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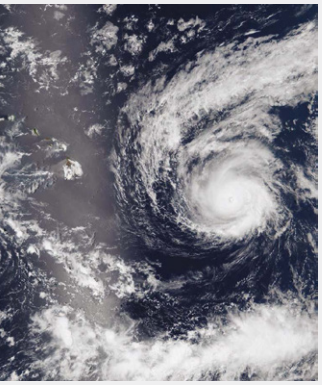
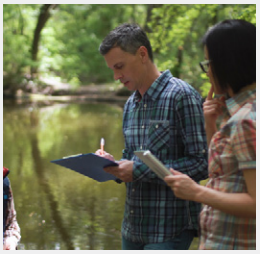

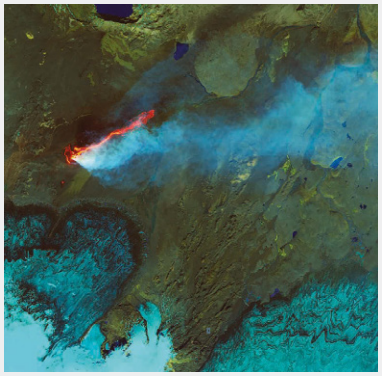


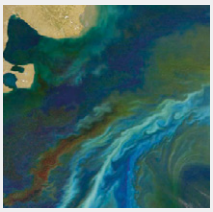


2018
Annual Summary

NASA Earth Science
Applied Sciences Program

Health & Air Quality

Health & Air Quality: 2018 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 the 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 (including Air Quality), Disasters, Ecological Forecasting, Agriculture/Food Security, and Water Resources.[1] The Program includes climate-related influences and impacts within each of these themes.

The Health and Air Quality Applications area encourages the use of Earth observations in air quality management and public health, particularly involving environmental health and infectious diseases. The area 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 2018

The past year was a productive one for the Health and Air Quality Applications area, with projects concluding or achieving significant milestones. Projects addressed public health issues such as air quality, infectious diseases, vector-borne diseases, environmental health, and harmful algal blooms (HABs). Eleven new investigators were selected through the ROSES 2017 Health and Air Quality Applications solicitation. 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.

The Health and Air Quality 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 2018, the

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

program continued monthly Health and Air Quality newsletters that were circulated online and via mailing list. The program expanded a website focusing on the GEO Health Community of Practice and showcased results across NASA web platforms. The applications area distributed applied research results and led or participated in meetings across the health/air quality and Earth-science community, at both the national and international levels.

The following report summarizes a few challenges and many achievements that occurred during 2018. The Health and Air Quality Applications area looks eagerly toward the coming years, 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:

- A New York State Department of Health project, led by Tabassum Insaf, combined Earth-observing data with public health information to determine the impacts of extreme heat on New Yorkers. The results showed adverse health effects began affecting citizens at lower temperatures than previously thought. The project's findings prompted National Weather Service Forecast Offices in upstate New York to officially lower their threshold for issuing heat advisories in the summer of 2018 from 100 degrees Fahrenheit to 95 degrees Fahrenheit. These results were showcased in a NASA web feature in June: https://www.nasa.gov/feature/nasa-helps-new-yorkers-cope-with-summer-swelter

- Effective and efficient characterization of West Nile Virus (WNV) risk is very important is South Dakota since, per capita, it has the largest incidence of WNV in the U.S. A project led by Michael Wimberly of South Dakota State University developed models which rely on both mosquito infection data and environmental data to make long/short term predictions of human WNV risk for every county in South Dakota. NASA data used in these models included meteorological fields (temperature, precipitation, and humidity) from the North American Land Data Assimilation System. This project has successfully applied the Arbovirus Monitoring and Prediction (ArboMAP) system for the third consecutive WNV season in the northern Great Plains. In 2018, there was direct coordination with the South Dakota Department of Health (SDDOH) to bring this system into operational use. In particular, WNV forecasts were directly integrated into the weekly reports disseminated by the SDDOH. The project completed the development of software that will ensure the sustainable application of these forecasts, including a user guide. The project principal investigator (PI) and staff

held a workshop at SDDOH headquarters in August, and SDDOH epidemiologists were trained on how to use this software. Based on these accomplishments, and with SDDOH assuming operational use of this system, the project has reached the maximum goal of Application Readiness Level (ARL) 9 -- sustained use of the application in operational decision making.[2]

- Cholera is caused by eating food or drinking water contaminated with a bacterium called *Vibrio cholerae*. The disease affects millions of people every year, resulting in severe diarrhea and even death. It remains a major threat to global health, especially in developing countries. Measurements from NASA Earth-observing satellites were used for the first time in 2018 to help combat a potential outbreak of the life-threatening cholera in Yemen. Humanitarian teams on the ground are targeting areas of Yemen identified by a NASA-supported project led by Antar Jutla from West Virginia University, which precisely forecasts high-risk regions based on environmental conditions observed from space. In spring 2018, the British government and international aid groups in Yemen began using these new cholera forecasts to target their work reducing cholera risk. This work includes promoting proper hygiene to prevent spread of the water-borne disease and distributing hygiene and cholera treatment kits. The positive results to date suggest that the forecast model has the potential to fundamentally change how the international community addresses cholera. This project was the subject of a NASA web feature in August: https://www.nasa.gov/press-release/nasa-investment-in-cholera-forecasts-helps-save-lives-in-yemen

- Florida was affected by one of the most severe Harmful Algal Blooms (HABs) in history during 2018, prompting a State of Emergency to be declared by the governor. Toxic alga blooms occur in the Gulf of Mexico from Texas to Florida mainly during the late summer/early fall. These “red tides” can kill fish, birds, dolphins, and manatees. The aerosolized toxin can also cause respiratory distress, including coughing, watery eyes, runny nose, and sinus pain. Starting in October 2018, people looking to avoid the hazardous effects of toxic red tides around St. Petersburg and Pinellas County turned to a new smartphone-based pilot information resource updated several times a day to help them know the risks before they headed to the beach. The new 24-hour Experimental Red Tide Respiratory Forecast allows the public to see which beaches are most impacted by red tide. This new forecast, updated every three hours, was developed by NOAA's National Centers for Coastal Ocean Science in partnership with NASA, GCOOS, the Florida Fish and Wildlife Conservation Commission, and Pinellas

[2] A video (“Mosquito Meets MODIS”) was produced in 2016 to further explain this project: https://www.youtube.com/watch?v=ag-Zo0izSNg.

County Environmental Management. It builds on NOAA's Harmful Algal Bloom Forecast System and the Near Real-Time Integrated Red Tide Information System from the University of South Florida, both of which use NASA satellite data. This project, led by Richard Stumpf of NOAA, was highlighted through a story on NASA Earth Observatory in August (https://earthobservatory.nasa.gov/blogs/earthmatters/2018/08/24/how-scientists-are-tracking-red-tides-with-satellites-and-smartphones/) and a NASA web feature in October (https://www.nasa.gov/feature/space-views-aid-florida-red-tide-health-alerts-1).

- A project led by Jeffery Pierce of Colorado State University (CSU) estimated the respiratory and cardiovascular health risks for specific demographic populations exposed to wildfire particulate matter (PM) in order to assist air quality forecasters in Colorado. Forecast tools were developed that predict wildfire PM concentrations, population exposure, and the potential increase in morbidity due to wildfire smoke. The Smoke Health Impact Assessment (HIA) Forecaster tool (http://rgan.atmos.colostate.edu/smoke_forecaster/) is currently being tested through systematic surveys conducted by CSU collaborator Marilee Long in the Department of Journalism and Media Communication with funding from the Kauvar Foundation. Air-quality forecasters in the Colorado Department of Public Health and the Environment (CDPHE), as well as the public, are the target audience for testing the tool. Once testing is complete, CDPHE plans to use the tool as part of their forecasting system. Elements of the tool are also being included in the Centers for Disease Control and Prevention (CDC) Environmental Public Health Tracking Network.

- The project, *Improving the Representation of Physical Atmosphere in Air Quality Decision Support Systems Used for Emissions Control Strategy Development*, led by Arastoo Pour Biazar (University of Alabama in Huntsville), supported the Texas Commission for Environmental Quality (TCEQ) meteorological modeling staff to fully integrate the cloud assimilation system (CAS) software developed at UAH into the TCEQ computing cluster for operational use. Following the successful transition of CAS into TCEQ's operational environment, TCEQ tested the system in their State Implementation Plan (SIP) activity for pollution reduction and mitigation strategies. The results, with respect to surface observations, showed significant improvement in temperature, wind speed and direction statistics and improved the modelling capabilities at TCEQ.

The program announced the selection of 11 new investigators through the ROSES 2017 A.39, *Earth Science Applications: Health and Air Quality* solicitation. This solicitation sought results-oriented projects focused on the integration of Earth observations into decision-making activities related to health and air quality. The objectives of a proposed project were a) to develop and prove the potential enhancements of an application of

specific Earth observations to one or more decision-making activity; and b) to transfer and enable the adoption of this application by one or more specific end-user organizations in a sustainable manner (i.e., without continued NASA financial support post-project). Fifty-seven proposals were received and the peer review panel completed deliberations on June 1. Selections were announced in August. Abstracts of selected proposals can be found at the following link: https://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=646203/solicitationId=%7BD8C7A6B4-ABDC-C9DD-6EC7-09B41E02A5C7%7D/viewSolicitationDocument=1/HAQ17%20SELECTIONS.pdf

IV. Health and Air Quality Applied Sciences Team

In 2018, the NASA Health and Air Quality Applied Sciences Team (HAQAST) (http://haqast.org), led by Tracey Holloway at the University of Wisconsin-Madison, continued its mission of linking NASA's satellites and data products to public stakeholders in the air quality and public health communities. Of special note was the completion of four Tiger Team projects in the summer of 2018, and the launch of four new Tiger Team projects, to be completed in the summer of 2019. Each Tiger Team is a short-term, high-impact collaborative effort between HAQAST members and public stakeholders to identify and solve an immediate problem using NASA data and products. Each Tiger Team draws on the expertise of multiple HAQAST PIs to find the best, multifaceted solutions to pressing health and air quality issues.

The four recently completed Tiger Teams include:

1. *Demonstration of the Efficacy of Environmental Regulations in the Eastern U.S.*, co-led by Bryan Duncan (NASA Goddard) and Jason West (University of North Carolina).
2. *Supporting the Use of Satellite Data in State Implementation Plans (SIPs)*, led by Arlene Fiore (Columbia University/Lamont-Doherty Earth Observatory).
3. *High Resolution Particulate Matter Data for Improved Satellite-Based Assessments of Community Health*, led by Pat Kinney (Boston University).
4. *Improved NEI NOx Emissions Using OMI Tropospheric NO_2 Retrievals*, co-led by Daniel Tong (George Mason University) and Brad Pierce (director, Space Science and Engineering Center, University of Wisconsin-Madison).

Each team, in addition to working in concert with public stakeholders on specific projects, has also made publicly available a variety of final, sustainable deliverables.

1. The work of the *Demonstration of the Efficacy of Environmental Regulations in the Eastern U.S.* Tiger Team has been archived at

https://airquality.gsfc.nasa.gov (see especially the tabs for **Pollutants**, **Impacts**, and **Resources**).

2. The *Supporting the Use of Satellite Data in State Implementation Plans (SIPs)* Tiger Team has generated a series of detailed, yet easy-to-follow, technical guidance documents that will help air quality managers use NASA data for SIPS. These documents can be found here: https://airquality.gsfc.nasa.gov/state-implementation-plans.
3. The *High Resolution Particulate Matter Data for Improved Satellite-Based Assessments of Community Health* Tiger Team culminated in a public webinar (so popular that it reached its audience capacity) available here: https://www.youtube.com/watch?v=2q9hBjmA3Cs
4. The *Improved NEI NOx Emissions Using OMI Tropospheric NO_2 Retrievals* Tiger Team has documented its work here: http://cimss.ssec.wisc.edu/education/gl/ttnox.

Four new Tiger Teams were launched in the summer of 2018. These four were chosen from among eight proposals that underwent a competitive and rigorous evaluative process. Seven peer reviewers read and scored each of the eight proposals. The winning teams were:

1. *Satellite-Evaluated and Satellite-Informed O_3 Distributions for Estimating U.S. Background O_3*, led by Jessica Neu (NASA JPL).
2. *Supporting the Use of Satellite Data in Regional Haze Planning*, led by Arlene Fiore (Columbia University/Lamont Doherty Earth Observatory).
3. *Using Satellite Remote Sensing to Derive Global Climate and Air Pollution Indicators*, led by Susan Anenberg (George Washington University).
4. *Air Quality and Health Burden of 2017 California Wildfires*, led by Susan O'Neill (U.S. Forest Service).

All four Tiger Teams met regularly with stakeholders in 2018 and are making progress on their objectives. Final deliverables will be available in late summer/early fall 2019.

HAQAST continues to benefit from its communication outreach efforts, which include regular newsletters (sent to a mailing list of 718 subscribers, an increase of approximately 12 percent over 2017), Twitter (where @NASA _HAQAST currently has more than 4,000 followers—a five percent increase over 2017), and a focus on media outreach and public engagement of applied research. HAQAST's applied research has been profiled in *Sierra Magazine*, *EOS*, the EPA's 2018 *Air Trends Report*, *Online Education's* "Women Breaking Barriers" series, and numerous NASA outlets.

In particular, the 2018 EPA *Air Trends Report* released in August included a NASA *Aura*/Ozone Monitoring Instrument (OMI) sulfur dioxide (SO_2) animation as part of the National Ambient Air Quality Standards (NAAQS) chapter. HAQAST created the

animation, which is available at https://airquality.gsfc.nasa.gov/particulate-matter and https://gispub.epa.gov/air/trendsreport/2018/#naaqs. This is the third year in a row that the EPA *Air Trends Report* has included NASA Earth observations.

