Remote Sensing of Atmospheric Methane: A Primer for Policymakers on the Science of Methane Satellites

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UCLA School of Law
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Introduction

This paper provides an accessible introduction to the science and technology of methane remote sensing, focusing especially on new satellite-borne methane detection instruments. It aims to help support and build capacity for legal and policy officials concerned with control of methane emissions in diverse national and subnational jurisdictions worldwide by aiding understanding of methane satellites and how they work.

Methane is an important greenhouse gas, whose atmospheric concentration has nearly tripled over the past century due to human activities. In addition, reducing methane emissions is an effective near-term climate change mitigation tool. Because of methane's high contribution to global heating over a relatively short atmospheric lifetime, cutting emissions today will achieve a reduction in global heating that is concentrated over the next ten years or so.

Effective control of methane emissions has been hindered, however, by the limited information available about how much is emitted, when, where, from what sources. Emissions estimates have typically used "bottom-up" methods, in which an observed level of some emissions-producing activity – e.g., volume of oil produced or number of cows – is multiplied by an "emissions factor" derived from prior research – e.g., methane emitted per barrel of oil produced or per cow – to yield an estimate of total methane emitted.[2]

These estimates are important and useful, but they have serious limitations.They rely on emissions factors that are in many cases old and unrepresentative. They neglect variation over time, location, and activity. And they are too coarse-grained and fixed over time to support some forms of effective monitoring and control. Many direct observations have shown bottom-up estimates of methane emissions to be inaccurate, in most cases to seriously under-estimate actual emissions. For these reasons, it can be very useful to supplement bottom-up estimates with direct observations of methane emissions.

Until recently, direct observations of atmospheric methane required costly, limited-duration field campaigns with airborne or ground-based instruments.[3] Current advances in airborne and especially satellite-borne instruments are transforming the ability to observe methane directly and allow for

1 The authors are affiliated with the Emmett Institute on Climate Change and the Environment at UCLA School of Law. The views expressed in this paper are those of its authors, not UCLA or the Emmett Institute. To share feedback on this discussion paper or the Advancing Methane Regulation Project, please contact Cara Horowitz at horowitz@law.ucla.edu. Support for this project was generously provided by the Global Methane Hub.

2 IPCC. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*; https://www.ipcc.ch/2019/05/13/ipcc-2019-refinement/.

synergistic use of diverse tools to improve methane emission estimates. Satellite instruments now enable more precise, complete, and reliable observations of atmospheric methane and estimates of emissions, at scales ranging from individual point sources to the world.

Notable advances from these satellite observations include the following:

- Imaging the methane plume from the 2015 leak at California's Aliso Canyon gas storage facility, independently confirming prior measurements from airborne surveys.[4]
- Detection and quantification of methane emissions from multiple large point-source releases, including leaks and well blowouts in Turkmenistan, Kazakhstan, Algeria, and several US states, coal mines in Russia and Australia, and landfills in Spain and Bangladesh.[5]
- Quantitative emissions estimates at the scale of major oil and gas production basins. For example, an analysis of the largest producing region in the United States, the Permian Basin, found basin-wide methane emissions more than double prior bottom-up estimates, while also identifying specific high-emissions point sources within the region.[6]
- Multiple quantitative estimates of total national emissions from the oil, gas, and coal production sectors, improving the accuracy and detail of previous emission inventories.[7]

Capabilities are advancing rapidly, with the recent launch of satellite instruments specifically designed to observe methane and with ongoing development of systems to calculate emissions from satellite observations, integrate data from multiple sources, and make the data widely accessible. These advances represent a revolution in the ability to monitor methane emissions worldwide, nearly continuously, at scales ranging from point sources to nations and the world. The advances will both strengthen current approaches to controlling methane emissions and enable new approaches not previously available or considered.

3 Alvarez, R. A.; Zavala-Araiza, D.; Lyon, D. R.; Allen, D. T.; Barkley, Z. R.; Brandt, A. R.; Davis, K. J.; Herndon, S. C.; Jacob, D. J.; Karion, A.; Kort, E. A.; Lamb, B. K.; Lauvaux, T.; Maasakkers, J. D.; Marchese, A. J.; Omara, M.; Pacala, S. W.; Peischl, J.; Robinson, A. L.; Shepson, P. B.; Sweeney, C.; Townsend-Small, A.; Wofsy, S. C.; Hamburg, S. P. Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain. *Science* **2018**, 361 (6398), 186–188. https://doi.org/10.1126/science.aar7204; Duren, R. M.; Thorpe, A. K.; Foster, K. T.; Rafiq, T.; Hopkins, F. M.; Yadav, V.; Bue, B. D.; Thompson, D. R.; Conley, S.; Colombi, N. K.; Frankenberg, C.; McCubbin, I. B.; Eastwood, M. L.; Falk, M.; Herner, J. D.; Croes, B. E.; Green, R. O.; Miller, C. E. California's Methane Super-Emitters. *Nature* **2019**, 575 (7781), 180–184. https://doi.org/10.1038/s41586-019-1720-3.

4 Thompson, D. R.; et al. Space-Based Remote Imaging Spectroscopy of the Aliso Canyon CH_4 Superemitter. *Geophys. Res. Lett.* **2016**, *43* (12), 6571–6578. https://doi.org/10.1002/2016GL069079; Pandey, S.; et al. Satellite Observations Reveal Extreme Methane Leakage from a Natural Gas Well Blowout. *Proc. Natl. Acad. Sci. U.S.A.* **2019**, *116* (52), 26376–26381. https://doi.org/10.1073/pnas.1908712116; Maasakkers, J. D.; et al. Reconstructing and Quantifying Methane Emissions from the Full Duration of a 38-Day Natural Gas Well Blowout Using Space-Based Observations. *Remote Sens. Environ.* **2022**, *270*, 112755. https://doi.org/10.1016/j.rse.2021.112755; Cusworth, D. H.; et al. Multisatellite Imaging of a Gas Well Blowout Enables Quantification of Total Methane Emissions. *Geophys. Res. Lett.* **2021**, *48* (10), e2020GL090864. https://doi.org/10.1029/2020GL090864; Varon, D. J.; et al. High-Frequency Monitoring of Anomalous Methane Point Sources with Multispectral Sentinel-2 Satellite Observations. *Atmos. Meas. Tech.* **2021**, *14* (4), 2771–2785. https://doi.org/10.5194/amt-14-2771-2021; Guanter, L.; et al. Global Monitoring of Methane Emissions from Space: Current Capabilities and Future Perspectives. *Earth Syst. Sci. Data* **2024**, *16*, 2841–2860. https://doi.org/10.5194/essd-16-2841-2024; World Geospatial Industry Council. Methane Emissions from Pipelines and Landfills. https://wgicouncil.org/methane-emissions-from-pipelinesand-landfills/; GHGSat. Russian Mine Produces Biggest Methane Leak Ever Seen by GHGSat. June 15, 2022. https://www.ghgsat.com/en/newsroom/russian-mine-produces-biggest-methane-leakever-seen-by-ghgsat/; Sadavarte, P.; et al. Methane Emissions from Superemitting Coal Mines in Australia Quantified Using TROPOMI Satellite Observations. *Environ. Sci. Technol.* **2021**, *55* (24), 16426–16435. https://doi.org/10.1021/acs.est.1c03976.

5 Schneising, O.; Buchwitz, M.; Reuter, M.; Vanselow, S.; Bovensmann, H.; Burrows, J. P. Remote Sensing of Methane Leakage from Natural Gas and Petroleum Systems. *Atmos. Chem. Phys.* **2020**, *20* (15), 9169–9182. https://doi.org/10.5194/acp-20-9169-2020; Zhang, Y.; et al. Quantifying Methane Emissions from the Largest Oil-Producing Basin in the United States from *Space. Sci. Adv.* **2020**, *6* (17), eaaz5120. https://doi.org/10.1126/sciadv.aaz5120; Irakulis-Loitxate, I.; et al. Satellite-Based Survey of Extreme Methane Emissions in the Permian Basin. *Sci. Adv.* **2021**, *7* (27), eabf4507. https://doi.org/10.1126/sciadv.abf4507; Lauvaux, T.; et al. Global Assessment of Oil and Gas Methane Emissions with Satellite Observations. *Science* **2022**, *375* (6580), 557–561. https://doi.org/10.1126/science.abj4351.

6 Shen, L.; et al. Quantifying National Methane Emissions. *Nat. Commun.* **2023**, *14*, 4986. https://doi.org/10.1038/s41467-023-40671-6.

