United States Department of Commerce
National Oceanic & Atmospheric Administration

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AiRMAPS

Airborne and Remote sensing Methane and Air Pollutant Surveys

A NOAA OAR and NESDIS investigation of greenhouse gas and air pollutant emissions and impacts

Objectives

1. Establish a current top-down evaluation of U.S. oil and gas (O&G) methane and air pollutant emissions;
2. Demonstrate the use and value of a tiered, integrated satellite, airborne and ground-based greenhouse gas (GHG) observing system;
3. Evaluate civilian and commercial spaceborne remote sensing methods and long-term monitoring for methane, other GHG and air pollutants; and
4. Quantify GHG and pollutant emissions and impacts from downstream O&G end use in urban testbeds.

NOAA Office of Atmospheric Research (OAR)

Chemical Sciences Laboratory (CSL): Steven Brown, Brian McDonald, Carsten Warneke, Jeff Peischl, Sunil Baidar

Air Resources Laboratory (ARL): Xinrong Ren, Winston Luke

Global Monitoring Laboratory (GML): Colm Sweeney

Climate Program Office (CPO): Monika Kopacz, Annarita Mariotti

NOAA National Environmental Satellite, Data and Information Service (NESDIS)

Center for Satellite Applications and Research (STAR): Shobha Kondragunta

National Centers for Environment Information (NCEI): Jeff Privette

csl.noaa.gov/projects/airmaps

The United States has committed to ambitious goals to reduce national greenhouse gas emissions. The Nation requires accurate information to underpin current emissions inventories, voluntary carbon markets and credits, and the efficacy of mitigation policies. The 2023 White House National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System (GHG MMIS) calls for a coordinated effort to integrate capabilities currently spread out across federal and non-federal entities. GHG MMIS objectives are to improve both top-down (atmospheric based) and bottom-up (activity based) emissions estimates, coordinate these approaches, and improve their latency, completeness and accuracy. The U.S. Greenhouse Gas Center is a demonstration phase, multi-agency effort to consolidate and coordinate access to GHG data in order to provide decision makers with a single location for trusted data and analyses. New and more accurate information will be needed in support of the 2023 EPA Rule for Oil and Natural Gas Operations intended to reduce emissions of methane and other air pollutants from the O&G sector.

The NOAA Office of Oceanic and Atmospheric Research (OAR) has committed to organizing its research around societal challenges that include *Confronting Challenges from our Changing Climate* and *Sustaining a Healthy Environment and Economy*. In support of the White House National Strategy, and to address these societal challenges, NOAA OAR and NESDIS will lead a series of airborne campaigns in 2024–2028 to provide comprehensive and quantitative topdown emissions data for methane, other GHGs and major air pollutants from the O&G sector at basin scale and from selected urban areas. NOAA surveyed a large majority of U.S. O&G production regions in a series of campaigns in 2013, 2014 and 2015 in work that has contributed to the most comprehensive evaluation of onshore O&G methane emissions to date (Alvarez 2018, Peischl 2018). Oil and gas production, methane detection technologies and national emissions targets have all evolved markedly since that time. Newer and more comprehensive surveys are critically needed.

The deliverable of the NOAA strategy will be a **quantitative assessment of current U.S. methane emissions from the majority of O&G production regions and selected urban testbeds.** The assessment will include an evaluation of other GHGs and co-emitted air pollutants. Additional sources such as agriculture, landfills, coal mining and wetlands will be assessed as the opportunities arise. Airborne and satellite-based observations will be integrated and evaluated to achieve this objective.

OAR and NESDIS intend to execute this strategy in collaboration with airborne, remote sensing and ground-based assets from NOAA and partner agencies to **demonstrate the value of an integrated, tiered GHG observing system**. One purpose of this white paper is to foster community and partner engagement. The envisioned activities are based on current programs and conditional on the availability of resources. Participating OAR laboratories and programs include the Chemical Sciences Laboratory (CSL), the Air Resources Laboratory (ARL), the Global Monitoring Laboratory (GML) and the Atmospheric Chemistry Carbon Cycle and Climate Program (AC4) of the Climate Program Office (CPO). Participating NESDIS Programs include the Center for Satellite Applications and Research (STAR) and the National Centers for Environmental Information (NCEI). OAR and NESDIS will seek collaboration with other NOAA line offices (NWS), federal agencies (NIST, NASA, DOE, EPA, DOI), academic partners, and stakeholders (state and tribal agencies, the O&G industry, NGOs, private sector entities and data providers). NOAA NESDIS and NASA support spaceborne and airborne remote sensing of GHGs, and NOAA OAR, NIST and DOE support ground-based GHG networks. EPA, NOAA and NIST compile activity-based inventories. NOAA airborne surveys and satellite observations described further below link these components together, evaluate their accuracy and completeness and support the development of more accurate emissions inventories.