The HAQAST website continues to be a "one-stop shop" for relevant NASA data and tools. The website logged 6,483 unique users in 2018. The most popular pages were the ones relating to HAQAST meetings, tiger teams, PI biographies, and NASA tools.

HAQAST hosts meetings every six months to review progress and meet with key stakeholders. Action items are identified at these meetings on the basis of the needs expressed by participating partners. HAQAST 4 was hosted by the University of Wisconsin-Madison, from July 16–17. A myriad of stakeholders were in attendance, including LADCO, the American Lung Association, Maricopa County (Ariz.) Air Quality Department, SCAQMD, TCEQ, Missoula City-County (Mont.) Health Department, NOAA, the Nisqually Indian Tribe, CDC, and WESTSTAR-WRAP. The near-final results of the first round of Tiger Teams were discussed, the second round of Tiger Teams were formally announced, and much discussion of collaboration occurred during the many opportunities for networking that were built into the conference's schedule.

Stakeholders and end users also presented on HAQAST collaborations and current challenges. PIs met in closed session at the conclusion of the meeting to collaborate and discuss the second round of tiger teams.

Participation at the semi-annual HAQAST meetings continues to grow at an exceptional rate (see Fig. 1). For example, HAQAST 4 was attended by 140 in-person conference-goers, with more than 200 additional attendees joining by remote connection. HAQAST conferences have gained the reputation as friendly, intellectually fulfilling, and publicly useful venues for disseminating the latest and greatest applied air quality research, as well as a valuable space for researcher/public stakeholder networking.

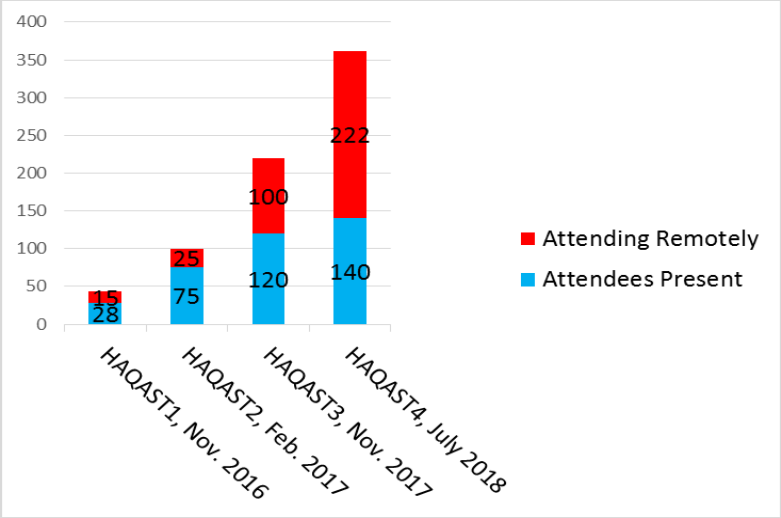

Fig. 1: All attendees (both remote and in-person) at HAQAST semi-annual meetings to date.

HAQAST scored the NASA Earth Observatory "Image of the Day" on December 10, 2018 (*The Seasonal Rhythms of Ammonia*). Ammonia (NH_3) is a key component of $PM_{2.5}$. Though there are naturally occurring sources of NH_3, most of it is a byproduct of agricultural fertilization. Until now, it has been very difficult to quantify how much NH_3 is given off by agriculture, but PI Mark Zondlo (Princeton University), drawing on CrIS, TES, AIRS, and IASI has been able to construct monthly maps of unprecedented detail showing the seasonal variations of NH_3.

The year 2018 saw the publication of HAQAST members' applied research in a host of top tier journals, including *Proceedings of the National Academy of Sciences*, *Environmental Science & Technology*, *Environmental Health Reports*, *Journal of Atmospheric Chemistry and Physics*, *Journal of Allergy and Clinical Immunology*, *Environmental Research Letters*, *EM*, *Environmental Health Perspectives*, *Elementa*, and *Atmospheric Environment*.

The *Journal of Applied Remote Sensing* ran a special section for the Volume 12 (Number 4) (https://www.spiedigitallibrary.org/journals/journal-of-applied-remote-sensing/volume-12/issue-04#SpecialSectiononAdvancesinRemoteSensingforAirQualityManagement), entitled, *Special Section in Remote Sensing for Air Quality Management*, to which HAQAST members contributed three papers, including an overview of HAQAST: "Short history of NASA Applied Sciences Teams for Air Quality and Health."

HAQAST members Bryan Duncan (NASA Goddard) and Ted Russell (Georgia Institute of Technology) were authors of the *Decadal Survey for Earth Science and Applications from Space*'s Weather and Air Quality panel, HAQAST collaborator Steve Ackerman

(UW-Madison) was the panel's co-chair, and HAQAST team lead Tracey Holloway (UW-Madison) was a reviewer. The Decadal Survey was released in January 2018.

Finally, in December 2018, the NASA Applied Sciences Program, after consultation with NASA Earth Science Division leadership, decided to extend the period of performance of HAQAST by one additional year. Therefore, HAQAST will extend through Summer 2020. This decision was made in recognition of the outstanding work of HAQAST over the past two years, through expanding the environmental health and air quality management community and increasing the use of NASA data and tools for societal benefit. HAQAST is currently working on several critical issues related to U.S. air quality and environmental health, including wildfires in California. It is expected that this additional year of service will allow HAQAST to continue addressing these needs, along with other quick-turnaround, high-priority projects.

V. Assessment

Overall, the portfolio exceeded expectations on technical performance in 2018 with several projects reaching top-tier ARLs of 7 to 9.

The portfolio continued to carry a relatively high burden of uncosted funds in 2018. Associates worked diligently with PIs to uncover issues at their particular institutions. Many times this appeared to be an issue of "invoice lag" between NASA and the institutions, with costed funds not showing on NASA accounts until long after invoices had been submitted by grantees. However, significant progress was made -- FY17 uncosted funds were down ~82 percent from December 2017 to December 2018.

Overall, the portfolio had a good track record for remaining on schedule in 2018 and accomplished significant results in all areas, with a bright outlook for 2019.

VI. Project Portfolio

At the end of 2018, the Health and Air Quality portfolio included 15 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, four projects had an ARL of 1-3; three projects were ARL 4-6; and eight projects had achieved an ARL of 7-9. Over 25 percent of projects increased at least one ARL from November 2017 to November 2018. The appendix of this report includes project highlights for 2018.

VII. Program Management

The program conducted its 2018 Annual Team Meeting in September in Burlington, Vt. Approximately 40 attendees participated. Highlights included a local perspective address from the Environmental Health Surveillance Chief of the Vermont Department of Health and a Federal partner address from the CDC. Each project in the portfolio presented their milestones achieved over the past year, plans for the coming year, ARL estimates, budgets, and any risks/opportunities foreseen. This included presentations from the satellite application awards (*S-NPP*) and the GEO Earth Observations for Health (EO4HEALTH) awards. Additionally, there were presentations from the VALUABLES consortium, Applied Remote Sensing Training (ARSET), SERVIR, and DEVELOP of the Capacity Building program, and an update on HAQAST. Participants were also introduced to the new leads for Applied Sciences Communications, as well as to the new NASA Open Innovation and Community Applications Manager, Shobhana Gupta. Presentations from the 2018 review can be found at the following link: https://weather.msfc.nasa.gov/conference/phconference_vt_home.html.
Associates and Headquarters program management continued to meet regularly through 2018 to coordinate on costing issues, progress on project metrics, conference and workshop presentations, and on project results highlighted through web features or other internal and external venues. These discussions were briefed bi-monthly to Applied Sciences leadership at regularly scheduled program reviews.

Associates for Health and Air Quality in 2018 continued to be Sue Estes (University of Alabama in Huntsville) and Ali Omar (NASA Langley Research Center (LaRC)). However, in late 2018, Ali Omar was promoted to a new position at NASA LaRC and the program announced the selection of Jacquelyn Witte (NASA Goddard Space Flight Center/SSAI) as the new associate for Health and Air Quality. The program was proud to continue to host Helena Chapman as our AAAS Science and Technology Policy Fellow.

VIII. Community Leadership

The applications area presented and led sessions at meetings of the American Thoracic Society, the Air and Waste Management Association, and the American Meteorological Society (AMS). Sessions at the AMS annual meeting in Austin, Texas, in January were held as part of the Ninth Conference on Environment and Health, of which NASA is a standing committee member. The theme was *Transforming Communication in the Weather, Water, and Climate Enterprise*. NASA co-chaired the conference, and several investigators from the Health and Air Quality Applications area presented papers in a session titled, *NASA Earth Observation Systems and Applications for Health and Air Quality Models and Decisions*. Additional talks were given at the NASA Hyperwall at the booth in the exhibit hall.

In February, John Haynes gave a brown-bag seminar entitled, *Earth Observations Applied to a Changing World: NASA Health and Air Quality Applications*, at the Milken Institute School of Public Health at the George Washington University. The seminar was well attended, with more than 30 in-person participants and many more through WebEx. John Haynes and Helena Chapman also met with several faculty members of the Milken Institute. Both faculty and students were interested in ways that they could participate and collaborate on projects utilizing remote sensing. This included grant opportunities, NASA fellowships and internships (including DEVELOP), HAQAST, and capacity building activities (ARSET).

The Association for Schools and Programs of Public Health (ASPPH) Annual Meeting 2018 was held in March 2018 in Arlington, Va. John Haynes and Helena Chapman presented the scientific poster, *Using Satellite Data for Applications in Public Health Practice*. NASA HAQ Team and ASPPH Board Members held a first telecon to discuss potential collaborations, including Earth observation data capacity-building activities. For National Public Health Week in April 2018, the NASA HAQ and Communications Teams shared five projects on the NASA Applied Sciences Program website and social media that promoted the use of Earth observations in public health applications. These projects included: Using NASA Satellite Data to Predict Malaria Outbreaks, U.S. Air Quality Monitoring through Earth Observations, Space-based Observations are Helping Eradicate River Blindness in the Americas, Satellites are Helping Detect and Forecast Harmful Algal Blooms, and Earth-observing Data are Helping South Dakota's Department of Health Stay One Step Ahead of West Nile Virus Outbreaks. Through NASA Earth Facebook and Twitter portals, these five public health stories were widely disseminated to more than 1.2 million users.

The American Thoracic Society's annual meeting was held in May 2018 in San Diego, California. On May 19, NASA co-sponsored a session entitled, *Using NASA's Satellite-Remote Sensors for the Study of the Environment and Respiratory Related Disease*, with more than 80 people in attendance.

NASA and the Wilson Center sponsored the GPM 2018 Vector-borne and Water-based Diseases Workshop in May 2018 held at the Wilson Center in Washington, D.C. This workshop showcased the use of Earth-observation data to inform and predict vector-borne and water-related diseases. It also served as an educational and professional networking event, connecting Earth scientists and other practitioners and expanding the end-user community. More than 100 attendees participated in-person and virtually in this workshop. John Haynes moderated the first panel (New and Emerging Research) of three researchers, Antar Jutla (West Virginia University), Mike Wimberly (South Dakota State University), and Ben Zaitchik (Johns Hopkins University). Helena Chapman served as an invited panelist for the second panel (Health, Data, and Complexity), promoting the use of Earth observations in One Health applications. The final

discussion marked future steps for workshop participants to maintain connected networks and attend future capacity-training opportunities.

As part of the One Health Academy monthly seminar series, held at the American Society of Microbiology, Helena Chapman presented, *Using Earth Observation Data in One Health Applications for Societal Benefits*, in May 2018. She described the integration of Earth observation data in the "One Health" toolkit for applications that influence societal benefits. The discussion period addressed questions about data access and availability, especially in relation to other environmental data that the "One Health" community uses.

John Haynes delivered the keynote address at the GLOBE Midwest Student Research Symposium in Detroit on May 18, 2018.

The program co-sponsored the 2018 Air and Waste Management Association (A&WMA) Annual Conference & Exhibition (ACE) Meeting in June in Hartford, Conn., and convened a panel to discuss and present NASA's satellite and sub-orbital measurements and models to address air quality and health applications. John Haynes presented an overview of the program portfolio, followed by presentations by Jeffery Pierce (Colorado State University) and Ali Omar (on behalf of Jun Wang, Iowa State University). The panel was chaired by Sue Estes. The NASA exhibit booth and Hyperwall display showcased NASA satellite observations and modelling animations, and Hyperwall talks were presented by Helena Chapman, John Haynes, Ali Omar, and Sue Estes. A&WMA's ACE is the most comprehensive conference on environmental technology and regulation and brings environmental professionals from around the world together to hear technical presentations on cutting-edge topics and to interact with exhibiting businesses and organizations demonstrating the latest environmental products and services. The program has identified A&WMA as one of the boundary organizations that will provide a bridge between applications research and air quality practitioners. NASA has agreed to continue its participation at the 2019 Annual Meeting in Quebec City, Quebec, Canada.

NASA Health and Air Quality investigators and stakeholders presented at the ARSET Advanced Webinar, *Satellite Remote Sensing of Dust, Fires, Smoke, and Air Quality*, July 10–11 in Pullman, Washington.

The Joint Annual Meeting of the International Society of Exposure Science and the International Society for Environmental Epidemiology (ISES-ISEE 2018) was held in Ottawa, Canada, from August 26–29, 2018. The program convened a session titled, *NASA Applications for Public Health and Air Quality Models and the Translation of Research into Policy and Other Decision Making*, with approximately 85 attendees. The ISES-ISEE 2018 Joint Annual Meeting leveraged local and international expertise to

address complex local and global topics relevant to exposure science and environmental epidemiology.