7 Bell, C.; et al. Performance of Continuous Emission Monitoring Solutions under a Single-Blind Controlled Testing Protocol. *Environ. Sci. Technol.* **2023**, *57* (13), 5794–5805. https://doi.org/10.1021/acs.est.2c09235; Sherwin, E. D.; et al. Single-Blind Test of Nine Methane-Sensing Satellite Systems from Three Continents. *Atmos. Meas. Tech.* **2024**, *17* (4), 765–782. https://doi.org/10.5194/amt-17-765-2024.

The new data also present various novel limitations and challenges stemming from factors such as instrument detection thresholds, seasonal and geographic limitations on coverage, and sensitivity to local weather conditions. Moreover, many policymakers are unfamiliar with the new data sources, their scientific and technical foundations, and their strengths and limits – not just in jurisdictions with significant capacity constraints, but also in many well-resourced jurisdictions.

The UCLA Emmett Institute Advancing Methane Regulation project explores how these new observational capabilities can expand the ability to control methane emissions, under existing regulatory frameworks and potential new ones, in diverse jurisdictional settings. One goal of the project is to strengthen interaction and knowledge sharing between the law/policy and the scientific/technical sides of methane monitoring and control. This briefing note supports that aim by providing an accessible introduction to the science and technology of methane remote sensing for policy and legal officials, including the basics of how current and planned instruments work, what scientific principles they rely on, what information they can provide in what form and on what timeframe, with what accompanying limitations and challenges. It aims to help support and build capacity for legislators, officials, and others concerned with control of methane emissions, in diverse national and subnational settings worldwide. Future work will build on this foundation with additional implications for policymakers' efforts to advance methane control.

2. Basics of remote sensing: What it is and how it works

Remote sensing is the process of gathering information (sensing) about an object of interest at a distance (remote) from the object. Remote sensing (RS) can be used to observe a wide range of objects at a distance – a speeding automobile, an aircraft approaching a landing, a school of fish in the ocean, and many aspects of the Earth and its atmosphere, including pollutants in the air. Human vision is an example of remote sensing, because we see distant objects by sensing the light that originated in the sun or a light bulb and reflected, or scattered, off the object into our eyes.

Like human eyes, RS instruments operate by sensing light that travels to the instrument from the thing being observed. But RS can see much more than human eyes, mainly because RS instruments can see a much wider range of light than the thin slice visible to human eyes. As the text box on the next page explains in more detail, human eyes can see light with wavelengths between 0.4 and 0.7 micrometers or microns. Within this narrow range of wavelengths, we see different wavelengths as different colors, from red with the longest wavelengths (~ 0.7 microns) to violet with the shortest (~0.4 microns).

RS instruments, by contrast, can be designed to see light of one wavelength, or several, or a wide continuous range of wavelengths. RS instruments may see wavelengths that overlap with those visible to human eyes, or longer or shorter wavelengths, depending on the purpose.

Remote sensing instruments are used to observe many characteristics of the Earth's surface, oceans, and atmosphere, and can be carried on a wide range of platforms. They can be fixed in place, hand-held, or carried on vehicles, but most important environmental remote sensing is done from airborne or space-borne instruments, carried on aircraft, balloons, drones, or satellites.

Wavelengths: Different “colors” of light

Light, or electromagnetic radiation (these are equivalent terms – one informal, one scientific), comes in a vast range of different varieties.

In some respects, light acts like waves, similar to waves on the surface of a body of water. All waves are described by their speed of travel, their wavelength (the distance between the top of one wave and the next) and their frequency (the number of waves that pass a fixed observation point per second). Because all light – unlike other waves – travels at the same speed, describing light by its wavelength and by its frequency are equivalent: light with shorter wavelength has higher frequency. In this note, we describe light by its wavelength, because that is how it is most frequently described in discussing RS.

Only a thin slice of light, with wavelengths between about 0.4 and 0.7 micrometers or microns (μm), is visible to the human eye. A micron is one millionth of a meter or 10^{-6} meters. For comparison, a human hair is roughly 50 to 100 microns in diameter, so visible light has a wavelength about one hundred times smaller than a human hair.

Light of different wavelength ranges, both longer and shorter than visible light, is called by different names. Light with wavelengths slightly longer than visible light, from about one to a few hundred microns, is called “infrared.” The most important wavelengths for observing methane lie in the “near infrared” with wavelengths of a few microns, slightly longer than visible light. Light with still longer wavelengths is called microwaves (wavelengths from about 1 mm to 1 m) or radio waves (from 1 m to hundreds of kilometers). Light with shorter wavelengths than visible is called ultraviolet (UV), X-rays, and gamma rays. These shorter wavelengths are usually expressed in smaller units than microns, such as nanometers (nm), one billionth of a meter or 10^{-9} meters. The wavelength range of visible light can also be expressed in nm, as 700-900 nm. These different names do not denote fundamentally different things; they simply refer to light with wavelengths in different ranges, which is usually emitted by different sources and used in different ways. It is reasonable to think of these different wavelength ranges of light as different colors, although of course with a vastly wider range of colors than human eyes can see.

While some light sources emit light of just one wavelength, many emit light of many different wavelengths. A description of light that specifies the mix of wavelengths present – what specific wavelengths are present, how brightly – is called its “spectrum.” We can speak of the spectrum of sunlight, or the spectrum of a particular type of light bulb. Similarly, the spectrum of an instrument describes how sensitive it is to light of different wavelengths. The term “the electromagnetic spectrum” describes the totality of all wavelengths of light and their division into different named ranges, as shown in Figure 1.

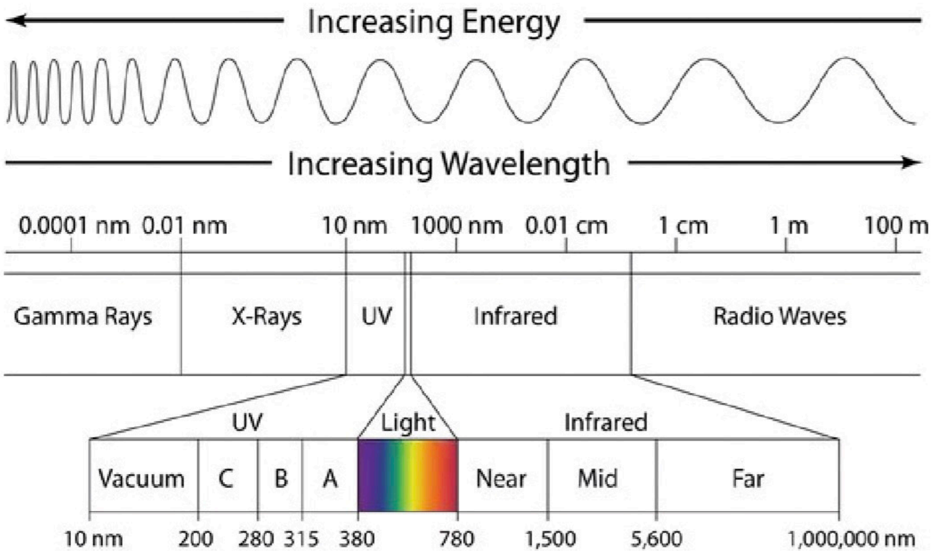


Figure 1: *The electromagnetic spectrum. The visible region (called "light" in this figure, but better labeled "visible light") is shown by the narrow band of rainbow colors, between the longer-wave infrared radiation (IR) to the left, and the shorter-wave ultraviolet radiation (UV) to the right. (Source: NASA)*

Satellite instruments measure the brightness (or "radiance") of light reaching the instrument at each wavelength that the instrument is able to see. For an RS instrument to observe any target object, the target must interact with wavelengths of light that the instrument can detect. Much RS for environmental and earth-science purposes, and nearly all RS of atmospheric methane, observe sunlight that has scattered from the target to the instrument. Methane and other atmospheric constituents can be seen by this method because their molecules interact strongly with light at highly specific wavelengths, affecting the brightness of light scattered back to the instrument at these wavelengths.

Any chemical compound present in the atmosphere – whether water vapor, carbon dioxide, or methane – consists of molecules made up of specific combinations of atoms held together in a specific shape by chemical bonds. For example, a molecule of methane consists of one carbon atom joined by chemical bonds to four hydrogen atoms to make a tetrahedral shape. These bonds stretch, wobble, and vibrate like tiny springs, and their movement can be excited by absorbing specific wavelengths of light, rather like a bell has a specific characteristic frequency that can be excited by striking the bell, or by exposing the bell to sound of that frequency.

