April 2024

AIRMAPS 2025 - Baltimore Air Quality and Marcellus Methane Survey (BAQMMS)



A NOAA OAR investigation of atmospheric photochemistry and emissions of air pollutants and greenhouse gases in Baltimore-Washington, DC and Marcellus Shale in summer 2025 with the following objectives:

1. Assess emissions of greenhouse gases and air pollutants in the Baltimore-Washington, DC region.
2. Investigate chemical and meteorological mechanism that leads to summertime air pollution in the Baltimore-Washington, DC region.
3. Quantify methane emissions from oil & gas operations in the Marcellus Shale.

NOAA Air Resources Laboratory (ARL): Xinrong Ren, Winston Luke, Phillip Stratton, Paul Kelley, and Jiayang Sun

NOAA Chemical Sciences Laboratory: Sunil Baidar, Alan Brewer, Jeff Peischl, Steven Brown, Brian McDonald and Carsten Warneke

NOAA Global Monitoring Laboratory (GML): Colm Sweeney and Kathryn McKain

Collaborators and Partners: NOAA/NESDIS, NIST, DOE, NASA, EPA, University of Maryland, Maryland Department of Environment, Johns Hopkins University, Penn State University, and Howard University

1. Research Objectives and Science Questions

Changing climate favors deteriorating air quality, particularly in urban areas, where rising temperatures contribute to increased levels of ozone and particulate matter. While air quality in the majority of U.S. cities has improved dramatically during the past decades due to reduction of emissions of air pollutants, several northeast U.S. urban areas, including Baltimore, MD and Washington, DC, are still experiencing persistent air quality issues, including recent pollution events associated with wildfires. Urban decision makers need a better understanding of the scientific basis of air pollution formation and greenhouse gas (GHG) emissions to address both air quality and climate change issues. Chemical and meteorological measurements from field campaigns like the Baltimore Air Quality and Marcellus Methane Survey are needed to improve our understanding of air pollution formation and to better mitigate GHG emissions.

Natural gas production in the U.S. has increased rapidly over the past two decades, along with concerns of fugitive emissions of methane (CH_4) and their associated climate impacts. Accurate quantification of CH_4 emissions from oil and gas operations is crucial to the development of scientifically grounded policies aimed at mitigating GHGs. The Marcellus Shale region, responsible for producing about 32% of the nation's shale gas in 2023, also contributes significantly, accounting for about 21% of the methane emissions within the U.S. oil and gas sector (McDonald et al., 2023). Understanding and addressing methane emissions from this region is part of NOAA's overall goal to evaluate total current U.S. methane emissions from oil and gas (O&G) operations to benchmark the efficacy of future mitigation policies and strategies.

NOAA OAR plans to investigate atmospheric photochemistry and emissions of air pollutants and GHGs in the Baltimore-Washington, DC and Marcellus Shale areas in summer 2025 (Figure 1) with the following objectives:

- Assess emissions of GHGs and air pollutants in the Baltimore-Washington, DC region.
- Investigate chemical and meteorological mechanisms that lead to summertime air pollution in the Baltimore-Washington, DC region.
- Quantify methane emissions from the oil & gas operations in the Marcellus Shale region.