At the American Public Health Association (APHA) Annual Meeting & Expo 2018, held in San Diego in November, Helena Chapman represented the program and presented two oral presentations to approximately 50 attendees per session: *Operationalizing "One Health": Integrating Remote Sensing and Citizen-Based Observations* (APHA Veterinary Public Health Special Primary Interest Group) and *Integration of Satellite Data into Environmental Health Education, Practice, and Research* (APHA Environment Section). She also assisted with educational outreach activities at the U.S. Global Change Research Program (USGCRP) and American Association for the Advancement of Science (AAAS) exhibit hall booths.

For One Health Day in November 2018, the NASA HAQ and Communications Teams shared three projects on the NASA Applied Science Program website and Making Space for Earth blog. These projects included: Preventing Heat-Related Illnesses in New York, NASA Investment in Cholera Forecasts Helps Save Lives in Yemen, and Space Views Aid Florida 'Red Tide' Health Alerts. By encouraging public engagement from a wide range of disciplines, the One Health Day campaign promotes the development of transdisciplinary projects that address health threats to humans, animals, and the environment.

As part of the CDC Zoonoses & One Health Update (ZOHU) monthly calls, Helena Chapman was one of three invited panelists on the December 2018 ZOHU call. She presented the topic, *Using Earth Observation Data in One Health Applications for Societal Benefits*, to over 270 attendees. This ZOHU panel presentation can be found on YouTube.

The American Geophysical Union's (AGU) Fall Conference was held in Washington, D.C., in December 2018. The meeting offered multiple general sessions, each covering a different and exciting topic applicable across Earth and space science. The program convened an oral session on December 12 and a poster session on December 13 entitled, *Using NASA's Satellite and Suborbital Measurements and Modeling for Health and Air Quality Applications*. The oral and poster sessions were chaired and organized by Sue Estes. John Haynes presented an overview of the program at the oral session and was followed by eight additional speakers. The session was part of the newly organized GeoHealth track at AGU. Multiple portfolio investigators presented papers, and posters in additional sessions, as well as talks at the NASA Hyperwall.

HAQAST participated in a wide range of targeted meetings and ongoing stakeholder engagement. For example, Talat Odman (Georgia Institute of Technology) led a well-attended webinar for air quality specialists, smoke managers, and prescribed-burn program coordinators to demonstrate the science and management of the Southern

Integrated Prescribed Fire Information System (SIPFIS). The webinar is publicly available at: https://www.youtube.com/watch?v=Q7XVO_8PIeg.

Minghui Diao (San Jose State University) presented on downscaling retrospective daily fine particulate matter at the American Thoracic Society conference in May 2018. Daven Henze (University of Colorado-Boulder) presented on whether or not ozone, and not $PM_{2.5}$, is the largest contributor to premature death associated with the transcontinental transport of air pollution at the AGU 2018 Fall Meeting. Of special note is Susan O'Neill's (USFS) myriad and ongoing work with the agencies responding to the 2018 California wildfire season. Her recently launched Tiger Team, Air Quality and Health Burden of 2017 California Wildfires, has more than 31 stakeholders contributing to it, and is in the midst of developing a series of training modules to help support in-the-field fire professionals.

The program continued its active participation in the USGCRP Climate Change and Human Health Working Group (CCHHG) in 2018. NASA researchers and members of the Health and Air Quality program leadership contributed to the development of health-related material for the Fourth National Climate Assessment (NCA4). NCA4 was published in November 2018.

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. It seeks to use environmental observations to improve health decision-making at the international, regional, country, and district levels. The GEO Health and Environment CoP expanded its activities in 2018 under the leadership of 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 2017-2019 GEO Work Programme, and foster the development of a Work Plan to inform the 2020-2022 GEO Work Programme. The CoP also expanded a new website to keep the community informed of activities, news, and opportunities (http://www.geohealthcop.org).

In March 2018, the GEO Health CoP held a telecon to provide updates on scientific initiatives and continued elaboration of the Work Plan in working groups. Two GEO Earth Observations for Health (EO4HEALTH) projects, *Multi-sensor Data for Myanmar Malaria Early Warning System* (Tatiana Loboda, University of Maryland), and *Earth Observations for Cholera Prediction in Africa* (Antarpreet Jutla, West Virginia University), were highlighted among project updates. A total of 29 participants, representing different agencies in public and private sectors, participated on the telecon.

In November 2018, the GEO Health CoP held another telecon to provide updates on scientific initiatives and elaboration of the Work Plan. The leads of three GEO CoP Small Working Groups—Heat (Tatiana Loboda, University of Maryland, College Park), Infectious Diseases (Antarpreet Jutla, West Virginia University), and Cross-cutting Issues (Dorian Janney, NASA Goddard Space Flight Center)—provided brief reports on their Work Plan sections. Doug Cripe (GEO Secretariat representative) and Kym Watson (Fraunhofer Institute of Optronics, System Technologies and Image Exploitation) offered program and project updates. Invited speaker Lisa Conti (One Health Initiative/Florida Department of Agriculture and Consumer Services) noted that the One Health approach can bring Earth observation data and technology to strengthen transdisciplinary research and community collaborations. A total of 24 participants, representing different agencies in public and private sectors, participated on the telecon.

In December 2018, the GEO Health CoP and the American Geophysical Union (AGU) partnered to hold the GEO Health CoP Meeting at AGU 2018 in Washington, D.C. Presenters included experts from the GEO Secretariat (Doug Cripe), PAHO (Marcelo Korc), AGU (Mark Shimamoto), NASA (John Haynes, Helena Chapman, Argyro Kavvada), NOAA (Juli Trtanj), NIH (John Balbus), and AquaWatch/Blue Planet (Emily Smail). GEO project updates were provided by Antarpreet Jutla (West Virginia U.), Ben Zaitchik (Johns Hopkins University), and Tatiana Loboda (University of Maryland, College Park). This meeting provided an opportunity for Earth and health scientists and practitioners 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 Work Plan, which supports GEO efforts and furthers development of the GEO Earth Observations for Health community activity to a potential initiative.

The NASA Applied Sciences Program issued a solicitation to support the GEO Work Programme through ROSES 2016. This solicitation included a section targeting the EO4HEALTH community activity. Awards from this solicitation were announced in October 2017 for a three-year period of performance. Accomplishments achieved during 2018 from the four awarded EO4HEALTH projects can be found in section C of the Appendix.

X. Looking Ahead

During 2019 and beyond, the program will continue to expand its relationship with current and future relevant NASA missions and designated observables, as well as field and Earth Venture (EV) campaigns. The program looks forward to the results of the second round of HAQAST Tiger Team initiatives. Two HAQAST team meetings are planned in 2019. The first meeting will be at Arizona State University in Phoenix in January, with the second meeting at a TBD location in July.

Sessions in 2019 are planned for the AMS Annual Meeting, the Air and Waste Management Association, the American Thoracic Society, and the American Public Health Association, among other conferences.

In fall 2019, the program will celebrate the fifteenth anniversary of its partnership agreement with the CDC. Planning is underway to showcase the myriad results of this partnership at an event in Atlanta.

The program will continue to keep abreast of studies and opportunities related to Program of Record missions (e.g., PACE) and Designated Observables outlined in the new *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. Additionally, the program is active in applications planning for the upcoming TEMPO Earth Venture mission, the MAIA Earth Venture mission, and the GeoCarb Earth Venture mission.

The program will continue to examine “grand challenges” to the community. For example, accurate ground-level aerosol and constituent measurements from remotely-sensed columnar values represent another grand community challenge. While progress has been made in this area, thanks to investments in algorithm development and targeted field campaigns, large discrepancies still remain. Ozone is a critical issue in this regard; 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 with remotely-sensed observations providing critical data to fill coverage gaps. Developing countries have even fewer ground sensors, and sometimes none at all. Satellite observations for air quality will be increasingly vital in the coming years. The upcoming launch of TEMPO and its Korean (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 Health and Air Quality 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 related transition to operations activities currently performed 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. Active Health & Air Quality 2018 Project Highlights

Project: Enhancing Data-driven Decision Support for Highly Invasive Vectors

PI: Christopher Barker

Organization: University of California, Davis

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, was developed for the creation of distribution and suitability maps for invasive mosquitoes, *Aedes albopictus* and *Aedes aegypti*. These mapping systems will use near-real-time mosquito surveillance data, as well as NASA and non-NASA Earth observations. These maps will be used to drive generalizable stochastic models for mosquito dynamics and spread on real landscapes to guide surveillance and control. This mapping system will be used to link models to real-time surveillance data through integration and evaluation in the CalSurv Gateway decision support system. The package models are expected to be adopted in other locations in the U.S. and southern Europe. A supplement was added in 2016 to this proposal to include Zika as well as dengue and chikungunya transmission models to predict human disease risk. Initial models for mosquito spread and suitability were developed in 2017, and multiple publications are in preparation concerning the global distribution of invasive mosquitoes. This project solicited input on new decision-support tools from several key partners in mosquito control and public health through meetings and one-on-one conversations. The project solicited feedback on the utility of developed model-based tools for targeting mosquito control to reduce invasive *Aedes* mosquitoes and prevent local transmission of Zika virus, and suggestions have been incorporated into the map tools that came online in September 2017. The latest version of the Zika virus risk map (2018) includes a time slider and now averages NASA TOPS temperatures over the past week to provide a more stable indication of recent Zika virus risk for any particular date. Risk is based on surveillance data (models fitted to mosquito trap collections by region), NASA TOPS temperatures, and a model for Zika virus' basic reproductive rate. This project is in a no-cost extension until February 28, 2019.

Project: Incorporating Space-borne Measurements to Improve Air Quality Decision Support Systems

PI: Arastoo Pour Biazar

Organization: University of Alabama in Huntsville (UAH)

- The main objective of this project is to improve the representation of physical atmosphere in air quality management Decision Support Tools (DSTs) used in the State Implementation Plan (SIP) process for development and evaluation of emission controls under the provisions of the Clean Air Act. SIPs are at the nexus of health effects and economics. Nationally, the economic costs of such decisions can amount to billions of dollars. Thus, accuracy in the DST is critical to determining efficient cost-effective strategies for attaining National Ambient Air Quality Standards. The target DST in this project is the Weather Research and Forecasting (WRF) and Community Multiscale Air Quality (CMAQ) modeling systems. CMAQ is an EPA-developed photochemical modeling system typical of the modeling systems now used by many states. This project will provide a system for routine utilization of NASA science and satellite products in the DST. The satellite products include surface skin temperature, insolation, and albedo from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor onboard polar orbiting satellites and Geostationary Operational Environmental Satellite (GOES) observations under NASA legacy science to complement polar-orbiting observations. UAH also will be producing Photosynthetically Active Radiation (PAR) as a new satellite product to be used in the DST. The applied partners in this project are EPA's Atmospheric Modeling Division at the National Environmental Research Laboratory, the California Air Resources Board, Bay Area Air Quality Management District, Texas Commission on Environmental Quality (TCEQ), and Georgia Environmental Protection Division. In 2018, the project fully integrated the cloud assimilation system (CAS) software developed at UAH into the TCEQ computing cluster for operational use. Following the successful transition of CAS into TCEQ's operational environment, TCEQ tested the system for a SIP activity. The results with respect to surface observations for this episode showed significant improvement in temperature, wind speed and direction statistics and improved the modelling capabilities at TCEQ. These tools are used for preparing State Implementation Plans (SIPs) for pollution reduction and mitigation strategies.

  Due to high priority of this research for the state of Texas in its SIP modeling activities, the Texas Air Quality Research Program provided complementary funding ($200K in 2016) and, in 2017, it funded complementary projects titled, *Use of Satellite Data to Improve Specifications of Land Surface Parameters*, at $148K, and

Support for Cloud Assimilation into the Weather Research and Forecasting (WRF) 2012 Modeling at the TCEQ, at $100K.

The approach to generate satellite-based PAR was to devise a parametric formulation to convert satellite-derived insolation into PAR. Thus, the first step in this process was to ensure that the insolation product used in the conversion was of highest quality. Two periods, summers of 2006 and 2013, were identified for evaluation. Also in 2016, the evaluation and use of skin temperature as a model evaluation metric was provided for the period of September 1-30, 2013, which was part of the Houston campaign of Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) project. Aircraft measurements of skin temperature and air temperature were also used in this evaluation. The National Oceanic and Atmospheric Administration (NOAA) Comprehensive Large Array Data Stewardship System (CLASS, www.class.ncdc.noaa.gov) was the source of the first skin-temperature data tested. These data were derived from *GOES* and is under the CLASS category of *GOES* Surface and Insolation Products (GSIP). The evaluation of the NOAA-GSIP skin-temperature product revealed unphysical air temperatures over the western U.S. including parts of Texas when compared to the Moderate Resolution Imaging Spectroradiometer (MODIS) observation. The project is in a no-cost extension through June 2019.

Project: A Multi-Sensor Remote Sensing Approach to Predict Cholera

PI: Antarpreet Jutla

Organization: West Virginia University

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, is developing a satellite-derived cholera prediction system, linking macro- and micro-environmental processes, for better decision-making strategies to prevent or minimize the impact of an outbreak. This team is identifying and synthesizing the role of acro-environmental processes for epidemic, mixed-mode endemic, and endemic cholera; developing a satellite data driven hydro-climatological risk model from conditions favorable for the three types of cholera; and developing a population-based cholera outbreak index. This project will enhance the decision making of several health organizations; provide tools to justify development of appropriate water and sanitation infrastructure in the susceptible regions; and aid in understanding the impacts of climate change on the occurrence of outbreaks. This project hopes to inform the development of suitable long-term climate change adaptation policies regarding cholera. This project was awarded a socioeconomic benefits study augmentation in 2016.

Through techniques developed in this project, the team concluded in May 2017 that an epidemic outbreak of cholera was possible and very likely to occur in Yemen in summer 2017. This prediction was validated. The forecast was made at least four weeks in advance of the outbreak based solely on Earth observations. Thus, scalability of this project to other areas of the world is likely to be successful. The project employs *GPM*, MERRA-2, NOAA-NCEP and SEDAC data.

