National Aeronautics
and Space Administration

NASA EARTH SCIENCE

APPLIED SCIENCES PROGRAM

HEALTH & AIR QUALITY

2017

Health & Air Quality: 2017 Annual Summary

Table of Contents

I. Introduction

The 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 nine Societal Benefit Areas (SBAs) of the interagency U.S. Group on Earth Observations (USGEO): 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 2017

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). Four new investigators in "Earth Observations for Health" were selected for funding through the ROSES 2016 GEO Work Programme 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

[1] The nine USGEO SBAs are Agriculture, Climate, Disasters, Ecological Forecasting, Energy, Health, Oceans, Water Resources, and Weather.

2017, the program continued monthly Health and Air Quality newsletters that were circulated online and via a mail list. The program launched a new website focusing on the GEO Health Community of Practice. The applications area distributed applied research results and led or participated in meetings across the 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 2017. 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:

In the US, 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 more than 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. A project led by Dr. Yang Liu of Emory University has developed solar radiation and UV exposure datasets for the CDC Environmental Public Health Tracking Network (EPHTN), and also works with the CDC's Division of Cancer Prevention and Control on its melanoma epidemiological research. In 2017, for the first time, an OMI surface UV irradiance product was spatially interpolated to the county level in the US to be matched with existing demographic and economic factors available from 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. The data can be found at: https://ephtracking.cdc.gov/showUVLanding.action. This permanent platform will maintain and update data that were provided by this project.

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 US. A project led by Dr. 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 include meteorological fields (temperature, precipitation, and humidity) from the North American Land Data Assimilation System. The South Dakota Department of Health will maintain this model and continue to use it to provide public bulletins on a weekly basis. 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 the Amazon Rainforest, few animals are as dangerous to humans as mosquitos that transmit malaria. The tropical disease can cause high fever, headaches, and chills. It is particularly dangerous for children and the elderly, and can cause complications for pregnant women. In rainforest-covered Peru, the number of malaria cases has spiked. In the past five years, the country has had the second highest rate in South America, on average. In each of the years 2014 and 2015, there were 65,000 reported cases. To tackle this problem, Duke University researchers have turned to data from NASA's fleet of Earth-observing satellites (including the Land Data Assimilation System (LDAS), MODIS, Landsat, GRACE, TRMM, GPM, SMAP, and GOES) which are able to track the types of human and environmental events that typically precede an outbreak. Under a grant from the program, they are working in partnership with the Peruvian government to develop a system that uses satellite and other data to help forecast outbreaks at the household-level months in advance and prevent their occurrence. This project was featured on NASA and YouTube with an explanatory video, which can be accessed at the following link: https://www.nasa.gov/feature/goddard/2017/using-nasa-satellite-data-to-predict-malaria-outbreaks.

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 in healthy people; including coughing, watery eyes, runny nose, and sinus pain. In 2017, scientists from Motes Marine Laboratory, the National Oceanic and Atmospheric Administration, and the Gulf of Mexico Coastal Ocean Observing System teamed up to create a NASA-funded cellphone microscope app, the "HABscope," that 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 1-2 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.

A project led by the National Centers for Atmospheric Research (NCAR) aims to enhance the accuracy of NOAA/NCEP short-term predictions of ground-level ozone (O_3) and particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) and to provide reliable quantification of their uncertainty. In 2017, the project demonstrated that the assimilation of MODIS retrievals of aerosol optical depth

(AOD) resulted in improved model estimates of $PM_{2.5}$. The project advanced to an Applications Readiness Level (ARL) of 7 after prototype applications functionality was tested and demonstrated at the NOAA facility.

A project led by Colorado State University aims to estimate the respiratory and cardiovascular health risks for specific demographic populations exposed to wildfire PM. The project also plans to evaluate and develop forecast tools that predict wildfire PM concentrations, population exposure, and the potential increased morbidity due to wildfire smoke. In 2017, smoke exposure estimates were coupled with health data to determine the health effects for several cases, including wildfires in Washington State in 2012 and Oregon in 2013. The beta version of the tool was also released in 2017: http://rgan.atmos.colostate.edu/smoke_forecaster/.

The program released a new solicitation in 2017. ROSES 2017 A.39, "Earth Science Applications: Health and Air Quality," 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). Proposals were due on November 17, 2017, with project awards projected for summer 2018.

The Health and Air Quality program continued collaboration with Capacity Building's Applied Remote Sensing Training program (ARSET) to bring remote-sensing resources to the public health community through training sessions focused on health applications. The training entitled, "Methods in Using NASA Remote Sensing for Health Applications," occurred in June 2017 and engaged a broad cross-section of applied researchers and end-users. The training covered topics including how to access and knowledgably use remote-sensing data and juniper pollen phenology and dispersal. In September, ARSET conducted in-person training on, "Satellite Remote Sensing of Air Quality." This training was held at the University of California, Riverside in partnership with the South Coast Air Quality Management District.

The program was honored with a NASA HQ Team Excellence Award in October 2017 for outstanding execution of Space Apps 2017, leading to a record-breaking 25K international participants, creating over 2000 solutions to global challenges using NASA products. The program's AAAS Policy Fellow, Dr. Shobhana Gupta, led this effort.

In 2017, the NASA Health and Air Quality Applied Sciences Team (HAQAST) (http://haqast.org), led by Dr. 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 launch of four Tiger Teams in summer 2017. 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 principal investigators (PIs) to find the best, multifaceted solutions to pressing health and air quality issues. The four Tiger Teams were chosen from among twelve proposals that underwent a competitive and rigorous evaluative process. Eight peer reviewers (four representing public health and four representing air quality) read and scored each of the twelve proposals. The winning teams were:

1. Demonstration of the Efficacy of Environmental Regulations in the Eastern U.S.
2. Supporting the Use of Satellite Data in State Implementation Plans (SIPs)
3. High Resolution Particulate Matter Data for Improved Satellite-Based Assessments of Community Health
4. Improved NEI NOx Emissions Using OMI Tropospheric NO_2 Retrievals

These Tiger Teams will finish their missions by early summer 2018. Meanwhile, a second round of Tiger Teams is planned for announcement in summer 2018.

HAQAST continues to benefit from its communication outreach efforts, which include regular newsletters (sent to a mailing list of over 640 subscribers, an increase of approximately 25 percent over last year's number), Twitter (where @NASA _HAQAST currently has over 3,800 followers—another 25 percent increase over last year's number), and focus on media outreach and public engagement of applied research. HAQAST's applied research has been profiled in *Newsweek*, *The Telegraph* (India), *Physics.org*, *PBS News Hour*, *ThinkProgress, ABC News*, *The Guardian*, *Scientific American*, and many other popular outlets. An overview of HAQAST and the tools and data NASA makes freely available was published in *Physics Today* and, as of January 2018, has received more than 14,000 shares.

Of special note is the redesign of the HAQAST website to feature a "one-stop shop" for relevant NASA data and tools. In consultation with ARSET, HAQAST developed short descriptions and, in some cases, how-tos and video guides to help users orient themselves (see https://haqast.org/nasa-tools/). The website remains a prime method for public communication efforts that promote new team applied research, connects the team with stakeholder organizations, and offers a mechanism to communicate NASA science related to air quality and health to the public and professionals.

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 2 was hosted by the University of Washington and the USFS in Seattle, February 27-March 1, 2017.

A myriad of stakeholders were in attendance including USDA, NOAA, CDC, WESTSTAR-WRAP, and BAAQMD. Tiger teams were formed, and metrics of success were also discussed.

