conferences can be found at the Past Meetings tab of the HAQAST website.

HAQAST meetings were highly successful in expanding the Earth observation user community—growing from an initial count of 30 in-person and 15 remote attendees to 115 in-person and 194 remote attendees for our last in-person meeting, HAQAST6. In particular, HAQAST has demonstrated the audience demand for remote options as well as all-virtual webinars. (see Fig. 2).

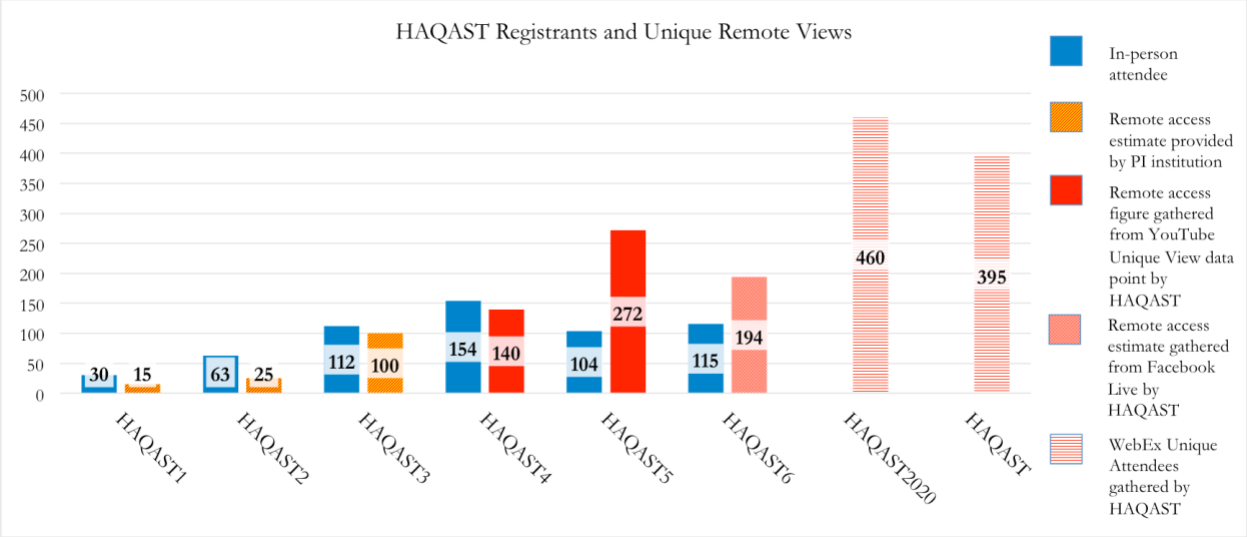

Fig. 2: Total HAQAST meeting attendance, both remote, in-person, and virtual, 2016–2020.

Active publication of HAQAST members' applied research culminated in more than 220 peer-reviewed articles since 2016, with more continuing to be published as the research publication cycle catches up with the backlog of submitted manuscripts.

Finally, the HAQAST team submitted its final report, detailing the activities, successes, lessons learned, and suggestions for future solicitations, to HAQ Applications Program Manager John Haynes in late 2020. The final report is also available on the HAQAST website.

In December 2020, the NASA Applied Sciences program announced the selection of the new iteration of HAQAST. The new iteration of HAQAST will build on the legacy of the previous team, in continuing to connect NASA Earth observation data and tools to environmental health and air quality decision-makers and stakeholders. Fourteen PIs were selected for the new four-year team, which will continue to be led by Tracey Holloway of the University of Wisconsin. The kickoff meetings of the new HAQAST are scheduled for February and March 2021.

V. Assessment

2020 was a year unlike any other. As COVID-19 cases skyrocketed across the nation and the world, NASA instituted mandatory telework in March 2020 along with a suspension of all in-person meetings. The HAQ Applications team had to pivot to an entirely virtual workplace, which came with opportunities and challenges. 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 continuously considered, as the number of emails, videoconferences, and tasks were overwhelming at times. However, the HAQ Applications team performed superbly throughout the year, while managing costing and schedule impacts to many projects in the portfolio.

Overall, the HAQ Applications portfolio exceeded technical performance expectations in 2020, with several projects reaching top-tier Application Readiness Levels (ARLs) of 7 to 9.

The portfolio continued to carry a relatively high burden of uncosted funds in 2020. Associates worked diligently with Principal Investigators 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, significant progress was made – FY18 uncosted funds were down ~72 percent from December 2019 to December 2020; FY19 uncosted

funds were down ~65 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 Applications portfolio suffered schedule setbacks in 2020 due to the pandemic, significant results were accomplished in all areas. Schedule and costing issues will continue to be monitored and mitigated in 2021, with hopes for an easing of the pandemic and its impacts.

VI. Project Portfolio

At the end of 2020, the HAQ Applications portfolio included 18 active projects along with the activities of the 13-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; twelve projects had ARLs of 4-6; and six projects had achieved an ARL of 7-9. A total of 61 percent of projects increased at least one ARL from December 2019 to December 2020, and 33 percent increased by two or more ARLs over the same period.

VII. Program Management

The 2020 NASA Health and Air Quality Applications Annual Team Meeting was held virtually on September 15 and 21, 2020. Principal Investigators 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. Heather Strosnider, Section Chief of the 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. Presentations from this Team Meeting are available on the NASA Applied Sciences website: https://appliedsciences.nasa.gov/join-mission/publications-resources/health-and-air-quality-applications-program-review.