The socioeconomic benefits portion of this project has seen impressive results. This portion of the project utilizes ground data as well as volunteers to assist in canvassing at-risk populations. In 2018, a second study in Bangladesh was completed to verify previous results. The project has shown a significant benefit to the local communities to help predict cholera and take actions to prevent an outbreak.

The prototype applications functionality has been tested and demonstrated in the context of the targeted decision-making activity (Bangladesh and Yemen). The project has received a lot of attention from media as well as adding some new international partners. This project is in a no-cost extension until February 28, 2019.

Project: Evaluate, Enhance, and Apply *Aura* Products in Public Health Tracking

PI: Yang Liu

Organization: Emory University

- This interdisciplinary team brings together experienced remote-sensing experts, environmental-exposure modelers, and epidemiologists. By integrating ground observations and atmospheric chemical-transport model simulations, the team is enhancing the existing OMI surface UV (OMUVB) product by better accounting for the impact of absorbing aerosols in the retrieval of surface UVB irradiance and erythemal doses. In addition, OMUVB uncertainties due to SO_2 and NO_2 absorption will be analyzed and corrected primarily in polluted urban regions. The conversion from the dose rate estimated at OMI overpass time to that at the local noon time—and eventually to the daily-average dose—will also account for diurnal change of aerosols. After evaluating the accuracy of the enhanced OMUVB product with ground measurements, the project will spatially match OMUVB exposure doses to 3,100 U.S. counties to study the association with county-level melanoma incidences reported by the National Cancer Institute. Major confounding factors such as indoor tanning use, education, poverty, health insurance, and rural-urban status will also be processed and included in the epidemiological model. The project team is working closely with the CDC Tracking Branch to develop UV exposure indicators and

measures as well as detailed documentation for public release on the Tracking Network.

In the U.S., the annual number of adults treated for skin cancer increased from 3.4 million in 2002–2006 to 4.9 million in 2007–2011. The most severe type of skin cancer, melanoma, causes over 75 percent of skin cancer deaths (~9,500/year). Ultraviolet (UV) radiation derived from sun exposure is well known to be the most important cause of skin cancer. In 2017, the project developed solar radiation and UV exposure datasets for the CDC Environmental Public Health Tracking Net and also worked with the CDC's Division of Cancer Prevention and Control on their melanoma epidemiological research. In 2017, for the first time, an OMI surface UV irradiance product was spatially interpolated to the county level in the U.S. to be matched with existing demographic and economic factors available from the CDC. This unique product provides a data source to map national distribution and long-term trends in UV radiation for risk communication and health related studies.

In 2018, the CDC Environmental Public Health Tracking Network published the solar radiation and UV data on their national portal. The data is now available to the public to query and generate various statistics. The data description is here: https://ephtracking.cdc.gov/showUVLanding.action

The data query can be performed here: https://ephtracking.cdc.gov/DataExplorer/

This project met its goal of ARL 9 by the conclusion of the no-cost extension that ended in April 2018.

Project: Chemical Data Assimilation and Analog-Based Uncertainty Quantification to Improve Decision-Making in Public Health and Air Quality

PI: Luca Della Monache

Organization: University Corporation for Atmospheric Research

- One of the key tools used by decision makers across the U.S. to protect the public from adverse health effects caused by poor air quality is the National Oceanic and Atmospheric Administration (NOAA)/National Centers for Environmental Prediction (NCEP) operational air quality forecasting system; the National Air Quality Forecasting Capability (NAQFC). To enhance this decision-making activity, this project aims to improve the accuracy of NOAA/NCEP short-term predictions of ground-level ozone and particulate matter less than 2.5 µm in diameter ($PM_{2.5}$) and to provide reliable quantification of their uncertainty, by exploiting NASA Earth Science Data with chemical data assimilation and analog-based approaches. In

2016, the project achieved the major milestone of running the 2D-gridded deterministic procedure operationally on NOAA/NCEP computing platforms. The main components of the procedure include:

- Automatic quality control of observations to eliminate spurious measurement values
- Analog-based method applied to observation locations: for now only simple analog ensemble mean corrected with a Kalman filter bias correction
- Spreading technique to generate gridded maps from the estimates at the observation locations

This is a major step towards the transition to operations of the $PM_{2.5}$ deterministic predictions.

This project was awarded a socioeconomic benefits study augmentation in 2016. In 2018, the team developed three locations for further study (Denver, Los Angeles, and Pittsburgh). This study included looking at premature mortality for individuals age 65 and older and health estimates related to air pollution policies.

In 2018, the tool developed by the project for $PM_{2.5}$ deterministic predictions with analog-based methods and spreading techniques was fully integrated into the end-user's operational environment at NOAA. The $PM_{2.5}$ probabilistic predictions with analog-based methods and spreading techniques were tested and demonstrated in the context of the targeted decision-making activity at the same environment. Ozone deterministic predictions with analog-based methods and spreading techniques also became operational at NOAA. Five independent tasks are tracked in this project, and these tasks have achieved ARL values ranging from 6 to 9. The project is in a no-cost extension through January 2019.

Project: An Early Warning System for Vector-borne Disease Risk in the Amazon

PI: William Pan

Organization: Duke University

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, is a follow-on grant after successful completion of a feasibility study funded through the NASA Applied Sciences Health and Air Quality program (2011-2013). Members of the proposal team developed a pilot malaria Early Warning System (EWS) for the northern Peruvian Amazon. Results of this study showed that meaningful malaria risk prediction can be achieved using statistical methods informed by an advanced NASA Land Data Assimilation System (LDAS), satellite-derived land cover, and

human population and malaria surveillance data. Building on this study, this project will: 1) operationalize the malaria EWS to a larger geographic area with more fine-scale estimates of risk; 2) expand and evaluate system performance of cross-border risk estimates and add additional vector-borne disease endpoints, focusing initially on leishmania; and, 3) evaluate integrated Agent Based Model estimates into predictions. Operational status will be achieved by leveraging existing partnerships with the Ministries of Health of Peru and Ecuador.

In addition to the LDAS, the team utilizes data from MODIS, *Landsat, GRACE*, *TRMM*, *GPM*, *SMAP*, and *GOES* along with population models and indicators of malaria outbreaks along the Peru-Ecuadorian border. This has led to studies on genetic cycling of malaria parasites across international borders that could be related to more severe cases of malaria. The project plans Expansion of the EWS to all of Peru and along border regions with Colombia, Ecuador, and Brazil. In 2017, an important new partner, the Malaria Cero Program, joined the project. The Malaria Cero Program has the goal of eliminating malaria in Peru by 2021.

In 2018, the project made significant progress in applying a new "ecological region" (eco-region) approach to modeling and predicting malaria cases. Using historical case data from Peru, combined with 1-km resolution hydro-meteorological parameters from the NASA LDAS and an estimated annual population model, the team was able to accurately forecast cases of malaria in each eco-region of Loreto, Peru. A publication is currently being completed, and the team is planning to conduct training workshops with end users. Functionally, the project has achieved ARL 7 as the team has held meetings with key government stakeholders in Ecuador and Peru to demonstrate improved decision-making capacity. However, the project is awaiting confirmation from both governments on their willingness to adopt and integrate the system into their current surveillance programs. The project is in a no-cost extension until July 2019.

Project: Downwind of the Flames: Assessing and Predicting Wildfire Smoke-Related Morbidity using Satellites, In-situ Measurements, and Models

PI: Jeffery Pierce

Organization: Colorado State University, Fort Collins, Colo.

- Exposure to particulate matter (PM) in wildfire smoke plumes represents a growing and uncertain threat to public health in the western U.S. The area burned by wildfires in this region has increased in recent decades and is expected to increase dramatically over the next century. Wildfires pose a challenge to air quality managers and public health officials because: 1) the timing of wildfire events is

difficult to predict; 2) there are inadequate tools linking smoke forecasts to population exposures; and, 3) the health risks associated with population exposure to wildfire PM are poorly understood. This project addresses these issues and operational challenges through the following research objectives: 1) Estimate the respiratory and cardiovascular health risks for specific demographic populations exposed to wildfire PM; and, 2) Evaluate and develop forecast tools that predict wildfire PM concentrations, population exposure, and the potential increased morbidity from exposure to wildfire smoke. The work includes a set of retrospective studies using an array of NASA Earth observations (MODIS, MISR, CALIPSO), surface *in-situ* monitors, and high-resolution modeling (3-km WRF-Chem) to estimate past PM exposures during major wildfire events. The project compiles and analyzes health care records in the affected and nearby regions to estimate the health risks associated with exposure. The forecasting component will employ two tools currently used in decision making regarding wildfire PM: the WRF-Chem model and the BlueSky model framework. Both forecasting tracks require knowledge of current fires from NASA satellite observations. Evaluation of these tools is accomplished by running the same retrospective case studies (as pseudo-forecasts) and evaluating them using satellite and *in-situ* observations. The partnering agencies include the CDC, Colorado Department of Public Health and Environment, Washington State Department of Ecology, and the City of Fort Collins.

In 2016, the project completed WRF-Chem simulations for three retrospective fires and compared simulations to observations and conducted sensitivity simulations for special cases. The project has also completed comparisons to BlueSky framework for significant fires and analysis of hospital records for 2013 fires in Colorado. Below are some testimonials from users and partners:

"There is a clear need for improved smoke forecast models, especially those that can predict $PM_{2.5}$ concentrations at sufficient spatial resolution (~5km) and with improved accuracy." Gordon Pierce and Patrick Reddy, Colorado Department of Public Health and Environment

"The impacts of wildfires in our community have been dramatic and devastating. The data generated from this project, as well as the forecasting tool planned for development, will greatly enhance the City of Fort Collins' ability to plan for and respond to wildfire emergencies." Rosemarie Russo, City of Fort Collins

In 2017, the project tested a beta version of its application and upgraded it to a prototype made public at the beginning of August 2017. Currently, it pulls in smoke forecasts from Bluesky and then calculates the asthma and respiratory relative risk. The tool can be reached and executed at the following link using data calculated from case studies of previous fires: http://rgan.atmos.colostate.edu/smoke_forecaster/. It provides daily estimates for the

current day and the next day. Future advances include adding smoke forecasts (HRRR-Smoke) and additional options for risk calculations as well as calculating a county-level estimate from the grid estimates. As a result of these developments, the project advanced to an ARL of 6.

In 2018, the last performance year of the project, the forecast tool was tested through systematic surveys (through CSU collaborator Marilee Long in the Department of Journalism and Media Communication and funded by the Kauvar Foundation) by air quality forecasters in the Colorado Department of Public Health and the Environment (CDPHE), as well as private residents in Colorado. CDPHE plans to use the tool as part of its forecasting system. This project also partnered with the CDC to include wildfire smoke and population data to show risk of exposure in the national Environmental Public Health Tracking Network (https://ephtracking.cdc.gov/DataExplorer/#/). While this project was focused on the health effects associated with wildfire smoke exposure, the dataset generated is now publicly available through Colorado State University's digital repository (http://dx.doi.org/10.25675/10217/193258) and has been used for several other projects. For example, a study used the dataset to investigate the association between $PM_{2.5}$ and crime. The project is in a no-cost extension until February 2019.

Project: Improved Forecasts of Respiratory Illness Hazard from Gulf of Mexico Red Tide

PI: Richard Stumpf

Organization: NOAA Ocean Service

- This project was awarded through the NASA ROSES 2013-HEALTH solicitation. NOAA has conducted an operational forecast of algal blooms in Florida for ten years, and four years in Texas. This capability was developed by the PI's office and transferred to NOAA's Center for Operational Oceanographic Products and Services. The associated public conditions report provides an assessment of potential respiratory impact at county levels. The result has been successful in helping state monitoring, but much less so in supporting the broader community. The problem is that this forecast is issued twice per week and covers full-county regions, and current capabilities do not support higher forecast resolution. Because the blooms are patchy, the accuracy at individual beaches is extremely low. Mote Marine Lab has implemented a "Beach Conditions Reporting System" (BCRS) that provides immediate information on respiratory irritation at the beach, but does not provide forecasts. Improvements in the integration of field observations, satellite data, and meteorological models will provide the needed higher resolution of the risk of respiratory impact. The goal of this project is to forecast the resolution and

frequency of risk to "every beach, every day," rather than every county, twice a week. The methods should be applicable across the Gulf of Mexico. Currently, monitoring uses individual satellite sensors independently. This project will combine the standard products from multiple sensors and will improve the initial conditions going into the forecasts (e.g. removing clouds, loss of data, glint, etc.) and increase the temporal resolution, combining same day *Terra*, *Aqua*, and VIIRS (and ultimately *Sentinel-3*). The BCRS will be significantly enhanced with establishment of a smartphone based capability to allow trained volunteers to rapidly identify the presence of dense *K. brevis* blooms. Effective deployment of this network will be based on locations identified from the integration of new satellite products and previous reports. The result of the combination will be a finer spatial scale than currently available with the weekly water sampling and satellite images. The second part is forecasting the presence of aerosols onshore. The integration of the forecasts with improved daily detection would lead to simple and routine rapid forecasts that would be distributed through NOAA's operational HAB forecast system, the BCRS, the National Weather Service Beach Hazards Statement, as well as county and state public health departments.

In 2017, scientists from Motes Marine Laboratory, NOAA, and the Gulf of Mexico Coastal Ocean Observing System teamed up to create a cellphone microscope application called "HABscope," which can, within minutes, analyze the concentration of cells of the red tide organism, *Karenia brevis*, in any given water sample extracted from the shore. Combining satellite data (including MODIS/VIIRS), weather forecasts, and sampling from the HABscope device, respiratory distress forecasts are being now being produced one-to-two times per day along the Florida Gulf Coast. Previous to this project, these forecasts were issued at most twice-a-week and were less accurate. Current forecasts can be found at the following website: https://tidesandcurrents.noaa.gov/hab/beach_conditions.html.