HAQAST 3 was held in Palisades, NY, November 28-29, 2017. The meeting was co-hosted by the New York State Energy Research and Development Authority (NYSERDA). PIs presented milestones achieved and future plans for their core as well as tiger team projects. Stakeholders and end users also presented on HAQAST collaborations and current challenges, with ozone transport and PM as noted priorities. Presenting stakeholders included NOAA, EPA, Mid Atlantic Regional Air Management Association, New York State Department of Environmental Conservation, Connecticut Department of Energy and Environmental Protection, Northeast States for Coordinated Air Use Management, CDC, and USDA. PIs met in closed session at the conclusion of the meeting to formulate ideas for the second round of tiger teams. The fourth meeting of HAQAST is planned for Madison, WI, in July 2018.

Participation at the semi-annual HAQAST meetings continues to grow at an exceptional rate (see Fig. 1). For example, HAQAST 3 was attended by 120 in-person conference-goers, with 100 additional attendees joining by remote connection.

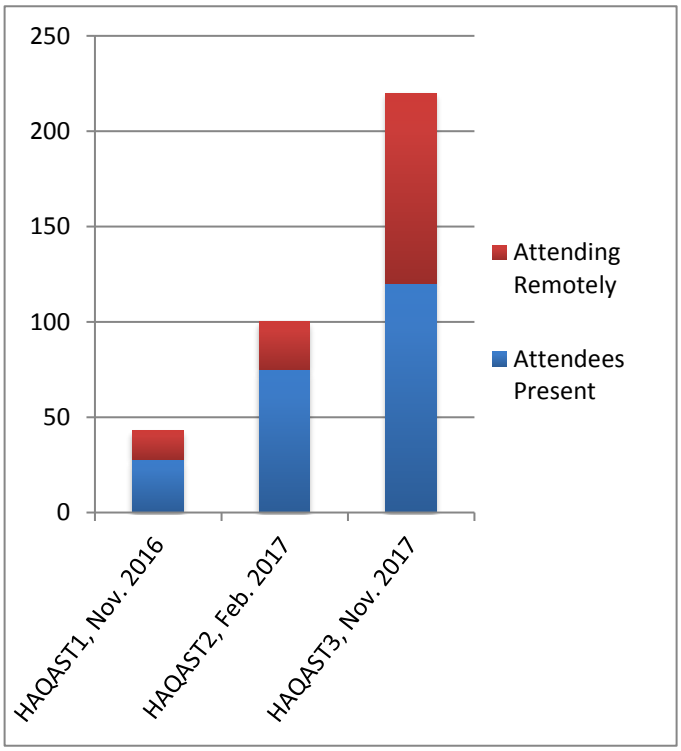

Fig. 1: All attendees (both remote and in-person) at HAQAST semi-annual meetings to date.

For the first time ever, data from NASA satellites and instruments (Terra and Aqua MODIS, Terra MISR, SeaStar SEAWiFS, CALIPSO CALIOP) were used to model ambient air pollution and associated health impacts of particulates from cook stoves apportioned to emissions by species and country. Air pollution from cook stoves currently contributes to 370,000-500,000 annual deaths worldwide. NASA's data can now help environmental and public health organizations focus their efforts. Results published in the *Proceedings of the National Academy of Sciences* in January 2017.

HAQAST scored the NASA Earth Observatory "Image of the Day" on November 7, 2017 ("Satellite Tracks Ozone Pollution by Monitoring Its Key Ingredients"). Ozone pollution near Earth's surface is one of the main ingredients of summertime smog and a primary cause of poor air quality. Yet it is not directly measurable from space because of the abundance of ozone higher in the atmosphere, which obscures measurements of surface ozone. Now HAQAST-funded researchers have devised a way to use satellites to measure the precursor gases that contribute to ozone formation. By differentiating among three possible conditions that lead to ground-level ozone production, the observations may assist air quality managers in assessing the most effective approaches to emission reduction and air quality improvements.

Building on HAQAST (and former AQAST) activities, Bryan Duncan and Anne Thompson of GSFC signed an inter-agency agreement (IAA) with the Bureau of Ocean Energy Management (BOEM). One of BOEM's mandates is to assess how pollution from shipping and oil and natural gas activities in the Gulf of Mexico affects air quality on land. The IAA provides a $500K investment by BOEM over 3 years to collaborate with NASA to assess the capability of using satellites to monitor air quality in the Gulf of Mexico.

There are two parts to this project. First, is to create a review document of the current state of satellite air quality data over the Gulf of Mexico. These data include oil slicks, lights at night, NO_2, SO_2, AOD, etc. NASA will work with experts to see if retrievals over open water can be improved. Second, NASA will execute a mini-campaign in the Gulf of Mexico during the summer when onshore flow predominates. The final objective is to determine how satellite data correspond to surface data in order to demonstrate that satellites can be used to monitor surface air quality over the ocean.

Finally, 2017 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*, *Journal of the Air & Waste Management Association*, *Environment International*, *Nature*, *Nature Climate Change*, *Geophysical Research Letters*, and *Atmospheric Environment*.

IV. Assessment

The most common technical issue in the portfolio in 2017 remained the final transfer of projects to sustainable operations. Many projects have performed admirably in this task, while others still faced hurdles in completing this final step. The most common hurdle appeared to be more related to partner budget issues rather than partner capacity. Overall, the portfolio exceeded expectations on technical performance.

The portfolio continued to carry a relatively high burden of uncosted funds in 2017. Associates worked diligently with principal investigators 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 -- FY16 uncosted funds were down ~70 percent from January 2017 to January 2018.

Overall, the portfolio had a good track record for remaining on schedule in 2017, with limited no-cost extensions approved based on new opportunities or partner issues.

In general, the portfolio accomplished significant results and accomplishments in all areas in 2017, with a bright outlook for 2018.

V. Project Portfolio

At the end of 2017, the Health & Air Quality portfolio included 12 active projects along with the activities of the 13-member Health and Air Quality Applied Sciences Team. The portfolio met or exceeded expectations on technical performance. By the end of the year, zero projects had an Application Readiness Level (ARL) of 1-3; seven projects were ARL 4-6; and five projects had achieved an ARL of 7-8. One hundred percent of projects increased by at least 1 ARL since the end of 2016, and 50 percent of projects increased by 2 ARLs. The appendix of this report includes project highlights for 2017.

VI. Program Management

The program conducted its 2017 Annual Team Meeting in September in Reno, NV. Approximately 40 attendees participated. Highlights included a local perspective address from the Washoe County, NV, Air Quality Management Division and the Desert Research Institute (DRI). 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 (Aura, S-NPP). Additionally, there were presentations from ARSET, SERVIR, and DEVELOP in capacity building, an update on HAQAST, an update from the GPM/PMM office

at GSFC, and an introduction to the VALUABLES consortium by Resources for the Future (RFF). Presentations from the 2017 review can be found at the following link: https://weather.msfc.nasa.gov/conference/phconference_nv_home.html.

Associates and Headquarters program management continued to meet regularly through 2017 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 & Air Quality continue to be Sue Estes (University of Alabama in Huntsville) and Ali Omar (NASA Langley Research Center). Unfortunately, AAAS S&T Policy Fellow Shobhana Gupta's term of service ended in August 2017. However, the program was proud to have Dr. Helena Chapman join as our new AAAS Fellow in September 2017, as she will continue to build on Shobhana's legacy.

VII. Community Leadership

The applications area presented and led sessions at meetings of the American Thoracic Society, the Air & Waste Management Association, and the American Meteorological Society (AMS). Sessions at the AMS annual meeting in Seattle in January were held as part of the Eighth Conference on Environment and Health, of which NASA is a standing committee member. The theme was "Observations Lead the Way." In all issues facing AMS and the professions it serves, the first priority should always be to obtain the necessary observations and information. Whether to address numerical weather prediction, climate, situational awareness, economic value of forecasts, societal impacts, or any other need, data-driven, science-driven decisions move the community and society forward. NASA co-chaired the conference, and several investigators from the Health & Air Quality Applications area presented papers in a session titled: "NASA Earth Observations and Climate Change." Additional talks were given at the NASA Hyperwall at the booth in the exhibit hall.