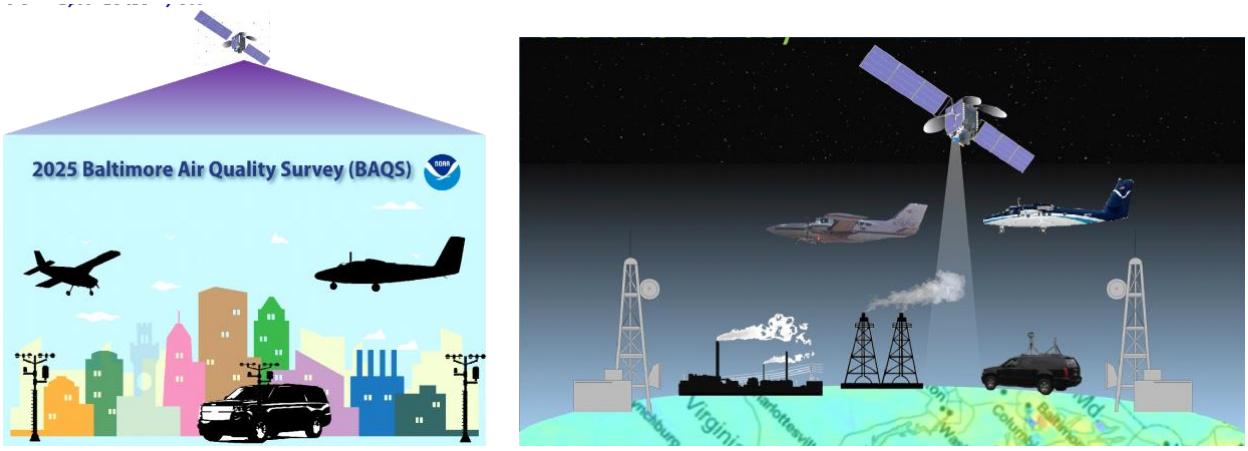

Figure 1. Schematic diagrams showing the Baltimore Air Quality Study (left) and Marcellus Methane Study (right) in summer 2025.

The study aims to characterize air pollutant emissions and transport within and around the Baltimore-Washington area and methane emissions from the Marcellus oil and gas operations

with acquiring high resolution observational dataset. Specific science questions this study aims to answer are:

- What is the spatial distribution of ozone and its precursors and what are the mechanisms that produce high ozone levels in and around the Baltimore-Washington area?
- How much of the ozone and its precursors are a result of local sources and/or pollutant transport into the Baltimore-Washington area?
- How do methane emissions from O&G operations in the southwest Marcellus Shale compared to existing inventories?
- Is there a discernible trend in methane emissions from the Marcellus O&G operations compared to previous observations?
- How can measurements of GHGs and air pollutants in the Baltimore-Washington area and Marcellus be better utilized to connect ground-level observations of GHGs and air pollutants to observations by satellite instruments such as TEMPO and other civilian and commercial greenhouse gas instruments?

2. Platforms and Methods

During the Baltimore Air Quality and Marcellus Methane Survey in summer 2025, we propose to conduct comprehensive aircraft and mobile measurements of air pollutants and GHGs in the Baltimore-Washington and Marcellus areas. Two research aircraft, a NOAA Twin Otter and a Cessna 402, as well as NOAA's Air Resources Car (NOAA's ARC) mobile lab will be deployed in this field campaign.

2.1. NOAA Twin Otter

The NOAA Twin Otter measurement systems (Figure 2) will consist of a scanning Doppler lidar, developed by the NOAA CSL Atmospheric Remote Sensing program, which will measure profiles of horizontal winds, turbulence and aerosol backscatter intensity through the atmospheric boundary layer. Depending on funding availability, researchers from the University of Colorado will deploy a MAX-DOAS on the Twin Otter to measure profiles of HCHO, glyoxal, and NO_2. An upward/downward multispectral radiometer will be used to identify land/ocean boundaries under the aircraft and will provide information on land usage, cloud cover and atmospheric haze conditions. These remote airborne wind and chemistry measurements will be augmented by those made by scanning ground-based Doppler lidars in existing networks and separately deployed to the area of study by other researchers and by other ground-based observations of chemical species.

