The View from Space

Overview

The atmospheric measurements group, based at the Smithsonian Astrophysical Observatory's Atomic and Molecular Physics Division at the Center for Astrophysics | Harvard & Smithsonian in Cambridge, MA currently leads the TEMPO satellite mission and heads the retrieval algorithm and calibration effort of the MethaneSAT satellite mission. Both missions will be operational in 2023 and will provide revolutionary measurements of gases and aerosols that are important for understanding climate change and its interactions with atmospheric composition, surface emissions and ecosystems, and underlying physical/chemical/biological processes. This opportunity provides a fellow with access to SAO scientists, resources, and extensive satellite data to explore scientific questions at the nexus of air quality and climate, such as understanding the roles of forest and coastal marine ecosystems in the climate system and the impacts of climate change on these ecosystems leveraging Smithsonian ForestGEO and MarineGEO measurements.

Importance

The link between climate change and atmospheric greenhouse gases of anthropogenic origin has been well established and forms the basis of climate science, climate projections and mitigation strategies. It is of paramount importance to continue and improve the monitoring of emissions, sinks and distributions of trace gases to quantify climate feedbacks in the Earth system, understand the impacts on the biosphere and inform mitigation policies. Numerous studies have demonstrated the importance of understanding how the transformation of ecosystems and landscapes through climate change can affect the emissions and sinks of greenhouse gases and other pollutants, and vice versa. These transformations, to name just a few, include the frequency and extension of wildfires, Arctic greening, permafrost thawing, changes in coastal wetlands, rapid urbanization, agricultural practices, and ecosystem stress under extreme atmospheric conditions. Space based observations of trace gases involved in these landscape transformations, such as methane, nitrogen dioxide and formaldehyde, are sensitive tracers of the physical, chemical and biological processes of ecosystems, providing pathways to understand climate feedbacks and climate change. Therefore, satellite remote sensing of the atmosphere is a powerful tool for observing trace gases on local to global scales.

The atmospheric measurements group at SAO pioneered spaceborne UV-Visible remote sensing of the Earth's atmosphere and conducts scientific research that encompasses a wide range of air quality and climate related topics. This research has included the first formaldehyde measurements made from space two decades ago, innovative mapping of global ozone profiles from space, and current projects building multi-decadal data records of global atmospheric formaldehyde, glyoxal and water vapor. SAO is also home to the gold standard spectroscopic database HITRAN, which is used by researchers around the world for remote sensing, astrophysical applications, and modeling radiative transfer in the Earth's atmosphere.

Potential Research Themes

The interaction between the forests and the climate is a project that integrates Smithsonian resources to investigate the synergies between the forest ecosystem, atmospheric composition, and climate change. Forests play important roles in the climate system. (1) Forests act as carbon stocks, carbon sinks, mediator of the water cycle, modifier of land surface roughness and albedo. (2) Forests are important sources of trace gases and aerosols. The oxidation of Volatile Organic Compound (VOCs) emitted by forests leads to formaldehyde, glyoxal and Secondary Organic Aerosols (SOAs); Forest fires strongly disturb the carbon cycle and emit large amount of pollutants, such as ozone, nitrogen dioxide, and aerosols. (3) Forests are susceptible to ecosystem stress such as those related to water scarcity and ozone damage.

The Smithsonian provides a unique opportunity to study the interaction of forests with the climate. The TEMPO mission will measure the suite of aerosols and trace gases (nitrogen dioxide, formaldehyde, glyoxal, water vapor), as well as vegetation indicators such as solar induced fluorescence and gross primary productivity needed to quantify emissions and understand physical, chemical, and biological processes from the atmospheric standpoint of view. The ForestGEO global earth observatory network can provide further constraints and insights on gases and aerosols from the forest function and plant physiology standpoint of view. Eighteen out of 74 ForestGEO sites are within the TEMPO spatial domain. Linking the space-based TEMPO observations with the ground-based ForestGEO observations will be highly valuable in understanding the roles of forests in a changing climate and how climate change may affect the forest ecosystem.

The interaction between coastal ecosystem and the climate is another project that integrates Smithsonian resources to investigate the synergies between the coastal marine ecosystem, land, atmospheric composition, and climate change. Like forests, coastal ecosystems play an important role in Earth’s climate, acting as carbon stocks and sinks, and in most cases are highly vulnerable to global climate change.