John Haynes serves as Program Manager for HAQ Applications at NASA Headquarters. The HAQ Applications program team includes Sue Estes (U. of Alabama in Huntsville) as Senior Associate Program Manager, and Helena Chapman (NASA Headquarters/Booz Allen Hamilton) and Laura Judd (NASA LaRC) as Associate Program Managers.

VIII. Community Leadership

The applications area presented and led sessions at meetings of the National Council for Science and the Environment (NCSE), American Meteorological Society (AMS), the American Thoracic Society (ATS), the Air and Waste Management Association (A&WMA), the International Society for Environmental Epidemiology (ISEE), the American Public Health Association (APHA), and the American Geophysical Union (AGU). In January 2020, the NCSE 2020 Annual Conference, with the theme *Science in Environmental Decision-making*, was held in Washington, DC. John Haynes and Helena Chapman presented invited talks at the NASA Hyperwall, which were well attended by NCSE 2020 attendees.

In January 2020, the 100th AMS Annual Meeting, using the theme, *The AMS Past, Present and Future: Linking Information to Knowledge to Society (LINKS)*, was held in Boston, Massachusetts. As part of the embedded 11th Conference on Environment and Health, NASA supported the session entitled, *NASA Earth Observation Systems and Applications for Health, Air Quality, Environmental Management, and Public Outreach*, with eight scientific talks and more than 70 attendees. The HAQ program also supported the Multi-Angle Imager for Aerosols (MAIA) and Tropospheric Emissions: Monitoring of Pollution (TEMPO) Applications Town Hall session entitled, *Upcoming NASA Health and Air Quality Missions*. Additional scientific talks were presented at the NASA Hyperwall in the exhibit hall. While attending AMS, the HAQ Applications leadership team visited the Boston University School of Public Health and presented an overview of the NASA Applied Sciences Program and highlighted selected HAQ projects that integrate Earth observations for public health. A total of 16 faculty and graduate students attended this roundtable discussion.

In January 2020, the HAQ Applications program conducted a site visit to San Juan, Puerto Rico, to attend the annual meeting and workshop of Pablo Méndez-Lázaro's (U. of Puerto Rico Medical Sciences Campus) project on Saharan dust in the Caribbean. The meeting agenda highlighted presentations by the research team and collaborators, focusing on three working groups – *Resilience, Public Health, and Well Being; Atmospheric Forcing and Air Quality; and Decision Support Tool: Computation and Visualization*. More than 100 researchers, students, and stakeholders attended this research meeting and workshop.

For Earth Day 2020 in April 2020, the NASA HAQ Applications program was interviewed by NASA's Earth Science News Team for the article, How NASA is Helping the World Breathe More Easily. This article highlighted several topics, including the Environmental Protection Agency's AirNow system, current use of Moderate Resolution Imaging Spectroradiometer (MODIS) and Ozone Monitoring Instrument (OMI) data, and the upcoming TEMPO and MAIA missions supported by the HAQ Applications Team and HAQAST. Additionally, John Haynes was an invited panelist for the *An Air of*

Positivity livestream panel, supported by the Trinity College (Dublin, Ireland) and Smithsonian's Earth Optimism Summit. This event explored positive solutions to achieving healthier and cleaner air quality, with over 300 views.

For National Public Health Week in April 2020, the NASA HAQ Applications and Communications Teams shared two projects on the NASA Applied Sciences Program's website that highlighted the valued role of citizen scientists in research applications that advance our understanding of two environmental health risks: dust storms (GLOBE Observer app) and harmful algal blooms (HABscope app). These public health projects, led by Daniel Tong (George Mason U.) and Richard Stumpf (NOAA), emphasized the benefit of transdisciplinary collaborations that integrate innovative data and technology into public health applications and advance scientific understanding of our ecosystem.

In May 2020, the NASA Applied Sciences Program supported the MAIA Science Team Meeting, led by Dave Diner (Jet Propulsion Laboratory). The three-day meeting offered expert talks on various topics related to MAIA instrument development and data products, including interagency and international partnerships, speciated particulate matter (PM) filter stations, science data systems and algorithms, data validation, and target area implementation details. It also expanded on previous discussions related to MAIA scientific goals and data products, as well as opportunities to enhance end-user community networks for using MAIA observations.

Additionally, the NASA Applied Sciences Program hosted a joint TEMPO/MAIA Joint Early Adopters Virtual Workshop, moderated by Abigail Nastan (Jet Propulsion Laboratory) and Aaron Naeger (U. of Alabama in Huntsville), with over 140 potential end-users in attendance. The workshop browsed the latest version of synthetic TEMPO data products, previewed the earliest version of MAIA aerosol and PM data products, and gathered feedback. As a result of the workshop, the TEMPO team will distribute L2 and L3 synthetic data products and consider different netCDF file structures for the "fast" synthetic data to better conform to the expected operational data product and ASCII files for health end-users. Due to the high-level of interest in MAIA-TEMPO synergistic applications, future MAIA-TEMPO joint workshops are planned to continue building on collaborations and unique applications between teams.

