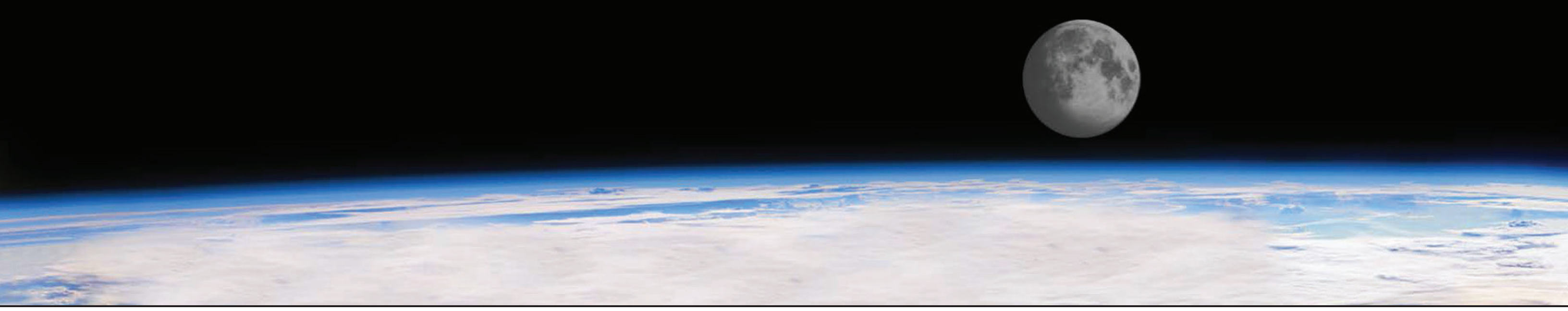

March 2017

Center for Space Policy and Strategy
Policy Paper

Global Satellite Data for Local Environmental Monitoring: Challenges and Opportunities

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Foreword

In just a few years, the European Space Agency will launch the Sentinel-5 satellite to monitor atmospheric gases such as methane and carbon dioxide. The mission will broadly and strongly influence greenhouse gas detection and potential mitigation. The United States can optimize its use of low-resolution Sentinel-5 data by augmenting it with high-resolution air and surface monitoring and in situ data collection. Absent such efforts, the United States will have difficulty integrating Sentinel-5 data effectively into policy and regulation. This paper outlines an approach to validating and applying environmental data from Sentinel-5.

Background and Impetus

On June 25, 2013, the United States issued its broad-based Climate Action Plan, which sought to cut domestic greenhouse gas emissions, prepare the United States for the impacts of climate change, and ensure American leadership in international efforts to combat global climate change.

Methane is a potent greenhouse gas[1] whose atmospheric concentrations are rising and whose mitigation offers potentially greater return on investment than carbon dioxide.[2] In January 2015, the White House announced plans to reduce methane emissions from the oil and gas sector by 40–50% from 2012 levels by 2025.[3] Consequently, in August of that year, the Environmental Protection Agency proposed regulations[4] for lowering methane emissions from oil and gas production and distribution.

These objectives present an important challenge: How best to monitor the nation's progress (and that of other nations) toward methane reduction? This is a daunting task for nonorbital approaches; despite significant investment, the NOAA network remains sparse even in the United States,[5] while airborne and other campaigns provide only a snapshot of a highly dynamic industry.

One solution would be to leverage the European Space Agency's Sentinel-5 mission, part of the "Copernicus"[6] Earth observation program, scheduled to launch in 2021. The Sentinel-5 mission[7] is dedicated to methane and air-quality monitoring using passive optical spectroscopy. The spectrometer will fly aboard the MetOp[8] Second Generation weather satellites. The mission aims to continuously monitor Earth's atmospheric composition with global coverage as part of the overall GEOSS program.[9] Resolution is approximately 7 kilometers. Although the system is focused on European needs, there are opportunities to broaden its scope to include international partners and address global challenges.