The OAR and NESDIS strategy encompasses four principal research objectives:

1. Establish a current top-down best estimate of U.S. O&G methane and air pollutant emissions for future evaluations and trend analysis;
2. Demonstrate the use and value of a tiered, integrated GHG observing system consisting of light and heavy aircraft providing comprehensive airborne surveys; satellite- and aircraft-based remote sensing; and ground-based long- and short-term observations (Figure 1);
3. Evaluate civilian and commercial spaceborne remote-sensing methods for the detection and quantification of methane and other pollutants from diverse source sectors with a wide dynamic range of emissions using a methodology consistent with current standards and definitions; and
4. Quantify GHG and co-emitted air pollutant emissions and impacts from the end use of O&G in urban testbed areas in support of evaluating and improving inventories (e.g., EPA GHGI and NOAA-NIST GRA^2PES).

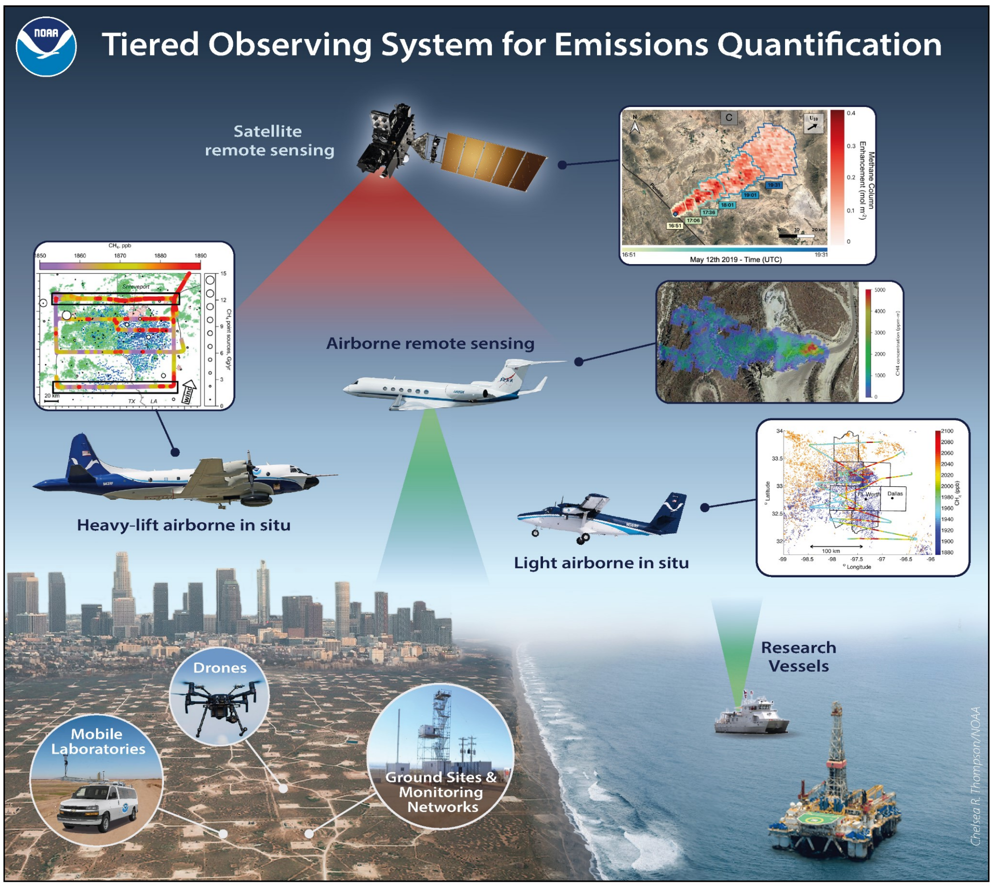

Figure 1. Schematic of a tiered observing system composed of surface, airborne and satellite assets that is used to evaluate and monitor U.S. O&G and urban emissions of methane and air pollutants. Adapted from (McDonald 2023).

Intensive Airborne Surveys

Long-term monitoring of GHG emissions and air pollutants associated with O&G production and urban areas requires a comprehensive observing system that is composed of ground monitoring systems as well as airborne and satellite remote sensing systems. The latter are powerful but nascent technologies that need rigorous verification. NOAA airborne surveys and remote sensing approaches represent the currently best-available methodology to validate and augment new remote sensing technology. OAR has developed state-of-the-art research aircraft instrumentation and has a long history in the execution of airborne campaigns. Based on this proven expertise, OAR will derive emissions using airborne surveys involving several detection and analysis methods.