In May 2020, John Haynes and Helena Chapman were invited to present talks at the UN Office for Outer Space Affairs (UNOOSA)'s Space4Health webinar. Presentation topics included *Utilizing Earth Observations for Improved Air Quality and Health Decisions* and *Using Earth Observations to Strengthen One Health Collaborations*. With over 100 views, the presentations were well received and contributed to the wider discussion of health applications using space-based technologies.

NASA HAQ Applications investigators and stakeholders presented at the ARSET webinar, An Inside Look at How NASA Measures Air Pollution, offered in English and Spanish, which was held on May 26 and 28, 2020.

In June 2020, the HAQ Applications program participated in the A&WMA 113th Annual Conference and Exhibition. The A&WMA is the most comprehensive conference on environmental technology and regulation; therefore, the program has identified A&WMA as one of the boundary organizations that will provide a bridge between applications research and air quality practitioners. The NASA HAQ Applications Team convened a session entitled, *Resolving Critical Air Quality and Health Issues from Space with NASA's Future Earth Observing Satellites*, attended by approximately 100 participants. In this session, five panelists discussed and presented NASA's satellite and sub-orbital measurements and models to address air quality and health applications. Helena Chapman also gave a presentation entitled, *One Health Collaborations: Key to Advancing Environmental Health Applications*, in the *Assessing Exposure and Health Effects* session. For promotional purposes, the NASA Communications Team prepared the web feature, Engaging with Waste and Air Quality Stakeholders at a Virtual Conference.

For National Mosquito Control Awareness Week 2020 in June 2020, the NASA HAQ Applications and Communications Teams promoted a web feature on NASA's Applied Sciences Program website. This web feature, NASA Contributes to National Mosquito Control Awareness Week 2020, was developed to support this campaign of the American Mosquito Control Association (AMCA). Featured HAQ projects included using ECOsystem Spaceborne Thermal Radiometer Experiment (ECOSTRESS) and Global Ecosystem Dynamics Investigation (GEDI) satellites to explore mosquito habitats, the potential transmission of Zika virus in California, developing early warning systems for human West Nile virus in South Dakota and Louisiana, and mapping malaria hotspots in the Amazon.

As a result of the COVID-19 pandemic, there has been increased attention on the One Health concept, which promotes the interconnectedness among humans, animals, and the environment. Helena Chapman was invited to present on the use of Earth observations in One Health applications at international webinars in English and Spanish. These events included the Latin American Cooperation of Advanced Networks (RedCLARA)'s Climate and Health webinar (over 130 views), the Dominican Republic's National Academy of Medicine monthly seminar series (over 430 views), the Dominican Republic's Universidad Central del Este's epidemiology and preventive medicine course (60 medical students), and the Lancet One Health Commission's webinar series on Developing a Career in One Health: Stories from the Next Generation (over 350 views).

Helena Chapman was an invited panelist for the UNOOSA Group of Friends webinar, *Space for Building Forward Better*, which was held in July 2020. She presented the talk, *Using Earth Observations in One Health Applications for Societal Benefit*, highlighting the use of Earth observation data to enhance health decision-making. This event aimed to unite experts from the United Nations (UN) and other space-based agencies to

discuss the role of space in disaster management and promote synergies and exchanges.

In July 2020, the NASA HAQ Applications Team presented at the International Space University Summer (ISU) Program 2020, with the theme, *Innovative Approaches of Utilizing Space for the Monitoring and Mitigation of the COVID-19 Crisis and for the Preparedness and Prevention of Future Pandemics.* This event had more than 90 participants from 25 countries in attendance. John Haynes presented on the panel, *Utilizing Big Data and Space for the Monitoring, Mitigation of COVID-19 and Prevention of Future Pandemics*, to over 83 participants. He stressed that NASA Earth-observing satellite data allow scientists to study environmental changes, such as fluctuations in air quality due to COVID-19 mitigation efforts and risk characterization of vector-borne diseases. He also encouraged attendees to explore the open access data from NASA and the NASA/ESA/JAXA Earth Observing Dashboard. Helena Chapman presented the talk, *How Space can Help Monitor COVID-19 and other Pandemics*, to 30 course participants. She highlighted the use of Earth observation data in global efforts to curb infectious disease transmission and enhance health decision-making.

The NASA HAQ Applications Team supported the NASA Earth Science Division (ESD)'s Seminar Series for summer interns in July 2020. John Haynes and Helena Chapman presented the talks, *Utilizing Earth Observations for Improved Air Quality and Health Decisions and Strengthened One Health Connections* and *Publishing in the Sciences,* to approximately 20 summer interns.

In July 2020, Laura Judd and team kicked off the TRacking Aerosol Convection ExpeRiment (TRACER-AQ) science team, currently comprised of collaborators from federal (US Department of Energy; NOAA), state (Texas Commission on Environmental Quality, TCEQ), and academic (U. of Houston, Baylor U.) institutions. For this study, NASA will deploy airborne and ground-based air quality observations in the Houston area in 2021, including over the marine environments of Galveston Bay. These measurements, linked with the dense air quality network operated by TCEQ, as well as specialized observations through TCEQ-supported research projects and TRACER partners, will provide a uniquely integrated perspective to examine local air quality challenges. Since its kickoff, this science team has met monthly.