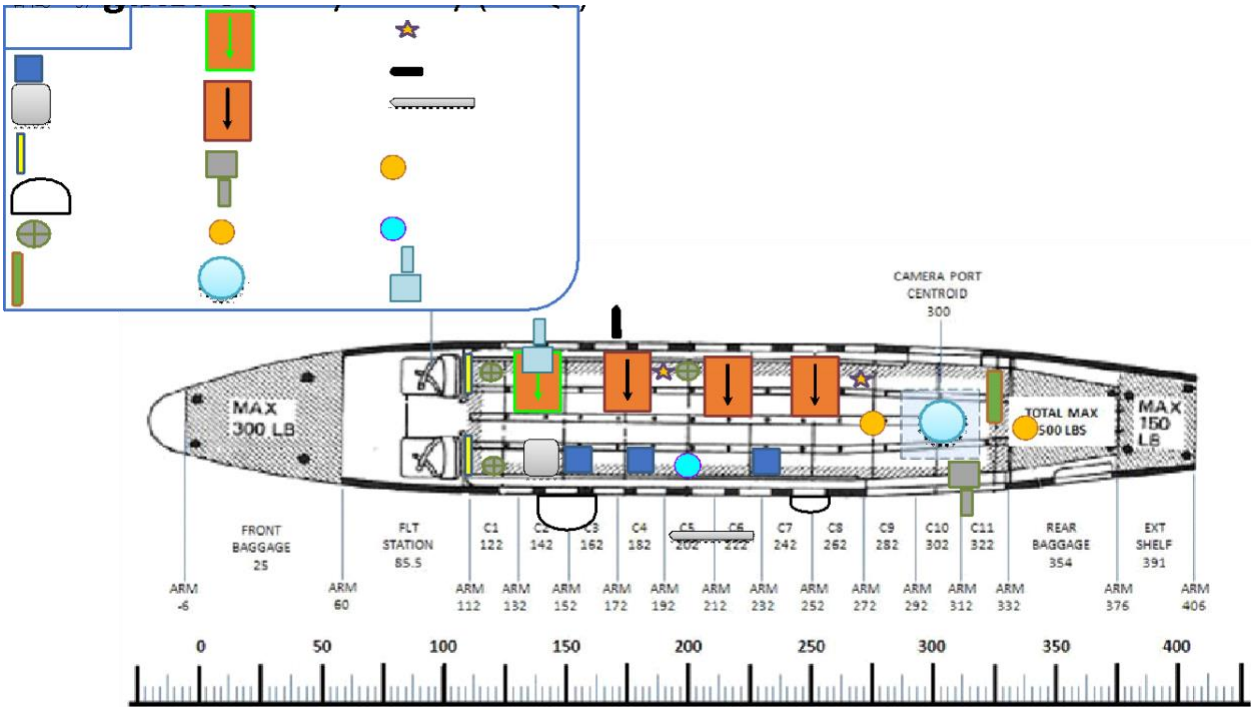

Figure 2. The proposed payload of the NOAA Twin Otter for the Baltimore Air Quality and Marcellus Methane Survey 2025.

The Twin Otter aircraft will also be equipped with instruments for in-situ measurements of O_3, $NO/NO_2/NOy$, CO, CO_2, CH_4, ethane, and H_2O to characterize photochemistry and the spatial extent of air pollution. The sum of NO and NO2 is collectively known as nitrogen oxides, or NOx, while NOy is total oxidized nitrogen or the sum of NOx and its oxidation products (e.g., nitric acid, HNO_3). Measurements of the spatial distribution of these species, along with meteorological data, will enable better understanding of factors that lead to high ozone in the Baltimore-Washington area. Table 1 lists the proposed measurements on the NOAA Twin Otter.

Table 1: NOAA Twin Otter payload for summer 2025

Instrument	**Measured species**
Scanning Doppler Lidar	3-D Wind and Aerosol Profiles, Boundary layer depth
Picarro G2401-m	CO_2, CH_4, CO and H_2O
Aeris Ultra Mid-IR absorption	C_2H_6
2B UV Ozone Analyzer	O_3
Direct Optics CRDS	NO, NO_2
Teledyne CAPS + Thermo dissociation	NOy
AMAX-DOAS*	NO_2 and formaldehyde column
Radiometers	Irradiance, surface temperature, jNO_2
AIMMS probe	Flight level temperature, pressure, winds

*AMAX-DOAS deployment depends upon additional funding availability.

2.2. UMD Cessna

The UMD Cessna research aircraft has been flown over the Mid-Atlantic States during the past two decades and will be deployed in the study to make in situ measurements of air pollutants and GHGs (Figure 3).

Figure 3. The proposed instrumentation on the UMD Cessna for the Baltimore Air Quality and Marcellus Methane Survey in 2025.

Table 2 lists the proposed measurements on the Cessna. These measurements will complement the measurements on the Twin Otter. The Cessna will characterize the urban core – the source region – as well as follow plumes downwind to characterize the spatial distributions of ozone and its precursors. Vertical profiles of winds, O_3, NOx, GHGs, and aerosol optical properties will help evaluate the remotely sensed data from the Twin Otter and satellites (e.g., TEMPO). Whole air samples will be collected for the analysis of VOCs that can be analyzed from canisters. When wind conditions are favorable (i.e., consistent wind direction and speed), mass balance flights will be conducted together with the Twin Otter to estimate emissions of GHGs and some air pollutants such as NOy and CO from the study areas.