The 17th National Conference and Global Forum for Science, Policy and the Environment (NCSE) was held in January 2017 in Washington, DC. NCSE highlighted such issues as climate change and health, translating science into policy, water safety, and more. The program sponsored a session at this conference, led by Shobhana Gupta, and also presented at the Hyperwall in the exhibit hall.

John Haynes gave lectures at the Uniformed Services University of the Health Sciences (USUHS) and the National Institutes of Health (NIH) in February 2017 in the Washington, DC, metro area.

Sue Estes represented the program at the Association for the Sciences of Limnology and Oceanography (ASLO) Annual Meeting, February 26-March 3, in Honolulu, HI. The purpose of ASLO is to foster a diverse, international scientific community that creates, integrates and communicates knowledge across the full spectrum of aquatic sciences, advances public awareness and education about aquatic resources and research, and promotes scientific stewardship of aquatic resources for the public interest. NASA's booth in the exhibit hall was well attended.

The American Thoracic Society's annual meeting was held in May 2017 in Washington, DC. On May 20, NASA co-sponsored a workshop entitled, "Air Pollution Monitoring for Health Research and Patient Care," with EPA and NIEHS. On May 24, NASA sponsored a session highlighting HAQAST with over 100 people in attendance.

The program co-sponsored the 2017 Air and Waste Management Association (A&WMA) Annual Conference & Exhibition (ACE) Meeting in June in Pittsburgh, PA, 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 Alana Wier (University of Wisconsin/HAQAST), Yang Liu (Emory University), and Robert Chatfield (NASA ARC). The panel was chaired by Ali Omar and Shobhana Gupta. The NASA exhibit booth/Hyperwall display showcased NASA satellite observations and modelling animations, and Hyperwall talks by John Haynes and Ali Omar and drew large crowds. They presented additional application results and research during the platform sessions. 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 2018 Annual Meeting in Hartford, CT.

The 2017 NCAR/CDC Workshop on Weather, Climate and Health (July in Boulder, CO) converged on both environmental health and vector-borne diseases related to human health and the uncertainty inherent in weather, climate and health systems. The purpose of the workshop was to train health professionals and early career climate and health researchers (public health officials, graduate students, post-docs, early career scientists and faculty) in the

development of robust interdisciplinary research projects in this complex arena. John Haynes presented an overview of the program portfolio.

Associate Program Manager Ali Omar delivered the keynote address titled, “NASA's Satellite and Sub-Orbital Measurements for Air Quality and Health Applications,” at the 16th Annual Community Modeling and Analysis System (CMAS), at the University of North Carolina, Chapel Hill, NC, on October 23, 2017. CMAS is an international community-based air quality modeling group that develops, applies, and analyses environmental models that leverage the complementary talents and resources of the modeling community in order to set new standards and develop state of the art air quality models. CMAS is also a boundary organization that provides the program a link to the modeling community. After the meeting, the president of the group expressed a strong desire to continue the partnership and invited the Program Manager or Associate to the next CMAS Annual meeting.

The American Public Health Association’s (APHA) annual meeting was held in November in Atlanta, GA. NASA sponsored a session entitled, “Observations from Space: A Unique Vantage Point for the Study of Climate Change and its Association with Disease.” The program presented a series of Hyperwall talks during the meeting at the NASA booth in the exhibit hall. These talks were well attended, and NASA won the blue ribbon as best exhibit at the conference for the second year in a row!

The American Geophysical Union’s (AGU) Fall Conference was held in New Orleans, LA, in December 2017. The meeting offered multiple general sessions, each covering a different and exciting topic applicable across all fields of Earth and space science. The program convened an oral and poster session entitled, “People and Pixels 20th Anniversary: Advances in the Use of Remote Sensing in Social Science, Public Health, and Air Quality Applications,” at which John Haynes presented an overview of the program and Yang Liu (Emory University) presented on the effects of wildfires on air quality. The session was chaired by Associate Program Manager Sue Estes. Multiple portfolio investigators presented papers, posters, and additional talks at the NASA Hyperwall. HAQAST investigators also presented in multiple oral and poster sessions. Discussions were held on the formation of a GeoHealth track at future AGU meetings.

HAQAST participated in a wide range of targeted meetings and ongoing stakeholder engagement. For example, PI Frank Freedman gave a presentation in Brawley, CA to Comite Civico Del Valle, Inc., a non-profit dedicated to improving public health and understanding its underlying environmental stressors in the Imperial Valley, CA and the U.S.-Mexico border area. PI Bryan Duncan spoke at the U.S. Army Public Health Center (APHC) on the “Environmental Impacts on Health Readiness Working Group Meeting” in Arlington, VA. He discussed health, air quality, and disaster-response applications of NASA

satellite data, and specifically highlighted how the data may be used by APHC for the benefit of military personnel.

The program continued its active participation in the USGCRP Climate Change and Human Health Working Group (CCHHG) in 2017. 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 is anticipated to be finalized in late 2018.

The program provided support for the *Fires, Asian, and Stratospheric Transport - Las Vegas Ozone Study* (FAST-LVOS) flight campaign which sought to understand the major sources of surface ozone in Clark County, Nevada, and why ozone levels there sometimes soar above healthy levels. The campaign was in partnership with NASA ARC, NOAA, and the Clark County Department of Air Quality.

VIII. 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 2017 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 and ways to support the 2017-2019 GEO Work Programme. The CoP also launched a new website to keep the community informed of activities, news, and opportunities (http://www.geohealthcop.org).

The GEO Health CoP supported the “One Earth One Health Workshop” in Montréal in June 2017. This workshop was sponsored by the Canadian Space Agency and the Public Health Agency of Canada. The workshop included presentations by the national and international communities on current Earth Observation applications, tools and solutions for public health issues. The workshop allowed participants to discuss different scenarios related to five public health themes (vector, water and airborne diseases, vulnerable human populations, and emergency management). A report based on the findings of this workshop is expected in 2018.

GEO’s Fourteenth Plenary Meeting was held in Washington, D.C., in October 2017. The GEO Plenary is the annual meeting of GEO’s 104 Member governments and 109 Participating Organizations, such as the European Space Agency (ESA), JAXA, NOAA, NASA, USGS, United Nations Environment Programme, the World Bank and Observers such as the Organization for Economic Co-operation and Development (OECD) and the United Nations

Secretariat on Global Geospatial Information Management (GGIM). The Plenary is preceded by Side Events organized through the GEO community and featuring global initiatives and activities to improve use of satellite, atmospheric, and *in-situ* Earth observations for better decision-making.

The GEO Health CoP hosted an in-person side event at the Plenary. This represented the first in-person meeting of the CoP since 2013. The standing-room only crowd heard presentations from a wide array of experts, including ones from the Bill and Melinda Gates Foundation, the World Health Organization, and Sustainable Development Goals (SDGs) Compacts 2020. A draft CoP strategy was composed, to be further refined in 2018. The Public Health Agency of Canada agreed to circulate a draft report from the "One Earth: One Health – Montreal" workshop for comments from the community. The "Earth Observations for Health" community activity was highlighted by GEO as an emerging success during the Plenary. The CoP also supported another side event entitled, "Operationalizing One Health: Observe, Analyze, Communicate." This side event was coordinated by the US State Department, EPA, and NASA. Key points from this side event included: 1) One Health (approaching human-animal-environmental health as parts of a whole) is a key measure for protecting public health and generating efficiencies, and 2) One Health relies on a cycle of observation, analysis, and communication. Helena Chapman spearheaded the discussion with her presentation, "Introduction to One Health and the Three-Step Cycle." Examples from the Arctic and from tropical regions dealing with mosquito-borne disease were presented.