In August 2020, the NASA Applied Sciences Program hosted Applied Sciences Week 2020, a four-day virtual event to learn the practical applications of NASA Earth science data by sharing global highlights from researchers and partners and interacting with early-career professionals. Sue Estes and Laura Judd invited three researchers – Daniel Tong (George Mason U.) for the Western US, Michael Wimberly (U. of Oklahoma) for the Central US, and Tabassum Insaf (New York Department of Health, DOH) for the Eastern US – to present their HAQ projects and participate in the group discussion at this event.

In August 2020, the NASA TEMPO Science Team Meeting held their annual science team meeting virtually. The meeting included coordinated 45-minute sessions that focused on the scientific algorithm development of trace gas products, validation plans, and modeling efforts. They organized sessions that discussed the data distribution plans by the Atmospheric Science Data Center (ASDC) and anticipated use of TEMPO data for fire, agricultural, and aerosol research and applications. The fire session highlighted the importance of Geostationary Operational Environmental Satellite (GOES) – R Series and TEMPO synergy for advancing TEMPO algorithms and products. This meeting included a session devoted to TEMPO Early Adopters and was moderated by Aaron Naeger (U. of Alabama in Huntsville).

In August 2020, Helena Chapman was an invited panelist on the APHA's Public Health Education and Health Promotion's webinar, Health Educators Leading a Way to a Post COVID-19 World. She presented the talk, *Bridging Earth and Health Science Communities during the COVID-19 Response: Focus on the One Health Approach*, to over 76 attendees.

The 32nd Annual Conference of the ISEE was held virtually in August 2020. John Haynes presented the talk, *Using NASA Earth Observations to Strengthen Air Quality Applied Research and Management*, as a panelist on the CDC's *Increasing Knowledge about Health Effects of Wildfire Smoke: A Summary of Multiagency Research Efforts to Inform Public Health Surveillance and Practice* session to an estimated 80 participants. Helena Chapman presented the e-poster, *Applying NASA Satellite Data to Examine Emerging One Health Threats: Going Beyond Traditional Epidemiologic Methods*, in the *Infection, Microbes, and Immunity* themed session.

In August 2020, Helena Chapman received the American Veterinary Epidemiology Society (AVES) Honorary Diploma Award, as part of the Veterinary Medical Society's annual meeting to recognize career contributions and distinguished service to improve animal and human health in the spirit of One Health. As the only physician among the 10 awardees, Helena encouraged AVES members to explore opportunities to integrate satellite observations in their research and applications, where data can bridge the Earth science and health science communities and promote the One Health concept.

In September 2020, Laura Judd was an invited panelist on a virtual event to highlight three successful women in Science, Technology, Engineering, Mathematics, and Medicine (STEMM) fields from NASA Langley Research Center. This event, which was supported by RMIT University (Australia), was attended by over 300 participants, including high school students from 34 Australian schools and students of RMIT's Vocational Education and Higher Education STEMM studies program.

In September 2020, John Haynes was invited to provide an overview of the NASA Applied Sciences Program on the Centers for Disease Control and Prevention (CDC)'s One Health Federal Interagency COVID-19 Coordination Group telecon. His

presentation highlighted the use of Earth observations for public health applications to other representatives of federal agencies.

In September 2020, the Clean Air for All: 50 Years of the Clean Air Act virtual symposium, hosted by the American University's Center for Environmental Policy, Center for Environmental Filmmaking, and the American Lung Association, was held to commemorate achievements since the Clean Air Act enactment. John Haynes and Susan Anenberg (George Washington U.) participated on the *Clean Air and Climate Change in the 21st Century* panel.

In September 2020, John Haynes spoke at the *Health Impacts of Food, Water and Air Resources* session of the virtual 2020 Environmental Security Summit. Hosted by the Environmental Security Working Group and the National Intelligence University, the Summit focused on health as a security issue and specifically addressed the influence of climate and other environmental factors on a range of health outcomes.

In October 2020, the Global Health Security Agenda Annual Ministerial Meeting included the side event, *Incorporating One Health into Global Security: Educating the Public and Governments*, to highlight the role of One Health in global security initiatives. In the second panel, John Haynes joined CDC and U.S. Department of Agriculture (USDA) colleagues to describe how One Health can be integrated into federal government activities and shared potential challenges, with over 75 participants in attendance.

In October 2020, Helena Chapman was invited to present on the use of Earth observations in One Health applications at international webinars in English and Spanish. These events included the World Medical Association/Junior Doctors Network biannual meeting (65 attendees), Portugal's Instituto de Medicina Molecular João Lobo Antunes Out of the Box seminar series (75 attendees), and the Dominican Republic's U. Católica del Cibao Research Seminar series (25 attendees).

The NASA HAQ Applications program supported the ARSET webinar, MODIS to VIIRS Transition for Air Quality Applications, which was held on October 22, 2020. Additionally, the article, Getting to the Heart of the (Particulate) Matter: NASA's MAIA to Study How Particulate Matter Air Pollution Affects Our Health, by Alan Buis (Jet Propulsion Laboratory), was published on the NASA Global Climate Change website.

At the APHA Virtual Annual Meeting & Expo in October 2020, Helena Chapman presented an e-poster presentation, *Integrating Satellite Data to Strengthen One Health Surveillance of Emerging Infectious Diseases*, in the APHA Veterinary Public Health Special Primary Interest Group session. This presentation described how NASA Earth-observing satellite data have been integrated into the development of risk maps for malaria and cholera.

