2021 Competition: AC4 and COM - **Atmospheric impacts due to changes in anthropogenic activity during the COVID-19 pandemic**

Competition Number: 2864457

Funding Opportunity Number: NOAA-OAR-CPO-2021-2006389

Human activity has been profoundly altered by orders in numerous countries to shelter in place and other restrictions on business as usual. With restrictions in place for weeks or months at a time, emissions of all trace gases and aerosols have decreased. It falls on careful curation and analysis of any existing measurements, either in situ or from satellites, to quantify the exact impact of the pandemic on atmospheric composition, including its place in a larger context of long-term trends, and its variability across the globe. The analysis of this extreme event in atmospheric composition will not only help to understand the episode itself, but could address fundamental questions in atmospheric transport and chemistry and inform future mitigation strategies, especially as chemical regimes might be changing with drastic emissions reductions.

In response to the unique opportunity to study the atmospheric composition effects of the ongoing pandemic in FY21, AC4 and COM programs invited proposals focused on, but not limited to, one or more of the following:

- Analysis of pandemic-related impacts within individual cities or regions in the United States, or impacts of changes in particular anthropogenic activity
- Comparative studies across different regions or sectors of varying characteristics
- The use of previously collected and existing in situ measurements
- Collection of complementary in situ data to fully document atmospheric changes after the pandemic
- Application of JPSS and GOES satellite products, including identification of the best suite of products for assessing and monitoring impacts on national and global scales
- Development of observational-based datasets (inclusive of satellites, in-situ) or emission inventories, through compilation or integration, that enable analysis of pandemic impacts
- Identification of atmospheric constituents, which can serve as markers of particular human and/or economic activity—agriculture, shipping, air traffic etc.—as affected by the pandemic disruptions and assessment of its return to previous levels
- Assessment of the overall magnitude of the event (as measured in changes in emissions and concentrations), and its place in a long term and/or national/global context

Please see the information sheet for a detailed description of specific requirements.

NOAA-OAR-CPO-2021-2006389

Changes in Aerosol Loading and Composition in Atlanta Driven by Changes in Anthropogenic Emissions during the COVID-19 Pandemic

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Project Summary: ***Objectives*** The extensive shelter in place orders and other restrictions during COVID-19 provide a unique opportunity to investigate the impacts of reduced human activity and anthropogenic emissions on air quality. The overall goal of the proposed project is to analyze a comprehensive suite of measurements conducted in urban Atlanta this year to investigate the impacts of COVID-19 containment efforts on the emissions and fates of volatile organic compounds (VOCs), as well as organic aerosol loading and composition in urban environments. Specific objectives are 1) To evaluate the impacts of changes in anthropogenic activity on VOC and oxidized VOC concentrations and 2) To characterize the impacts of changes in anthropogenic activity on organic aerosol (OA) loading and composition, and compare with our prior studies at the same site and other sites in the greater Atlanta region.

Research Approach We deployed an extensive suite of online gas and aerosol instrumentation to track atmospheric composition in urban Atlanta starting April 2020 on Georgia Tech campus. Measurements are still ongoing at the time of the proposal. This site has been used in multiple previous studies as a representative site of urban Atlanta to characterize aerosols in the southeastern US. It is also close to the SEARCH network urban Atlanta site, which has continuous data from 1999-2018. The instruments we deployed include PTR-MS, AMS, ACSM, SMPS, O3, NOx, and FIGAERO-CIMS. These comprehensive measurements track VOCs all the way from emissions to oxidations to formation of SOA. We propose to analyze these measurements to evaluate VOC emission inventories and the impacts of the pandemic on atmospheric composition.

Expected Outcomes The proposed study will provide comprehensive and quantitative insights into the impacts of reduction of anthropogenic activity on VOC/OVOC emissions, primary organic aerosols, gas-phase oxidation, and subsequent secondary organic aerosol (SOA) formation and properties. The southeastern US is characterized by intense biogenic-anthropogenic interactions, where a large fraction of SOA is biogenic but modulated by anthropogenic pollutants. Results from this study will provide new insights into how reduced anthropogenic emissions influences OA loading and composition in the region, as emissions continue to decrease in the future with mitigation strategies.