Table 2. UMD Cessna 402 payload for summer 2025

Instrument	**Measurement Species**
UV Ozone Analyzer	O_3
Picarro G2401-m	CO_2, CH_4, CO and H_2O
Aeris Ultra Mid-IR absorption	C_2H_6
Direct Optics CRDS and TECO chemiluminescence	NO-NO_2-NOy
Aethalometer 7-λ	Black Carbon
Whole air samples with GC-MS or GC-FID	VOCs
Vaisala Met Sensors	T, P, RH

2.3. NOAA's Air Resources Car

NOAA's Air Resources Car (NOAA's ARC) mobile lab will be deployed in this study to conduct surface mobile measurements of air pollutants and GHGs that will complement the aircraft measurements. We will coordinate with the Twin Otter and Cessna to make simultaneous mobile and aircraft measurements to better characterize spatial distribution and transport of air pollutants and GHGs. As we have done previously, we also plan to make mobile measurements in disadvantaged communities of concern in the Baltimore-Washington, DC area to help address environmental justice issues. These communities most suffer from a combination of economic, health, and environmental burdens.

Figure 4. Pictures showing the instrumentation in NOAA's Air Resources Car mobile lab proposed for the Baltimore Air Quality and Marcellus Methane Survey 2025.

Table 3. NOAA's Air Resources Car payload for summer 2025

Instrument	**Measurement Species**
2B UV Ozone Analyzer	O_3
Direct Optics CRDS	NO-NO_2-NOx
Picarro G2401-m	CO_2, CH_4, CO and H_2O
Aeris Ultra Mid-IR absorption	C_2H_6
7-λ Aethalometer	Black Carbon
Picarro Isotope CRDS	$^{13}CO_2$/$^{13}CH_4$
Whole air samples with GC-MS or GC-FID	VOCs
Vaisala Met Sensors	T, P, RH

2.4. Deployment Plans and Methodology

2.4.1. Deployment Plans

The NOAA Twin Otter, UMD Cessna, and NOAA's ARC mobile lab will be deployed to the Baltimore-Washington region and the southwest Marcellus Shale from approximately July 1 to Aug 15, 2025 for the Baltimore Air Quality and Marcellus Methane Survey (BAQMMS 2025, Figure 5). We expect to fly the Twin Otter for ~70 hours each in the Baltimore-Washington region and the Southwest Marcellus Shale. Similarly equal amount of but likely less total flight

hours (~50) for the Cessna to fly in each area. The ARC will make mobile measurements where/when there will be flights conducted.

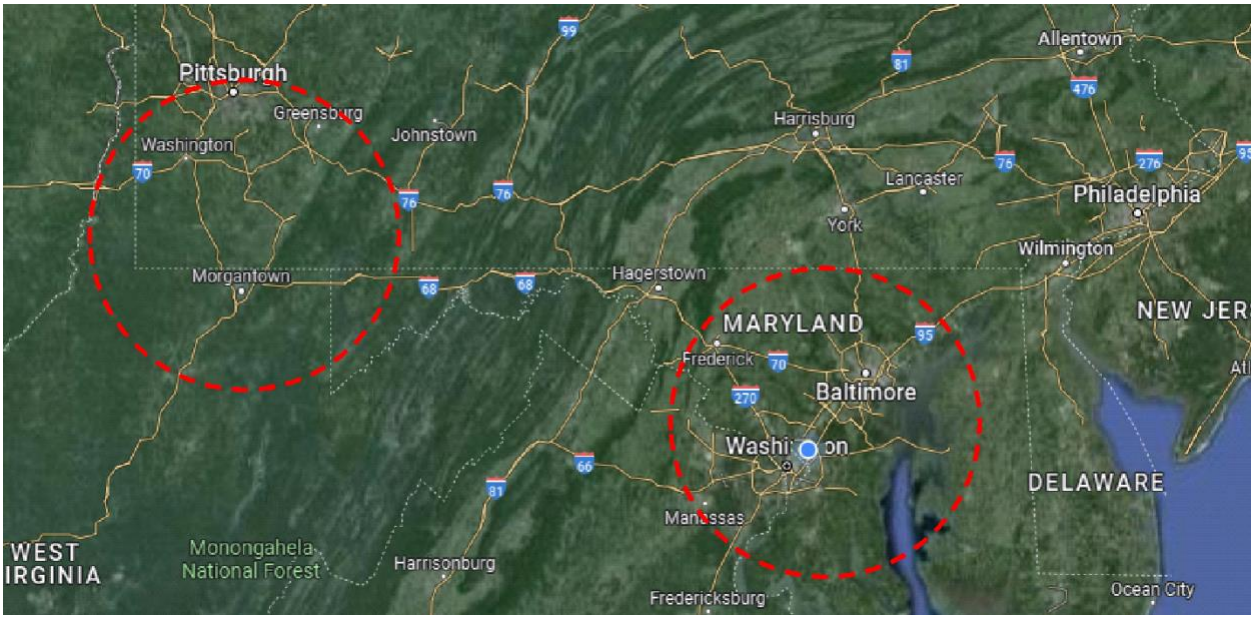

Figure 5: The study region for the NOAA Twin Otter, UMD Cessna, and NOAA's ARC mobile lab for the Baltimore Air Quality and Marcellus Methane Survey in summer 2025.