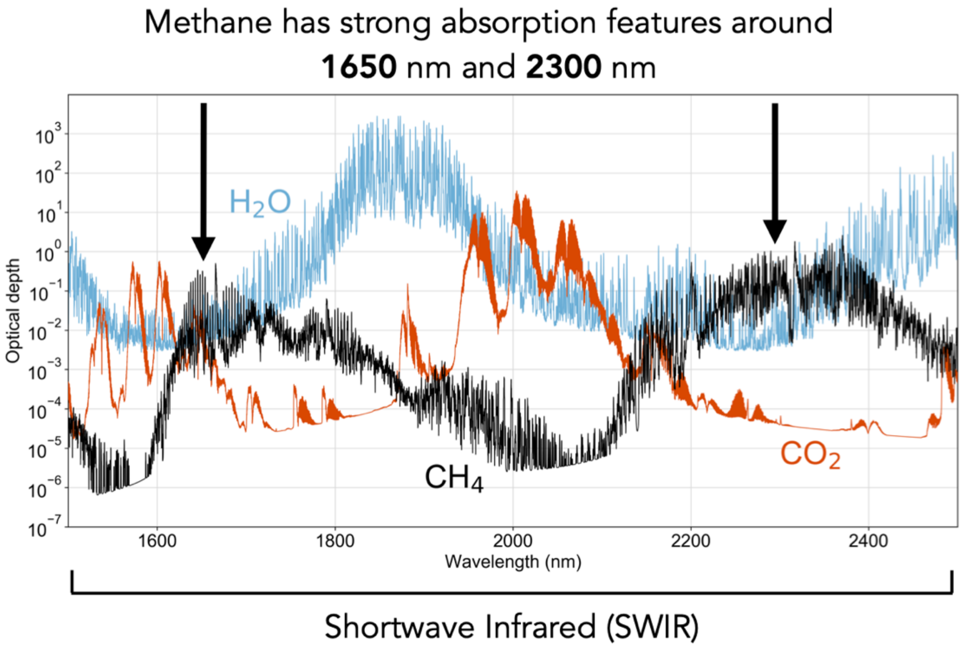
Because each molecule of methane is identical, each one absorbs wavelengths of light in the same way. But these interactions are different for different chemical compounds due to differences in the length, shape, and stiffness of their chemical bonds. Every compound thus has a highly specific pattern of stronger or weaker absorption of light at particular wavelengths. This pattern is called the molecule's absorption spectrum. Because these spectra are such uniquely identifying properties of specific molecules, they are sometimes called the molecule's spectral signature or spectral fingerprint.

RS instruments can identify how abundant specific molecules are in the atmosphere by seeing their spectral fingerprints in the mix of wavelengths scattered back to the instrument, using methods that we discuss further below.

3. Remote sensing of methane: How do RS instruments observe methane specifically?

Satellite instruments see methane in the atmosphere by taking advantage of its spectral fingerprint, in particular its strong absorption with light in two specific wavelength regions, or "bands," in the near-Infrared, around 1.65 and 2.3 microns, as shown in Figure 2 below.

Figure 2: *Methane IR absorption spectrum (in black), alongside that of water (blue) and carbon dioxide (red).*

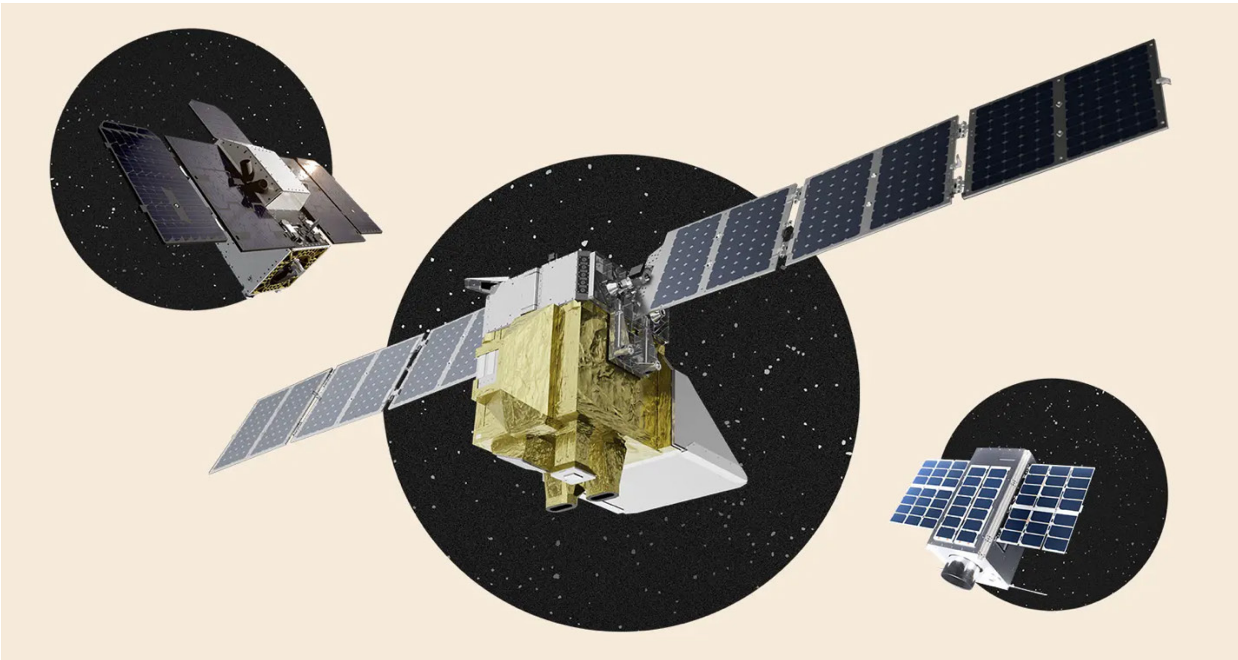


(Source: Varon et al. (2021))

As Figure 2 shows, methane's spectrum has two regions of strong absorption in the near-IR, around 1.65 and 2.3 microns. Although these are not the only wavelengths where methane absorbs light, they have the advantage of being relatively strong absorption regions for methane relative to absorption by other chemical compounds in the atmosphere. They are thus good places to look specifically for methane. All currently operational and planned RS methane instruments observe in one or both of these wavelength regions.

While RS instruments can be carried on various observation platforms, each with pluses and minuses for specific observational tasks, current excitement about methane observation is mainly driven by new instruments carried on satellites. There are more than a dozen satellite-based instruments in operation observing methane, including both instruments specifically designed to detect methane and multi-purpose instruments that have shown the capacity to do so. Two important methane-specific instruments were launched in 2024 and began to release data late that year, with several more scheduled or planned. Tables listing operating and planned methane satellite instruments are included in the Appendix.

It is now expected that satellite instruments will for the first time allow for practical global or near-global observation of atmospheric methane, at low cost, with rapid worldwide availability of data, and with consistent, high-quality measurements. Although every data source has strengths and weaknesses and other sources will remain important, this primer mainly covers satellite measurements on account of their potentially transformative impact on methane monitoring and control. The next section discusses four basic choices in designing a satellite methane instrument, how current and planned instruments have resolved them, and what they mean for the data produced and its uses.



Methane SAT, Carbon Mapper and GHG SAT

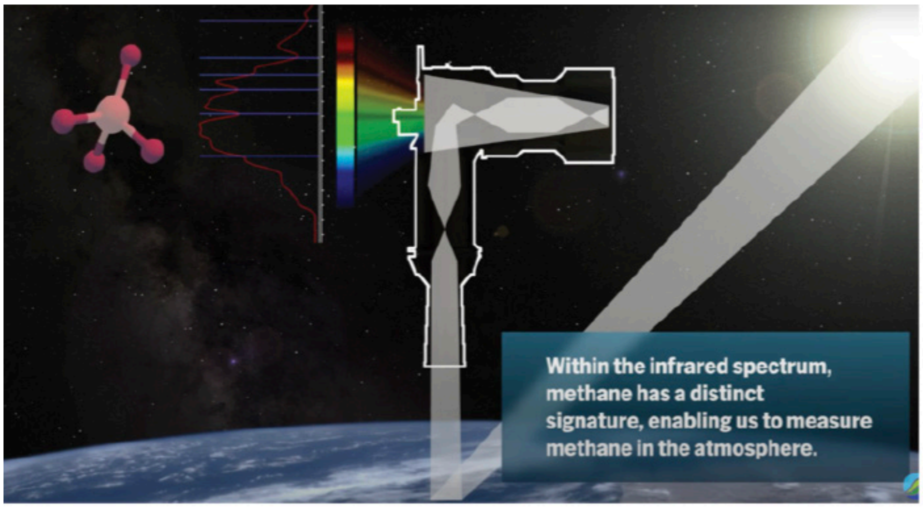


Figure 3: *Source EDF MethaneSAT*

4. Design of a methane RS instrument: Major design choices and their implications

Current and planned instruments reflect a range of choices on four basic design characteristics: passive versus active observation; spatial coverage and resolution; spectral coverage and resolution; and return time. Of these four characteristics, the first three are properties of the instrument itself, while the fourth depends on the orbit of the satellite carrying the instrument.

