

Riley Duren testimony
House Science, Space & Technology Committee
Space & Aeronautics Subcommittee
*NASA's Earth Science and Climate Change Activities:
Current Roles and Future Opportunities*

May 18, 2021

Statement

Thank you, Chair Beyer, Ranking Member Babin, and Members of the Subcommittee for the opportunity to contribute today. In convening this hearing you've already taken an important step in highlighting a persistent gap in ongoing US climate policy discussions. Satellite observations and data in general are critical not only for basic climate research but also in enabling science-based decision making by a broad cross section of our society. NASA and its partners absolutely belong in these discussions. As lawmakers consider investments in the nation's physical infrastructure it's also important to recognize the urgent need to address gaps in critical **data** infrastructure that can inform efforts to minimize climate impacts and improve environmental resiliency.

As an example of data gaps and opportunities for improvement I'd like to describe a new public-private partnership that is leveraging NASA science and technology to deploy a global decision support system for tracking and mitigating greenhouse gas emissions. In recent years, a growing number of public- and private-sector actors have signaled an interest in reducing their methane and CO₂ emissions including ambitious decarbonization targets by some of the world's largest economies and major oil and gas companies. Multiple field studies have conclusively identified the existence of methane "super-emitters" where a relatively small fraction of infrastructure is responsible for a disproportionate amount of emissions. My own NASA funded research team used advanced remote-sensing aircraft to conduct the first comprehensive, economy wide survey of methane emitters in California and found that less than 0.2% of the infrastructure is responsible for over a third of the state's entire methane inventory. Many of these super-emitters are highly intermittent, widely dispersed and difficult to find with conventional surface measurements. Our recent airborne surveys of the Permian basin and other regions add to this body of evidence. This false-color movie of methane plumes observed by NASA aircraft offers a vivid illustration: these super-emitters are broadly distributed across the landscape like invisible wildfires and they mostly go unseen even by operators who are motivated to find leaks to avoid product loss. Oil and gas companies that have reviewed our data indicate that at least a half of the methane super-emitters we're detecting are the result of leaks and malfunctions that were previously unknown.

This suggests "low hanging fruit" for near-term mitigation progress. A high-fidelity constellation of satellites could offer daily, facility scale methane monitoring over key regions globally to alert operators and regulators of leaks for more timely and cost-effective repairs.

However, in practice this means confronting both technical and institutional barriers. No single organization today has the mandate, resources or culture to field this kind of decision support system – at least not quickly or affordably. In this case,

- The necessary remote-sensing technology is unavailable outside NASA
- NASA itself lacks the capacity to launch constellations of satellites
- There's no government program to finance the build out of such a system
- Sustaining such efforts is difficult given shifting US federal priorities
- Purely commercial services often lack the transparency needed for global public trust

To confront these challenges we founded a new nonprofit organization called [Carbon Mapper](#) and a public-private partnership that includes

- *Remote sensing technology transfer from NASA JPL*
- *Planet's agile aerospace approach to constellations*
- *Science leadership from U. Arizona and ASU*
- *Policy expertise and transparency from California and non-profit partners*
- *All powered by philanthropy*

I know I speak for our other partners in thanking Dr. St Germain from NASA and Mr. Schingler from Planet and their teams for their vision and support. In closing: effective response to climate change and other environmental challenges requires action by a cross-section of society including governments, businesses and private citizens. The same applies to generating robust data and shared awareness to inform those actions. We don't have time for delayed action or false starts because of incomplete data or monolithic approaches. Our society needs the best possible science and systems engineering creativity of organizations like NASA to enable new innovative efforts to deliver actionable climate data. And we need the help of Congress in recognizing and supporting these kinds of efforts by NASA and its partners both domestically and globally.

Thank you.