2.4.2. GHG Mass Balance Flights

Aircraft mass balance flights over the Baltimore-Washington and southwest Marcellus will quantify emissions of GHGs (CH_4 and CO_2) and other air pollutants such as CO and NOy. This method relies on the assumptions of constant emissions and well-mixed stationary planetary boundary layer (PBL) depth during a given experiment period and has been proven to be robust for the estimate of total emissions from a given area. Wind carrying background concentrations of GHGs blows over the source region, where it picks up GHG and air pollutant emissions. Horizontal transects are flown perpendicular to the wind direction downwind of the target area, and enhancements in GHG above background are intercepted and detected. The GHG emission rate from the area can be calculated (Ren et al., 2019; Ahn et al., 2020):

$$Emission \quad Rate = \int_0^z \int_{-x}^{+x} \left([C]_{ij} - [\overline{C}]_b \right) \mathrm{x} U_{\perp ij} \, dxdz$$

where, $[C]_{ij}$ is the concentration of a GHG or air pollutant at a downwind location (xi, zi) ; $[C]_b$ is the background concentration detected upwind or on the downwind edges; $U_{\perp ij}$ is the perpendicular wind speed at a downwind location of (xi, zi); [-x, +x] defines the horizontal width of the plume from the surveyed area; and [0, z] defines the PBL height.

Based on wind and other meteorological conditions, mass balance flights will be conducted over either the Baltimore-Washington area or the southwest Marcellus (Figure 6). The two airplanes will be coordinated to conduct either upwind or downwind transects at different altitudes for better spatial and temporal coverage.

The Doppler lidar system that will be deployed on the Twin Otter has the potential to significantly improve the efficiency and accuracy of the traditional mass balance approach. The

custom airborne lidar system measures the vertically resolved wind field (both horizontal and vertical) above and below the aircraft, together with the depth of the planetary boundary layer. This capacity resolves some assumptions inherent in the use of in-situ winds alone and reduces the requirement for frequent vertical profiling to assess boundary layer depth.

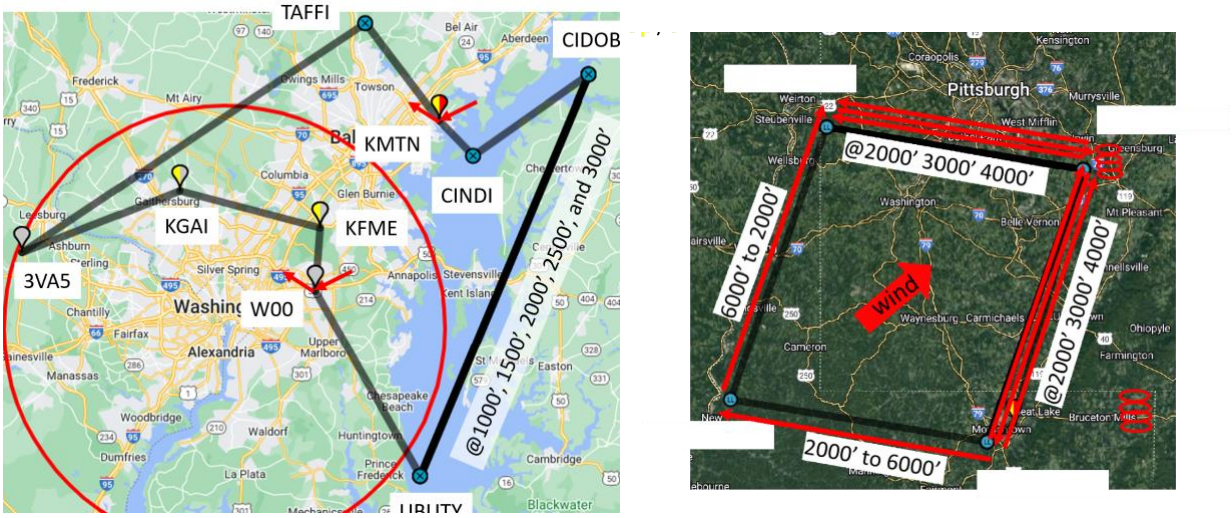

Figure 6. Examples of mass balance flight plans over the Baltimore-Washington area (Left) and southwest Marcellus (right) planned for summer 2025.