In 2018, the project has maintained a shadow version of the HABscope microscope system, which draws on volunteers. Cell counts are being generated and forecasts are routinely produced. The team is working through the mechanics of reviewing the HABscope videos to assure quality, both of the video and the automated counting method. The project received significant media attention due to the HAB emergency in Florida in 2018.

Project: Using Remote Sensing and Environmental Data to Quantify Social Vulnerabilities to Heat Stress and Strengthen Environmental Public Health Tracking and Heat Mitigation Effort

PI: Tabassum Insaf

Organization: New York State Department of Health (NYSDOH)

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, is integrating remote-sensing data into CDC Environmental Public Health Tracking (EPHT) and capacity building efforts for climate change resilience at both the state- and local health-department levels. This project is using NASA Earth observations to characterize risk related to excessive heat in two populous eastern U.S. states (New York and Florida). A fine-scaled daily heat metric will be developed using meteorological re-analysis and remote-sensing data for the years 2005–2013. Heat metrics will consist of daily maximum and minimum air temperatures, daily maximum heat index, and a newly defined measure called Net Daily Heat Stress (NDHS). The NDHS is an integrated measure of heat stress (and relief) over periods of a day or longer. Data for these metrics will then be incorporated into and made accessible to local health departments through the state EPHT portals. Air-temperature metrics derived from meteorological reanalysis and health data (hospital admissions and emergency department visits) are being developed, as well as exposure-response functions of heat stress, respiratory, cardiovascular and renal outcomes as functions of excessive heat (as defined by four daily heat metrics) and socio-demographic variables at the census tract level. This analysis will allow for development of social vulnerability maps at the census tract level and integrate this information into decision support systems currently used in New York and Florida for community health assessment.

  In 2017, the team set minimum thresholds for maximum and minimum temperatures, as appropriate for Florida in summertime, using MODIS land surface temperature data. The project provided training for end users by participating in the ARSET program webinar in June 2017. The team also worked with the NOAA/NWS Albany office and the Office of the State Climatologist in Florida to resolve differences between threshold temperatures.

  In November 2018, this project achieved an ARL 9 as a result of the National Weather Service accepting the results and changing its threshold of heat advisories from 100 degrees to 95 degrees Fahrenheit. National Weather Services offices with responsibility for the whole of upstate New York and surrounding areas of Vermont have reduced their heat advisory criteria based on results from this project. More details on this project can be found at the National Weather Service (http://www.nws.noaa.gov/os/notification/scn18-55ny_heat_products.htm), NASA (https://www.nasa.gov/feature/nasa-helps-new-yorkers-cope-with-summer-swelter), and New York State (https://www.governor.ny.gov/news/governor-cuomo-urges-new-yorkers-prepare-dangerous-heat-starting-weekend-and-lasting-through).

  The project has also made enhancements to NYSDOH Climate and Health page incorporating heat data including county Heat and Health Profile Reports

(https://www.health.ny.gov/environmental/weather/profiles/), Heat and Health Profile Report: Albany County (https://www.health.ny.gov/environmental/weather/profiles/docs/albany.pdf), and Heat and Health in New York State (https://www.health.ny.gov/publications/6636.pdf).

Results have been disseminated through presentations to National Weather Service, University at Albany, EPHT workgroups, BRACE/CRSCI workgroups, and the ARSET program—as well as several national conferences such as AGU, APHA, and AMS. This project is in no-cost extension until August 31, 2019.

Project: Evaluate and Enhance *Suomi-NPP* Products for Air Quality and Public Health Applications

PI: Jun Wang

Organization: University of Iowa

- This project is designed to evaluate and enrich the utility of *Suomi National Polar-orbiting Partnership* (*S-NPP*) data for applied science research. This project evaluating improvements in the application of the VIIRS aerosol product for operational monitoring of $PM_{2.5}$ air quality in the Remote Sensing Information Gateway (RSIG) at EPA. This information will also be provided to the CDC Environmental Public Health Tracking Network.

  In 2017, the team conducted GEOS-Chem and WRF-Chem $PM_{2.5}$ simulations, as well as collected CMAQ simulation data from the EPA. General good agreement was shown among these models, all indicating high concentration of $PM_{2.5}$ on both the West and East Coast, plus the outflow of pollutants from New England.

  In 2018, the team evaluated an ensemble approach for surface $PM_{2.5}$ estimates from VIIRS and other satellite missions. The team achieved an ARL value of 7 in late 2018.

Project: An Early Warning System for Human West Nile Virus (WNV) Disease

PI: Michael Wimberly

Organization: South Dakota State University

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, is

working to improve WNV forecasting and risk-mapping tools to advance the effectiveness of mosquito control by helping target limited resources more efficiently. This project is developing an improved WNV risk map highlighting infections across the state of South Dakota. The project will produce weekly predictive maps of WNV risk during the main transmission season. To improve predictions, the team will incorporate streams of environmental data from current NASA products (NLDAS) and missions (*SMAP*). These methods to improve predictions by integrating environmental monitoring data with entomological surveillance data may be used by other states/areas where outbreaks occur.

In late 2017, this project validated that recent model predictions were accurate over the past year. Additionally, the project produced new revisions of the model to evaluate potential changes to the mosquito surveillance system in South Dakota in order to find ways to continue making accurate predictions while saving money on mosquito surveillance. A video (*Mosquito Meets MODIS*) was produced to further explain this project on YouTube: https://www.youtube.com/watch?v=ag-Zo0izSNg.

In August 2018, the project PI and staff held a workshop at SDDOH headquarters, and SDDOH epidemiologists were trained on how to use this software. Based on these accomplishments, and with SDDOH assuming operational use of this system, the project achieved the maximum goal of ARL 9—sustained use of the application in operational decision making. The project is in a no-cost extension until February 2019.

B. HAQAST Project Highlights

Project: Satellite-Derived $PM_{2.5}$ Grids with Dispersion Model Downscaling: $PM_{2.5}$ Data to Support Community-Scale Air Quality Health Research and Policy Development

PI: Minghui Diao (note: beginning in 2018, Diao took over as project lead for Frank Freedman, the project's original PI)

Organization: San Jose State University

We propose deliverables aimed to support air quality management district decision-making related to $PM_{2.5}$ exposure reduction policies and health research at community scales (hundreds of meters to kilometers). The deliverables will be based on 10-km horizontal resolution MODIS satellite-derived daily $PM_{2.5}$ grids, currently available from 2003–2011 as daily time-series at the CDC Wonder data repository, and dispersion modeling to downscale these grids to community scales. The South Coast Air Quality Management District (SCAQMD) and Bay Area Air Quality Management District

(BAAQMD) will be end-user points of delivery. Deliverables will be provided through web accessible visualization platforms developed and housed at the NASA-MIRO-SJSU Center for Advanced Atmospheric Research and Education (CAARE) at San Jose State University.

Three deliverables are proposed. Deliverable 1 will provide daily satellite-derived 10-km $PM_{2.5}$ grids for California using an improved version of its generation algorithm that incorporates MODIS C6 "Deep Blue" AOD retrievals. Deliverable 2 will be a web-based visualization platform that allows end users to view these grids with other Earth-science reanalysis and WRF-CMAQ modeling fields. Deliverable 3 will be a web-based modeling and visualization platform that runs a dispersion model at fine scale and blends its results with the 10-km satellite-derived grids to downscale the $PM_{2.5}$ fields to community scale.

These deliverables will support SCAQMD and BAAQMD programs to reduce exposure to $PM_{2.5}$ and associated toxic fine particulate species at community scales, where highest impacts due proximity to major roadways and other industrial centers are found. These impacts are socioeconomically disproportionate since relatively less-wealthy minority populations tend to reside in such high-impact areas, which lends importance to this work beyond that motivated by reducing general population exposure. End-use of the high resolution $PM_{2.5}$ fields in air district applications of the U.S. EPA Environmental Benefits Mapping and Analysis Program (BenMAP) to assess health and monetary costs of $PM_{2.5}$ at community scale is planned.

Deliverable 1 will provide the daily regional $PM_{2.5}$ patterns at a 10-km resolution to capture the urban background of the South Coast and Bay Area air basins. By incorporating "Deep Blue" AOD retrievals to improve particulate distinction near the surface, and running the algorithm just for California, more accurate $PM_{2.5}$ grids should be produced. These grids will be updated quarterly, the latency period of EPA Air Quality System $PM_{2.5}$ surface measurements needed in the algorithm to regress on the satellite aerosol optical depth measurements. Deliverable 2 is intended to better familiarize the SCAQMD and BAAQMD with the satellite $PM_{2.5}$ grids, particularly focusing on evaluating the product's accuracy and utility in supporting agency operations pertaining to $PM_{2.5}$. The platform will allow the satellite grids to be either overlaid or viewed alongside other Earth-science gridded products, such as the NASA NDVI/EVI and WRF-CMAQ $PM_{2.5}$ grid modeling fields. WRF-CMAQ simulations of past high $PM_{2.5}$ episodes will be carried out to compare with the satellite-derived fields. Deliverable 3 will require development of a more efficient version of the AERMOD dispersion model, which we call C-MOD. We will design C-MOD similar to already developed C-TOOLS dispersion models, for efficient use by health researchers and public planners studying community-scale air pollution impacts. Two methods are proposed to blend the CMOD dispersion model with satellite-derived fields and

downscale the results to sub-10 km scale. Resulting fields from the two methods will be compared and evaluated.

Baseline NASA funding will support the core scientific parts of project. Funding and computational resources for developing the visualization and other front-end parts of the deliverables will be supplied by CAARE.

2018 progress includes:

Deliverable 1: The team has been developing, applying, and evaluating their regression model for California, as well as constructing AOD and $PM_{2.5}$ surfaces for California for the years 2016 and 2017.

Deliverable 2: The team has completed this deliverable and has developed visualization of MAIAC AOD and derived $PM_{2.5}$ for stakeholder-chosen days over Los Angeles, the San Francisco Bay Area, and the Imperial Valley. The team has also conducted an analysis and incorporation of HRRR wind fields.

Deliverable 3: The team is nearing completion on developing and evaluating their dispersion model simulations. They are mostly finished incorporating satellite-derived surface $PM_{2.5}$ into their dispersion model, which will further downscaled to a 100-meter scale.

Project: A Satellite-Based Global Health Air Quality Index (HAQI): Development and Assessment

PI: Bryan Duncan

Organization: NASA GSFC

We are working on several projects. First, we are developing and assessing a global, satellite-based, multi-pollutant Health Air Quality Index (HAQI), which is based on surface (i.e., “nose-level”) concentrations of particulate matter (< 2.5 microns; $PM_{2.5}$) and nitrogen dioxide (NO_2) inferred from satellite data from 2005 to 2017 at 10x10 km^2 spatial resolution, and simulated ozone from a global atmospheric model of chemistry and transport. Such a HAQI will better communicate the risks of exposure to multiple air pollutants than the current U.S. Air Quality Index. Our stakeholder is UNICEF. Second, we are working with the NASA Global Modeling and Assimilation Office (GMAO) to develop and evaluate a global, high-resolution air quality forecast system. Our stakeholder partner is UNICEF. Third, we are working on a scoping exercise to assess the feasibility of using satellite data to monitor offshore air pollution, particularly in areas

of oil and natural gas extraction activities. Our stakeholder is the Department of Interior Bureau of Ocean Energy Management (BOEM).

Duncan's team has several significant updates for 2018:

They have expanded the scope of their original project, due to the request of UNICEF, one of their stakeholders, to develop and evaluate a global AQ forecast system (https://airquality.gsfc.nasa.gov/forecast). This went live in November 2018. The team is currently evaluating and debugging this forecast. In the process of developing their forecast, the team has developed ongoing relationships with several partner cities, including Rio de Janeiro and Jakarta, Indonesia, and submitted additional collaborative proposals, which were accepted. They are also in the process of writing a global AQ forecast system description paper.

The team has completed the Development of a Global Health Air Quality Index (HAQI).

The team is developing novel applications of satellite data by:

- Working with NASA GSFC's new Food Security Office to develop a theme on the impact of air pollution on crop yields. Completed website and factsheet: https://airquality.gsfc.nasa.gov/food-security
- Submitted ATS Workshop (May 2017) report: "Air Pollution Monitoring for Health Research and Patient Care: An American Thoracic Society Workshop Report."

The team has partnered in an interagency agreement with the Department of Interior Bureau of Ocean Energy Management and has so far submitted a draft report on the feasibility of using satellite data to monitor offshore air quality in oil and natural gas areas. The team is planning a May 2019 ocean cruise in the Gulf of Mexico.

Project: Source Attribution Using Satellite Products and Models to Inform Air Quality Planning and Health Accountability

PI: Arlene Fiore

Organization: Columbia University

Recent space-based and modeling capabilities, combined with more than a decade of high-quality U.S. air pollution measurements and public health records, offer novel opportunities to quantify changing air pollution levels and associated health effects. There is a growing need for health-impact tools that draw on models and satellite products to quantify and prioritize sources that contribute to adverse health impacts. Our projects involve combining satellite products, ground-based measurements and

Earth-system models to: 1) conduct a multi-pollutant health impact analysis for at least the past decade over New York State (NYS); 2) attribute background versus U.S. anthropogenic sources on daily to inter-annual time scales; and, 3) estimate uncertainties in satellite-based and modeling approaches to source attribution and to exposure mapping at multiple time and space scales.

In 2018 Fiore's team has furthered their goal of assessing uncertainties in deriving surface $PM_{2.5}$ from satellite AOD over NYS by getting a paper accepted by *Atmospheric Chemistry and Physics* (ACP) which includes detailed evaluation (including with DISCOVER-AQ data) of different sources of uncertainty in deriving $PM_{2.5}$ from satellite AOD over the Northeast.