> *Mass balance.* Described as the "gold standard" for basin scale emissions, mass balance derives emissions from the difference between upwind and downwind trace gas concentrations. NOAA CSL's airborne Doppler lidar, currently deployable on the NOAA Twin Otter aircraft, provides high resolution wind velocities throughout the boundary layer, as well as mixed layer depth, to improve the efficiency and accuracy of this method.
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> *Tracer relationships.* Co-measurements of GHGs with other emitted pollutants provide quantitative emission estimates and source attribution (e.g., agriculture, O&G, urban). NOAA OAR has substantial expertise in developing and deploying airborne instrumentation for a wide range of pollutant species.
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> *Eddy covariance.* Variation of pollutant concentrations with vertical wind velocity provides surface emissions via an independent and complementary method.
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> *Inverse modeling*. Application of chemical transport models to satellite, airborne and ground-based GHG measurements provides complementary emission estimates.

Long-term Satellite Observations

Satellite observations augment ground monitoring capability and have become a viable source of information – they are the "eyes in the sky" that provide routine daily observations for long periods of time and thereby provide continuity and trends from regional to global scales. While well calibrated ground-based sensors often provide the most accurate GHG and pollutant measurements, NOAA and its partner agencies use a fleet of geostationary and polar-orbiting satellites to observe emissions from large sources as well as derive concentrations assuming a well-mixed atmosphere. In the last decade, a host of commercial and non-profit methane observing satellites have come into the fore (e.g., GHGSat, MethaneSAT). Civilian and commercial/non-profit satellite instruments serve diverse needs by observing methane emissions from different source sectors. However, detecting and quantifying depends on assumptions that require thorough validation:

> *Plume Detection*. Averaged over weekly to monthly to yearly time scales, methane concentrations from satellite sensors such as the Sentinel 5 Precursor Tropospheric Monitoring Instrument (S5P TROPOMI) can identify source regions, and observations combined with models provide emissions (fluxes). TROPOMI and similar instruments in a polar orbit measuring in the short-wave and near-infrared spectrum can detect plumes

from high-emitting facilities, but plume quantification involves assumptions about local meteorology. By contrast, frequent snapshots of high-emitting plumes observed by geostationary satellite imagers, such as the GOES-R series Advanced Baseline Imager (ABI), can be integrated over time to derive emissions without the need for meteorological data or models. *Quantifying plume concentrations and fluxes from remote-sensing data requires an independent source of information*.

3D Concentration Fields. Hyperspectral sounders measuring in the infrared such as the JPSS series or Metop Series sounding instruments (e.g., Cross-track Infrared Sounder) observe 3D fields of methane concentrations but retrievals are useful only on monthly to yearly time scales. These data need to be integrated with other in situ observations and models such as NOAA's CarbonTracker to be converted to fluxes. Prior to converting to fluxes, the data need to be well validated to ensure quality control.

The 2024–28 Timeline for Airborne Surveys

OAR laboratories have developed a strategy for a series of airborne campaigns in 2024–2028 to survey the majority of U.S. O&G production and selected urban emission testbeds. The NOAA Twin Otter and WP-3D aircraft can be instrumented to measure GHGs (methane, carbon dioxide) and other tracers (nitrogen oxides, carbon monoxide). The Twin Otter currently also measures wind velocities with a Doppler lidar, while a similar system is under development for the NOAA WP-3D. The enhanced NOAA WP-3D measurements also include co-emitted pollutants related to O&G and urban emissions (e.g., speciated volatile organic compounds (VOCs), oxidized nitrogen, speciated aerosol composition).

2024 Colorado & Utah. OAR will conduct a series of flights with a NOAA Twin Otter in Colorado's Denver-Julesburg Basin and Salt Lake City, Utah (a city with a long record of urban GHG measurements) with the airborne Doppler lidar, GHGs and other tracer measurements.

2025 Baltimore & Marcellus Shale. The Marcellus shale is one of the largest U.S. O&G basins and Washington, D.C. - Baltimore is a well-established urban GHG emission testbed. OAR will survey both regions with a NOAA Twin Otter.

2026 Texas and U.S. Southwest. OAR will deploy a comprehensive and detailed chemical payload on a NOAA WP-3D aircraft to survey GHGs and co-emitted pollutants from large O&G basins (e.g., the Permian) and major urban areas (e.g., Los Angeles, also an urban testbed). A NOAA Twin Otter will survey a series of O&G basins in Texas.

2027 Western U.S. O&G Basins. OAR will deploy a NOAA Twin Otter to additional basins in the western U.S., such as the Bakken, Uinta and San Juan basins in North Dakota, Utah and New Mexico, respectively.

2028 Marcellus Shale and Urban Midwest. OAR will survey urban areas in the upper Midwest (e.g., Chicago) and Northeast (e.g., New York) together with the entire (Northeast and Southwest) Marcellus Shale during wintertime with a NOAA WP-3D.