Active versus Passive Detection

RS instruments can be active or passive, meaning they can either carry their own light source to illuminate the target of observation, or can use light that originated in a different source. Whether an instrument observes actively or passively influences how well it can see under different conditions, and what information can be gathered about the target. While active observation has some advantages, all but one current and planned methane instruments are passive.

An active RS instrument shines light on the target to observe the light scattered back, like using a flashlight to illuminate objects in a dark room. Two well-known active RS methods are Radar, which reflects radio waves off target objects, and LiDAR (Light Detection and Ranging), which reflects a laser off a target to observe its distance, movement, or other characteristics. Only one proposed methane instrument will use an active sensor – MERLIN, a French-German LiDAR instrument planned to launch in 2027. Because LiDAR does not need sunlight, MERLIN will be able to see methane at night and in polar winter. It will also be less disrupted by atmospheric aerosols and fine clouds than instruments that rely on scattered sunlight. LiDAR is better suited for aircraft and ground-based use than on satellites, however, mainly due to satellites' tight limits on instrument mass, volume, and energy use.

A passive RS instrument does not have its own light source, but instead observes light that comes to it from the target. That light can be emitted by the target in a way that depends on its temperature, like the "thermal" infrared that night-vision goggles use to distinguish (warmer) people from their (cooler) surroundings in the dark. Or it can be light that was emitted by some other source, usually the sun, then scattered or reflected from the target to the instrument. Nearly all RS of atmospheric methane is passive, relying on sunlight scattered back from the target to the instrument.

Spatial Coverage and Resolution

An instrument's spatial coverage and resolution describe how large an area of the Earth's surface it can see at one time, and how fine the details it can distinguish within that area. These characteristics affect instruments' ability to detect sources of different sizes and emissions rates.

An instrument's spatial coverage, also called its swath or field of view, describes how much total surface area the instrument can see at one time. Spatial resolution, also called pixel size, describes the smallest areas within this field of view that the instrument observes separately and thus can distinguish. These two characteristics correspond to the total field of view and the pixel size in a digital camera – and in fact, a remote sensing instrument is just a special type of digital camera, albeit one that sees different light wavelengths than the camera on your mobile phone.

Area sources versus point sources

Many discussions of methane emissions distinguish between point sources and area sources. Although point sources aren't fully distinct from diffuse area sources – emissions sources vary widely in their size and how much they cluster together – a point source is often defined as a source with emissions of more than 10 kilograms per hour over an area smaller than 30 meters squared.

Satellite methane instruments reflect a range of choices on spatial coverage and resolution, by which instruments are often clustered into two broad classes: area flux mappers and point source imagers. As their names suggest, area flux mappers observe methane over larger areas, from regional up to global scale. They achieve this by having large fields of view and large, relatively coarse pixels within their field of view. A single pixel on an area flux mapper might have an edge length of 1 to 10 kilometers. Any variation smaller than this cannot be distinguished, but instead is averaged into a single observation of the whole pixel. Point source imagers, by contrast, have pixels with edge lengths of 60 meters to as small as 20 meters, in order to identify and quantify individual point sources. One instrument – MethaneSAT, launched in March 2024 but inoperational as of June 2025 – had spatial resolution intermediate between the point-source and the other area instruments, with pixels of about 100 by 400 meters. This mid-range resolution let MethaneSAT see both large point sources and clusters of multiple small sources within relatively small areas – kilometers to tens of kilometers square – typical of concentrated oil and gas production facilities, large coal mines, or large livestock operations.

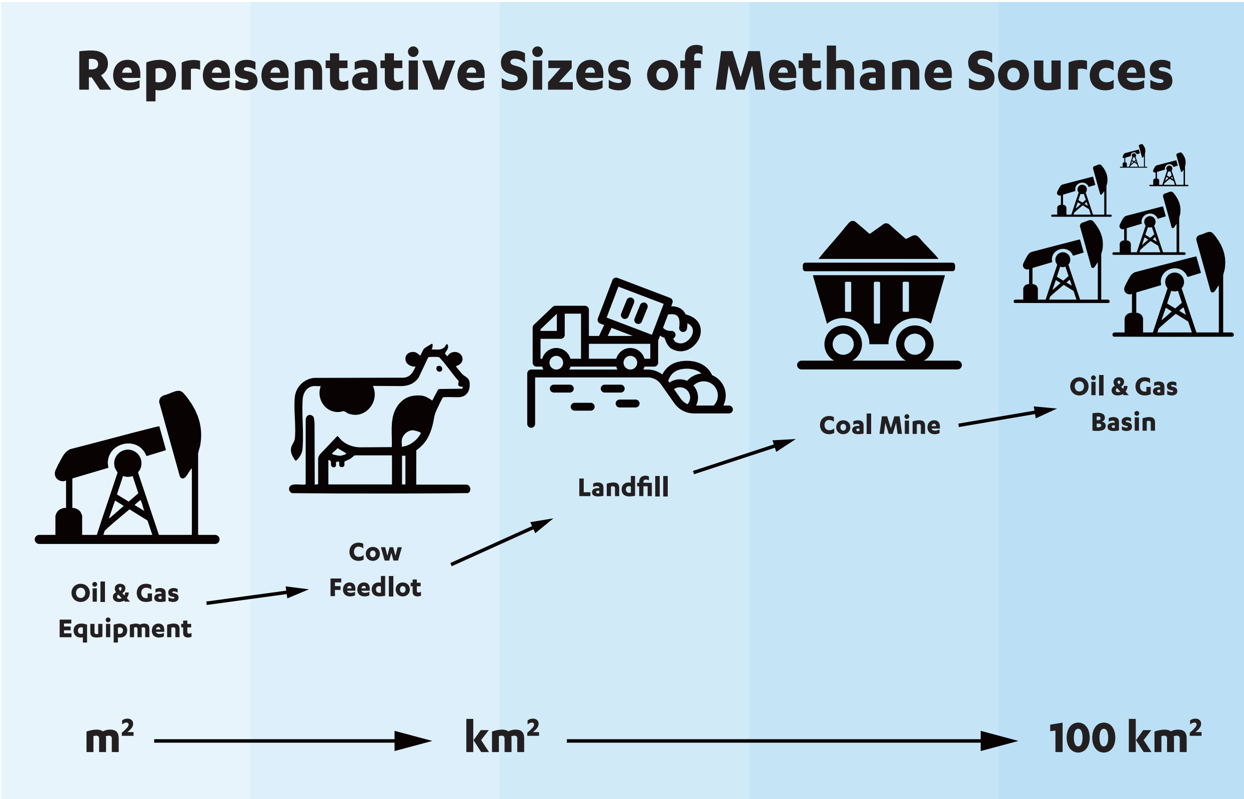


Figure 4: *Methane sources can vary widely in size. This diagram gives representative sizes of typical sources. Note that the scale is rough and imperfect: Some landfills are larger than some coal mines; some oil and gas basins are much smaller than others; etcetera.*

Instruments with finer and coarser spatial resolution are suited for different purposes. Point source imagers can support monitoring and control of individual sources, including by identifying leaks, accidents, or previously unidentified sources. They can thus help direct maintenance crews or enforcement authorities to respond to specific sources. Area flux mappers can observe total methane over relatively large areas, ranging from large livestock operations or oil and gas production basins to entire nations or regions. They can thus help to estimate organizational or jurisdictional emissions inventories, or detect the effects of policy or management changes, but have limited ability to distinguish between specific sources that are located close to each other.

An advantage of area flux mappers is that their observations have high precision, meaning that repeated observations of the same scene do not vary by much. They achieve this in part because many of the random factors that introduce error in measurements tend to average out over larger observed areas. Some area flux mappers claim precision of 1% or less, meaning repeated observations of the same scene would be expected to vary (have a standard deviation or RMS error) by less than 1% of the reported level of methane. The meaning and importance of observational precision is well understood in scientific research, as it gives an estimate of the uncertainty in any observation. For use of methane in regulatory and policy settings, the implications of greater or lesser precision, and the value of higher precision relative to other valued characteristics of emissions estimates, are thus far largely unexplored.

Spectral Coverage and Resolution

Spectral coverage and resolution describe what range of wavelengths an instrument can see, and how finely within that range it can distinguish different wavelengths from each other. These characteristics affect instruments' ability to distinguish methane from other atmospheric gases and the precision of their observations.

Spectral coverage and resolution correspond to spatial coverage and resolution, in that they describe how much the instrument can see and how finely it can distinguish details within what it sees. But these spectral concepts may seem less intuitive than their spatial counterparts, because they don't correspond to a feature of ordinary consumer cameras. A more intuitive analogy to help understand spectral coverage and resolution is human vision. Human vision has spectral coverage of 0.4 to 0.7 microns, the range of wavelengths human eyes can see, while its spectral resolution is the smallest difference in wavelength that people can distinguish as different colors.