In October 2020, John Haynes and Helena Chapman were invited lecturers to the Graduate Interdisciplinary Seminars in Global Infectious Diseases at the Georgetown University's Department of Microbiology & Immunology in Washington, DC. This lecture was part of continuing outreach by NASA HAQ Applications to Schools of Public Health and early-career professionals. In their talk, *Spatialization and Dynamics of COVID-19 and other Infectious and Vector-borne Diseases: Advances in Remote Sensing*, they provided an overview of the NASA Applied Sciences Program and described an array of HAQ projects that use Earth observations for public health applications.

In October 2020, John Haynes was awarded the NASA Exceptional Service Medal, and Sue Estes was awarded the NASA Exceptional Public Service Medal. These awards recognized their outstanding performance and creative ability that demonstrated significant contributions to NASA projects, programs, and initiatives.

In November 2020, the NASA GPM-ACCP Transport Logistics Workshop highlighted current applications and future opportunities of NASA precipitation and cloud data products to support transport and logistical activities for aviation, maritime, roads, and highway transportation systems. At this workshop, representatives from federal and state operational agencies, private companies, and boundary organizations discussed how NASA precipitation and cloud products could be better leveraged to inform decision-making for transport and logistical operations. John Haynes provided an overview of applications of precipitation, cloud, and convection data at this workshop. As a result of this workshop, Community Working Groups were established to encourage continued dialogue, and follow-up training sessions and case studies are planned to illustrate the use of NASA data and products for decision-making activities.

For One Health Day in November 2020, the NASA HAQ Applications and Communications Teams shared three projects on the NASA Applied Sciences Program website that highlighted multidisciplinary collaborations between scientists and community stakeholders that are fundamental to advance our understanding of environmental factors related to COVID-19. These projects included Understanding the Spread of Infectious Diseases When the Seasons Change (Ben Zaitchik, Johns Hopkins U.), Studying the Inconsistent Effects of COVID-19 Social Distancing on Air Quality in Global Cities (Susan Anenberg, George Washington U.), and Connecting Air Quality to the Health Effects of COVID-19 (Pablo Méndez-Lázaro, U. of Puerto Rico Medical Sciences Campus). This web feature was promoted by the One Health Commission's One Health Day global events.

In November 2020, Helena Chapman was an invited panelist for the *Planetary Health and One Health Approaches to the COVID-19 Pandemic and Beyond* virtual session at the Maryland Public Health Association's Annual Conference 2020. In her talk, she shared how COVID-19 activities have bridged the Earth and health science communities, paving a way for health professionals to contribute significantly to research and community applications. She also participated as a virtual panelist for the

One Health Young Professional Panel Discussion, moderated by Lt. Caitlin Cossaboom (CDC Division of High-Consequence Pathogens and Pathology). Part of the One Health Intellectual Exchange 2019 effort, this One Health course is an academic collaboration between Duke University, North Carolina State University, and the University of North Carolina.

In November 2020, the NASA Applied Sciences Program hosted the 2020 NASA TEMPO Early Adopters Virtual Workshop which was organized by Aaron Naeger (U. of Alabama in Huntsville). Over 150 participants attended to learn updates on the TEMPO mission and Early Adopters Program, synthetic data demonstrations and product developments, and an implementation plan for experiment requests using the standard and non-standard observing time of the mission. During discussion sessions, early adopters discussed advancement in HAQ applications with TEMPO, such as emission and air pollution exposure assessments, along with critical needs from future operational products and tools to improve decision-making activities. Based on participants' input, the TEMPO Early Adopters team will develop additional synthetic products and tools, including pre-launch training material, to facilitate use of operational TEMPO data and coordinate application groups in order to strategize for the observing time of TEMPO. Future workshops are planned.

In November 2020, the ISEE Annual Conference 2020 supported the MAIA Early Adopters Pre-conference Workshop through a virtual webinar. This workshop, moderated by Abigail Nastan (Jet Propulsion Laboratory), included presentations from John Haynes, Dave Diner (Jet Propulsion Laboratory), Jeff Walter (NASA ASDC), Sagnik Dey (Indian Institute of Technology Delhi), and Meredith Franklin (U. of Southern California).

In November 2020, the NASA Earth Observatory highlighted the article, Using Space to Monitor Air Quality at the Surface. Co-developed by SERVIR-Mekong, the Royal Thai Government's Pollution Control Department and SERVIR-Mekong launched the Mekong Air Quality Explorer (AQE) and the Geo-Informatics and Space Technology Development Agency (GISTDA). The AQE uses Earth observation inputs in a web-based platform that forecasts and monitors air quality in the Lower Mekong region.

The NASA HAQ Applications program supported the ARSET webinar, Satellite Remote Sensing for Urban Heat Islands, which was held on November 10, 17, and 24, 2020. This training was held in collaboration with the National Integrated Heat Health Information System (NIHHIS) and the Global Heat Health Information Network (GHHIN).