The team has worked to connect trends in air pollution exposure to hospital records over NYS from the last decade by conducting an ongoing analysis of multiple $PM_{2.5}$ datasets (including from satellite), for which a paper is in production, and deriving new exposure functions, considering uncertainty as represented by the spread in trends across multiple $PM_{2.5}$ products. They are considering expanding this work to O_3 and NO_2.

Finally, the team is fulfilling its goal of advancing the understanding of background O_3 across the U.S. by continuing to publish its research findings, including an *ACP* paper on interannual variability in individual background sources from 2004 to 2012, and a literature review in *Elementa*.

Project: Supporting Health Impact Assessment Tools Using Remote Sensing and Earth System Models

PI: Daven Henze

Organization: University of Colorado

Ambient exposure to $PM_{2.5}$ is one of the top global health concerns. Remote sensing and global modeling are key tools for assessing health impacts from ambient exposure to $PM_{2.5}$, and for quantifying the benefits of air pollution control strategies, as the distributions and sources of $PM_{2.5}$ cannot be sufficiently quantified by *in-situ* measurements alone in many parts of the world, especially developing regions where air quality is a burgeoning issue. Through our HAQAST work, we provide remote-sensing and model-based estimates of exposure and health impact response coefficients to public health and air-quality policy stakeholders to facilitate evaluation of the health impacts of emission control strategies.

Henze's team is in the process of completing its objectives. In its aim to provide source-receptor coefficients for $PM_{2.5}$ and O_3 to the Climate and Clean Air Coalition (CCAC) impact toolkit (LEAP-IBC), they have provided all $PM_{2.5}$ coefficients for Asia, Africa, Caribbean, Central and South America. They have provided O_3 coefficients for each CCAC member nation. LEAP-IBC is currently used in 25 countries, and Henze's team is preparing manuscripts on application in Nepal (Nakarmi et al., submitted) and Bangladesh (Kuylenstierna et al., in prep).

Henze's team is currently working on their goal of providing high-resolution coefficients for urban regions in Africa.

Henze's team has published the results of their research into expanding the health impacts of air pollution with the publication of Anenberg et. al., "Estimates of the Global Burden of Ambient $PM_{2.5}$, Ozone, and NO_2 on Asthma Incidence and Emergency Room Visits" in *Environmental Health Perspectives* (2018).

Project: Climate, Weather, Pollen, and Health: Quantifying Current and Future Risks

PI: Jeremy Hess

Organization: University of Washington

Aeroallergens, principally pollen, impose a substantial disease burden. In the U.S., allergenic pollens are released in spring, summer, and fall. Pollen causes significant morbidity among sensitized individuals, and approximately one-third of the population is sensitized. Syndromes associated with pollen exposure include allergic rhinitis and conjunctivitis, wheezing, and exacerbations of existing pulmonary disease. Higher pollen-count days are associated with increased emergency department visits for asthma and increased sales of over-the-counter allergy medications. Morbidity primarily results in work and school absenteeism and lost productivity, but life-threatening reactions sometimes occur.

Numerous meteorological and climatic factors affect pollen production, release, and distribution. Knowledge of these factors can be used to limit adverse impacts, principally by reducing exposure. Temperature, precipitation, sunlight, and CO_2 concentrations affect aeroallergen production through their influence on plant growth, pollen production, and timing of pollen release. Ground-level pollen concentrations are also influenced by weather—winds affect dispersal and rains affect persistence in the air. Better understanding of these factors facilitates short-term prediction of pollen levels, which can be used to limit exposure.

Most research on weather, pollen, and health has been done at local scales, and there have been limited efforts to link remotely sensed environmental data with changing pollen phenology. There have been few projections of climate change impacts on pollen phenology—and thus health—in the U.S. Few research findings have been translated into products to facilitate surveillance or reduce health impacts, and very little work has gone into activities facilitating climate change preparedness. Research relating climate, weather, pollen, and health on a national scale is needed to fill these gaps. Similarly, projections of climate change impacts on pollen and health are needed to facilitate public health adaptation activities.

Our goals are to advance understanding of the climate and weather factors affecting the spatial and temporal distribution of aeroallergens, to forecast pollen conditions a season in advance, and to project pollen conditions 10-40 years in the future. Specifically in year one, we will quantify the spatial and temporal relationships among climate and weather variables, vegetation, and taxon-specific allergenic pollen concentrations; develop regression models describing the pollen season; and use the derived historical associations in a predictive model to make an upcoming seasonal forecast and to project future pollen conditions with climate change. In year two, we will analyze the health outcomes associated with taxon-specific pollen concentrations using Google Trends data, produce seasonal risk maps of allergy disease burdens over the contiguous U.S., and identify synoptic weather patterns that are associated with allergic reactions. In year three, we will identify meteorological characteristics that occur on peak pollen days; use these relationships to project the frequency of peak pollen days in future climates; and project future health impacts using the relationships between climate, weather, pollen, and health from our work in years one and two.

Hess's team made great progress in 2018. Towards their goal of advancing understanding of the climatic and weather factors that affect the spatial and temporal characteristics of aeroallergens, they are continuing regression analyses of weather factors associated with total and speciated pollen; and developing proxy factors that can increase spatial resolution of pollen season parameters to facilitate other analyses.

Towards their goal of forecasting pollen conditions a season in advance, they have successfully developed species-specific models that are modestly more skilled than published models to date.

Their goal of *projecting* pollen conditions 10-40 years in the future has been postponed until forecast models have been developed.

And finally, towards the goal of generating applications from this research to facilitate public health activities related to aeroallergens and climate change adaptation, they have continued to develop exposure-outcome associations and data visualization products for allergy clinics.

Project: Membership Application for HAQAST: Satellite Data for Health and Air Quality Applications Across Scales

PI: Tracey Holloway (Team Lead)

Organization: University of Wisconsin-Madison

HAQAST has the potential to transform the role of satellite data and other NASA products in the health and air quality management communities. If selected to participate in HAQAST, Tracey Holloway and collaborators would bring to the team expertise in air quality, satellite data, and public health, especially as applied to policy needs and stakeholder engagement. Two challenges in particular relate to the expertise of our group:

1) Evaluation of satellite data products as air quality and health indicators; and,
2) Integration of satellite data into decision frameworks for air quality and health.

Our activities focus on the U.S., although most methods and data sources are transferable to a global context. We have four projects as part of our group's HAQAST individual project: 1) Integration of satellite-derived formaldehyde (HCHO) to support the National Air Toxics Assessment; 2) Enabling the use of satellite data for routine air-quality model evaluation; 3) Characterizing ozone production regime with satellite data, in support of policies, planning, and trend assessment; and, 4) Reconciling "top-down" constraints on NO_2 from the OMI instrument with "bottom-up" factors determining U.S. NOx emissions in urban areas. (Two additional projects were noted in our proposal, but these were speculative Tiger Team activities). Tracey Holloway is also HAQAST Team Leader. She has served as Deputy Leader of NASA AQAST, overseeing communication and outreach activities, and participating in broader team budget, planning, and evaluation activities.

Updates for 2018 include nine papers published, three papers in review, and three papers in preparation.

Holloway's team has advanced Project 1 of the HAQAST proposal by writing two papers, in collaboration with EPA co-authors, that connect OMI HCHO with EPA National Air Toxics Assessment.

They have advanced Project 2 by continuing the development of the Wisconsin Horizontal Interpolation for Satellites (WHIPS), and producing pre-gridded OMI NO_2 at the 12 km x 12 km U.S. model grid used by many air quality agencies (https://nelson.wisc.edu/sage/data-and-models/OMI_NO2.php). They are also writing

guidance documents, including for TROPOMI. They have published two papers assessing CMAQ over India.

On Project 3, they have published on birds and AQ, two papers on novel uses of NO_2 data (one on global cities, and one for Kazakhstan), and a review paper on HAQAST.

Project 4 on reconciling NOx emission estimates is being advanced through Co-I Brad Pierce's 2017 work on the Lake Michigan Ozone Study.

As HAQAST Team Lead, Holloway has continued to updated resources on our webpage haqast.org, increased social media engagement (~4,000 Twitter followers), and hosted the most well-attended HAQAST conference (HAQAST4) to date.

Project: Using Earth Observations to Support Regional and National Environmental Health Surveillance

PI: Yang Liu

Organization: Emory University

Numerous epidemiological studies links ambient air pollution to excess morbidity and mortality. Historically these studies relied on ground-monitoring stations, such as the U.S. EPA regulatory monitoring network, to estimate population exposure. The geographic sparsity of the monitoring network introduces exposure misclassification into the concentration-response (C-R) modeling process that can result in underestimated health risks. Limited data coverage also poses challenges for air quality and public health management agencies who need to evaluate the impact of background pollution levels and exceptional pollution events such as wildfires on both urban and rural populations. Methods that use NASA Earth observations to estimate air quality and to protect public health have advanced rapidly during the past 15 years, and this has become an active area of research worldwide. Satellite data can effectively extend air quality monitoring systems into poorly represented suburban and rural regions, and population-based exposure estimates at the regional and national scale are valuable tools for public health surveillance. In addition, NASA Earth observations advance our understanding of pollution sources and transport in three dimensions, which are important factors for air quality modeling routinely conducted at state environmental protection departments and the EPA.

For the baseline HAQAST activities, we propose to translate research knowledge to our public health partners in two projects. First, building on our long-standing collaboration with CDC's Environmental Public Health Tracking Network, we will conduct a national-scale epidemiological study to link age-specific county-level daily counts of emergency

department (ED) visits with fused air pollution exposure estimates from satellite observations, model simulations and EPA ground measurements to demonstrate an important application of Tracking's environmental health surveillance data. The expected deliverables will be a set of Tracking-style Environmental Public Health Indicators and Measures based on our results. The short-term societal benefits of our project will be to fulfill the Tracking Program's strategic goal of facilitating research and capacity building using Tracking data, and to enhance its capabilities to deliver spatially-resolved health risk information to its partners nationwide. In the long term, our work can potentially inspire similar studies, and attract more states to join the Tracking Network.

Second, partnering with the Colorado Department of Public Health and Environment (CDPHE), we will conduct a multi-year time series epidemiological study to evaluate the health impact of air-pollution levels elevated by wildfires in Colorado. The objectives of this project are: 1) to improve surface exposure estimates related to wildfire smoke using advanced data fusion approach; and, 2) to determine whether increases in air pollution level due to wildfire smoke contribute to ED visits and acute hospitalizations for respiratory and cardiovascular outcomes during the fire season in Colorado. The expected deliverables include: 1) region-specific CR functions of various health endpoints during the fire season; 2) gridded estimates of health impacts due to wildfires in Colorado; and, 3) gridded air-pollution estimates in the western U.S. Our results will help CDPHE to better understand the atmospheric processes that lead to pollutant accumulation due to wildfire smoke and refine its estimate of public health burdens of fire activities in Colorado. The short-term societal benefit of this project will be to help CDPHE refine its estimate of public health burdens of fire activities in Colorado. In the long term, our results will likely contribute to policy change in fire-prone states regarding public health actions before and during wildfires.

In 2018, the team has advanced our core project on several fronts, especially in regard to the effect of wildfire smoke on ED visits in Colorado. We have developed region-specific C-R functions of various health endpoints during the fire season. We have also revised exposure estimates with new ground observations from NCAR, and an epidemiologic analysis is underway. We have had one manuscript accepted, and another is in preparation.

Project: Satellite-Based Products and Tools to Support Quantification and Attribution of Background Ozone

PI: Jessica Neu

Organization: Jet Propulsion Laboratory

Increases in background ozone are a major air quality concern, particularly for the western U.S., where background ozone may limit states' ability to meet the new federal ozone standard in some locations. We plan to develop a program for applying satellite measurements to the quantification and attribution of background ozone, with an emphasis on air quality in the western U.S. Recent publications from our group demonstrate our capability for combining satellite measurements with both global-scale and regional models to quantify background ozone and attribute it to long-range transport, stratosphere-troposphere exchange, and wildfire emissions. These publications were brought in to the debate over the EPA's new ozone standard, and a new EPA white paper on background ozone as well as regional activities such as the California Baseline Ozone Transport Study show that background ozone is a major concern when it comes to meeting the new standard, particularly in the western U.S.

This proposal specifies the qualifications and expertise in both satellite measurements and modeling that the PI and her team would bring to HAQAST and describes three activities targeting the long-range transport, stratospheric, and wildfire components of background ozone that will be developed under baseline funding, with a particular focus on products to be delivered to our air quality management partners at California Air Resources Board and the South Coast Air Quality Management District. It also describes our potential contribution to Tiger Teams.

The proposed work addresses the HAQAST topic areas of long-range transport and its implications for air quality management approaches, assessment of the information content of satellite observations, and support for regional modeling capabilities.

As a member of the HAQAST team, the PI proposes to:

1) Develop a set of satellite-based analyses aimed at supporting quantification and attribution of changes in background ozone in the western U.S. We will provide critical information to policy makers by analyzing how background ozone has responded to changes in international emissions (particularly those from East Asia) as well as to natural variability in long-range transport and stratosphere/troposphere exchange over the past ~10 years.

2) Use assimilated satellite measurements to generate ozone lateral and upper boundary conditions for regional models. This work will improve the accuracy of these models and their estimates of the contribution of background ozone to high ozone days and thus support development of air quality management policies.

3) Exploit our group's unique capability to generate regional maps of tropospheric ozone profiles from a combination of AIRS and OMI to identify and quantify

ozone associated with long-range transport, stratospheric intrusions, and wildfires to aid in exceptional event (EE) analysis.

Background ozone has both health implications and serious regulatory impacts, and our work will provide much-needed observational constraints on the magnitude and variability of background ozone to aid air quality management decisions.

Our 2018 accomplishments include a paper in preparation describing the attribution of ozone changes in the western U.S., with a focus on contrasting the 2005–2010 and 2011–2016 periods. This will help satisfy our goal of analyzing how background ozone has responded to changes in international emissions, transport, and stratosphere-troposphere exchange.