Relevance: The proposed study addresses multiple aspects outlined in the solicitation, including analysis of pandemic-related impacts within individual cities in the US or impacts of changes in particular anthropogenic activity, development of inventories, identification of atmospheric constitutions which can serve as markers of particular human and/or economic activity as affected by the pandemic disruptions, and assessment of the overall magnitude of the event and its place in a long term context. Our comprehensive and long-term (spanning multiple

seasons) measurements will allow for thorough characterization of pandemic impacts on atmospheric composition in urban environments with intense biogenic emissions. The proposed research is in line with the broader AC4 mission “to determine the processes governing atmospheric concentrations of trace gases and aerosols” and relevant to Objective 1 of NOAA’s long-term Goal 1 “Improved scientific understanding of the changing climate system and its impacts”, where these unique observational constraints will allow for improved parametrization of OA (biogenic and anthropogenic; primary and secondary) in models and evaluation of their climate impacts.

Changes in Air Quality in Los Angeles Associated with COVID-19 ‘Safer-at-Home’ Traffic Reductions

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Introduction: Air quality in California’s South Coast Air Basin (SoCAB or Basin) has improved dramatically over the past half century, in spite of significant growth of the population, economy, and vehicle miles traveled over the same period. This is due to important regulations on motor vehicle and industrial emissions. However, reductions in ozone (O_3) and particulate matter (PM) levels over the last decade have slowed for reasons that are not well understood. As restrictions were put in place to slow the spread of SARS-CoV-2 in SoCAB, substantial reductions in nitrogen oxide (NO_x) and PM were observed - likely providing important new clues on the role of traffic emissions in the continuing air quality challenges in the Basin. The traffic reductions took place, however, within the context of precipitation at least three times the historical average. As the anomalously rainy period ended in the SoCAB, the levels of the secondary pollutant O_3 returned to values comparable or exceeding those of previous years despite the sustained decrease in traffic flow.

Rationale: In this project, we will analyze observations made during the dramatic reductions in traffic in spring and early summer 2020 (during the COVID-19 period) to better understand the factors contributing to poor air quality in the SoCAB. These observations include those from a suite of air quality monitoring instrumentation that was deployed on the campus of the California Institute of Technology in March 2020 (aerosol composition, $PM_{2.5}$ mass, NO, NO_2, NO_y, O_3, SO_2, and CO). Volatile organic compounds (VOC) sampling was performed in association with UCRiverside and UC-Irvine. CIMS observations of oxygenated VOC (OVOC) and acids were brought online shortly thereafter. We will also include air quality data (*i.e.*, O_3, NO_x, $PM_{2.5}$ mass, SO_2, and CO) collected by the South Coast Air Quality Management District (South Coast AQMD) across the Basin in our analysis to gain a better understanding of the spatial variations of these pollutants. Together, these data provide key observations that can inform what air quality management efforts will be most efficient to bring the Basin into attainment. Here, we propose to use a hierarchy of analysis and modeling approaches to study the 2020 data within the context of both previous observations (*e.g.* CalNex) and a repeat set of measurements proposed here for spring/summer 2022 when, presumably, traffic levels will be restored to normal.

Broader Impacts and Relevance: This research project directly addresses the AC4 program's effort to develop process-level understanding of the Earth System through observation, modeling, analysis, and field studies to support the development and improvement of models, and to inform carbon and air pollution management efforts.

COVID impact on urban GHG emissions: A multi-city investigation

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The COVID-19 pandemic has led to dramatic and potentially lasting changes in human activity, including changes in emission of pollutants. Traffic levels dropped dramatically in March, 2020 in North America as cities, states and nations ordered residents to stay at home to prevent transmission of the virus. This event provides a unique test of our ability to quantify rapid changes in greenhouse gas (GHG) emissions resulting from abrupt changes in social and economic behavior. An existing six-city network of urban GHG measurements, extensive work preparing data sets, numerical modeling tools and analysis methods from multiple prior projects, and a state of the art emissions inventory system combine to provide an outstanding opportunity to quantify and compare the impact of the pandemic on urban GHG emissions across these cities.