The AGU Fall Meeting 2020 was held virtually in December 2020. As part of the GeoHealth section, the NASA HAQ Applications Team coordinated an oral and poster session, *Using NASA Satellite Data to Advance Environmental Health Applications: Impact of Changing Global Ecosystems on Human Health*. The session, which was attended by 40 individuals, featured eight scientific talks and 10 posters, including the

HAQ poster, *A Closer Look at Earth Science Applications to Protect Population Health*. Helena Chapman also co-organized an oral session*, Impacts of Heat Stress on Infectious Disease: Drawing Biological Links Between Geoscience and Human Health I*, in the GeoHealth section. Seven invited speakers – including Josh Colston (U. of Virginia), Julia Gohlke (Virginia Polytechnic Institute & State University), and Tabassum Insaf (New York DOH) – highlighted how extreme heat events can stress physiology, influence disease transmission, and lead to adverse health impacts. Laura Judd also co-organized three oral and two poster sessions, highlighting research about *Advances in a Global Observing System for Air Quality.* Highlights from this session include, but are not limited to, preliminary results from Geostationary Environment Monitoring Spectrometer (GEMS), as well as highlights about TEMPO and MAIA applications. Additionally, Helena Chapman served as an invited panelist on the GeoHealth Early Career Panel, *Navigating a Career in GeoHealth*, where she shared her career trajectory and provided advice on interdisciplinary research and practice in Earth and health sciences. Rita Colwell (U. of Maryland, College Park) presented *Oceans, Climate, and Human Health: Lessons from Cholera for COVID-19* as a featured plenary, and the *Future of Infectious Diseases: How Earth Observations Can Help Predict the Next Pandemics* as a NASA Hyperwall talk. She was awarded the William Bowie Medal, in recognition of her outstanding contributions to fundamental Earth and space science research.

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 2020. In February 2020, Laura Judd partnered with U.S. Environmental Protection Agency (EPA) colleagues, Rona Birnbaum and Caitlin Gould, to co-lead the CCHHG Research Workstream. This goal of this workstream is to track the state of climate and human health research supported by federal agencies. By the end of 2020, the co-leads for this workstream were developing a compendium of publicly available research related to climate change and human health, which will be shared within the CCHHG in 2021.

IX. International Activities

The Group on Earth Observations (GEO) Health and Environment Community of Practice (CoP) is 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. Throughout 2020, the GEO Health CoP continued to expand its activities, under the chairmanship of HAQ Applications Program Manager, John Haynes. The CoP hosted membership-wide telecons to discuss key topics at the nexus of Earth observations and health, ways to support the 2020-2022 GEO Work Programme, and development of a work plan to implement the

2020-2022 GEO Work Programme. The CoP also expanded its website to keep the community informed of activities, news, and opportunities.

In March 2020, the GEO Health CoP held a regularly scheduled telecon to provide program and project updates as well as coordinate the next steps of the GEO Health CoP work plan. This work plan supports GEO efforts and advances development of the EO4HEALTH Initiative. At this meeting, Josh Colston (U. of Virginia) presented a brief update on the NIH grant, Global Geospatial Mapping and Modeling of Household-level Covariates of Infectious Disease Transmission and Child Health. John Haynes moderated a dialogue on current CoP activities and updates related to the ongoing COVID-19 pandemic. A total of 45 participants, representing different agencies in public and private sectors, participated on the telecon.

Notably, due to the COVID-19 pandemic, the GEO Health CoP was strategically placed to leverage expertise across sectors and geographies and share Earth observation data, tools, and knowledge to support COVID-19 responses. Beginning in March 2020, John Haynes and Helena Chapman coordinated weekly community teleconferences to offer CoP members an opportunity to discuss how satellite data can advance understanding of the direct and indirect impacts of COVID-19 transmission on human, animal, and environmental health. Topics have included air and water quality, disaster preparedness and management, environmental determinants and seasonality, and One Health and zoonotic disease transmission. Through these teleconferences, professional networks have expanded through small-group discussions on related topics to support global research applications. As each teleconference has engaged 40 to 120 participants, new GEO Health CoP members have joined and presented their research applications and community initiatives to the wider community. To showcase these efforts, Helena Chapman prepared a brief article, *Using Earth Observations for COVID-19 Response Efforts*, for the APHA Veterinary Public Health's *One Health Newsletter* (Summer Issue 2020).

Throughout 2020, Small Work Groups served as essential networking tools for CoP members. The leads and members of these five groups – Heat (Ben Zaitchik, John Hopkins U.); Infectious Diseases (Antar Jutla, U. of Florida); Air Quality, Wildfires, and Respiratory Health (Tatiana Loboda, U. of Maryland, College Park); Food Security and Safety (Dorian Janney, NASA GSFC/GPM); and Health Care Infrastructure (John Balbus, NIEHS; Andreas Skouloudis, iSteep.org) – leveraged expertise with CoP members to provide scientific and technical expertise on selected health-related topics for specific project tasks, projects, and activities. To promote these groups, the leadership team prepared the article, *Small Work Groups of the GEO Health Community of Practice*, for the GEO community blog.

In June 2020, the NASA HAQ Applications Team participated in the GEO Virtual Symposium 2020, with over 1,600 registered participants. This symposium highlighted the GEO Work Programme activities, initiatives, and flagships, sharing updates and

plans to enhance the use of Earth observation data for sustainable development. It also served as a professional networking event, connecting GEO members across agencies and institutions, disciplines, and geographic regions. A total of 14 sessions had pre-recorded presentations with interactive Q&A sessions, including leveraging advanced technologies, capacity development, monitoring essential variables, and regional GEOs. The Earth Observations for COVID-19 Response and Recovery session – facilitated by John Haynes, Juli Trtanj (NOAA), Astrid-Christina Koch (European Commission), and Helena Chapman – coordinated a "world tour", where seven panelists from across geographic regions shared preliminary findings on how climatological, environmental, and meteorological factors had influenced COVID-19 transmission to date, noting the lockdown restrictions implemented across countries. This virtual symposium promoted multidisciplinary collaborations that connected experts, promoted the use of innovative approaches, and aligned agendas to meet global objectives.