To reliably distinguish methane from other atmospheric gases, fine spectral resolution is crucial. A close look at the picture of methane's absorption spectrum in Figure 2 shows the reason. As Figure 2 shows, methane has regions of strong absorption around 1.65 and 2.3 microns. But these are not single values, with total absorption at exactly these wavelengths and none at any other. Rather, they are regions of generally high absorption, with a lot of fine-scale variation at slightly different wavelengths and a large decline as you move toward more distant wavelengths. The precisely identifying spectral fingerprint of methane is found not just in the fact that it absorbs strongly in these two regions, but also in this fine-grained variation over slightly different wavelengths in these regions, similar to the way you can recognize a particular mountain range by local features in the height and shape of specific peaks, passes, and valleys.

This fine-scale variation in absorption at specific wavelengths is crucial because, while these two wavelength regions are good places to observe methane, they do not absolutely distinguish methane from other atmospheric gases. For example, CO_2 has an absorption band at 1.61 microns, just beside and overlapping with methane's 1.65-micron band, as Figure 2 shows. Observations that don't distinguish different wavelengths finely enough can thus confound methane with other compounds, just as a fingerprint that smudges nearby lines together can impair the ability to attribute the fingerprint to a particular person.

For current methane instruments, instrument engineering and satellite payload limits impose a tradeoff between spatial and spectral resolution. The point-source imagers with fine spatial resolution (pixels of 10s of meters or smaller) thus have relatively coarse spectral resolution (~ 10 – 200 nm), while the area flux mappers with kilometer-scale pixels achieve spectral resolution of less than 1 nm. One consequence of this is that instruments that perform the best at seeing very small methane sources are not optimized for precisely distinguishing methane from other molecules, and vice versa.

Spectral resolution is one characteristic that distinguishes instruments designed specifically to observe methane from others that can detect methane but were designed for other purposes. This latter group includes several general-purpose instruments that observe multiple wavelength bands, called "multispectral" or "hyperspectral" instruments. Multispectral instruments typically observe 3 to 10 discrete wavelengths with spectral resolution of ~ 0.1 microns (100 nm), while hyperspectral instruments observe hundreds of different wavelengths within a continuous spectral range, with spectral resolution ~ 0.01 microns (10 nm). These multi-purpose instruments can detect methane because their spectral coverage includes wavelengths where methane absorbs strongly, but they are not optimized specifically for methane. For example, EMIT and Landsat-8 are instruments that were primarily designed for other purposes – EMIT to study desert dust, Landsat for images of land surface. These instruments can observe methane because their broad spectral coverage includes regions of strong methane absorption, but they tend to do so with lower precision and a higher observation threshold than specialized methane sensors.

Return Time and Orbital Path

Methane instruments observe places on the Earth's surface directly below them as they pass over, viewing larger or smaller places at each moment depending on the instrument's field of view. The specific places an instrument sees, and how often it returns to observe the same place, are determined by its satellite's orbit. Except for small adjustments, a satellite's orbital geometry is fixed when it is launched.

Orbits are described by their altitude, with higher orbits circling the Earth more slowly, and by their angle relative to the Earth's equator. Most satellites are in low-Earth orbit, at altitudes of a few hundred kilometers, where they complete an orbit of the earth in a couple of hours. Most methane instruments are in low-Earth polar orbits, which are oriented North to South and pass over the North and South poles on each circuit. Polar orbits are favored for many earth-science and environmental applications because they can observe the Earth at all latitudes. Even in polar orbit, whether and how often an instrument will see every place on Earth depends on how its orbit moves in the East-West direction on each successive pass.

The polar orbits of methane instruments are sun-synchronous, meaning their path moves eastward on each orbit just as much as the Earth has rotated in that time, so the instrument passes over every location at the same time each day. Small differences in this orbital movement, along with how wide an East-West view the instrument sees, determine the time between its successive views of the same place, or its return time.

An instrument's return time determines its ability to interpret individual readings and estimate trends. More frequent returns allow more accurate estimation of methane trends and assessment of the effectiveness of actions to cut emissions. A shorter return time also helps in determining whether a single high reading is an error, an anomalous event (such as a brief release due to maintenance), or an indication of sustained high emissions. Current and planned systems have return times ranging from about one day to one week.

A few instruments – including Carbon Mapper and GHGSat – are able to point away from the nadir (straight-down) direction, and thus overcome some limitations related to their spatial coverage and orbital path. Pointing side to side can enable them to see point sources not directly under their orbital path, and thus view sites of interest more frequently. Pointing forward or backward along their direction of travel can enable them to focus on a source for a longer time as they pass over, and thus improve their precision and detection threshold.

There is one instrument not in low-earth polar orbit that reports methane observations, and others have been proposed. The EMIT instrument is carried on the International Space Station in an inclined orbit ranging between about 50 degrees North and South, with a return time over that area of about 3 days. Other methane instruments have been proposed for satellites in geostationary orbit. Geostationary orbits are located over the Equator, at such high altitude that completing one orbit takes 24 hours. Viewed from Earth, a satellite in geostationary orbit appears to be standing still over one location, allowing communications equipment to be permanently aimed at that location. This characteristic makes geostationary orbit locations so valuable that they are allocated to equatorial countries by international agreement. A methane instrument in geostationary orbit would always see the same longitude slice, with its view extending as far North and South of the Equator in that region as its spatial field of view and ability to point allowed.

5. From instrument data to useful information: Generating emissions estimates

Most practical applications of methane observations – for policy or regulation, management, or other purposes – require estimates of emissions, defined over some relevant scale of space and time. Satellite instruments do not provide these directly. Generating emissions estimates from instrument data requires two computational steps, each of which may incorporate additional sources of information and can introduce new sources of uncertainty.

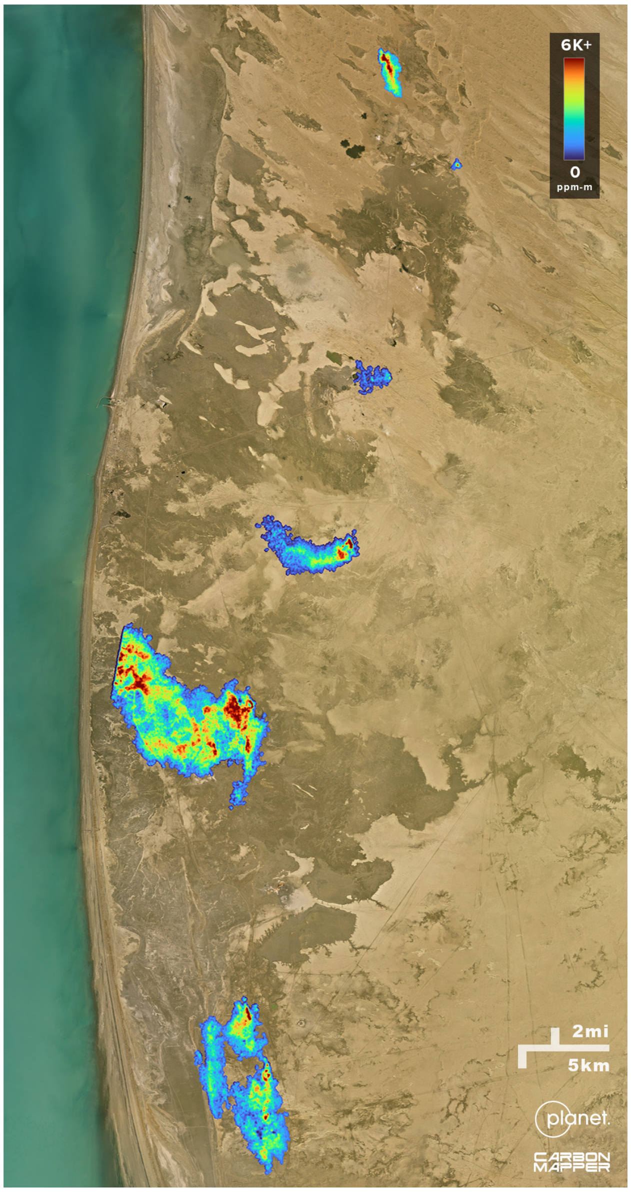
What instruments actually measure is the brightness (or "radiance") of light reaching the instrument at specific wavelengths (determined by the instrument's spectral scope and resolution), at specific pixels at known locations (determined by the instrument's spatial scope and resolution), at specific times. From these measurements of wavelength-specific radiance, the first computational step toward making the data useful involves calculating how much methane is in the atmospheric column between the instrument and the Earth's surface. This can be expressed as the total number of methane molecules in that column of air (column abundance), or as the fraction of methane in that air column. The latter form – methane fraction or average concentration – is easier to understand and use, because it does not vary with land elevation, air pressure, or humidity.