Our work will be focused on five research questions: 1) Can our six urban in situ atmospheric measurement networks quantify the impact of the pandemic on urban GHG emissions? 2) Do tracer ratio methods encompassing CO2, CH4 and CO, and 14CO2 yield improved understanding of the changes in GHG emissions, particularly in identifying changing sectoral emissions? 3) What benefits can micrometeorological measurement approaches bring to an urban GHG observational network? 4) Are current inventory methods able to quantify abrupt, high-resolution changes in sectoral GHG emissions such as those caused by the pandemic? and 5) What is the overall impact of this event on urban GHG emissions across our multi-city network?

We will use existing tower-based measurement networks, GHG data sets, atmospheric models, ecosystem models, atmospheric inversion systems, and urban emissions inventories where possible, building on years of development of the NIST urban testbeds and the NOAA CO2-USA programs, to 1) estimate whole-city GHG emissions before the pandemic, during the pandemic shutdown, and during recovery, 2) investigate the application of tracer ratio methods to improve both whole-city and local-scale, micrometeorological understanding of urban emissions changes, 3) apply micrometeorological analyses to our tower network data to quantify emissions changes locally and with high temporal resolution, and 4) update urban emissions inventories to weekly, 1km2 resolution across five of the six cities, and to hourly, 0.5km2 resolution at two cities, developing and testing near-real-time inventory methods. These results will be used both to document the impact of the pandemic on GHG emissions from these cities, and to test our ability to develop high spatial and temporal resolution, sector-specific GHG emissions monitoring. We will focus on both the March-April, 2020 lockdown, and on the recovery period, ideally through the summer of 2021 to document any longer-term impacts of the pandemic on urban emissions.

This project will address this research call's request for analysis of pandemic-related impacts within individual cities or regions in the United States, comparative studies across different regions or sectors of varying characteristics, the use of previously collected and existing in situ measurements, development of observational-based datasets and emission inventories that enable analysis of pandemic impacts, and assessment of the overall magnitude of the event (as measured in changes in emissions), and its place in a long term and/or national/global context. The project supports NOAA's mission to advance our understanding of the Earth's climate system by enhancing society's ability to monitor and understand changes in the emissions of GHGs.

Developing an enhanced bottom-up and top-down emissions inventories over the U.S. during the pandemic outbreaks by satellite data and chemical transport model

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The COVID-19 outbreak caused more than 1,343,000 deaths globally from January to November 2020. All Countries affected by COVID-19 made emergency stay-at-home orders for limiting in-person contact to slow down the diseases spread. In March 2020, the U.S. federal and many state governments implemented these orders in multi-phases which impact significantly on human activity and behaviors. The dramatic reduction of human activities caused the emission of air pollutants to decrease, and surface measurements and satellite remote-sensing confirmed that. This significant reduction of emissions during the pandemic period serves as a controlled experiment to understand how anthropogenic activities affect the local and regional air quality. Thus, the COVID-19 pandemic responses not only provide us a rare opportunity to test scientific understanding of the emission sources in real-world and how air quality responds to those changes, but also give us a glimpse into the future air quality control policy for cleaner vehicles with cleaner fuel and cleaner power energy sources.

The main idea of this project is to incorporate human activity, observational data, and chemical transport model (CTM) outcomes to calibrate the human-activity-based bottom-up emissions inventory during the pandemic period. The measurement data includes human activity, Air Quality System (AQS), and satellite datasets (OMPS and CrIS); the CTM tool will be Community Multiscale Air Quality Modeling (CMAQ) developed by U.S. Environmental Protection Agency (U.S. EPA). CMAQ is the state-of-science model that can simulate complex atmospheric chemistry and physics between air pollutants under various meteorological conditions and understand risk assessments to local and regional air quality.

This proposal will first establish a high-resolution bottom-up emissions inventory based on the latest U.S. EPA. National Emissions Inventory (NEI) during the COVID-19 pandemic that reflects the changes in human activity and emission patterns. The detailed daily county-level COVID-19 human activity data can be found on public databases from the U.S. Department of

Transportation (US DOT), Federal Highway Administration (FHA), the Energy Information Administration (EIA), and other sources. Once the enhanced bottom-up emissions inventory, the COVID-19 NEI, is developed, we will apply the CMAQ modeling system to simulate the air quality during COVID19 and then evaluate them with the AQS and the satellite observations. Furthermore, those observational data will be applied to compare the COVID-19 NEI using a top-down approach based on emission inverse emission modeling. As a result, this process can further reduce the uncertainties of the COVID-19 NEI and allow us to develop accurately calibrated bottom-up emissions data for the air quality modeling community and policymakers.