The GEO Health CoP supported the tri-agency collaboration – NASA, European Space Agency (ESA), and Japan Aerospace Exploration Agency (JAXA) – to develop the COVID-19 Earth Observation Dashboard. This web platform integrated relevant Earth observation data, technical knowledge, and 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. Notably, NASA prepared the web feature on this open access data resource, NASA, Partner Space Agencies Amass Global View of COVID-19 Impacts, to showcase this robust global collaboration.

In July 2020, Juli Trtanj and Helena Chapman facilitated the U.S. GEO Booth for the EO4HEALTH Initiative at the Esri User Conference 2020. They provided an overview of the topics presented at the GEO Virtual Symposium 2020 and facilitated an open discussion with attendees.

In August 2020, several GEO Health CoP members joined the Scientific Committee of the three-day international Climatological, Meteorological, and Environmental Factors in the COVID-19 Pandemic virtual symposium, supported by the World Meteorological Organization (WMO) and endorsed by GEO. After this event, an Outcomes Statement was widely disseminated among the scientific community as a benchmark on the current state of knowledge concerning connections between environmental factors and COVID-19.

In September 2020, more than 800 participants attended virtual sessions of the AmeriGEOSS Symposium 2020. Using the theme, *Bridging the Divide: Better Together: Geospatial Information for Decision Making in the Americas*, the symposium aimed to identify synergies and priorities using Earth observation data that can strengthen regional collaborations. Sessions provided an opportunity to identify challenges and share approaches to enhance communication, strengthen capacity building, and identify knowledge gaps for end-user communities. Notably, health was adopted as a fifth focus

area, following biodiversity and ecosystem sustainability, disaster resilience, food security, and sustainable agriculture, and water resources management.

World Space Week 2020 was held in October 2020. John Haynes and Helena Chapman presented invited talks at the Australian Space Health Symposium, as a result of discussions held during the GEO Health CoP telecons. They presented talks on *Satellite Applications for Health Decision-making*, highlighting the use of Earth observations to inform health and air quality management and enhance public health surveillance. Over 45 people were in attendance. Helena Chapman also presented an invited talk in Spanish, *EO4HEALTH and GEO Health CoP: Using Earth Observation Data to Inform Health Decision-making*, at the Paraguay Space Agency's 4th Space Conference of Paraguay.

In November 2020, John Haynes and Juli Trtanj (NOAA) presented the invited talk, *GEO Health CoP and EO4Health Initiative: A Global Framework for Improving Health Decisions*, at the New Space Korea 2020: Uplift Conference.

In November 2020, the GEO Plenary 2020 was held virtually with pre-recorded and live sessions. This event aimed to highlight initiatives from GEO members, participating organizations, and associates in a series of live discussions and interactive content as well as implement the Canberra Declaration. The GEO 2020 Highlights Report provided major highlights and updates to the GEO Work Programme activities, including the GEO Community's Response to COVID-19.

In December 2020, the GEO Health CoP and the American Geophysical Union (AGU) partnered to hold the GEO Health CoP Meeting at AGU Virtual Fall Meeting 2020. Presenters included experts from the GEO Secretariat Team (Steven Ramage), AmeriGEO (Angelica Gutierrez), AGU (Mark Shimamoto), WMO (Joy Shumake-Guillemot), NASA (John Haynes), NOAA (Juli Trtanj), and Rensselaer Polytechnical Institute (Kathy Fontaine, Thilanka Munasinghe). Project updates were provided by Gina Tsarouchi (HR Wallingford), Antarpreet Jutla (U. of Florida), Tatiana Loboda (U. of Maryland, College Park), John Malone and Moara Rodgers (Louisiana State U./A&M College), and Ben Zaitchik (John Hopkins U.). Small Work Group leads offered updates on leveraging expertise with CoP members. With over 75 attendees, this meeting provided an opportunity for Earth and health scientists to describe key international projects and updates, enhance professional networks, and discuss priority focus areas that advance GEO/AGU efforts. It also allowed active engagement for the review of the GEO Health CoP Goals and Small Work Group activities, which support the 2020-2022 GEO Work Programme and further development of the GEO EO4HEALTH Initiative.

The NASA Applied Sciences Program issued a solicitation to support the 2020-2022 GEO Work Programme through Research Opportunities in Space and Earth Sciences (ROSES) 2016. This solicitation included a section targeting the EO4HEALTH Initiative.