2.4.3. Air Pollution Lagrangian Flights

We will also fly Lagrangian flight patterns (Figure 7) to characterize the transport and transformation of air pollutants in the Baltimore-Washington area during ozone events or wildfire influence that contribute to the formation of summertime air pollution associated with elevated levels of ozone and particulate matter.

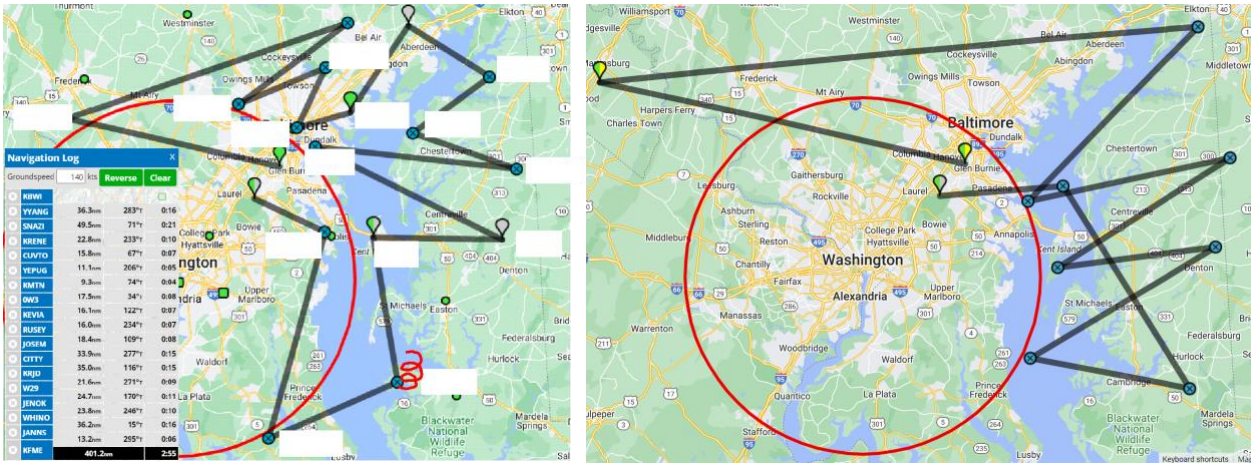

Figure 7. Examples of air pollution Lagrangian flight pattern over the Baltimore-Washington area planned for summer 2025.

3. Collaboration and Partnership

Collaborators and partners for BAQMMS 2025 include NOAA/NESDIS, NIST, DOE, NASA, EPA, University of Maryland, Maryland Department of Environment, Johns Hopkins University, Penn State University, and Howard University. Coordination with concurrent field projects in the Baltimore-Washington area is described further below.

3.1. DOE's BSEC and COURAGE projects

We will be collaborating with two concurrent DOE projects in the Baltimore-Washington region during our field study. As one of the DOE's Urban Integrated Field Laboratories, the Baltimore Social-Environmental Collaborative (BSEC) aims to create a community-centered urban climate observatory to contribute to climate action plans that make environmental justice a priority. The Coastal-Urban-Rural Atmospheric Gradient Experiment (COURAGE) project will study the interactions among the Earth's surface, atmospheric boundary layer, aerosols and atmospheric composition, clouds, radiation, and precipitation at four field sites and examine how the spatial gradients across the region interact to create the climate conditions in Baltimore. These two projects will provide ground-based meteorological and chemical measurements that will complement our Baltimore Air Quality and Marcellus Methane Survey. Our collaborative efforts with BSEC and COURAGE underscore our commitment to advancing environmental research through collective expertise and shared resources. By synergizing our strengths, we aspire to generate findings that not only enrich our individual projects but also contribute significantly to the broader scientific understanding of air pollution, climate, and environmental justice.