The NASA Applied Sciences Program issued a solicitation to support the GEO Work Programme through ROSES 2016. This solicitation included a section targeting the "Earth Observations for Health" community activity. Awards from this solicitation were announced at the GEO Plenary and are as follows:

1) **Antarpreet Jutla**, West Virginia University, "EO for Cholera Prediction in Africa";
2) **Tatiana Loboda**, University of Maryland, "Multi-sensor Data for Myanmar Malaria Early Warning System";
3) **John Malone**, Louisiana State University, "Surveillance for Vector-borne Disease in the Americas";
4) **Benjamin Zaitchik**, Johns Hopkins University, "Environmental Determinants of Enteric Infectious Disease."

John Haynes represented the program at the Third Meeting of the Global Platform on Air Quality and Health in Madrid, Spain, in March 2017. This meeting was sponsored by the WHO. Delegates expressed widespread interest in upcoming NASA missions including TEMPO and MAIA and were also interested in connections to GEO. More information can be found at the following link: http://www.who.int/airpollution/global-platform/en/.

The WHO Global Task Force on Cholera Control (GTFCC) held their Joint Meeting of the Working Groups on Surveillance in London in April 2017. For the first time, satellite-based prediction information was included on the agenda. The program was represented by Dr. Antar Jutla of West Virginia University.

In many parts of the world, mosquitoes are more than just a summertime nuisance. They spread diseases that kill nearly 2.7 million people a year. Now, citizen scientists can use a NASA app to help those working to understand and reduce mosquito-borne diseases. NASA has introduced the Mosquito Habitat Mapper as part of its GLOBE Observer app available for iPhone and Android. The app includes training, making it easy for anyone to use. The Mosquito Habitat Mapper guides users through the process of identifying and eliminating mosquito-breeding sites. It also gives citizen scientists the option to identify the mosquito species to determine whether it could transmit Zika, dengue fever, yellow fever, chikungunya, and other diseases. More information can be found at the following link: https://www.nasa.gov/feature/nasa-citizen-science-app-tackles-mosquito-borne-disease.

IX. Looking Ahead

During 2018 and beyond, the program will continue to expand its relationship with current and future relevant NASA missions, as well as field and Earth Venture (EV) campaigns. The program looks forward to the results of the first round of HAQAST Tiger Team initiatives and anticipates a second round of Tiger Teams to be selected. Two HAQAST team meetings are planned in 2018. The first meeting will be at the University of Wisconsin in Madison, WI, in July with the second meeting at a TBD location late in 2018.

The program looks forward to the competitive selection of proposals from the ROSES 2017 A.39, “Earth Science Applications: Health and Air Quality,” solicitation. Awards are expected to be announced in summer 2018.

Sessions in 2018 are planned for the AMS Annual Meeting, the Air & Waste Management Association, the American Thoracic Society, and the American Public Health Association. A seminar is also planned at the Milken Institute School of Public Health, George Washington University (Washington, DC), in February 2018.

The program will continue to keep abreast of studies and opportunities related to the *PACE*, ASCENDS, OCO-2, *HyspIRI*, and GEO-CAPE decadal survey missions. The program will monitor potential changes in these missions in light of findings from the new “Decadal Survey for Earth Science and Applications from Space,” of the National Academies of Sciences, Engineering and Medicine, anticipated for release in January 2018. 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 US, 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.

X. Appendix

Active Health & Air Quality Project Highlights (as of December 2017)

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 US 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.

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 (NAAQS). 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 2017, the project demonstrated that using satellite-derived PAR improved biogenic emission estimates in the model and consequently led to better ozone prediction. The results were presented at scientific forums and documented in a peer-reviewed publication: Zhang et al. (2017). The tools and data products were delivered to the state of Texas (TCEQ) and the tool was tested in their modeling platform. While the use of satellite-based PAR improved the emission estimates, it also pointed out an inherent problem in the emissions model for Texas. This issue is currently being addressed by TCEQ. The project also delivered data and tools to states of Wisconsin and California and worked on the implementation of the technique in their modeling systems. Preliminary results have been satisfactory and a mechanism for data delivery for other modeling periods has been established.

Due to high priority of this research for the state of Texas in their SIP modeling activities, the Texas Air Quality Research Program provided complementary funding ($200K in 2016) and, in 2017, they 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 1-30 September 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 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.

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 hydroclimatological 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.

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 US 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 US, 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 Network (EPHTN), 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 US to be matched with existing demographic and economic factors available from 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. The data can be found at: https://ephtracking.cdc.gov/showUVLanding.action. This permanent platform will maintain and update the data that was provided by this project.

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 US 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 2017, project demonstrated that the assimilation of MODIS retrievals of aerosol optical depth (AOD) resulted in improved model estimates of $PM_{2.5}$. Experiments included the assimilation of AOD by generating the error background covariance matrix with perturbations of the meteorological field, and perturbations of the meteorological field and emissions. Furthermore in calculations of the probabilistic predictions for ground-level ozone (O_3), analog ensemble mean was found to be much closer to the observations than the CMAQ model. The project advanced to an ARL of 7 after prototype applications functionality was tested and demonstrated at the NOAA facility.

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 Land Data Assimilation System (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.

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 US. 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:

Gordon Pierce and Patrick Reddy, Colorado Department of Public Health and Environment:
"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."

Rosemarie Russo, City of Fort Collins:
"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."

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.

Project: Aura Chemical Reanalysis in support Air Quality Applications

PI: R. Bradley Pierce

Organization: NOAA/NESDIS/STAR

- This project utilizes the Real-time Air Quality Modeling System (RAQMS) in conjunction with the Operational Gridpoint Statistical Interpolation (GSI) 3-dimensional variational data assimilation (DA) system to conduct a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements. It ingests several observations from NASA satellites including OMI (Total Column O_3, Tropospheric NO_2 Column), MLS (Stratospheric and

upper tropospheric O_3, H_2O, CO, HCL, and potentially HNO_3 and N_2O profiles), AIRS (Tropospheric CO, and potentially CH_4 and N_2O profiles), MODIS (Aerosol Optical Depth, Fire Detection), TES (Tropospheric O_3, CO, CH_4 and N_2O validation) and ACE (Stratospheric and upper tropospheric O_3, H_2O, CO, HNO_3, CH_4 and N_2O validation). The main objectives of the project are to provide the air quality community with a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements, conduct regional chemical data assimilation experiments to quantify the influences in changes in NOx emissions on US air quality during the Aura period, and collaborate with international, federal, state and local air quality management communities in the utilization of the Aura and A-Train measurements and reanalysis for air quality assessment activities.

In 2016, NOAA Air Resources Laboratory used July 2011 RAQMS chemical and aerosol analyses for NAM/CMAQ re-analysis to support Maryland SIP modeling.

This project concluded in July 2017. It reached a final ARL of 7 after completing the first year (2006) of Real-time Air Quality Modeling System (RAQMS) Aura Reanalysis and demonstrating it in a relevant environment. The results were evaluated with NASA INTEX-B aircraft measurements. Comparisons with airborne *in-situ* ozone measurements from the NASA DC8 show very good agreement over the Central Pacific and Gulf of Mexico. These results provide confidence that the Aura Reanalysis can provide realistic boundary conditions for regional air quality modeling applications addressing the influence of long-range transport of pollutants on US air quality.

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, the NOAA, and the Gulf of Mexico Coastal Ocean Observing System teamed up to create a cellphone microscope app, the "HABscope," that 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 1-2 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.

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

- 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 US 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 LST 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.

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.

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.

HAQAST Project Highlights

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 US 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).