The Smithsonian provides a unique opportunity to study the interaction of coastal ecosystems with Earth’s climate. TEMPO and MethaneSAT provide the suite of measurements of trace gases (e.g., pollutants, greenhouse gases, halogen species) and aerosols over coastal areas that affect the coastal ecosystem, and solar induced fluorescence and chlorophyll indicating the coastal biodiversity and its health. The Marine Global Earth Observatory (MarineGEO) led by Simothsonian’s Tennenbaum Marine Observatories Network (TMON) focuses on understanding how coastal marine ecosystems work—and how to keep them working and provides measurements of the biodiversity of near-shore marine ecosystems. It currently has 13 sites, 7 of them located in the TEMPO domain. Integrating these satellite observations with MarineGEO measurements will be highly valuable in understanding the roles of coastal ecosystems in a changing climate and how climate change may affect the coastal ecosystem. For example, TEMPO will resolve tidal effects on estuarine circulation and the pollution outflow plume in the Chesapeake Bay area and their relationship to ecosystem variability. Atmospheric chemistry of halogen oxides over the ocean, and especially in coastal regions, play a significant role in ozone destruction, atmosphere oxidizing capacity, and formation of cloud condensation nuclei. The budgets and distribution of reactive halogens along the coastal areas of North America are poorly known. TEMPO provides a unique measure of the budgets and diurnal evolution of coastal halogen oxides important to understand their roles in atmospheric photochemistry of coastal regions and the coastal ecosystem.

The SAO Atmospheric measurement group also welcomes other projects from the fellow to address other topics related to climate and air quality. Possible areas of research include, but are not limited to, trace gas retrievals, data analysis and numerical modeling. Novel research projects are also welcome, particularly those that exploit SAO derived data and leverage other Smithsonian datasets, activities (e.g., ForestGEO, MarineGEO, Methane Working Group) and expertise at other Smithsonian units, such as the Smithsonian Environmental Research Center and the Smithsonian Tropical Research Institute. These synergistic projects are expected to integrate into the group's overall theme of satellite observations and climate studies, and expand or enhance climate science investigations. In addition to TEMPO, MethaneSAT and MethaneAIR, the fellow is encouraged to utilize the Smithsonian's pan-institutional resources such as SI's high-performance computing facility.

PROGRAMS AND ASSETS

TEMPO: The Tropospheric Emissions: Monitoring of Pollution (TEMPO; tempo.si.edu) instrument will measure trace gases and aerosols at unprecedented spatial and temporal scales over North America. The instrument's spectroscopic measurements provide data for monitoring air pollutants at hourly to annual timescales and beyond, and for understanding the interplay between air quality and climate. The measurement suite includes tropospheric ozone, aerosols, ozone precursors (nitrogen dioxide and formaldehyde), halogen oxides (e.g., bromine monoxide and iodine monoxide), and other atmospheric constituents. Moreover, TEMPO spectra can provide highly useful information on vegetation, such as vegetation indices and gross primary productivity over land, solar induced fluorescence over land/ocean, and chlorophyll over ocean. TEMPO will be launched into geostationary orbit in January 2023. For the first time, scientists will be able to observe the diurnal cycle of trace gas and aerosol distributions and use the information to quantify the diurnal cycle of emissions and atmospheric chemistry over North America. This revolutionary dataset will help improve emission inventories and air quality forecasting, assist in monitoring population, agriculture and ecosystem exposure to pollutants, provide measurements of neighborhood-level pollution inequities in support of environmental justice, and enable effective emission-control strategies.

Climate and air quality are intricately linked through numerous feedbacks, such as radiative forcing, atmospheric circulation and tropospheric chemistry. Changes in specific physical processes (e.g., biomass burning, volcanic eruptions, lightening, dust storms, biogenic sources, soil emissions, evapotranspiration and atmospheric rivers) have implications for both air quality and climate change. TEMPO will help address the following science questions: 1) What are the temporal and spatial variations of emissions of gases and aerosols important for air quality and climate?; b) How does air pollution drive climate forcing and how does climate change affect air quality on a continental scale?; and c) How do various physical processes, such as those mentioned above, affect air quality and climate? TEMPO products will also be exploited to improve air quality model performance and provide timely information for decision makers.

As TEMPO's PI institution, SAO is leading the science team, science algorithm development, ground systems, science data processing, and education and public outreach. During TEMPO's operational phase, SAO is responsible for instrument operation control, instrument calibration, improvement of science algorithms, production of geophysical products and public distribution of the data in coordination with NASA.

MethaneSAT: MethaneSAT (www.methanesat.org) is a satellite mission funded by the Environmental Defense Fund,partnered with the New Zealand Space Agency, and is the United States' first dedicated satellite mission to measure methane emissions. MethaneSAT will be used to determine global methane concentrations and leakage rates from oil and gas fields as well as natural and agricultural sources. It will also simultaneously measure carbon dioxide and water vapor. Furthermore, MethaneSAT will produce actionable data to reduce methane emissions from the oil and gas industry by 45% by 2025. MethaneSAT is scheduled to launch in mid-2023. SAO is leading the retrieval algorithm development and instrument calibration of the MethaneSAT mission. SAO has been involved in the project since its beginning, including building and maintaining its airborne precursor MethaneAIR, which has been critical for the development of high precision methane retrieval algorithms.

Advisors

The following Smithsonian staff scientists are available to advise climate fellows, facilitate access to datasets and project assets, and provide guidance to link research to management actions and policy decisions: Caroline Nowlan, Gonzalo Gonzalez Abad, Xiong Liu, Huiqun Wang, Iouli Gordon, and Kelly Chance.