Quantifying the impacts of COVID-19 on U.S. national and regional non-CO2 greenhouse gas emissions from atmospheric observations

Lei Hu (CIRES, University of Colorado NOAA Global Monitoring Laboratory), Stephen Montzka, Arlyn Andrews, Colm Sweeney (NOAA/GML), Scot Miller (Johns Hopkins University)

The coronavirus 2019 (COVID-19) pandemic is one of the most devastating events in the late contemporary human history. Although its human, economic, and environmental impacts have been of a central public interest, quantitative measure on such impacts is still lacking. A few studies estimated the impact of COVID-19 on anthropogenic GHG emissions based on inventory-based accounting methods; but those estimates often contain large uncertainties and need to be verified by observations. Furthermore, estimates of emission reduction on potent GHGs such as CH_4, N_2O, fluorinated gases, and ozone depleting substances associated with COVID-19 are near absent. Unlike CO_2, these gases have a much lower fraction of biogenic sources across the U.S. and their atmospheric mole fractions are more sensitive to changes of anthropogenic emissions. Because many of these gases are primarily emitted from a specific sector, their emission reductions can further inform us on the COVID-19 impacts upon specific activities. Here, we propose to leverage the NOAA's extensive long-term atmospheric observations over the U.S., in combination with complementary airborne campaigns and space-based atmospheric observations, to fully characterize the evolution of COVID-19 impacts on U.S. national and regional emissions of non-CO_2 GHGs, including CH_4, N_2O, HFC-134a, HFC-143a, HFC-125, HCFC-22, SF_6, CF_4 and SO_2F_2. We will first use NOAA's long-term observations and high-resolution regional inverse model CarbonTracker-Lagrange (CT-L) to estimate any impact of COVID-19 (during 2020 - 2021) on U.S. non-CO2 GHG emissions relative to emissions during the previous 12 years. We will then detail the regional impact of COVID-19 on U.S. CH_4 emissions by combining NOAA long-term observations with intensive airborne campaign data and high-resolution TROPOMI CH_4 retrievals before and during the COVID-19 pandemic. Finally, we will compare our atmosphere-based top-down estimates with inventory-based bottom-up approaches to assess their differences and to learn processes causing the emission changes during COVID-19.

The proposed work will heavily leverage NOAA's operational and research products, including the global and regional long-term atmospheric monitoring network operated by the NOAA Global Monitoring Laboratory, NOAA's CT-L, CarbonTracker-CH_4, and HYSPLIT models to provide observation-based information that is of keen societal interest. The invested research outcome, e.g., strategies on how to integrate NOAA's in situ observing systems with the emerging high-resolution satellite GHG measurements, will be directly incorporated into the NOAA's CT-L data assimilation system to better assimilate surface-to-space observations in the future. The proposed analyses will also allow us to evaluate the rigor and effectiveness of the current in situ and space-based atmospheric monitoring systems for constraining GHG emissions and their variabilities at policy relevant scales.

The proposed work directly responds to the AC4 / COM FY2021 solicitation "Atmospheric impacts due to changes in anthropogenic activity during the COVID-19 pandemic", especially in areas of: assessment of the overall magnitude of the impact in a long term and national context; analysis of pandemic-related impacts in individual regions of the U.S. and comparisons across different regions; the use of NOAA's previously collected and existing in situ measurements; development of observational-based datasets that enable analysis of pandemic impacts; identification of atmospheric constituents that can serve as markers of particular activity as affected by the pandemic.

Tracking impacts of COVID-19 lockdowns & recovery on urban atmospheric composition at neighborhood scales with public-transit based measurements

Logan Mitchell, John C. Lin, Derek V. Mallia (University of Utah), Brain McDonald (NOAA/CSL)

Introduction: The primary non-pharmaceutical intervention to address the COVID-19 pandemic included widespread shelter in place actions that caused dramatic reductions in travel in MarchApril 2020, otherwise known as "lockdowns." This created a natural experiment in cities around the world with reduced emissions creating stark differences in urban atmospheric composition compared to prior years.