Awards from this solicitation were announced in October 2017 for a three-year period of performance. In 2020, the following key accomplishments were noted for these projects:

- A project led by Antarpreet Jutla (U. of Florida) has integrated satellite data systems into the weekly time step for the epidemic and endemic models of cholera for Africa. The team is collaborating with the United Kingdom Department for International Development (UK-DFID), UNICEF, and AfriGEO. In 2020, the team tested the cholera trigger model in India, Syria, Yemen, and Sudan and produced cholera risk maps along coastal regions. The team is confident that these risk maps are ready to be integrated into health decision-making processes of these four countries. To date, since the model has successfully guided decision-making activities in Yemen, the team is working to integrate the cholera transmission model into the surveillance system, to enable scenarios on how cholera may be spread in the general population which will subsequently guide decision-making activities. This project was highlighted on NASA Earth Observatory web features in July 2020 (Of Mosquitoes and Models: Tracking Disease by Satellite) and August 2020 (Predicting Cholera Risk in Yemen).

- A project led by Tatiana Loboda (U. 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 is collaborating with Duke U. and Duke Global Health Institute in Myanmar. In 2020, the team has implemented the Malaria Burden Potential model of the MMEWS at spatial (30m) and temporal (8-day) resolutions and completed historical runs (2017-2018) to compare with available reports of malaria prevalence across Myanmar. The team continues to engage with stakeholders to refine the reporting system and ensure overall performance. With international travel restrictions, limited communication with Myanmar government officials, and collaborators reassigned to COVID-19 response efforts, scheduled site visits and training activities are on hold. The team will request a no-cost extension to finalize the operationalization of MMEWS. This project was highlighted on a NASA web feature in June 2020 (Gathering On-the-Ground Data with Tatiana Loboda).

- A project led by Jack Malone (Louisiana State U.) has used NASA satellite data (e.g. ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station, ECOSTRESS and Soil Moisture Active Passive, 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 is collaborating with Sao Paulo State

University, Adolfo Lutz Institute, Federal University of Bahía, University of Antioquia, Federal University of Uberlandia, and Butantan Institute. In 2020, models assimilating SMAP data showed similar eco-epidemiological patterns of visceral leishmaniasis and vector distribution in Sao Paulo and Bahia states, as compared to WorldClim Version 2 models based on temperature maximum/minimum, precipitation, and water budget (precipitation-potential evapotranspiration). These findings indicate that SMAP data on soil moisture can enhance models calculated from classical thermal and precipitation climate station data to assess risk of visceral leishmaniasis and guide control program interventions.

- A project led by Ben Zaitchik (Johns Hopkins U.) has 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 is collaborating with Johns Hopkins University and Brigham Young University. In 2020, the team has developed and integrated risk maps for target diseases (e.g. shigella, rotavirus) on the visualization platform, and shared results with end-user disease control partners. Feedback received from end-users has indicated the potential value of the information and provided a foundation for improvement. This project is highlighted in the *International Journal of Environmental Research and Public Health* manuscript (Pathogen-Specific Impacts of the 2011–2012 La Niña-Associated Floods on Enteric Infections in the MAL-ED Peru Cohort: A Comparative Interrupted Time Series Analysis).

The leadership team has continued its active participation and contribution to the monthly U.S. GEO and Americas Caucus meetings in 2020. They have provided regular updates on the GEO Health CoP and EO4HEALTH Initiative, including highlights from teleconferences, EO4HEALTH research projects, and small work group activities.

X. Looking Ahead

2021 will be a year of continued challenges as the COVID-19 pandemic continues, but with hope emerging as vaccine distribution is expanded. During 2021 and beyond, the HAQ Applications 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 TRACER-AQ field campaign in Summer 2021. The program looks forward to the launch of the new HAQAST in February and March 2021, with selection of the first round of HAQAST tiger teams in Summer 2021.

The program also plans to release an open solicitation to seek new three-year applications projects as part of ROSES 2021 in February 2021. Selections are expected to be announced in October 2021.

In 2021, HAQ Applications program personnel plan to participate in relevant sessions of the AMS Annual Meeting, the AMCA Annual Meeting, the Association of Schools & Programs of Public Health (ASPPH) 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 2021, a special 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., Plankton, Aerosol, Clouds, ocean Ecosystem [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. The ACCP missions are expected to move into pre-phase A in 2021, 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, the MAIA Earth Venture mission, and the GeoCarb mission.

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. Ozone is a key issue in this regard; measurements of aerosols over land areas with high albedo also have large errors. Even developed countries, such as the U.S., have relatively sparse ground-level aerosol networks and remotely-sensed observations provide critical data to fill coverage gaps. Developing countries have even fewer ground sensors, and sometimes none at all. Boundary layer processes are critical to air quality forecasts, as this is where people live and breathe. Satellite observations for air quality will be increasingly vital in the coming years. The launch of TEMPO in 2022, 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 address some of these challenges.

The HAQ Applications 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
AGU: American Geophysical Union
AMCA: American Mosquito Control Association
AMS: American Meteorological Society
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
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

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
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
NAQFC: National Air Quality Forecast Capability
NASA: National Aeronautics and Space Administration
NCAR: National Center for Atmospheric Research
NIEHS: National Institute of Environmental Health Sciences
NIHHIS: National Integrated Heat Health Information System
NLDAS: North American Land Data Assimilation 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
RSIG: Remote Sensing Information Gateway
S5P: Copernicus Sentinel-5 Precursor
SBA: Societal Benefit Area
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

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
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 Applications Area:

Program Manager:
John Haynes
jhaynes@nasa.gov

Senior Associate Program Manager:
Sue Estes
sue.m.estes@nasa.gov

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

Laura Judd
laura.m.judd@nasa.gov