We have several 2017 updates. First, Co-I Cromar is leading the development of the HAQI formulation using methodologies that have previously been used to develop similar indices for research purposes using datasets in the US and internationally. He created a globally uniform HAQI that accounts for the additive health risks of multiple outdoor air pollutants (e.g., $PM_{2.5}$, O_3, and NO_2) which can be applied to monitored and forecast pollution estimates. We are currently evaluating the HAQI. Second, we began evaluating the air quality forecasts for various cities around the world. We reached out to various city governments and government agencies (i.e., Rio de Janeiro, South Africa, Indonesia, Singapore) to get air quality data and to access local expertise in our evaluations. We began work with UNICEF to aid them in the processing and interpretation of the air quality forecasts. Third, in 2017, we began working on our scoping report for BOEM and planning for the May 2018 ship cruise in the oil and natural gas extraction areas of the Gulf of Mexico.

Regarding communications in 2017, we were involved in several activities. First, we updated our website, https://airquality.gsfc.nasa.gov, to include OMI NO_2 data through 2016 and also added 200 US cities to the site. Second, on May 20th, 2017, Cromar and Duncan co-led an American Thoracic Society Workshop, "Air Pollution Monitoring for Health Research and Patient Care". There were about 30 participants with wide-ranging expertise, including monitors (low cost, sub-regulatory, and regulatory), epidemiologists, satellite experts, and air quality forecasting. Third, Duncan presented at a number of health and air quality conferences, including the GEO: Air Quality Side Event, International Society of Exposure Science Annual Meeting, World Bank/EPA: Filling the Gaps Workshop, DoD Army Public Health Center: Environmental Impacts on Health Readiness Working Group meeting, American Thoracic Society Annual Meeting, and SatSummit.

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 US 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 US 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 2017, we have a few manuscripts addressing these goals. *Jin et al. (Journal of Geophysical Research-Atmospheres, 2017*) is a multi-year investigation of the use of formaldehyde-to-nitrogen dioxide ratios as an indicator for the sensitivity of ozone formation to its precursor sources of nitrogen oxides versus volatile organic compounds and examines trends in this indicator over the past decade in northern mid-latitude source regions. Her findings were featured as a NASA Image of the Day and in a few web articles. *Guo et al. (submitted to Atmospheric Chemistry and Physics)* attributes background versus US anthropogenic sources to surface ozone over the US for 2004-2012, with a focus on the days with the highest observed ozone levels. Fiore also contributed to a scientific assessment on background ozone (*Jaffe et al., submitted to Elementa*).

We have also made substantial progress on our multi-pollutant health impact analysis over New York State, with at least two manuscripts planned. We are characterizing uncertainties in obtaining surface fine particulate matter ($PM_{2.5}$) distributions across New York State from current satellite Aerosol Optical Depth (AOD) products. We are compiling datasets, including at least one of our own, generated following different approaches to estimate exposure to $PM_{2.5}$, nitrogen dioxide, and ozone distributions across New York State. County-level averages are being combined with hospital admission records to identify exposure-response relationships across New York. Health Sector team members are currently developing a method to quantify the health benefits of emission control actions over space and time in New York State.

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: Frank Freedman

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 (100s 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 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.

During 2017, PI Frank Freedman presented material related to HAQAST project goals at two conferences. At the MAC-MAQ Conference (University of California, Davis, September 2017), Dr. Freedman highlighted localized receptor-oriented particulate dispersion modeling results, a concept underlying Deliverable 3 work. A journal article to *Atmospheric Environment* on this work is in review. For the CMAS 2017 conference (University of North Carolina, Chapel Hill, October 2017), he presented a poster and prepared a technical abstract summarizing the project team's developments to date on the HAQAST core project of coupling daily satellite-derived $PM_{2.5}$ fields with dispersion modeling to generate high-resolution $PM_{2.5}$ fields (https://www.cmascenter.org/conference/2017/agenda.cfm). Dr. Freedman also presented analysis of MAIAC AOD fields over Southern California at a recent ARSET training organized by SCAQMD (Riverside, CA, September 2017), and gave a talk to the community group Comite Civico Del Valle and stakeholders at California Department of Public Health (Brawley, CA, December 2017), highlighting the potential capabilities of MAIAC AOD in assessing air quality in the Imperial Valley, associated with his Tiger Team project work.

Current work status is as follows:

Deliverable 1: Led by Co-I Mohammad Al-Hamdan, we have produced a year 2016 satellite-derived $PM_{2.5}$ 3-km daily gridded $PM_{2.5}$ field over California, summarized in the above CMAS technical abstract. We are in the process of expanding these for 2010–2017 in coordination with a newly formed (since project commencement) stakeholder group at the California Air Resources Board (Cynthia Garcia, primary contact). We anticipate completion of these fields by

May 2018 for integration into dispersion modeling (Deliverable 3). The Co-I is also developing a MAIAC-based field for year 2012 for SCAQMD as part of Tiger Team project work.

Deliverable 2: We are working with BAAQMD to integrate MAIAC AOD into their operations. A poster, in collaboration with NASA ARC scientists Meytar Sorek-Hamer and Robert Chatfield, was presented at the HAQAST-3 meeting. We have extended this by developing ArcGIS layers of MAIAC fields for a set of winter days during 2016 screened for good AOD retrieval, which will be used by BAAQMD to assess agency CMAQ simulations and to identify potential emission or concentration hot spots outside of their current monitoring framework. We will be integrating model fields from WRF-CMAQ and/or WRF-Chem into these ArcGIS layers, led by Co-I Sen Chiao.

Deliverable 3: Led by Co-I Akula Venkatram, we have developed the dispersion modeling system to couple with the satellite fields of Deliverable 1, summarized in the above CMAS technical abstract. Current efforts are aimed at finalizing an evaluation of the fine-scale dispersion model component of system against field data from the Interstate-710 near-roadway monitoring study carried out by SCAQMD. A journal submission of this work is in preparation. We are also exploring a more comprehensive field evaluation across California using newly available Purple Air low-cost sensor measurements, an effort in collaboration with stakeholders at CARB and SCAQMD.

Starting in 2018, the PI on the project is Dr. Minghui Diao at San Jose State University. Dr. Freedman will still be involved as a technical lead, overseeing the major developments of the core project and completing Tiger Team work.

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. Our work has contributed to the release of a new health impact

assessment tool (LEAP-IBC), two published journal articles, three more articles currently under review in *Nature*, *Proceedings of the National Academy of Sciences*, and *Elementa*, plus six more articles currently under review for an *ACP* special issue.

For our core project, we have provided emissions response coefficients, constrained by satellite remote-sensing data, to the Climate and Clean Air Coalition (CCAC) of the United Nations Environment Programme. This work stems from a CCAC initiative to develop and apply National Action Planning Toolkits, which allows member nations to rapidly estimate air quality and climate impacts of arrays of mitigation options as part of their decision-making process. Through AQAST, NASA data were incorporated into the initial version of one such tool—the LEAP-IBC Toolkit. As part of HAQAST, we have expanded the number of countries supported by LEAP-IBC, and we have now provided emission response coefficients for more than 100 countries around the globe. The toolkit was officially launched at the UN Science-Policy-Business Forum on the Environment in Nairobi, Dec 2-3, 2017.

The results that we have generated for the LEAP-IBC toolkit have also been used for our own application investigating the climate and health impacts of aerosol and greenhouse gas emissions from cookstoves. In Lacey et al. (*PNAS*, 2017), we used this information to help constrain projections of the impacts of residential solid fuel use for cooking (i.e., cookstoves) on ambient air quality and the attributable fraction of global deaths. This study also estimated the associated impacts of the emissions of aerosols and long-lived greenhouse gases on global mean temperature change, using climate sensitivities derived from the GISS model (Shindell, 2012). Several regions were identified where the per-cookstove benefits of cookstove emissions mitigation would be particularly pronounced (such as Azerbaijan and Ukraine), owing to higher baseline-mortality rates and efficient transport of aerosols to northern latitudes.