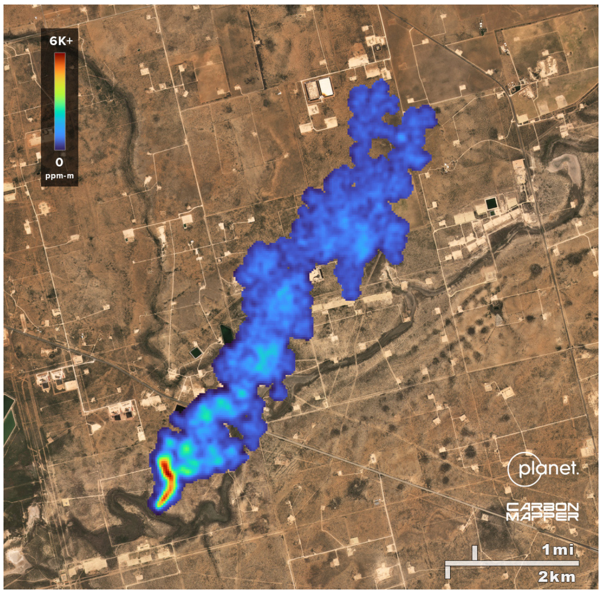
This calculation depends on knowing how radiation of different wavelengths is absorbed and re-emitted by all the gases in the vertical column of air the instrument is observing. These processes are represented by quantitative "radiative-transfer models." In their normal use, radiative-transfer models take as inputs how much of each gas is present at each height in the atmosphere and calculate the resultant radiation. For example, if you already knew how much methane was present at every altitude below the instrument, you could use a radiative-transfer model to calculate what brightness the instrument should see at each wavelength it observes.

In this case, however, we don't know how much methane is present in the atmosphere but instead must calculate it from the observed radiation. This calculation, reversing the model's outputs and inputs, effectively runs the model backwards in a process called inverting the model or retrieving the column methane. There are a few different ways to do this retrieval, each with distinct strengths and weaknesses, but they all use statistical estimations whose success depends on observational conditions in the atmosphere. Retrievals tend to do best in dry areas with clear skies, and more often fail when the atmosphere is hazy or cloudy or the surface is complex or too dark.

Turning the map of column methane produced by this retrieval process into an estimate of methane emissions from particular sources requires a second computational step. Different methods are used in this step depending whether the aim is to estimate emissions over extended areas with many sources, or to detect, locate, and quantify concentrated point sources.

For larger areas, from tens of kilometers square to continental or global scales, the aim is usually to quantify average emissions and trends over periods from weeks to years. These estimates can be used to attribute emissions to area sources, to make or check jurisdictional emissions inventories, or to measure trends to assess effectiveness of emissions-control measures. Since area source emissions are more consistent over time than leaks or point sources, estimates for these larger areas can be based on many repeated observations. Using multiple observations improves the precision of estimates, as random errors in each individual measurement tend to average out. It also lets you fill in locations that are missing in a single overpass due to clouds or other factors that cause the column retrieval calculations to fail.





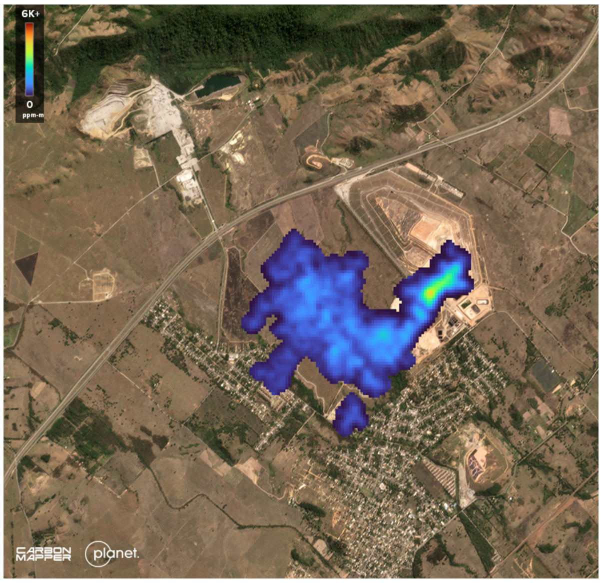


Figure 5, LEFT: *Thanks in part to satellite observations, Turkmenistan has deepened their methane reduction efforts over the past few years, joining the Global MethanePledge in 2023. Observations like these can help them further refine their programs and policies to tackle methane in the oil and gas sector. Tanager-1observed this coastal region of Turkmenistan with a single image on Nov. 11, 2024. Carbon Mapper's preliminary emissions estimate of these plumes is approximately 57 tons of methane per hour.*

Figure 6, TOP: *A large methane plume leaking from an oil and gas pipeline was detected by Carbon Mapper in the Texas Permian Basin using data from Tanager-1 on Oct. 9, 2024.*

Figure 7, BOTTOM: *Carbon Mapper methane detections from Planet's Tanager-1 satellite show a large plume of methane from the Seropédica landfill in Rio de Janeiro, Brazil, on Sept. 29, 2024. Carbon Mapper's estimated preliminary emissions rate is 2,836 kilograms per hour.*

As with the prior step of calculating column methane from radiation measurements, going from column methane to area emissions estimates requires calculations based on models. Here, the models are atmospheric transport and chemistry models, which calculate the concentration of atmospheric gases over space and time as they move, mix, and interact chemically after specified patterns of emissions. Like the previous step, this calculation requires inverting the model via statistical estimation processes, to calculate the pattern of emissions most likely to have led to the observed pattern of column concentrations.

Data Levels, Availability, and Uses

The various forms of data available from methane instruments are often labeled by a set of numerical levels, ranging from Level 1 data to Level 4 data.

These refer to general data standards established by NASA in the 1990s to organize the rapidly expanding amount and diversity of data coming from the first generation of earth-observation satellites then being launched. Different levels denote different levels of processing and calculation, with higher levels being more processed to produce quantities useful for management, policy-making, or other practical applications.

In this system, Level 1 data are direct instrument observations, with only minimal processing to map each observation to a precise time and place and add information about instrument performance and calibration. For most instruments, Level 1 data is some measure of brightness, or radiance, at each wavelength that the instrument sees. Level 1 data are not directly useful for policy or other applications, nor are they often useful for scientific research without further processing.

Level 2 data describe some meaningful physical quantity that can be calculated from the Level 1 instrument observations, often some property of the land surface, vegetation, or atmosphere. For methane, Level 2 data describe the total methane in the atmospheric column between the instrument and the surface, at the same spatial scale and resolution as the original instrument observations.

Additional processing then translates these Level 2 data to a uniform spatial and time scale so data from instruments with different resolution can be compared or aggregated (Level 3), then does further calculation – often including additional data from other observations or models – to generate data in forms directly useful for specific applications (Level 4). For methane, Level 4 data are calculated emissions rates, at time and spatial scales ranging from individual point sources to large regions or jurisdictions. Of the various data levels, Level 4 data thus embody the most extensive processing and are the most directly useful for policy or other applications.

For point sources, calculations of emissions estimates rely on the fact that large point sources have a plume, a clear trail of elevated concentrations around or downwind from the source as the air is moved by wind or mixed by turbulence. Instruments with fine spatial resolution can detect plumes if the increased concentration within the plume is large enough relative to the instrument's sensitivity. When a plume is detected, it is possible to estimate the emissions rate even from just one satellite pass, using various methods that map the size and shape of the plume, or observe changes in concentration between nearby pixels. These methods are highly sensitive to wind, which can be observed separately or estimated from characteristics of the plume itself and is a major source of uncertainty. Quantitative emissions estimates are typically more uncertain for point sources than for area sources, but for some purposes – such as enabling timely response to leaks, accidents, and unexpected or unauthorized emissions – simply identifying and locating sources may be higher priority than creating precise estimates of emissions rates.

6. Measuring performance of instruments and systems

Just as methods to calculate estimates of emissions differ between point sources and larger areas, so too do ways to measure and compare instrument performance. For large areas, where emissions estimates are generated by making repeated observations, performance can be measured by how long it takes to detect a specified emissions rate over a given area. Detecting emissions is more difficult, and thus takes longer, if the area of measurement is small and emissions rates are low and variable over time. It these conditions are held fixed, the time needed to detect the emissions – the measure of instrument performance – depends on the combined effects of several instrument characteristics, including its precision, spatial resolution, return time, and rate of successful retrieval of column methane.

