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Advances in Satellite Methane Emissions Measurement

This In Focus discusses the role of evolving satellite technologies, their ability to monitor methane and identify large-scale emissions events, and how data from these detection technologies fit into federal methane rules and programs. Interest in detecting methane and observing and locating emissions events stems in large part from efforts to reduce the release of greenhouse gases (GHGs). In particular, advances in remote sensing of methane from satellites may improve monitoring and detection of methane emissions from oil, coal, and natural gas operations. Congress may consider the use of satellite methane emissions information in U.S. programs.

Background on Methane Emissions

Methane has a global warming potential 27-30 times greater than carbon dioxide over a 100-year period. It is second only to carbon dioxide in contributions to global temperature increases from human emissions of GHGs. Fossil-fuel-related industries are among the sectors that emit methane into the atmosphere. Some stakeholders support reducing methane emissions as part of efforts to mitigate climate change and to improve public health. Regulation of methane emissions has been opposed by other stakeholders for reasons of cost, among others.

Fugitive emissions are generally described as unintended leaks from pressure containment systems, which can include leaks from valves or flanges, in fossil fuel facilities. Fugitive emissions also include methane that escapes to the atmosphere from incomplete combustion during flaring (the burning of excess gas).

Regulatory and Policy Context

Under the authority of Section 111 of the Clean Air Act (CAA), the U.S. Environmental Protection Agency (EPA) promulgated more stringent standards for methane emissions from oil and natural gas facilities. Specifically, it published a rule that finalized revisions to the new source performance standards (NSPS) and emission guidelines (EG). The rule requires states to submit and implement plans to establish performance standards that limit GHG emissions from existing oil and natural gas facilities (89 *Federal Register* 16820, March 8, 2024).

One set of actions in the 2024 rule is lessening *fugitive emissions* by constraining them from large emissions sources known as super-emitters. The rule established standards for methane release events greater than 100 kilograms per hour, known as *super-emitter events.* The rule also established the Methane Super Emitter Program to allow certified third parties to submit data on methane release events to the EPA Super Emitter Portal (as defined in the final rule). Under this program, certified third-party submitters may only use EPA-approved technology, which includes (1) satellite detection of methane emissions, (2) remote-sensing equipment located on aircraft, or (3) mobile monitoring platforms. This rule adds to previous actions on methane emissions. In accordance with CAA Section 111, the Crude Oil and Natural Gas source category was first listed as a source category subject to performance standards in 1979. EPA's 2016 rule expanded the emission sources covered by the 2012 rule and added performance standards for methane emissions.

Satellite measurement of methane emissions can contribute to meeting U.S. treaty obligations under the United Nations Framework Convention on Climate Change (UNFCCC). This includes an annual Greenhouse Gas Inventory that includes methane. On January 20, 2025, President Trump issued an executive order directing the withdrawal of the United States from agreements under the UNFCCC.

Methane Emissions Estimation Methods

Comprehensive measurement and estimation of methane emissions is difficult, and the measurement technologies continue to evolve. Methane emissions estimation methods are often placed in two general categories. One type of methods, sometimes referred to as "bottom up" (BU), extrapolates measurements from individual natural gas facility components to estimate total emissions for industrial facilities. BU methods rely on averaging numerous leak test measurements of these components to develop "emissions factors." These emissions factors are used to estimate emissions for facilities based on the number and types of components and the levels of production. However, because emissions factors are based primarily on leakage measured under normal conditions, they may not fully account for super-emitter events and may understate total emissions.

The second type of methods, referred to as "top down" (TD), provide empirical measurements of methane at specific locations, rather than estimates based on emissions factors. They use either ground-based instruments or those on aircraft or satellites to estimate methane emissions. The downsides of TD are its relative cost and coverage limitations. At present, satellite- and aircraft-based measurements cost more than the BU strategy described above. Also, some TD methods (e.g., orbiting satellites) typically occur at infrequent intervals and may miss detection of sporadic emissions events. As remote detection technologies mature, costs may drop. Increasing satellite sampling frequency offers an opportunity to improve accuracy and precision.

Satellite Measurement of Emissions

Remote measurement of methane using satellite-based sensors typically detects the abundance of methane by measuring the methane-specific pattern of light absorption. Since the launch of the Greenhouse Gases Observing Satellite (GOSAT) by the Japanese government in 2009, the number and capabilities of methane emissions observing satellites has increased. Participants in satellite methane emission observation now include the private sector and nongovernmental organizations. The satellite platforms described here are not operated directly by the U.S. government, although U.S. researchers use the data.