Data from Sentinel-5 and -5P (the precursor satellite) could help U.S. planners prioritize regions and industrial processes needing further survey and study—but a number of steps must be taken first. These satellites will provide a temporal record of large-scale emissions, providing an excellent basis for the Climate Action Plan, but they will miss the finer detail needed for action at the local level. Such information could be acquired by fusing satellite data with local air and surface sampling and optical imaging. This broader dataset could be used to:

- improve the local and national greenhouse gas inventories that form the basis for regulation;
- monitor the progress of the Climate Action Plan;
- support enforcement of the Clean Air Act (which often relies on facility self-reporting);

- encourage compliance at (and even beyond) regulatory levels; and
- improve the global greenhouse gas inventories used for treaty validation.[10]

Trust, but Validate

The Sentinel-5 mission will strongly influence scientific understanding of atmospheric gases while providing a globally accessible tool to industry, decisionmakers, and the public; but before relying on this resource to make real-world decisions, policymakers would do well to ask: *how valid are the data for North America and other countries*? Sentinel-5 algorithms will be optimized for Europe; however, weather patterns and other atmospheric characteristics spanning vast segments of North America are highly distinct. Thus, validation and algorithm improvements are a critical step before reaping the benefits from the satellite's data collection and dissemination.

Accurate methane inventories can have a profound impact on existing and future regulations and specific industries. Measurements must be "defensible" to foster broad acceptance of regulation and implementation of effective mitigation strategies. Sentinel-5 data can be validated using airborne and ground-based measurements at select locations. In particular, the validation effort would need to address emissions derived from gas plume "maps" (including specific compounds), emission source locations, dispersion characteristics (correcting for complex winds), and atmospheric vertical and horizontal variations.

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Such an effort would provide the confidence needed to facilitate effective adaptation of new satellite tools for application in North America and across the globe. These tools could be used to identify U.S. methane hotspots for future studies and mitigation strategy assessment; characterize methane emission variations by industry, sector, region, and season; and identify areas for improvement in EPA's methane inventory and possible shortcomings in the underlying assumptions.

Best Available Technology

One successful example of this can be found in a NASA-supported campaign in 2015 that fused imaging spectroscopy with mobile surface and airborne data to estimate methane flux directly over Southern California. The GOSAT-COMEX Experiment[11] combined data from the COMEX[12] sensors, which measured carbon dioxide and methane from airplanes flying at low and high altitudes and cars on the ground, and the Japanese GOSAT satellite, which measured these concentrations from space. The COMEX campaign validated models of methane emissions from dairy farms, oil fields, and landfills near major urban centers. These fluxes were then used to validate coarse-resolution fluxes derived from GOSAT.

For airborne remote sensing, which looks down on gas plumes, only imaging spectroscopy can rapidly survey vast areas, pinpointing sources and assessing their strengths. In situ data—acquired by flying through the plume—are needed to evaluate detection limits and characterize the weaker source contributions; they also aid in validation and characterization of critical atmospheric components. The GOSAT-COMEX Experiment merged remote and in situ data to fully characterize emissions across a full spectrum of emission and length scales.

For airborne remote sensing, the GOSAT-COMEX Experiment relied on the Mako thermal-infrared hyperspectral sensor developed by Aerospace. It was flown on a Twin Otter propeller-engine aircraft. For airborne in situ sensing, the experiment relied on the AlphaJet (also known as AJAX) developed by NASA Ames. For in situ sensing, speed is important to capture a true snapshot and to minimize uncertainty from changing winds and environmental conditions. The AlphaJet can collect multiple data curtains (or walls) rapidly—in less than half an hour, and far faster than prop engine planes; moreover, it has the necessary maneuverability to follow precise flight lines. Thus, AJAX played a key role in the GOSAT-COMEX Experiment.

Speed and accuracy are also critical for mobile surface-based in situ measurements. Although a number of platforms are available to conduct surveys on the ground, the AMOG Surveyor (from Bubbleology Research International) was developed specifically for satellite validation and is unique in its ability to cover multiple satellite pixels in a short time while collecting highly accurate data. The AMOG Surveyor played both primary and supporting roles in the GOSAT-COMEX Experiment.