3.2. NIST Northeast Corridor GHG Testbed project

The NIST Northeast Corridor (NEC) project was established in 2015 as the third NIST urban testbed following those for Indianapolis and Los Angeles. The NEC project is currently quantifying greenhouse gas (GHG) fluxes throughout the Washington and Baltimore urban regions and has plans to include Philadelphia and New York. The GHG measurements from the Baltimore-Washington testbed (Figure 8) will complement the GHG measurements from BAQMMS 2025 to better quantify GHG emissions in the Baltimore-Washington area.

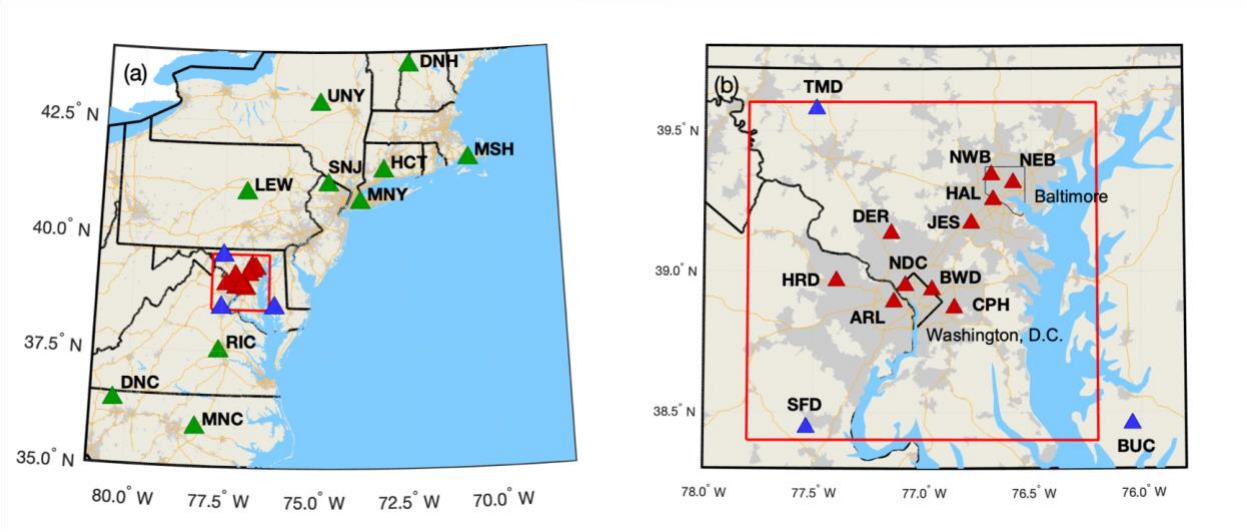

Figure 8. Tower sites sponsored by NIST, with continuous CO_2 and CH_4 observations. Left: larger regional network. Right: urban network located in DC/Baltimore. Blue triangles indicate background stations. Gray shading indicates urban areas.

3.3. EPA and Maryland Department of Environment's Air Quality Monitoring

We will collaborate with the U.S. Environmental Protection Agency (EPA) and the Maryland Department of the Environment (MDE) on their ground-based measurements from air quality monitoring sites in the study area. The persistence of elevated ozone levels and poor air quality along the Northeast Corridor during summer, exacerbated by wildfire smoke, poses significant challenges for public health and environmental management (Figure 9). By leveraging data collected from these established monitoring sites, we can enhance the comprehensiveness and accuracy of our study on air quality. This collaboration allows us to tap into existing resources, expertise, and infrastructure, which can lead to more robust research outcomes and informed decision-making regarding environmental management and public health policies. Additionally, collaborating with governmental organizations like the EPA and MDE can enhance the credibility and relevance of our research findings, potentially leading to greater impact and influence in addressing environmental challenges.