Satellite detection methods can involve trade-offs between geographic coverage and image resolution that may allow some fugitive emissions to go undetected. These trade-offs may be addressed as technical capabilities improve and datasets from satellites with complementary capabilities are combined. As satellites pass overhead, they scan a continuous strip of the Earth's surface known as a *swath*. The swath width is the horizontal width of this strip. Existing satellite technologies present a trade-off between the swath width and the resolution of the image. For instance, a satellite such as the European Space Agency instrument TROPOMI has a swath width of 2,600 kilometers (km) and spatial resolution of 7 km x 3.5 km. This relatively wide swath scans a large area but typically lacks the resolution to distinguish individual surface features, such as specific oil or gas facilities.

Other satellites, such as the Italian Space Agency instrument PRISMA—with a swath width of 30 km and a spatial resolution of 30 meters (m), with a high-resolution sensor—may be able to distinguish such facilities. Such a narrow swath width restricts the area that can be sampled on any given overpass of a satellite. The trade-off between these two types of satellites means that a wide-survey satellite may detect an area of high emissions but lack the resolution to attribute it to a specific facility, whereas a high-resolution satellite may miss a sporadic emissions event altogether if it is outside the narrower swath width.

Researchers have strategies to address these trade-offs and improve the detection, quantification, and attribution of fugitive methane emissions. These strategies include increasing satellite survey capacity to detect elevated regional methane concentrations in order to detect areas of high emissions, increasing satellite capacity for direct location attribution of such events, and using data from satellites with complementary capabilities. One way of increasing the capacity of satellites to detect methane emissions is making available more high-resolution satellites for observations. For example, 12 high-resolution private-sector Canadian GHGSat satellites and the Tanager-1 satellite (a Carbon Mapper project with an instrument developed by NASA's Jet Propulsion Laboratory) with spatial resolution approximately 30 m x 30 m are currently operational. These systems are generally able to discern individual point sources of fugitive emissions at the facility level, allowing specific attribution in some cases. These satellites are capable of sampling areas of high emissions that are identified by wide-area survey satellites such as the European Space Agency TROPOMI instrument on board the Copernicus Sentinel-5 Precursor satellite launched in 2017.

Recent scientific advances in hyperspectral sensing may also increase the capacity for detecting emissions. Hyperspectral instruments collect data on hundreds of narrow bands across the electromagnetic spectrum. Experiments have shown that hyperspectral sensors can be used to measure atmospheric methane. Satellites such as PRISMA (launched in 2019), Copernicus Hyperspectral Imaging Mission for the Environment (CHIME; a European Space Agency mission in collaboration with NASA), and ZY-1 02D (a Chinese satellite launched in 2019) combine this ability to measure methane with a spatial resolution better than 50 m x 50 m. This is likely sufficient to allow fugitive emissions attribution to a specific facility. Making use of the data from these satellites for fugitive emissions detection could add to current attribution capabilities.

The capacity to detect emissions may also be enhanced by MethaneSAT, which has area coverage and resolution capabilities between wide-area survey satellites such as TROPOMI and high-resolution satellites such as Tanager-1. MethaneSAT is a joint project of the Environmental Defense Fund (a U.S. nonprofit) and the New Zealand Space Agency. Its specifications include a swath width greater than 200 km, a spatial resolution of 100 m x 400 m, and a detection threshold of approximately 3 parts per billion (ppb) of methane. MethaneSAT is able to survey large areas and detect methane emissions with some spatial specificity, although its ability to attribute an emissions event to a specific facility is limited.

EPA's Methane Super Emitter Program

EPA established the Methane Super Emitter Program as part of the agency's final 2024 rule for NSPS and EG for the Crude Oil and Natural Gas source category. Under this program, third parties apply for certification to submit data to EPA using approved remote-sensing technology. If a third party is certified, it may submit to EPA notifications that contain specified information on methane releases. The notification must be submitted within 15 calendar days of the date the release event is detected. EPA reviews the submission for accuracy and completeness and then notifies the owner or operator of the source responsible for the potential super-emitter event. According to the 2024 rule, the responsible entity must then initiate an investigation of the event within 5 days and report the findings to EPA within 15 days. When an emissions event has been identified, the owner or operator must report details about that event. The required reporting details are dependent on the source of the emissions, such as an oil or natural gas facility. The super-emitter event investigation may include various actions, such as reviewing maintenance activities, reviewing monitoring data, reviewing the results of a fugitive emissions survey, and screening the whole facility with optical gas imaging. If the super-emitter event was found to be from fugitive methane emissions, the owner or operator must comply with the fugitive emissions monitoring and repair requirements of the NSPS and EG for the Crude Oil and Natural Gas source category.

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