Rationale: Urban public transit systems provide an ideal, cost-effective platform for urban atmospheric monitoring. Public transit covers large spatial domains across divergent urban typologies and were operational through the COVID-19 lockdown period. Measurements on the light rail system in Salt Lake City (TRAX) include greenhouse gases (CO2 & CH4) that can be used to evaluate primary combustion emission inventories and further develop modeling techniques to understand the spatiotemporal patterns of emissions. TRAX also measures air pollutants (PM2.5 and O3) that form from secondary chemical reactions. The dramatic change in emissions during the COVID-19 lockdown period and the resulting shifts in urban atmospheric composition observed by TRAX provides a unique opportunity to examine the relationship between primary combustion and secondary pollutants and will accelerate our fundamental understanding of urban atmospheric chemistry.

Scientific Questions:
1. How did emissions change during the COVID-19 lockdown (sectoral & spatiotemporal)?
2. What was the relationship between primary combustion and secondary air pollutants?
3. What are the implications of emission reduction policies on urban atmospheric composition?

Summary of work:

• Quality Control (QC) TRAX data, continue data collection, & analysis of observations
• Quantify GHG emissions during the COVID-19 lockdown using an inverse analysis
• Use the updated GHG emissions to create co-emitted air pollutant emission inventories
• Investigate relationships between primary combustion emissions and secondary pollutants
• Engage stakeholders, policymakers, and the scientific community

Relevance to competition and NOAA's long-term goals: The AC4 & COM announcement calls for the "*use of previously collected & existing in-situ measurements*" as well as the "*development of observational datasets or emission inventories that enable analysis of pandemic impacts*" that assess and contextualize the "*overall magnitude of the event*" across "*sectors of varying characteristics*" and "*identify atmospheric constituents that serve as markers for human/economic activity during the pandemic & recovery periods.*" Our proposal utilizing measurements from a unique public transit platform, developing emissions inventories, & modeling primary emissions & secondary air pollutants is directly responsive to these requests. In addition to understanding the episode itself, our project "*will address fundamental questions in atmospheric transport and chemistry to inform future mitigation strategies, especially as chemical regimes might be changing with drastic emissions reductions*" and communicate these findings to stakeholders & policymakers.

Understanding methane changes in cities affected by COVID-19 shutdowns

Roisin Commane (Lamont-Doherty Earth Observatory of Columbia University), Lucy Hutyra, (Boston University), Steve Wofsy (Harvard University), Luke Schiferl (LDEO), Maryann Sargent (Harvard University)

COVID-19 shutdowns throughout 2020 offers an unprecedented opportunity to understand the sources of various trace gases, particularly in cities. Our study areas, the Boston metro and New York City metro areas, were impacted by COVID-19 earliest and hardest in the US, with incidence and mortality rates among the highest on the globe at the time. Shutdowns in these cities were among the most complete in the US. Behavioral changes were significant and continue to this day. Many companies and schools have extended work/learn from home guidelines to 2021 and beyond. These profound changes in how people work, move, and recreate, have changed the urban atmospheric composition dramatically.

During the spring shutdown, we observed declines in methane mixing ratios of ~40% in Boston and New York, relative to previous months and years. Do the large declines we observe in methane indicate 'lost and unaccounted for' methane or an incorrectly attributed source? Are end-user methane emissions being erroneously attributed to leaking pipe infrastructure? This proposal focuses on the COVID-19 shutdown as a unique opportunity to observe changes in the major sources of methane in dense urban areas, in order to help determine which sector contributes emissions that fill the large gap between bottom-up and top-down analyses of urban emissions. We expect to observe a spatial re-distribution of peak methane use as restaurants and offices closed and slowly reopened over the summer. But little change may initially be anticipated in residential heating, wastewater treatment or pipeline emissions. We also expect a rapid change in traffic related methane emissions with the large-scale changes in traffic patterns.

We propose to (a) calculate methane emissions sampled by urban core sites for the full year, (b) develop baseline and COVID-19 shutdown period high resolution methane inventories, and (c) test a suite of hypotheses about causal mechanisms for emissions change. Using these insights, we will refine bottom-up emissions models and reassess the relative contributions of pipeline, compressor station, and beyond-the-meter sources. The shutdown therefore provides a unique opportunity to partition out the impact of different methane emission sectors, in order to identify the sources of missing methane in bottom-up inventories. This analysis is designed to provide the kind of robust methane source information needed for effective mitigation policies.