In Anenberg et al. (*Nature*, 2017), we investigated the impacts of excess diesel NOx emissions on health impacts from $PM_{2.5}$ and O_3, as well as the impacts of these emissions on crop damages and climate. Excess diesel emissions correspond to the amount that is emitted in real world driving conditions is above certification limits. We found that presently these excess diesel NOx emissions contribute to 38,000 premature deaths globally, mostly owing to heavy-duty vehicles. By 2040, adoption of Tier6/VI standards would alleviate a significant fraction of the burden of disease associated with this sector; tightening regulatory practices to implement Real Driving Emissions programs could provide further benefits.

Our HAQAST work has contributed to several other manuscripts currently in review. The work of Jiang et al. (*PNAS*, in revision) evaluates the trends of US NOx emissions using multiple remote-sensing products, *in-situ* measurements, and models, and finds an unexpected slowdown in the reduction of US NOx

emissions. This work contributes to multiple Tiger Team projects. We also contributed modeling and remote-sensing data for an evaluation of the global burden of air pollution on asthma (Anenberg et al., *Nature*, in review). With support from AQAST and HAQAST, my group participated in a multi-modeling study of long-range pollution transport commission by the United Nations Environment Programme; the results from this are being published in at least 6 journal articles submitted in December 2017 and January 2017 to a special issue of Atmospheric Chemistry and Physics. Lastly, through HAQAST, Henze became involved with a review of background O_3, which lead to a manuscript recently submitted (Jaffe et al., *Elementa*, submitted).

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 US, 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 US. 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 US, 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.

This study will provide a more comprehensive understanding of the spatial and temporal links between environmental conditions and pollen production and will clarify impacts of climate change on allergic disease burden. We will develop several applied products, including applications in environmental health tracking and disease surveillance, risk mapping, prevention messaging, and warnings to limit adverse health impacts. Our public health partners and the general population can use these products and tools to limit pollen exposure, thereby reducing associated health impacts and financial burdens associated with aeroallergens.

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 US, 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 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; 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). Dr. Holloway is also HAQAST Team Leader. Holloway has served as Deputy Leader of NASA AQAST, overseeing communication and outreach activities, and participating in broader team budget, planning, and evaluation activities.

2017 updates include five papers published, all which have links with the goals of the HAQAST activity. Karambelas et al., *Atmospheric Environment* (2017), use OMI data to evaluate the CMAQ over India (part of Project 2 of HAQAST activities); Sanderfood and Holloway, *Environmental Research Letters* (2017), review the impact of air quality on birds, highlighting the potential of satellite data to support a large-scale assessment of ecological health impacts from air quality; other papers focus on energy and air quality modeling, where the CMAQ has been evaluated with satellite data and/or undergraduate researchers were supported.

We have advanced Project 1 of our HAQAST proposal by working with the EPA to evaluate model simulations of HCHO used in the NATA. We have provided a series of interim reports to Kirk Baker and Barron Henderson at EPA to promote dialogue throughout the project. We are now working with our EPA partners to prepare a publication for peer-review. We 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 my many air quality agencies (https://nelson.wisc.edu/sage/data-and-models/OMI_NO2.php). We are working on Project 3 in collaboration with the West Virginia Department of Environmental Protection and the City of San Antonio, both of which are interested in O_3 production issues and the application of satellite data. 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, we have significantly updated resources on our webpage haqast.org, increased social media engagement (~3,500 Twitter Followers), and developed guidance on use of NASA data products, and written outreach articles (HAQAST Communications Coordinator Daegan Miller wrote an overview article for *Physics Today* with over 14,000 shares as of February 2018.)

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 US 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 US. 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 2017, we have advanced our core project in several fronts. First, we have completed the development of a Bayesian ensemble model that combined information from the 1-km resolution AOD products, CMAQ model simulations and ground measurements to predict daily $PM_{2.5}$ concentrations over fire seasons in Colorado for 2011−2014. The model has complete coverage in space and time with an out-of-sample R^2 of 0.66 and cross-validated root-mean-squared error of 2.00 $\mu g/m^3$. We have contributed to the theoretical paper that describes this advanced Bayesian modeling technique, and the manuscript to document our application in Colorado is near completion. Elevated $PM_{2.5}$ concentrations over large fire events were successfully captured by our model. Second, model-predicted daily $PM_{2.5}$ concentrations were aggregated into a 4-km grid and matched with emergency department visits due to respiratory illness provided by the CDPHE. We are in the process of developing an epidemiologic model to estimate wildfire-specific Exposure-Response functions. Finally, we have completed the compilation of a long-term national dataset at 12-km resolution to support a national machine learning model to estimate multi-year $PM_{2.5}$ exposure levels. A manuscript to document our work is being prepared. The outcome of this model will be used as inputs to a national epidemiologic model for the acute health effect assessment of $PM_{2.5}$ exposure.

Regarding the first round of Tiger Team projects, we have also made significant progress. We have completed the development of a random forest model to estimate daily $PM_{2.5}$ levels at 1-km resolution in New York State as part of Bryan Duncan's TT project. The goal is to test our approach to fill the satellite data gaps left by cloud cover and snow cover. We have delivered the entire model prediction dataset to Arlene Fiore's group for a comparison study with $PM_{2.5}$ estimates from other methods such as CMAQ. As part of Pat Kinney's TT project, we have communicated extensively with our stakeholders in California and New York City to design our modeling domain and time period as well as finalizing our modeling strategy. We are currently working with other HAQAST investigators on

compiling the Southern California 1-km modeling dataset for 2012 as well as the New York City 100-m resolution modeling dataset for 2015.

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 US, 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 US. 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 US.

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 US. 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 2017 accomplishments include two publications relevant to our HAQAST activities. Cady-Pereira et al (*ACP*, 2017) explores the role of biomass burning in megacity air quality and Young et al. (*Elementa*, 2018) assesses the ability of models to capture critical features of the distribution, variability, and trends of tropospheric ozone. An additional publication exploring differences in satellite records of tropospheric ozone is in review. Our team has also presented HAQAST results at the CMAS and AMS meetings during the past year.

We have completed five years of two of the model simulations needed to achieve our first objective and are evaluating the simulations against independent measurements. We have also completed a 2008 simulation that will be used to provide boundary conditions to our South Coast Air Quality Management District stakeholders (objective 2) and are working with them to implement the boundary conditions in their SIP model. Documentation of the process is being done under the SIPs Tiger Team effort led by Arlene Fiore. For objective 3, we are processing CrIS CO and ozone measurements during the Thomas Fire that took place in the Los Angeles Basin in December 2017 and will work with SCAQMD to determine how we can support their activities related to the fire.

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).

Progress has been made on several items related to Task 1 - Earth Observation Synthesis (Task 1a) and Dissemination and Delivery (Task 1b). A statistical model predicting daily $PM_{2.5}$ concentrations was implemented for the Western US, based on the previous day's $PM_{2.5}$ value, MODIS fire radiative power, MODIS aerosol optical depth, smoke plume perimeters from the NOAA Hazard Mapping System, and the National Fire Danger Rating System Energy Release Component index from the Wildland Fire Assessment System. For the summer 2017 wildfire season, this system was used to initialize the Air Resource Advisors (ARA) Smoke Outlooks when forecasting at permanent monitoring locations. A publication is in preparation for submission to the Special Issue in the Journal of Applied Remote Sensing. Training on satellite products was conducted as part of the annual one-week ARA training (May 2017) and included hands-on training

with NASA WORLDVIEW, GOES and NOAA Hazard Mapping System (HMS) products and included some E-IDEAS. This was the first time that satellite products were explicitly included in the training. Finally, by working one-on-one with ARAs deployed on wildfire incidents, satellite information was infused into the information they disseminate via public briefings, smoke blogs, and with Incident Public Information Officers. Examples include posting of GOES-16 products on the California smoke blog during the Island and Detwiler wildfires, and use of the GOES-16 fire-temperature product to conduct custom smoke modeling of nighttime fire activity. Progress also continues building an archive of ground-based and remotely-sensed data, and in particular, a real-time data access request has been made for GOES-16 data. This involved briefings up the USFS command chain and with other USFS groups. We have disseminated information regarding HAQAST opportunistically during meetings and conference calls such as with the National Wildfire Coordinating Group Smoke Committee (SmoC), NW-AIRQUEST and the US/Canadian fire emissions sharing workgroup.