We also will be delivering 2008 boundary conditions to SCAQMD in March 2019. We are processing 2016 AIRS/OMI data for assimilation and generation of 2016 boundary conditions. This helps satisfy our goal of using assimilated satellite measurements to generate ozone lateral and upper boundary conditions for regional models.

Finally, we are completing carbon monoxide maps for the 2018 California wildfires, and have submitted a paper on the health impacts of the December 2017 wildfires to the *Journal of Geophysical Research* (JGR). In addition, Neu is leading a round two Tiger Team on estimating background O_3.

Project: Facilitating the Integration and Adoption of Satellite Products for Decision Support During Wildland Fire Smoke Episodes

PI: Susan O'Neill

Organization: USDA Forest Service

We propose to create the customized products, tools, and training to foster adoption of satellite products into the decision making and public health advisory discussions that occur during wildland fire smoke episodes. Specifically, we propose to work with the dedicated incident command smoke specialists—Air Resource Advisors—that are part of the Wildland Fire Air Quality Response Program to incorporate satellite information into their workflow. Air Resource Advisors work directly with local public health agencies and air quality agencies to craft public information and advisories. Incorporating satellite information into these products directly affects the public, as well as affecting decisions occurring within the fire's incident command. To accomplish this we propose a baseline activity composed of three components: 1) mine, analyze, synthesize, and deliver Earth observations in tailored formats to Air Resource Advisors (ARAs) and public air quality and health agencies; 2) enhance the use of Earth observations for smoke-model

evaluation and validation; and, 3) enhance the use of Earth observations within the smoke-prediction modeling chain. We—the U.S. Forest Service (USFS) AirFire Research Team—are ideally positioned to achieve our objectives and project goals because we are an applied science team with a long history of extensive collaborative development of fire and smoke related tools in use by managers and regulators across the US and internationally. We are also the primary science advisors to the interagency US. Wildland Fire Air Quality Response Program (WFAQRP) and work directly with WFAQRP Air Resource Advisors, technical specialists focused on smoke that serve as part of fire incident and regional command structures, to enable their communication with local public health agencies in creating public smoke advisories and guidance. Satellite information are currently available from a variety of sources; the goal is not to duplicate such efforts, but rather to mine and distill them to deliver the information important to periods of widespread wildfire smoke impacts in a manner easily understood and useful to technical specialists such as ARAs, air quality (AQ) agencies, public health agencies, and the public through customized and tailored products. Information created by this project will take advantage of the existing communication pathways and delivery systems in use by the operational fire and health communities (customized websites, blogs, infographics, sound bites, social media including Facebook and Twitter).

Toward task 1: (Earth-observation information synthesis, dissemination and delivery methods of Earth observations), O'Neill has led five trainings on incorporating satellite products for smoke forecasting; presented at six conferences; interacted with five stakeholder groups; and written a section of the *Wildfire Smoke: A Guide for Public Health Officials* whitepaper entitled, *Where is the Smoke Coming from? Seeing Smoke from Space*.

Toward task 2: (Earth observations for smoke model evaluation), O'Neill has worked with NASA's CALIPSO group to use CALIPSO, MISR and CATs vertical profiles to evaluate smoke plume rise, in near real-time and retrospective analysis.

Toward task 3: (Earth observations to improve the science of smoke modeling), O'Neill has drafted a paper on data fusion techniques (AOD, modeling, monitoring) applied to retrospective evaluations for 2017 Pacific Northwest wildfires; has worked with NASA GEOS5 to ingest AOD and boundary conditions improving operational forecast smoke modeling systems; and helped to develop a *GOES*-16 Fire Detection Product – Fire emission time profile, a web-based tool for custom modeling runs in support of wildfire Incident Command teams.

Project: HiRes-X: Scientific and Geographic Extension of an Operational High Resolution, Prognostic Air Quality System Providing Smoke Impacts Forecasts for Health Protection, Ecosystem Management and Economic Development Using Earth Observations

PI: Armistead Russell

Organization: Georgia Institute of Technology

Wildland fires constitute the largest source of primary fine particulate matter ($PM_{2.5}$) in the U.S., in addition to being among the largest sources of secondary $PM_{2.5}$ and ozone precursors. Fire emissions are of specific concern from a health standpoint as a variety of studies suggest that biomass-burning-generated PM is more toxic than other components. However, fires are important to ecosystem, forest, and crop health, so land and forest managers are looking to increase prescribed burning both for economic and ecosystem benefits. Balancing these benefits with the potential impacts on air quality is being accomplished in Georgia using the HiRes air quality/burn impact forecasting system.

We propose to advance the operational HiRes system to HiRes-X, expanding its capabilities and use of Earth observations, and extending its domain to additional states in the Southeast. Burn forecasts would be used by local, state and federal health, forest, agriculture and air quality agencies in the region. More extensive use of Earth observations are planned, including high-resolution products from the Visible-Infrared Imaging Radiometer Suite (VIIRS) and NASA *Aqua* Atmospheric Infrared Sounder (AIRS) for improved detection of prescribed burns. A new tool will be added to the system to allow rapid updating of when and where actual fires occur. Comparisons between HiRes-X fields, satellite observations, and ground-based measurements are expected to improve remote- sensing-based emissions estimates. Additional objectives include using forecasts in CDC's public surveillance and epidemiologic analysis and the deployment of air quality sensors in burn-impacted regions to provide additional information for system improvement, public safety, and educational purposes.

While the system is operational in Georgia, where the benefits have been recognized, the expansion to additional states will further the health, economic, and ecosystem benefits. During the conduct of this study, we plan to extend the fire forecasting to Alabama, Florida, and South Carolina, though further growth is possible. Health benefits will be derived from both an ability to warn areas where impacts will be most severe and a capacity to plan fires with minimal impacts on populated regions. Economic and environmental benefits will be realized through additional opportunities for burning, which would improve forest health. These benefits are particularly important in regions currently most impacted by fires as they are typically lower socioeconomic status areas

and suffer from a lack of air quality monitoring such that they have little warning or knowledge of potential adverse air quality events. We will deploy multisensory air quality monitors at high schools in the region to enrich the current monitoring network. We will also provide educational opportunities to those high schools to learn about air quality, health and Earth observation systems. Public and stakeholder engagement is planned via workshops and our current roles in regional air quality studies that have regulatory impacts. As part of the research, we explicitly include the evaluation of how well the system advances and extension to additional regions are meeting the objectives and achieving the desired benefits.

The potential health, economic and ecosystem benefits and making use of the rapidly growing array of Earth observations, are directly aligned with NASA's objectives. Further, the system is designed to adapt to additional observational systems expected in future years. Our website is used by regional stakeholders, and will be updated to further educate people on the types and uses of Earth observations.

The team includes experts in the areas of air quality, health, and forest management. Not only do they conduct fundamental and applied research and publish in leading technical journals, they work closely with local, state, and federal agencies and regional stakeholders to identify and address specific needs.

Major accomplishments in CY2018:

- We have enhanced HiRes-2 using Earth observations by expanding prescribed (Rx) fire forecasts to the southeastern U.S. using satellite fire observations. We have completed our first year of operation.
- We have provided Rx fire impacts forecasts to local and state agencies by holding a workshop, launching and operating the SIPFIS website, hosting a Southern Fire Exchange webinar, and producing one manuscript.
- We have made progress on maintaining a sensor network by deploying and operating a low-cost sensor network in Southwest Georgia. We have completed evaluating this network, and have one manuscript in preparation documenting our work.

Project: Novel Use of NASA Data with Emission Data Assimilation to Support U.S. National Air Quality Forecasting Capability and WMO Regional Chemical Reanalysis

PI: Daniel Tong

Organization: George Mason University

The WHO estimated that exposures to air pollution in 2012 caused 7 million premature deaths worldwide, making it the single-largest environmental risk today. Among all pollutants, fine particles ($PM_{2.5}$) are most closely associated with increased lung cancers and other cardiovascular diseases. In the U.S., more than one third of the population lives in areas not attaining the health-based National Ambient Air Quality Standards. To mitigate the widespread health risk, regional and national air-quality forecasting systems, including the National Air Quality Forecast Capability (NAQFC), were established to enable the nation to foretell pollution levels with 48-hour lead time, so that health authorities can take actions to protect sensitive groups with early warnings and other mitigation measures.

A team of air-quality forecasters, Earth scientists, and air-quality managers has been assembled to substantially enhance the nation's pollution forecasting capability through:

- Emission data assimilation: Assimilate NASA observations in the emission modeling processes to improve emission inputs. Use OMI NO_2 to update anthropogenic emission inventories, OMI HCHO (formaldehyde) retrieval to constraint biogenic isoprene emissions, and MODIS and MISR aerosol data to improve dust and fire emissions.0/3.

- Using NASA data in regional chemical analysis: Built upon the success of the previous AQAST Tiger Team project, Regional Chemical Reanalysis, our team has completed a prototype using an Optimal Interpolation (OI) scheme to generate 12-km resolution hourly atmospheric chemical reanalysis over the Continental US. The AQAST project finishes appropriately by transitioning the prototype system to a production system through the replacement of the OI scheme with the NCEP operational Grid Statistical Interpolation 3DVar scheme.

- Using NASA data in chemical-data assimilation: Leverage the data-assimilation framework developed from ongoing AQAST projects to assimilate a suite of satellite and ground data (MODIS AOD, VIIRS AOD, AIRNOW $PM_{2.5}$) to improve a) the initialization of NAQFC chemical fields, and b) deterministic prediction with detailed quantification of uncertainties using either Optimal Interpolation (OI) or Gridpoint Statistical Interpolation (GSI) method.

- Evaluating NAQFC prediction: NAQFC outputs will be evaluated with NASA satellite, suborbital and ground observations (MODIS, DISCOVER-AQ, AERONET and CALIPSO).

The proposed work directly contributes to the HAQAST objectives by applying Earth observations to improve a key decision-making tool: air-quality forecasting (AQF). The new emission data assimilation capability improves AQF performance and enhances responsiveness of such a tool to air quality and public health managers. Although the

proposed study focuses on improving the national AQF system, the NASA data assimilation capability can be applied to similar regional and international forecasting systems. AQF is critically relevant to air managers to produce air quality advisory. Therefore, improvement of AQF performance through utilizing Earth observations is an integral part of the HAQAST efforts to advance the health and air quality management communities' sustained use of NASA data in decision-making.

CY2018 Updates:

We have made progress in all three core projects:

1) Emission data assimilation. We have written up the results of our work in one paper on air quality forecasting, and another on NH_3 emissions from fires.

2) Chemical-data assimilation. We have released version 1 of the North American Chemical Reanalysis and have published one paper on our work.

3) NAQFC evaluation with NASA data. We have published one paper on using MODIS AOD to improve $PM_{2.5}$ forecasts.

Additionally, Tong has given 10 academic talks, delivered more than a dozen stakeholder or public talks, generated guidance documents on analyzing satellite NO_2 trends tailored for three specific cities, and provided three media interviews.

Project: Health and Air Quality Applied Sciences Team: Using Science to Inform Management

PI: Jason West

Organization: University of North Carolina

Over the past decade, the PI has established himself as a leader in using atmospheric science and modeling to drive health impact and quantitative policy analyses, connecting air pollution, climate change, and energy with human health and policy. He was the first to use a global atmospheric model for a health impact analysis, and his research group was the first to use a single global model and later an ensemble of global models to estimate the global burden of disease due to outdoor air pollution. His abilities to conduct interdisciplinary studies that address key policy questions are exemplified by studies of the costs and health benefits of methane mitigation as a tool for ozone air quality management, and of the co-benefits of global greenhouse gas mitigation for global air quality and health. As a member of HAQAST, the PI can also offer a strong understanding of atmospheric science, air pollution health effects, and

climate change, leadership and communication of science for informing decision-making, and abilities to work in atmospheric modeling on global, regional, and local scales, human health impact assessment, economics and quantitative policy analysis, and energy-economic modeling.

Here we aim to make atmospheric science meaningful for government decision making through two tasks:

First, we will estimate global surface ozone concentrations through a statistical fusion of global surface observations and global multi-model ensembles. The combined global ozone dataset will be then provided to the Global Burden of Disease (GBD) team for their use in evaluating the global health burden of ambient ozone. Since previous GBD exercises estimated ozone concentrations using a single model and no observations, we expect our work to significantly improve forthcoming GBD estimates, leading to a more accurate understanding of ozone exposure and its health effects globally. We will use an unprecedented global database of ozone observations currently being compiled for the Tropospheric Ozone Assessment Report and multiple global model simulations for the HTAP-2, ACCMIP, and AerChemMIP multi-model intercomparisons. Three methods of statistical data fusion will be used in succession based on their complexity, using observations to correct for model biases. This project uses NASA satellite products for model evaluation, directly by our study or by the modeling teams. The target audience will be the GBD team, and by strengthening the GBD assessment, we will reach governments and decision-makers globally.

Second, we will model the global air quality and health co-benefits of greenhouse gas (GHG) reductions currently pledged under the 2015 Paris Agreement to address climate change. Our previous co-benefits research has revealed that for global GHG reductions, a significant fraction of the co-benefits realized in the US may result from foreign emissions controls. Here, we will use simulations of a reference scenario and of the Paris Agreement commitments, as modeled previously in the global energy-economics model GCAM, to give global air pollutant emissions. A global atmospheric model will simulate concentrations of ozone and $PM_{2.5}$ in 2030 (the current Paris target period), and in 2050 and 2100 for scenarios that continue Paris goals with the same level and increased levels of commitment. Global mortality impacts of reduced air pollution will be assessed using the PI's methods. We will further conduct simulations that separate co-benefits due to emissions from the US vs. foreign nations. This project will use NASA meteorological re-analyses as input, and NASA satellite products to evaluate the simulation for the base year (2008–2012). This project will aim to inform decisions by the U.S. EPA and other government agencies, as well as air quality and health managers worldwide.