Surface-based remote sensing data was also acquired by Aerospace's RamVan mobile laboratory, which houses an infrared spectrometer that can measure the air column directly above the vehicle while it is in motion. This provided an observational geometry complementary to that of Mako.

The GOSAT-COMEX Experiment succeeded by fusing these mobile ground and airborne in situ methodologies to validate airborne and space-based remote sensing methodologies.

Conclusion

The United States can play a leading role in understanding how best to leverage the global Sentinel-5 satellite data. An approach similar to that of the COMEX-GOSAT Experiment could help increase confidence in satellite, airborne, and ground-based sensors, with an eye toward developing meaningful and accurate local, regional, and international understanding of methane emission rates and the effect of wind transport. Such an effort would establish a methodology for multiscale calibration and validation by data fusion across a range of technologies and platforms. Knowledge gained from this campaign has important international implications for:

- gathering and sharing information on methane emissions, national policies, and best practices;
- launching national strategies for addressing methane emissions and adapting to expected impacts; and
- allocating financial and technological support to developing countries.

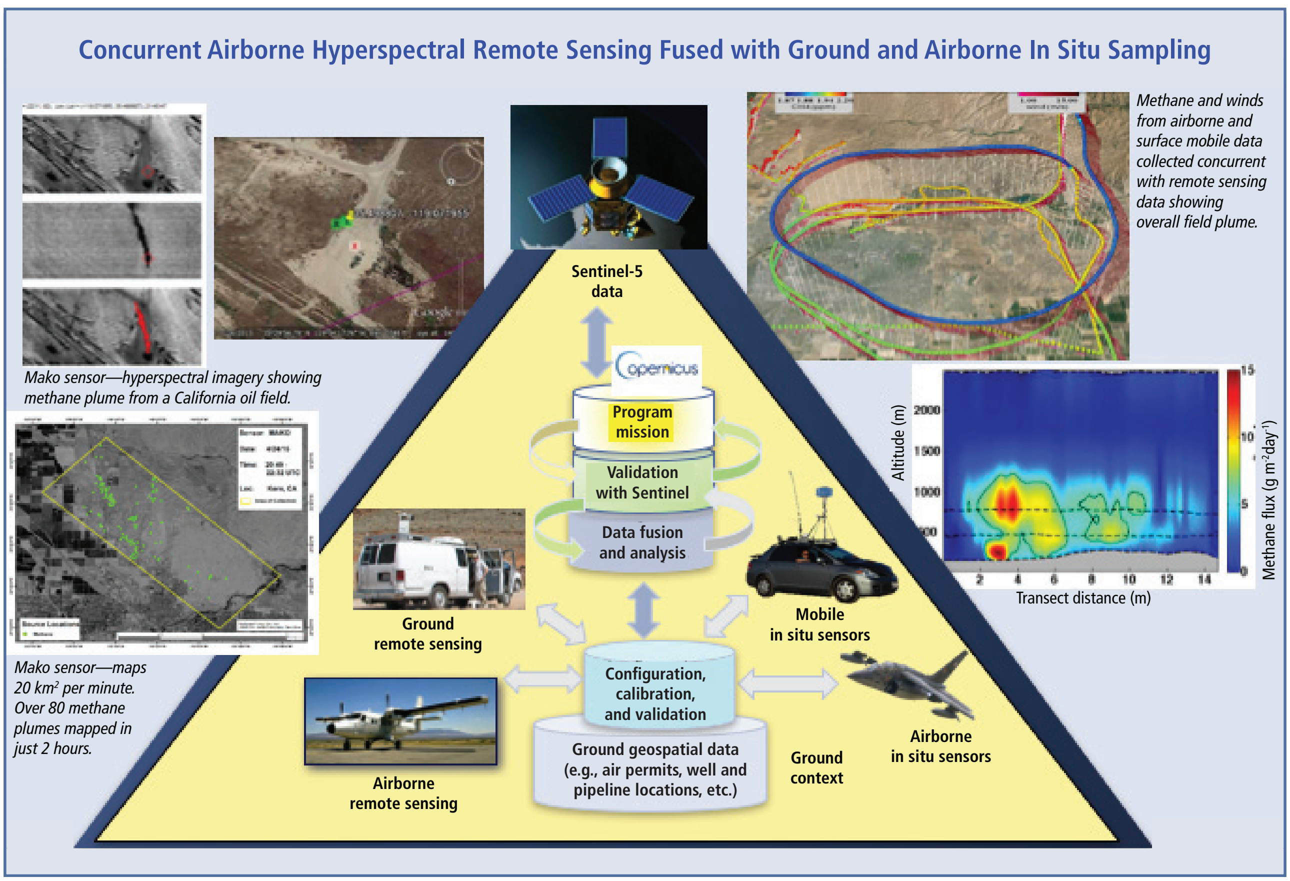

Figure 1: Collection, analysis, and validation of methane emissions: data fusion of airborne and surface remote sensing and in situ sensors.

The United States can prepare for the upcoming Sentinel-5 mission through activities that demonstrate methodologies for different regions, providing improved methane inventories in the process. Before accepting Sentinel-5 products, the United States must first validate the data and its interpretations for North American environments. In the longer term, ongoing remote and in situ airborne and surface data will still be needed to augment the lower-resolution satellite data with high-spatial-resolution contextual information to support regulatory decisions and other actions. Toward this end, the United States might develop a plan to:

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Figure 2: Twin Otter airplane and AMOG Surveyor used in the COMEX campaign. The AMOG Surveyor makes mobile measurements of meteorology and atmospheric trace gases, including methane, under COMEX flights.