Our proposed work addresses a number of the focus areas identified in the solicitation. We will use *in situ* atmospheric observations collected before, during, and after the COVID-19 shutdown to assess pandemic-related changes to the methane budget in two cities in the Northeast US with markedly different sector characteristics. Detailed urban methane emissions inventories are difficult to construct and currently available inventories are very uncertain. We will build new spatially explicit, sector-resolved methane inventories for Boston and New York. Since the new bottom-up models will have been rigorously confronted with atmospheric observations and the COVID-19 shutdown perturbations, we will deliver new understanding about diffuse methane fluxes in urban areas. The work enables progress towards a key climate mitigation goal - reducing urban CH_4 emissions - by helping to prioritize where to target the mitigation policies.

Using Observations of Gaseous Compounds in the LA Basin during COVID-19 to Elucidate Sources and Atmospheric Processes Affecting Urban Air Quality

Kelley Barsanti (University of California Riverside), Donald Blake (University of California Irvine)

Abstract: Despite decades of emissions reductions, the South Coast Air Basin, which includes Los Angeles, CA and surrounding areas, experiences some of the worst air quality in the country; with violations of the National Ambient Air Quality Standard (NAAQS) for 8-hr ozone (O_3) on 1 in 3 days. Further, while the past decades have also seen steadily decreasing levels of O_3 and fine particulate matter ($PM_{2.5}$), of which secondary organic aerosol (SOA) is a significant fraction, recent years have seen a leveling of these trends. Thus there are many unanswered questions about what drives production of O_3 and SOA formation in Southern California, which are relevant in the broader context of improving the process-level understanding of atmospheric chemistry under relatively low nitrogen oxide (NO_x) conditions, and as influenced by a changing mix of emissions; and the ability to represent these processes and sources in predictive models.

Here we propose to build on a collaborative effort initiated in March 2020, to collect in-situ data in Pasadena, CA within the South Coast Air Basin. A suite of gas- and particle-phase instrumentation was co-located on the Caltech campus and samples were collected from April-August 2020. The collaboration included PIs from three institutions: UC

Riverside (Barsanti); UC Irvine (Blake); and Caltech (Wennberg/Seinfeld). While the efforts of all groups are briefly discussed herein, this is a stand-alone proposal for the Barsanti and Blake groups. The Wennberg and Seinfeld groups are submitting a stand-alone but synergistic proposal (see P. Wennberg Letter of Support). The ***major activities*** proposed here are collection of a complimentary data set from April-August 2022; analysis and modeling of the 2020 and 2022 data sets; and data sharing and reporting for 2020 and 2022. The ***objectives*** of the proposed research are to: 1) identify and quantify the ambient gas-phase organic compounds (intermediate and volatile organic compounds, I/VOCs) across a gradient of human activity during and after the COVID-19 shelter-in-place orders; 2) quantify I/VOC source markers and evaluate the contribution of source-specific emissions to measured I/VOCs; 3) compare calculated emission ratios to published emission ratios, to assess spatial and temporal changes in these values and to evaluate the localized impacts of reduced human activity during COVID-19 on atmospheric composition; and 4) assess the contribution of identified compounds to O_3 and $PM_{2.5}$ formation and the sensitivity of O_3 and $PM_{2.5}$ formation to observed changes in I/VOCs and meteorological parameters.

The data collected and analyzed during this unprecedented time of reduced human activity will be of great utility to the atmospheric chemistry, observational, modeling, and regulatory communities in developing the understanding and model representation of the sources and processes that affect atmospheric composition and urban air quality. Analysis of trends in atmospheric composition, during and after the COVID-19 shelter-in-place orders, and comparison with historical data sets will provide insight regarding the relative roles of chemistry and climate in controlling observed air pollution levels. Further the proposed research supports NOAA's long term goals in the area of climate adaptation and mitigation: improved scientific understanding (to understand and predict changes on monthly-decadal timescales at local-regional scales, and understand the role of climate on atmospheric composition) and a weather ready nation: healthy people and communities (to develop integrated predictions and analyses to improve health of communities) as articulated in NOAA's Next Generation Strategic Plan.