Earth Observations for Smoke Model Evaluation (Task 2): In December 2017, we brought a post-doctoral researcher on-board whose initial work includes air quality modeling over the western US from wildfires in September 2017, using CALIOPE (for opportunistic vertical smoke allocation information) and MAIAC AOD (smoke aerial extent) to evaluate the system. The goal is to implement significant operational improvements to our systems in the coming summer 2018 wildfire season with this work.

Earth Observations to Improve the Science of Smoke Modeling (Task 3): GOES-16 was added to the HMS fire-detection data this past year. It required a new approach to how we aggregate fire location information and estimate fire size for our operational forecast runs. Currently, we are requesting real-time data access to the GOES-16 AOD and fire-detection products to take advantage of the high-temporal resolution of the products to initialize our systems. In related collaborative work, we work with the University of California, Davis assessing small fire activity using satellite data from GOES, MODIS, Landsat, and VIIRS. Small fires (< 100 acres) account for approximately half of the fire activity nationally, and are dominant in regions such as the southeastern US. Results of this work will be used in national emission inventories.

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 Tech University

Wildland fires constitute the largest source of primary fine particulate matter ($PM_{2.5}$) in the US, 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.

Annual Report for CY2017:

Description: This project is designed to provide accurate and targeted information for dynamic air quality and public health management, and particularly for use by forest-service and air-quality managers in their daily prescribed burn management practices in the southeastern United States. The project is intended to utilize Earth observations to evaluate and calibrate real time air quality and health impacts information.

End users: Air-quality, health, and forest-management agencies at the local, federal, and state levels as well as health-effects researchers.

Data sources, models, technology: MODIS and GOES satellite and derived data; WRF and CMAQ models, including direct sensitivity analysis approaches; Inexpensive air quality sensors.

Major accomplishments in CY2017:

- We redesigned our website to disseminate the HiRes2 forecasting products more interactively. This fully updated public website (now in testing mode at https://forecast.ce.gatech.edu/hires2test/forecast/map/) can provide a user-friendly tool to regional stakeholders on a daily basis, especially for dynamic management purposes to better achieve ecological and air quality goals with prescribed burns and reduce adverse health impacts. The new website uses webgis technologies to display the forecasting products, real time and historical measurements, and Earth-observation datasets. We import and update ozone and $PM_{2.5}$ air quality as well as fire observations and forecasting products into a MySQL database on a daily base. By further using Leaflet and OpenStreetMap, the webgis system can overlap the above datasets with geographical information and display them interactively on dynamic maps that allow users to move around and zoom in/out, and virtually show air pollution and fire impacts on sensitive places. The webgis system can also overlay the modeled air quality and fire impact fields using the GeoJSON format on the same map for easy comparison

with sparse air quality observation, fire detections, and burning permits locations. The historical observational and forecasting database are current to present and back to January 2015. We presented this progress in 2017 CMAS conference held in Chapel Hill, NC on October 24, 2017, the AMS annual meeting, Austin, TX, January 7-11, 2018, and HAQAST 3 at Columbia University, November 28-29, 2017.

- We expanded the HiRes2 forecasts for prescribed burning source impacts to include parts of Florida, Alabama, South Carolina, North Carolina, and Tennessee surrounding Georgia. We used the historical BBEP dataset to derive the monthly county-level typical burn-size database for each of the above southeastern states. Combining the typical burn-size database with meteorological criteria at representative weather stations, we built a burn activity forecasting model. Then, using fuel loading estimates based upon the wildland forest land-use database, we developed a new prescribed burn emissions forecasting model for these five surrounding states. We started the operational forecasting of prescribed burning impacts in the Southeast since the fire season of 2018.

- We deployed a system of inexpensive air-quality sensors at schools in southwestern Georgia and collected sensor data that measures air quality impacts from prescribed burns nearby. We analyzed the sensor data which we will later combine with satellite AOD products and air-quality model fields to provide spatiotemporal smoke-impact fields for potential health-impacts assessments.

- Huang, R., M.T. Odman (2017). “Burn Area Comparisons between Prescribed Burning Permits in Southeastern USA and two Satellite-derived Products.” was submitted to *Journal of Geophysical Research* (under revision).

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 US, 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:

1) 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 retrieval to constraint biogenic isoprene emissions, and MODIS and MISR aerosol data to improve dust and fire emissions.

2) 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.

3) 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;
4) 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.

CY2017 Updates:

We have made progress in all three core projects:

a. Emission data assimilation. A new emission data assimilation algorithm has been developed and applied to study the impact of the 2008 Great Recession on U.S. air quality (Tong et al., GRL, 2016). Emission generated with this approach has been tested with NOAA's experimental $PM_{2.5}$ forecast (Lee et al., 2017). Working with the TT project with PI B. Pierce, we are further developing this approach to consider process budget (local emission vs transport) of NOx to improve satellite-based emission-adjustment approach.

b. Chemical-data assimilation. Three papers were published using various NASA data in chemical-data assimilation (Chai et al., *JGR*, 2017; Tang et al., *Geoscientific Model Development*, 2017; Huang et al., *Weather Forecasting*, 2017). In Chai et al. (2017), MODIS AOD and AirNow $PM_{2.5}$ are assimilated into the Community Multi-scale Air Quality (CMAQ) model using an optimal interpolation (OI) method, and we demonstrate that assimilating the total AOD observations is more beneficial for correcting the $PM_{2.5}$ underestimations than directly assimilating the AirNow $PM_{2.5}$ ground measurements. The Tang et al., 2017 paper applies the Gridpoint Statistical Interpolation (GSI) 3D-Var assimilation tool to improve surface $PM_{2.5}$ predictions over the U.S. by assimilating MODIS AOD and AirNow $PM_{2.5}$ observations. Finally, we have tested a Kalman-Filter bias correction algorithm with the NOAA NAQFC modeling system to improve $PM_{2.5}$ forecasting (Huang et al., 2017).

c. NAQFC evaluation with NASA data. Two papers were published using ammonia measurements from two DISCOVER-AQ field campaigns and satellites to evaluate model performance (Baytte et al., *Atmospheric Environment*, 2017; Bray et al., *Atmospheric Environment*, 2017). This is the first time that this important $PM_{2.5}$ precursor was carefully looked in the national forecasting model.

In addition, our team has been working on an additional (fourth) project: dust and Valley fever (Tong et al., *Geophysical Research Letters*, 2017). Using a satellite-aided dust detection algorithm, we found that the frequency of dust storms in the US has increased 240 percent in the western US. In the same region frequented by dust storms, the infection rate of Valley fever, an infectious disease caused by inhaling soil-dwelling fungus, has increased 800 percent in just 10 years. This work has been covered by more than 30 news articles, a documentary (in production), and two TV interviews, and have resulted in several ongoing collaborative projects with the CDC and states.

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 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 US EPA and other government agencies, as well as air quality and health managers worldwide.