For example, for an emissions rate of 5 kilograms per square kilometer per hour over a 10-kilometer square – a pattern typical of a large livestock feeding area (CAFO) – the time needed to detect these with current area flux mappers varies from a few weeks to about one year. For more diffuse emissions over larger areas – e.g., a rate of 0.5 kilograms per square kilometer per hour over a 100-kilometer square, typical of a major oil and gas production basin – the time to detect these ranges from a few days to a few weeks. (In this second example the larger area makes detection easier, more than offsetting the lower emissions density.)

For point sources, there is more priority on detecting, locating, and quantifying emissions sources rapidly. For these, instrument performance is measured by the ability to precisely locate sources, particularly when multiple sources are located near each other; and by the detection threshold, the lowest emissions rate that can be detected in a single satellite overpass. The difficulty of detecting a point source, and thus any instrument's detection threshold, depends on the clarity of sky conditions, the nearby land surface, and the wind speed. Detection is easier with clear skies, over a bright uniform surface, with consistent winds of around 2 to 5 meters per second. These moderate winds are easiest because calm conditions can produce complex, folded-over plumes that hinder quantitative emissions estimates, while strong winds can dilute plumes so quickly that they make it hard to see point sources at all. For given conditions, an instrument's detection threshold improves with its precision and its spatial and spectral resolution, with some instruments improving their threshold by adjusting their viewing angle to point toward a source and focus on it for longer as they pass over.

There are many estimates of specific instruments' detection thresholds, but these are not fully comparable because they are based on a wide range of viewing conditions and there are still relatively few controlled intercomparisons.[8] Absent such precise comparative measurements of detection thresholds, current and planned point-source instruments can instead be roughly grouped in broad categories, as follows:

- Detection thresholds of about 100 kg/hour (CarbonMapper, GHGSat, and Worldview-3).
- Detection thresholds of about 500 kg/hour (EMIT, PRISMA, and EnMAP).
- Detection thresholds of about 1 to 10 tons/hour (Sentinel-2 and Landsat).

The 100-kilogram per hour detection threshold of the most sensitive satellite instruments should be able to detect between 75 and 99 percent of total point-source emissions worldwide. This represents a large advance over the first satellite area-source mapper to provide global daily coverage, TROPOMI, which can only detect point sources above about 25 tons/hour, larger than the largest landfills (about 20 tons/hour) and about half the peak emissions rate from the peak emissions rate of the 2015 Aliso Canyon gas reservoir failure in California (50 tons/hour). Aircraft-borne instruments can detect much smaller sources, as low as about 10 kg/hour, because they observe sources from much closer than satellite instruments, but these of course require special missions with limited spatial coverage.

7. Current and projected advances

The basics of methane remote sensing that we discuss in this note – e.g., the design of instruments, the principles on which they operate, and the methods available to calculate emissions from their observations – do not change fast. But the specifics of currently operating instruments, their capabilities, and the quantity, quality, and terms of availability of data from them – are changing rapidly. Consequently, we can only provide a snapshot of the current state of affairs and plans as they stand in 2025.

Major advances in methane observations have been reported in scientific papers over the past ten years. These have drawn on data from several satellite instruments, notably the TROPOMI instrument since its 2018 launch, often combined with other instruments or data sources. These advances, however, have mostly required costly, specifically targeted campaigns. They have demonstrated capabilities and drawn attention to overlooked emissions sources, but until recently have not provided a clear path toward general, practically usable capability. This situation is now being transformed by fundamental advances in the comprehensiveness, quality, and usability of satellite-based methane data.
Two long-anticipated methane satellite instruments, MethaneSAT and Carbon Mapper, launched

8 Růžička, V.; Mateo-Garcia, G.; Gómez-Chova, L.; et al. Semantic Segmentation of Methane Plumes with Hyperspectral Machine Learning Models. *Sci. Rep.* **2023**, *13*, 19999. https://doi.org/10.1038/s41598-023-44918-6.

in 2024 and released their first images and emissions estimates in November 2024. By combining an intermediate, hundred-meter spatial resolution with a wide field of view and high sensitivity, **MethaneSAT** targeted emissions from the oil and gas sector, aiming to capture both high-emitting point sources and smaller sources spread over a wide area. But MethaneSAT unexpectedly lost communication with its operators in June 2025 and is not expected to be revived. The reasons for its loss are still being investigated. The data MethaneSAT collected and transmitted during its time in operation will continue to be analyzed and released over the months to come.

Carbon Mapper's data portal, which integrates observations from satellites and aircraft, provides data on methane plumes and emissions, free to non-commercial users, after a 30-day delay as specified by their agreement with Planet. Several other methane instruments are planned, including additional satellites in existing constellations and new independent efforts, including the first active methane sensor, the Merlin LiDAR instrument, planned for 2027 launch.

In addition to new instruments, there are also continuing advances in systems to generate emissions estimates from satellite observations quickly, reliably, and cheaply; and to make the resultant data available in forms that can be used, understood, and trusted by policy-makers and other relevant decision-makers.[9]

These include the following:

- The "**Integrated Methane Inversion**" (IMI) system, a cloud-based tool developed by Harvard researchers to let users calculate estimated emissions from TROPOMI data for any region and time period of interest.

- UNEP's **International Methane Emissions Observatory** (IMEO), which provides methane point-source data from multiple satellites and other sources that make the data publicly available. IMEO is linked to UNEP's Methane Alert and Response System (MARS), which notifies governments of large methane point-source detections.

- "**Methane Watch**," a portal provided by the environmental information and analysis company Kayrros, which integrates publicly available methane satellite data with related commercial and energy data and its internally developed estimation algorithms.

- "**WasteMAP**," or the Waste Methane Assessment Platform, created by civil society organizations RMI and the Clean Air Task Force to improve waste methane emissions transparency, and to highlight mitigation opportunities and best practices to reduce solid waste methane emissions. The portal consolidates modeled and reported waste data and methane emissions data from Carbon Mapper, Climate TRACE, EDGAR, RMI, SRON, UNFCCC, UN-Habitat, and the World Bank.

9 Růžička, V., Mateo-Garcia, G., Gómez-Chova, L. et al. Semantic segmentation of methane plumes with hyperspectral machine learning models. Sci Rep 13, 19999 (2023). https://doi.org/10.1038/s41598-023-44918-6

8. Conclusions: Advantages, limitations, and uses of RS atmospheric methane data

Although application of satellite methane observations is still in early stages, their potentially transformative effect on the ability to manage and control methane emissions is already evident. The new data make it possible to locate and quantify emissions that were previously invisible without costly field campaigns. They are moving toward near-global, near-continuous estimates of emissions at scales from individual point sources to the world, in some cases with commitments to free, timely, widely available data. Parallel advances are building the ability to integrate, disseminate, and interpret methane data from multiple instruments and platforms.

At same time, the new data come with certain challenges to their usability, accessibility, or acceptability in certain policy and legal applications. Some of these challenges are technical, related to the instruments and how they work; while some are socio-political, related to how and by whom the data are collected and used. These limits do not weaken the expectation that the new data represent a transformative advance in the ability to manage methane, but they do suggest challenges in some applications and highlight the need for policy actors to understand the data and their origins.

Potential challenges include:

- Limited and uncertain spatial coverage. Quality of measurements depends on surface, weather, and sun-angle conditions. Measurements cannot be made at night or in polar winter, and can fail due to clouds or surfaces that are too bright (ice and snow) or too dark (water, except with special viewing techniques). These conditions introduce consistent regional and seasonal limits to reliable observations.

- Intermittency of observations, and related challenges of consistently integrating diverse data sources to reduce intermittency;

- Data availability, timeliness, and cost, as well as policy-makers' capacity to utilize it;

- Policy-makers' willingness to rely on and respond to data produced by diverse entities (national governments, IGOs, non-profits, private firms) based in multiple jurisdictions;

- Industry cooperation and engagement in developing, interpreting, and responding to new data; and

- Reliability of continued availability of data and terms of access.

Present discussions of the new data stress two types of uses, both clearly in line with current and projected capabilities.

- Rapid precise identification of large or unexpected point sources, to inform the responsible parties, legal and regulatory authorities, or other potentially concerned actors such as government bodies, commercial or financial parties, or community and civil-society groups;

- Improving jurisdictional emissions inventories through well validated measures of area emissions.

Additional uses are possible, including incorporating observations at intermediate scale, between individual point sources and entire jurisdictions, into the design and implementation of regulations within jurisdictions. Rapidly expanding capabilities, both via additional satellite instruments and advancing integration of data from diverse sources, may enable development of new approaches to policy and regulation, support stronger implementation and enforcement of existing approaches, or simply help to identify control priorities and provide feedback on results.