A 2018 Progress Update:

1) For the project on global ozone data fusion, we have delivered the first global map to the Global Burden of Disease team. We also have one paper currently under review.

2) For the project on the co-benefits of the Paris Agreement pledges, we have analyzed emissions from GCAM and will begin simulations in Spring 2019.

Project: Spatiotemporal Variability of Ammonia through Syntheses of In-Situ-, Ground-Based, and Remote-Sensing Measurements

PI: Mark Zondlo

Organization: Princeton University

The focus of this proposal is to identify how remote-sensing measurements of ammonia (NH_3) can be used to help improve air-quality forecasts of $PM_{2.5}$, a criteria pollutant that has proven difficult to reduce in urban region.

Gas phase NH_3 is well-recognized to be a critical aerosol precursor species and key component of nitrogen deposition in sensitive ecosystems, but unlike criteria pollutants NOx and SOx, NH_3 emissions are currently unregulated in the US. Part of the problem is the extreme difficulty of measuring gas phase NH_3. Recent advances in remote-sensing measurements of NH_3 from IASI, CrIS, TES, and AIRS provide a great opportunity to improve NH_3 emission inventories and capture the high spatiotemporal emissions related to agriculture. However, they remain unvalidated and it is unclear how useful measurements are at small spatiotemporal scales needed for air-quality research and forecasting. The proposed activities will validate IASI and CrIS at the single pixel scale and examine spatial and temporal variations of NH_3 by synthesizing *in-situ* and remote-sensing data. In addition, case studies of nitrogen deposition and agricultural emissions will provide additional data to improve NH_3 modeling efforts. External collaborators on the air quality model sides will provide feedback on case studies to detect NH_3 plumes from agriculture. Field data will also be integrated into reactive nitrogen components of land and atmosphere Earth-System models to assess relationship with other biogeochemical emissions and how climate change may alter future emissions.

CY2018 Update:

We have validated satellite NH_3 at pixel scale, for IASI, and are preparing a paper on our work to be submitted to the Journal of Geophysical Research (JGR).

We have published our work on the oversampling algorithm used for the spatial variability of NH_3, and have published another detailing our work on ammonium nitrate formation in the San Joaquin Valley.

In determining the temporal variability of NH_3, we have one paper in preparation on monthly U.S. emissions at high spatial resolutions; had our work published in Earth Observatory's *Image of the Day*; have another paper in preparation on ammonia dry deposition in North Carolina, and a third in preparation on the effectiveness of NH_3 control for $PM_{2.5}$ using observational datasets.

We have added a new project, due to stakeholder demand, on integrating satellite and surface data for the Kilauea eruption of 2018, and we are currently examining how satellite data can help fill in gaps of the existing surface network and be an indicator for volcanic activity.

We have given stakeholder talks to Western Regional Air Partnership Regional Technical Operations Working Group, Colorado Dept. of Public Health and the Environment, California Air Resources Board, EPA ORD, New Jersey DEP, as well as eight academic talks in 2018.

C. GEO Work Programme Project Highlights ("Earth Observations for Health")

Project: Earth Observations for Cholera Prediction

PI: Antar Jutla

Organization: West Virginia University

Cholera continues to be a public health threat, particularly in regions that lack access to safe drinking water and sanitation (WASH) infrastructure. Africa is rapidly becoming the new homeland of cholera (66 percent of the total cholera outbreaks reported in the continent). Outbreaks of cholera can be divided into two components: the trigger in the environment and the transmission of the disease in human population. Growth of cholera bacteria in the environment is linked to hydroclimatic processes influencing the ecological niche of the vibrio. Consequently, consumption of water containing an infective dose of the bacteria forms the trigger component. The transmission component of cholera is the mechanism of spread of infection within the human population. *V. cholerae* exists naturally in the environment, therefore, it is not realistic or feasible to consider eradication of the pathogen from the aquatic environment. Therefore, the goal of this project is to employ Earth observations to predict the risk of outbreak (trigger and

transmission) of cholera in the environment and human populations in Africa, and thereafter develop a comprehensive capacity building plan to engage end-users to incorporate this information into decision making, so that appropriate intervention strategies can be devised and deployed. This project intersects AfriGEOSS.

In 2018, the project continued developing models with a weekly time step for the epidemic model of cholera and included newer datasets in the revised algorithm. The model was tested on the countries of Algeria and Zimbabwe. Two new end users/partners were added to the project—UNICEF and the Department for International Development, UK. The project achieved an ARL of 4 in 2018.

Project: Multi-sensor Data for Myanmar Malaria Warning

PI: Tatiana Loboda

Organization: University of Maryland

The United Nation's Sustainable Development Goals target to eliminate global malaria epidemics by 2030. Considerable progress has been made towards this goal across the world. However, the recent emergence of artemisinin-resistant populations of malaria carrying parasites in the Greater Mekong posed not only to slow down the progress but potentially undermine the entire elimination campaign by rendering the most efficient malaria treatment available to date ineffective. Myanmar, one of the five countries with documented cases of emergence of artemisinin resistance, carries a disproportional malaria burden in the region with ~4 percent of the region's population and 20 percent of the region's malaria. The project aims to support these efforts by developing a robust satellite data driven early warning system to forecast malaria hotspots dynamically in space-time. Myanmar Malaria Early Warning System (MMEWS) will be designed to move the satellite-based malaria forecasting beyond the narrow scope of monitoring and forecasting vector habitat suitability and potential for surge in vector prevalence. The project brings together a team of experts in optical and microwave remote sensing, spatial analysis, and malariology to develop a system that will support medical intervention activities.

The major focus of the project activities for year one were focused on development of methodologies and required datasets for the compilation of the baseline land cover and land use map and development of environmental monitoring capacity from coarse resolution instruments following the major activity schedule within the project plan. In addition to the MMEWS development, the team has undertaken several meetings with the stakeholders both at the Duke Global Health Institute (DGHI) in Duke University, NC, and in the DGHI Myanmar office where the model will be transferred upon completion. As outlined in the project plan, the team held Expert Advisory Team

meeting in Yangon, Myanmar, in June 2018. A follow-up meeting with the Expert Advisory Team was held in November 2018 during PI Loboda's visit to Myanmar. In addition to consulting with stakeholders, PI Loboda is initiating capacity building activities to ensure that the technology can be transferred to in-country teams for continuous operation upon the completion of the project. The project currently has achieved an ARL of 3.

Project: Surveillance for Vector Borne Disease

PI: John Malone

Organization: Louisiana State University (LSU)

Implementation of a geospatial surveillance and response system resource for vector-borne disease in the Americas will be tested using NASA satellite data, geographic information systems, and ecological niche modeling to characterize the environmental suitability and potential for spread of selected endemic and epizootic vector borne diseases. The initial focus will be on developing prototype geospatial models on visceral leishmaniasis, an expanding endemic disease in Latin America, and geospatial models for dengue and other *Aedes aegypti*-borne arboviruses (Zika, chikungunya)—emerging arboviruses that have potential for epizootic spread from Latin America and the Caribbean and establishment in North America. This project intersects AmeriGEOSS.

In 2018, geospatial image and feature data in interoperable format were compiled from a previous PAHO project for six countries in Latin America to provide initial databases and template for GIS project studies. *GPM* and *SMAP* satellite data (full disc) and regional MODIS and ECOSTRESS imagery data were downloaded and clipped to boundaries of Colombia and Sao Paulo and Bahia state study areas for use in mapping and modeling studies using ArcGIS and Maxent software. An SOP/tutorial was prepared for on-line data access and similar analysis by others in future courses. Co-Investigator Jeff Luvall (MSFC) transferred additional ASTER, Worldview 3-4, and ECOSTRESS imagery to LSU for municipality level Brazil study sites in Feira de Santana, BA and Bauru, SP.

Results from risk model mapping of visceral leishmaniasis (VL) indicate direct measurement of soil moisture by *SMAP* can be used en lieu of models calculated from standard thermal and precipitation climate station data.

Project: Environmental Determinants of Enteric Infectious Disease

PI: Benjamin Zaitchik

Organization: Johns Hopkins University

Childhood undernutrition is linked to more than 50 percent of child deaths worldwide. A key aspect of malnutrition is the role of environmental enteric dysfunction, in which exposure to enteropathogens alters intestinal integrity and metabolic state. In response the Interactions of Malnutrition and Enteric Infections: Consequences for Child Health and Development project (MAL-ED) established an unprecedented coordinated cohort study at sites in eight countries across three continents. But enteric infectious disease (EID) transmission is environmentally mediated, and many EID exhibit some form of seasonality or other environmental sensitivity. MAL-ED is limited because it does not have an Earth-observation component, sites are point locations. This project will develop a database of relevant climate, hydrology, ecology, and human activity at each study site. This database will be used to develop statistical models of high impact EID, with the goal of informing understanding, monitoring, and prediction. The project will use the global coverage available from Earth observations to perform objective regionalization of global tropical land areas on the bases of seasonality and environmental associations of specific EID. This project intersects AmeriGEOSS and AfriGEOSS and leverages MAL-ED funding from the Bill and Melinda Gates Foundation.

In 2018 the team sought to: 1) assess performance of relevant EO at MAL-ED sites; and, 2) implement EO-informed predictive models of enteric pathogens, beginning with rotavirus. Results of EO assessment are reported in Colston et al. (2018) and results of rotavirus modeling are reported in Colston et al. (*In Review*). The project has also added enteric disease doctors and public health professionals to the team. Currently the project stands at an ARL 3.

D. Abbreviations and Acronyms:

AAAS: American Association for the Advancement of Science
ACCMIP: Atmospheric Chemistry and Climate Model Intercomparison Project
AerChemMIP: Aerosol Chemistry Model Intercomparison Project
AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model
AERONET: AErosol RObotic NETwork
AGU: American Geophysical Union
AIRS: Atmospheric Infrared Sounder
AMS: American Meteorological Society
AOD: Aerosol Optical Depth
AQ: Air Quality

AQAST: Air Quality Applied Sciences Team
ARL: Application Readiness Level
ARSET: Applied Remote Sensing Training program
ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer
BAAQMD: Bay Area Air Quality Management District
BCRS: Beach Conditions Reporting System
BOEM: Bureau of Ocean Energy Management
CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CCHHG: Climate Change and Human Health Working Group
CDC: Centers for Disease Control and Prevention
CMAQ: Community Multiscale Air Quality
CoP: Community of Practice
CrIS: Cross-track Infrared Sounder
CY2018: Calendar Year 2018
DISCOVER-AQ: Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DST: Decision Support Tool
EE: Exceptional Event
EID: Enteric Infectious Disease
EPA: Environmental Protection Agency
EPHT: Environmental Public Health Tracking
ESD: Earth Science Division
EWS: Early Warning System
GCAM: Global Change Assessment Model
GCOOS: Gulf of Mexico Coastal Ocean Observing System
GEO: Group on Earth Observations
GEO-CAPE: GEOstationary Coastal and Air Pollution Events
GEOS-Chem: Goddard Earth Observing System–Chemistry
GOES: Geostationary Operational Environmental Satellite
GPM: Global Precipitation Measurement
GRACE: Gravity Recovery and Climate Experiment
GSFC: Goddard Space Flight Center
GSIP: GOES Surface and Insolation Products
HAB: Harmful Algal Bloom
HAQAST: Health and Air Quality Applied Sciences Team
HAQI: Health Air Quality Index
HTAP-2: Hemispheric Transport of Air Pollution-2
IASI: Infrared Atmospheric Sounding Interferometer
JPL: Jet Propulsion Laboratory
LADCO: Lake Michigan Air Directors Consortium
LDAS: Land Data Assimilation System
LEAP-IBC: Long-range Energy Alternatives Planning-Integrated Benefits Calculator
MAIA: Multi-Angle Imager for Aerosols

MISR: Multi-angle Imaging Spectroradiometer
MODIS: Moderate Resolution Imaging Spectroradiometer
MSFC: Marshall Space Flight Center
NAQFC: National Air Quality Forecast Capability
NASA: National Aeronautics and Space Administration
NCAR: National Center for Atmospheric Research
NCEP: National Centers for Environmental Prediction
NDHS: Net Daily Heat Stress
NDVI: Normalized Difference Vegetation Index
NIH: National Institutes of Health
NLDAS: North American Land Data Assimilation System
NOAA: National Oceanic and Atmospheric Administration
OMI: Ozone Monitoring Instrument
OMUVB: OMI surface UVB
PACE: Plankton, Aerosol, Clouds, ocean Ecosystem
PAHO: Pan American Health Organization
PAR: Photosynthetic Active Radiation
PI: Principal Investigator
PM: Particulate Matter
$PM_{2.5}$: Fine Particulate Matter
ROSES: Research Opportunities in Space and Earth Sciences
S-NPP: Suomi National Polar-orbiting Partnership
SBA: Societal Benefit Area
SCAQMD: South Coast Air Quality Management District
SIP: State Implementation Plan
SMAP: Soil Moisture Active Passive
SIPFIS: Southern Integrated Prescribed Fire Information System
TCEQ: Texas Commission on Environmental Quality
TEMPO: Tropospheric Emissions: Monitoring of Pollution
TES: Tropospheric Emission Spectrometer
TOPS: Terrestrial Observation and Prediction System
TRMM: Tropical Rainfall Measuring Mission
TROPOMI: TROPOspheric Monitoring Instrument
UAH: University of Alabama in Huntsville
USGCRP: U.S. Global Change Research Program
USGEO: U.S. Group on Earth Observations
UVB: Ultraviolet B
VIIRS: Visible Infrared Imaging Radiometer Suite
WHO: World Health Organization
WMO: World Meteorological Organization
WNV: West Nile Virus
WRF: Weather Research and Forecasting
WRF-Chem: Weather Research and Forecasting–Chemistry

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