This series of flights will survey more than 90% of currently estimated O&G methane emissions (Figure 2) and a similar fraction of O&G production to achieve the most comprehensive airborne methane and air pollutant assessment to date. Survey emissions estimates will provide critical evaluation of top-down and bottom-up methods to reduce uncertainty and improve reliability. Intercomparison of estimates from remote sensing and surface data will aid in assessing the accuracy of these approaches that provide longer-term monitoring of emission trends.

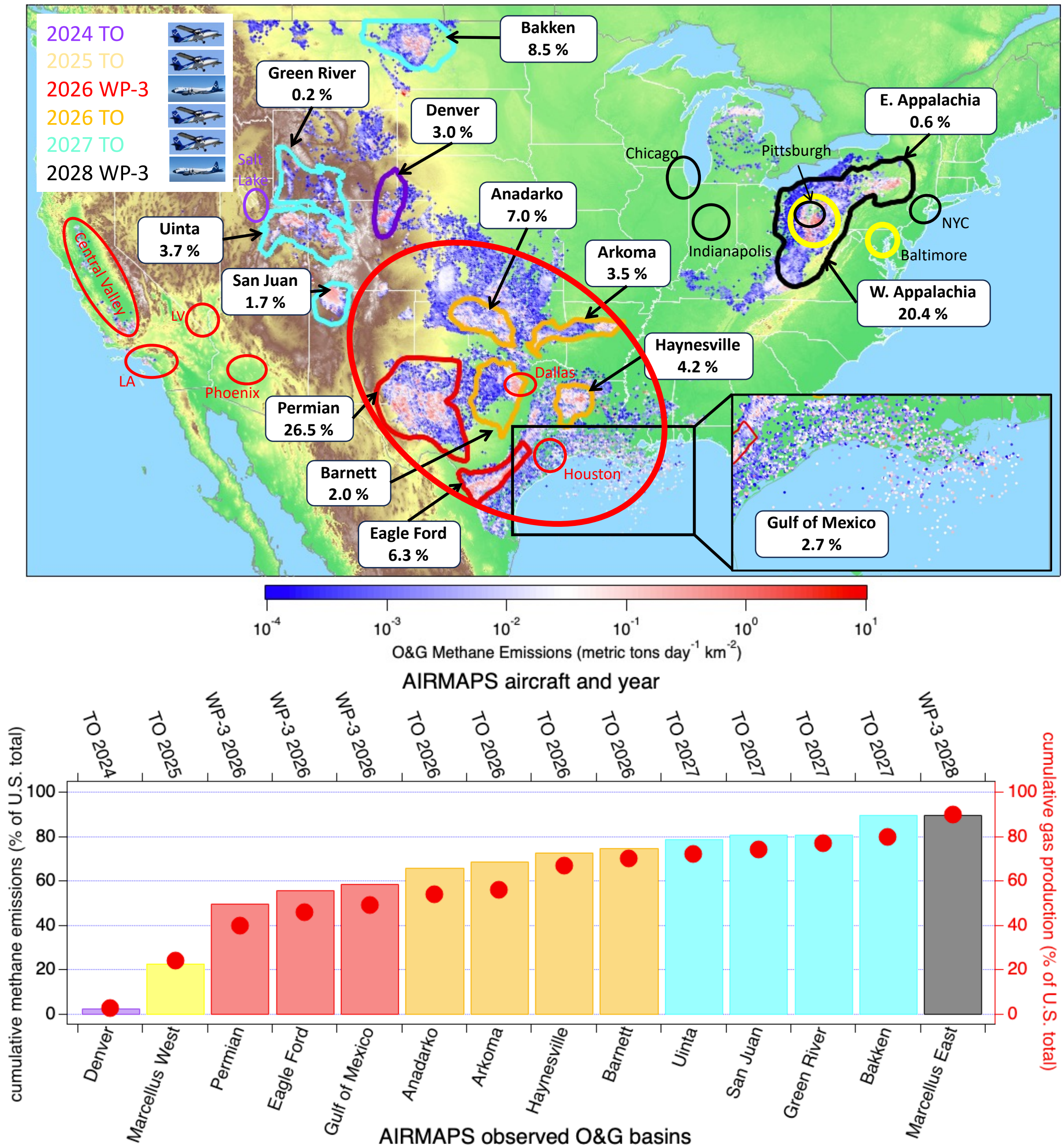

Figure 2. Upper panel: Methane emissions (in metric tons per day per square km) from facilities in U.S. O&G production basins. The percentage of total estimated U.S. O&G methane emissions is shown under each basin name for 2020. The legend and colored circles show proposed AIRMAPS survey regions by year and aircraft (NOAA Twin Otter and WP-3D). Lower panel: Cumulative methane emissions (%, bars) and cumulative gas-production (%, dots) for the principal O&G production regions (bottom scale) ordered by year of sampling. The top scale shows the aircraft and survey year in the AIRMAPS proposed schedule.

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