- explore approaches to the integration of mobile in situ assets, airborne surveys, and ground-based networks for a long-term sustainable framework within the Copernicus services;
- establish ongoing data collection by fused airborne and ground-based platforms[13] to provide calibration and validation of space-based information and fill gaps related to fine-scale processes not characterizable from space observations; and
- formulate optimal temporal and geographical requirements for correlative calibration and validation campaigns.

References

[1] According to the EPA "Pound for pound, the comparative impact of CH_4 on climate change is 25 times greater than CO_2 over a 100-year period"; http://epa.gov/climatechange/ghgemissions/gases/ch4.html.

[2] Shindell, D., et al. (2012). "Simultaneously mitigating near-term climate change and improving human health and food security." *Science*, 335(6065), 183-189. http://dx.doi.org/10.1126/science.1210026.

[3] https://www.whitehouse.gov/the-press-office/2015/01/14/fact-sheet-administration-takes-steps-forward-climate-action-plan-anno-1.

[4] http://www.epa.gov/airquality/oilandgas/actions.html.

[5] Dlugokencky, E., et al. (2011). "Global atmospheric methane: budget, changes and dangers." *Philos. Trans. Roy. Soc. A*, 369(1943), 2058-2072. http://dx.doi.org/10.1098/rsta.2010.0341.

[6] Copernicus's goal is to establish a modern, capable infrastructure for Earth observation and geo-information (http://www.copernicus.eu).

[7] https://sentinel.esa.int/web/sentinel/missions/sentinel-5.

[8] Meteorological Operational Satellite Programme (MetOp) is a European undertaking providing data services to monitor and improve weather and climate forecasts.

[9] Copernicus is the European Union's contribution to the Global Earth Observation System of Systems (GEOSS).

[10] EPA helps developing countries assess national greenhouse gas inventories; therefore, improved EPA methodologies and metrics will improve assessment from other countries using similar methodologies/analyses.

[11] https://espo.nasa.gov/home/comex/content/GOSAT_COMEX_Experiment; COMEX = CO_2 Collection Experiment; GOSAT = Greenhouse Gas Observing Satellite.

[12] CO_2 and Methane EXperiment. https://espo.nasa.gov/comex.

[13] GMES In Situ Coordination (GISC) emphasizes collection from terrestrial sources, including ground-based, airborne, and ship/buoy-based observations and measurements that are needed to implement and operate the Copernicus services.