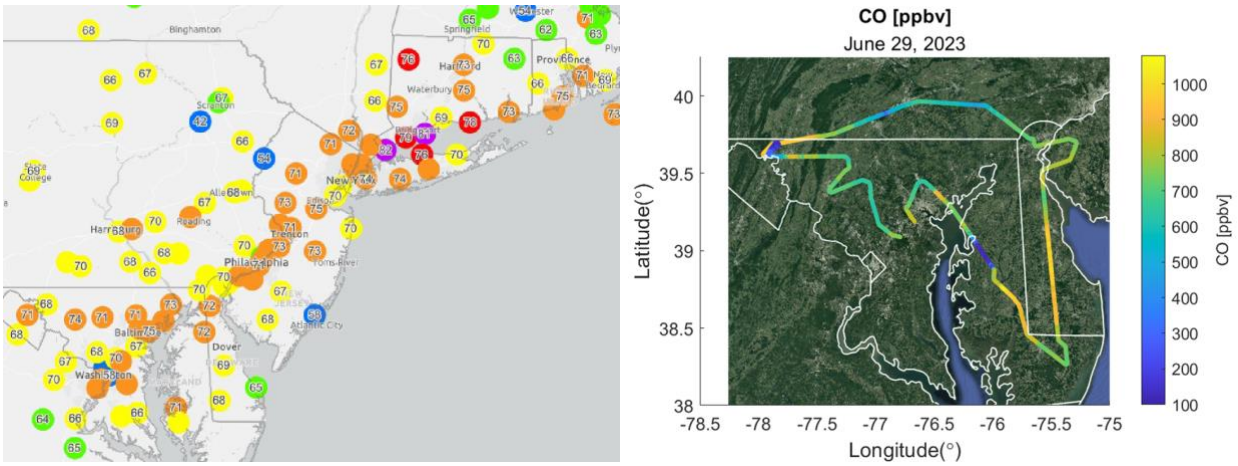

Figure 9. *Left:* the 4th high 8-hour ozone concentrations in ppb along the Northeast Corridor region in 2023. *Right:* Concentration of CO along the flight track during a research flight conducted in a wildfire smog event on June 29, 2023.

3.4. NASA Ground-based and Airborne Measurements

In summer 2025, NASA has plans to deploy some ozone lidar and Pandora instruments in the Baltimore and Washington area as well as the regular Student Airborne Research Program (SARP) to conduct research flights in the area. We will collaborate with these activities during the BAQMMS 2025, particularly for coordination of flights with the SARP over the Baltimore and Washington area. Coordination with other NASA aircraft and instruments, such as the G-V or G-III with the GCAS, Halo lidar and/or AVIRIS-NG instruments, presents additional opportunities to expand the scope and depth of BAQMMS 2025. These platforms offer advanced capabilities for remote sensing and atmospheric profiling, allowing us to investigate various aspects of air quality and greenhouse gases as well as pollutant transport with high spatial and temporal resolution. The collaboration will contribute to a more comprehensive understanding of air quality dynamics and support informed decision-making for environmental management and public health policies in the Baltimore and Washington area.

3.5. Satellite Validation

Collaborating with NOAA/NESDIS and other satellite partners on satellite data validation is crucial for ensuring the accuracy and reliability of observations from space-based instruments. By leveraging measurements of air pollutants and greenhouse gases (GHGs) obtained from

BAQMMS 2025, can contribute to the validation efforts of satellites such as TEMPO, TROPOMI, and others, thereby improving the quality of satellite-derived atmospheric data. Measurements from BAQMMS 2025, including those from ground-based instruments and aircraft vertical profiles, offer valuable ground truth data that can be compared and validated against satellite observations. Specifically, observations of air pollutants like nitrogen dioxide (NO_2) from PANDORA instruments and TEMPO can be validated using both surface-level and vertical profile data obtained from your study. Similarly, assessments of GHG columns from satellites like TROPOMI and MethaneSat can benefit from the validation provided by the airborne measurements. This collaborative effort strengthens the scientific basis for addressing environmental challenges and informs decision-makers about the state of the atmosphere and potential impacts on human health and ecosystems.

4. **Expected Outcomes**

The project anticipates generating a detailed air quality data set for the Baltimore-Washington area during the summer of 2025. The data set will include spatial and temporal variations in pollutant concentrations, identification of pollution hotspots, and an assessment of compliance with air quality standards. The findings will contribute to developing targeted air quality improvement strategies.

The Marcellus Methane Survey aims to identify and quantify methane emissions from shale gas activities. By pinpointing emission sources and estimating their contributions, the project seeks to provide valuable insights for regulatory measures and industrial best practices. This information will contribute to environmental sustainability and public health.

Based on the collected data and analysis, this study will conclude with actionable recommendations for regulatory bodies, environmental agencies, and stakeholders. These recommendations will aim to improve air quality, mitigate GHG emissions, and enhance overall environmental management practices.

This project represents a crucial initiative to understand and address air quality challenges in the Baltimore-Washington region and methane emissions from the Marcellus Shale. The integration of advanced monitoring technologies, comprehensive surveys, and meteorological data analysis will provide a nuanced understanding of the factors influencing air quality and GHG emissions. The findings and recommendations of this project will contribute to informed decision-making for sustainable environmental management.

References

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