Appendix

Table 1 – Currently operational methane observing satellites

Note: List is not exhaustive. Satellite missions that have been previously retired are not included. MethaneSAT is included but, as discussed in section 7 of this report, is no longer operational after an unexpected failure.

SATELLITE AND/OR INSTRUMENT NAME	OPERATOR	LAUNCH DATE	DESCRIPTION
Government satellites			
GOSAT, GOSAT-2, GOSAT-GW ("Greenhouse Gases Observing Satellite")	Japanese Aerospace Exploration Agency (JAXA)	2009, 2018, Planned launch in 2025[9]	Measures CO_2 and methane
Landsat 8 and 9	US Geological Survey & the National Aeronautics and Space Administration (NASA)	2013	Primarily focused on land use and land cover changes; also provides data related to methane emissions
Sentinel-2A, 2B, 2C	European Space Agency (ESA)	2015, 2017, 2024	Primarily provides high-resolution imagery for land and vegetation monitoring but can detect methane through specific analyses
Sentinel-5P, TROPOMI ("Tropospheric Monitoring Instrument")	European Space Agency (ESA)	2017	Monitors methane with the TROPOMI instrument; part of the Copernicus program
Gaofen 5 and 5-02	China National Space Administration (CNSA)	2018, 2021	Contains multiple instruments for environmental monitoring
Ziyuan-1 02D and 02E	China National Space Administration (CNSA)	2019, 2021	Used primarily to study natural resources
PRISMA ("Precursore Iperspettrale della Missione Applicativa")	Italian Space Agency (ASI)	2019	Provides detailed observations of Earth's surface, including the ability to detect methane
EMIT ("Earth Surface Mineral Dust Source Investigation")	National Aeronautics and Space Administration (NASA)	2022	Designed to study mineral dust but also measures methane; sits aboard the International Space Station
EnMAP ("Environmental Mapping and Analysis Program")	German Aerospace Center (DLR)	2022	Measures both terrestrial and aquatic ecosystems

SATELLITE AND/OR INSTRUMENT NAME	OPERATOR	LAUNCH DATE	DESCRIPTION
Public and public-private satellites			
MethaneSAT	Environmental Defense Fund (EDF)	2024	Designed to observe methane emissions over wide areas, especially of oil and gas production regions; developed by a subsidiary of the non-profit Environmental Defense Fund
Carbon Mapper's Tanager-1	Carbon Mapper, NASA's Jet Propulsion Lab, & Planet Labs	2024	Measures greenhouse gas point-source emissions on a global scale; part of a broader effort by the nonprofit Carbon Mapper
Private satellites			
Worldview-3	Maxar	2014	Provides high-resolution imagery
GHGSat	GHGSat Inc.	2016, with many subsequent launches	Detects methane from industrial facilities worldwide; Canadian company
GHOSt ("Global Hyperspectral Observation Satellite")	Orbital Sidekick	2023, with subsequent launches	Produces high-resolution commercial imagery

Source for Table 1: *Table reproduced with permission from Shukla et al., "Hunting Methane Using Satellites: A Guide for Policymakers" (UCLA Emmett Institute and UC Berkeley Center for Law, Energy, & the Environment, April 2025).*

Appendix

Table 2 – Instrument specifications

Government satellites

Satellite and/or Instrument Name	Temporal Resolution – Return Time (days)	Spatial Resolution – Pixel Size (m)	Spectral Resolution (nm)	Methane bands covered (microns)	Coverage	Point-Source Detection Threshold Approximate (KG CH_4/HR)
GOSAT	3	10,000 x 10,000	0.06	1.65, 2.3	Global	n/a
Landsat 8	16	30 x 30	200	2.3	Global	1500
Sentinel-2	2.5	20 x 20	200	2.3	Global	1500
Sentinel-5P, TROPOMI ("Tropospheric Monitoring Instrument")	1	5500 x 7000	0.25	2.3	Global	10000
Gaofen 5 GMI-II	51	10,500 x 10,500	0.27	1.65	Global	1500
Ziyuan-1 02D and 02E Advanced Hyperspectral Imagers (AHSI)	17	30 x 30	10	1.65, 2.3	Targeted	1500
PRISMA ("Precursore Iperspettrale della Missione Applicativa")	4	30 x 30	10	2.3	30 x 30 km^2 targets	500-1000
EMIT ("Earth Surface Mineral Dust Source Investigation")	3	60 x 60	9	2.3	Dust-emitting regions	500-1000
EnMAP ("Environmental Mapping and Analysis Program")	4	30 x 30	10	2.3	30 x 30 km^2 targets	500-1000

Public and public-private satellites

Satellite and/ or Instrument Name	Temporal Resolution – Return Time (days)	Spatial Resolution – Pixel Size (m)	Spectral Resolution (nm)	Methane bands covered (microns)	Coverage	Point-Source Detection Threshold Approximate (KG CH_4/HR)
MethaneSAT (no longer operational)	3-4	100 x 400	0.3	1.65	200 x 200 km^2 targets	10000
Carbon Mapper's Tanager-1	Typically 1-7 days (taskable)	~ 30 X 30	~ 5.5	2.3 (primary retrieval window; instrument spans 0.4-2.5 μm and 1.65 μm)	~ 18 km swath (taskable scenes; no fixed target size)	100

Private satellites

Satellite and/ or Instrument Name	Temporal Resolution – Return Time (days)	Spatial Resolution – Pixel Size (m)	Spectral Resolution (nm)	Methane bands covered (microns)	Coverage	Point-Source Detection Threshold Approximate (KG CH_4/HR)
WorldView-3	<1	3.7 x 3.7	50	2.3	66.5 x 112 km^2 targets	100
GHGSat	1-7	25 x 25	0.3	1.65	12 x 12 km^2 targets	100
GHOSt ("Global Hyperspectral Observation Satellite")	1	8 x 8	unknown	unknown	Targeted observations – revisit time depends on tasking, not continuous global coverage	unknown

Appendix

Table 3 - Planned methane observing satellites

Satellite / Instrument and Operator	**Expected Launch** Date/Year	**Notes**
GOSAT-GW (JAXA, ESA)	2025	Will employ a different spectroscopy method than previous GOSAT satellites, allowing for observations over a whole area rather than grid-like observations. Using two modes, a focus and wide observation mode, the satellite will be able to combine a wider detection step with more targeted area observations. This will advance detection of large point sources. Will focus on Japanese cities.
Sentinel-5 (ESA)	2025 *or later*	Will extend the capabilities of Sentinel-5P by enhancing spectral coverage and instrument sensitivity. While its spatial resolution is not as fine as that of GHGSat or Carbon Mapper—and thus is less well adapted for smaller, fainter sources—it offers daily global revisit time, making it well-suited to detect super emitters and large, intermittent emissions. Its enhanced spectral resolution, with two SWIR bands (1.6 and 2.3 μm), improves upon the single-band coverage of Sentinel-5P, allowing strong, localized methane plumes to stand out more clearly against background gases.
CO2M (ESA)	2026	Will comprise three satellites designed to distinguish anthropogenic methane emissions from natural sources. This advance will be achieved by striking a balance between spatial resolution fine enough to detect individual industrial sources and a wide enough swath for national-level emission mapping. The satellites integrate advanced gas and aerosol correction technology not seen together in earlier missions.

Satellite / Instrument and Operator	**Expected Launch** Date/Year	**Notes**
MERLIN (CNES/DLR)	TBD (roughly 2028)	Will be the first methane LiDAR satellite, allowing it to detect large methane sources at night and during polar winters. Will be less affected by aerosols and thin clouds than passive sensors, improving detection over challenging environments like offshore oil and gas facilities, estuaries, and reservoirs.
Carbon-I (NASA)	2030/2032	Will address major methane data gaps in the humid tropics, where persistent cloud cover has led to data yields that are 2–3 orders of magnitude lower than in other regions. Will combine global land coverage with very high spatial resolution (30–300 m), enabling the detection of both broad regional methane emissions and individual point sources. Unlike most current missions, which are optimized for either regional mapping or point-source detection, Carbon-I is designed to do both, using high spectral resolution to distinguish methane from other gases and minimize interference from surface and atmospheric conditions.
SBG-VSWIR (NASA) CHIME (ESA)	TBD (2030+) 2028–2030	SBG-VSWIR (NASA) and CHIME (ESA) are complementary hyperspectral imaging missions planned for the late 2020s/early 2030s, with overlapping global coverage and revisit cycles that together may offer 8-day revisit time over most land areas. While some current methane-observing satellites have faster return times, SBG and CHIME are distinct in combining high spectral resolution across a wide range of visible to shortwave infrared wavelengths with broader land monitoring objectives (e.g., vegetation, geology, and soil), enabling frequent, context-rich methane plume detection.

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