2017 Progress Update:

1) For the project on global ozone data fusion, we have created a first product and delivered it to the Global Burden of Disease ambient air pollution team. Our analysis uses global observations from the Tropospheric Ozone Assessment Report (TOAR), five global atmospheric models from the Chemistry-Climate Model Initiative (CCMI), and one model at fine resolution from NASA (GEOS-5), focusing on 2008-2014. We have selected the combination of models that best reproduces observations in each world region, bias corrected those models based on observations uniformly within each region, and bias corrected again within close proximity to monitors. In the coming year, we hope to make further progress toward a full data fusion of observations and models.

2) For the project on the co-benefits of the Paris Agreement pledges, we have made progress in processing emissions, setting up global atmospheric model simulations, and in defining the scenarios to be evaluated. In the coming year, we plan to continue this progress by completing the atmospheric simulations and starting the analysis of health co-benefits.

3) For our Tiger Team project on air quality and health trends in the US, our team has completed an assessment of trends in air pollution-related deaths in the US-based on a 21-year CMAQ simulation. We are currently finalizing that work and plan to submit for publication soon. We have also completed an analysis of health trends based on the North American Chemical Reanalysis dataset, and find that it agrees well with the results of the 21-year CMAQ simulation and extends that simulation to more recent years. We have also begun analysis of health trends based on satellite observations.

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 regions. 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.

CY 2017 Update:

As part of our base activities, we continue to compare satellite ammonia measurements from CrIS and IASI with *in-situ* measurements from aircraft, ground-based (mobile laboratory *in situ* and stationary FTIR), and surface networks (Ammonia Monitoring Network). These activities are important because while satellite ammonia measurements offer unprecedented daily and global coverage, there are limited means against which to validate them. Because both satellite measurements are sensitive to thermal contrast between the surface and lower troposphere (where most ammonia is located), it is important to quantify the accuracy and precision associated with the satellite measurements. For example, most satellite measurements have used significant temporal (months-years) and spatial (~ 100 km) averaging to locate emission sources and their relative magnitude when coupled to chemical transport models. Yet ammonia emissions are likely to be strongly episodic (e.g. fertilizer application) and highly-localized (agricultural regions), scales where daily or weekly measurements at the level of an individual footprint may be useful for understanding the high spatial heterogeneities of $PM_{2.5}$. In addition, where signal averaging is relevant (e.g. seasonal, regional), it is important to quantify potential biases in the satellite measurements that

are being used input to derive emission inventories. In the San Joaquin Valley of California in winter, CrIS ammonia profiles show good correlation with spatial gradients observed by *in-situ* measurements nearest the surface (<0.5 km) but has a tendency to underestimate the observed ammonia by a factor of two. Correlations degrade above the boundary layer, though this may be due to biases in the *in-situ* measurements in the relatively clean free troposphere. IASI ammonia column amounts in Colorado in summer also generally underestimate the observed column profile in the boundary layer. We note that these are quite challenging environments for validation: CriS measurements are in winter in the San Joaquin Valley where strong thermal inversions (CrIS) exist even at the overpass time at 13:30 local, and IASI samples in the morning (08:45, 09:30 local) when thermal inversions have not necessarily been broken. Overall, both satellites capture high-concentration spatial gradients in ammonia that can be observed at the footprint scale.

To examine spatial variability further, we have developed an oversampling routine that captures sub-pixel resolution when averaging over longer timescales (e.g. weeks to months to years). Effective resolution depends upon the averaging time and the number of valid satellite measurements in the domain. We have used the IASI 2008-2016 ammonia data to show the strong spatial gradients in the Cache Valley in northern Utah, San Joaquin Valley in California, and mid-Atlantic regions. Effective resolution was 2 km, and we have worked with stakeholders at US EPA, Colorado Department of Public Health and the Environment, New Jersey Department of Environmental Protection, and Utah Department of Environmental Quality. One particularly interesting finding was that the Ammonia Monitoring Network site in the Cache Valley—by far the largest ammonia measurements nationwide—was actually located in part of the valley with relatively lower ammonia concentrations than elsewhere. This example shows how satellite ammonia data can be used to put limited surface network sites in a larger context.

Finally, our group has examined spatial trends between the Ammonia Monitoring Network and satellite-based measurements. The Ammonia Monitoring Network is limited to about 50 locations in the US, a density that cannot capture the large spatial gradients in short-lived ammonia. To examine how satellites can be used to augment this network, we have examined time series of satellite data around 50 km radii of existing surface sites (2-3 day temporal resolution). Excellent temporal correlations are observed between satellite and the surface measurements except in winter, presumably due to the challenges of low thermal contrast. The intra-annual variations in the surface-based measurements show excellent agreement temporally and in magnitude with the satellite-derived measurements. These results suggest that satellites provide a valuable tool for assessing ammonia measurements outside the network, though the caveat remains that caution must be exercised under conditions of strong inversions.

Publications from the base HAQAST activities:

Sun, K., L. Tao, D.J. Miller, D. Pan, L.M. Golston, M.A. Zondlo, R.J. Griffin, H.W. Wallace, Y.J. Leong, M.M. Yang, Y. Zhang, D.L. Mauzerall, and T. Zhu (2017), “Vehicle

emissions as an important urban ammonia source in the United States and China", *Environ.. Sci. Technol.*, *51*, 2472-2481, doi:10.1021/acs.est.6b02805.

Kelly, J., C. Parworth, Q. Zhang, D. Miller, K. Sun, M. Zondlo, K. Baker, A. Wisthaler, J. Nowak, S. Pusede, R. Cohen, A. Weinheimer, A. Beyersdorf, G. Tonnesen, J. Bash, L. Valin, J. Crawford, A. Fried, and J. Walega (2018), "Modeling NH_4NO_3 over the San Joaquin Valley during the 2013 DISCOVER-AQ campaign", submitted to *J. Geophys. Res.-Atmos.*, manuscript #2018JD028290.

Abstracts from ROSES 2016 GEO Work Program Awards ("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.

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.

Project: Surveillance for Vector Borne Disease

PI: John Malone

Organization: Louisiana State University

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.

Project: Environmental Determinants of Enteric Infectious Disease

PI: Benjamin Zaitchik

Organization: Louisiana State 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.

Abbreviations and Acronyms:

AAAS: American Association for the Advancement of Science
ACCMIP: Atmospheric Chemistry and Climate Model Intercomparison Project
AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model
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
ASCENDS: Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
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 Multi-scale Air Quality
CoP: Community of Practice
CrIS: Cross-track Infrared Sounder
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
FTIR: Fourier-Transform Infrared Spectroscopy
GCAM: Global Change Assessment Model
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
HyspIRI: Hyperspectral Infrared Imager
IASI: Infrared Atmospheric Sounding Interferometer
LDAS: Land Data Assimilation System
MAIA: Multi-Angle Imager for Aerosols
MAL-ED: Child Health and Development
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
NESDIS: National Environmental Satellite, Data, and Information Service
NLDAS: North American Land Data Assimilation System
NOAA: National Oceanic and Atmospheric Administration
OCO-2: Orbiting Carbon Observatory-2
OMI: Ozone Monitoring Instrument
OMUVB: OMI surface UVB
PACE: Plankton, Aerosol, Clouds, ocean Ecosystem
PAR: Photosynthetic Active Radiation
PI: Principal Investigator
PM: Particulate Matter
$PM_{2.5}$: Fine Particulate Matter
RAQMS: Real-time Air Quality Modeling System
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
STAR: The Center for Satellite Applications and Research
TCEQ: Texas Commission on Environmental Quality
TEMPO: Tropospheric Emissions: Monitoring of Pollution
TES: Tropospheric Emission Spectrometer
TRMM: Tropical Rainfall Measuring Mission
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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