Prepared Statement

Introduction

Thank you, Chair Beyer, Ranking Member Babin, and Members of the Subcommittee for the opportunity to contribute today. In convening this hearing you've already taken an important step in highlighting a persistent gap in ongoing US climate policy discussions. Satellite observations and data in general are critical not only for basic climate research but also in enabling science-based decision making by a broad cross section of our society. NASA and its partners absolutely belong in these discussions. As lawmakers consider investments in the

nation's physical infrastructure it's also important to recognize the urgent need to address gaps in critical **data** infrastructure that can inform efforts to minimize climate impacts and improve environmental resiliency.

Today I'd like to share some thoughts about needs and gaps for satellites (and other) observing systems that can help support and accelerate efforts to mitigate greenhouse gas (GHG) emissions in the US and globally along with some specific recommendations for this committee. Additionally, as an example of potential new approaches for addressing observational gaps, I'll describe a new public-private partnership that is leveraging NASA science and technology to deploy a global decision support system designed to track and help mitigate GHG emissions. This example addresses one of many facets of this challenging topic and should be considered representative rather than comprehensive

Methane and carbon dioxide (CO₂) are the two dominant anthropogenic climate-forcing agents. Methane in particular packs a powerful climate punch, with a global warming potential that's nearly 90 times greater than CO₂ on 20 year time-scales. Methane is also relevant to air-quality given its role as an ozone precursor and the tendency for co-emitted reactive trace gases that can impact human health. While atmospheric levels of methane and CO₂ at global scale are very well known thanks to decades of accurate surface observations, they are driven by activity at millions of facilities across the planet whose individual emissions are not directly measured in most cases – in part due to the high cost of deploying localized sensors everywhere. These uncertainties are serious impediments to efforts by businesses to reduce product loss while remaining competitive in global markets and also threaten the accuracy of greenhouse emission inventories compiled by national, state and local governments. Efforts to mitigate (reduce) methane and CO₂ emissions are complicated by inconsistencies between estimates derived from atmospheric measurements, greenhouse gas inventories, and self-reporting programs. Contributing to these discrepancies are a population of facilities that emit anomalously high amounts of greenhouse gases, often in an unpredictable and intermittent fashion. Multiple field studies have conclusively identified the existence of methane “super-emitters” where a relatively small fraction of infrastructure is responsible for a disproportionate amount of emissions.

Starting in 2016, my own research team, jointly funded by NASA and California's Air Resources Board and Energy Commission, used advanced remote-sensing aircraft to conduct the first comprehensive, economy wide survey of methane emitters in California and found that less than 0.2% of the infrastructure there is responsible for over a third of the state's entire methane inventory (Duren *et al.*, 2019). Figure 1 illustrates examples spanning the oil and gas, waste management and agriculture sectors. Many of these super-emitters are highly intermittent, widely dispersed and difficult to find with conventional surface measurements. With the support of NASA and other sponsors we have since expanded our airborne studies to other key US regions where we're finding additional evidence that strong methane point sources (concentrated plumes released from infrastructure typically <10 meters across) can contribute up to 20-50% of a region's total emissions and are highly intermittent in some sectors – particularly for oil and gas production, where half of the high emitting point sources

are often active less than 25% of the time. We also seeing methane super-emitter activity at natural gas infrastructure, refineries, landfills, waste-water treatment plants, large dairies, etc.

Our recent airborne remote sensing surveys of the Permian basin and other regions add to this body of evidence (Cusworth *et al.*, 2021a). Figure 2 offers a vivid illustration of typical methane plumes in the Permian observed by remote sensing aircraft: these super-emitters are broadly distributed across the landscape like invisible wildfires and they mostly go unseen even by operators who are motivated to find leaks to avoid product loss. Additionally, oil and gas companies that have reviewed our data in California, Texas and New Mexico indicate that at least a half of the methane super-emitters we're detecting are the result of leaks and malfunctions that were previously unknown. We are currently working to verify this with independent follow-up observations and planning future collaborative field studies with our research partners and industry participation to further explore and confirm mitigation potential.

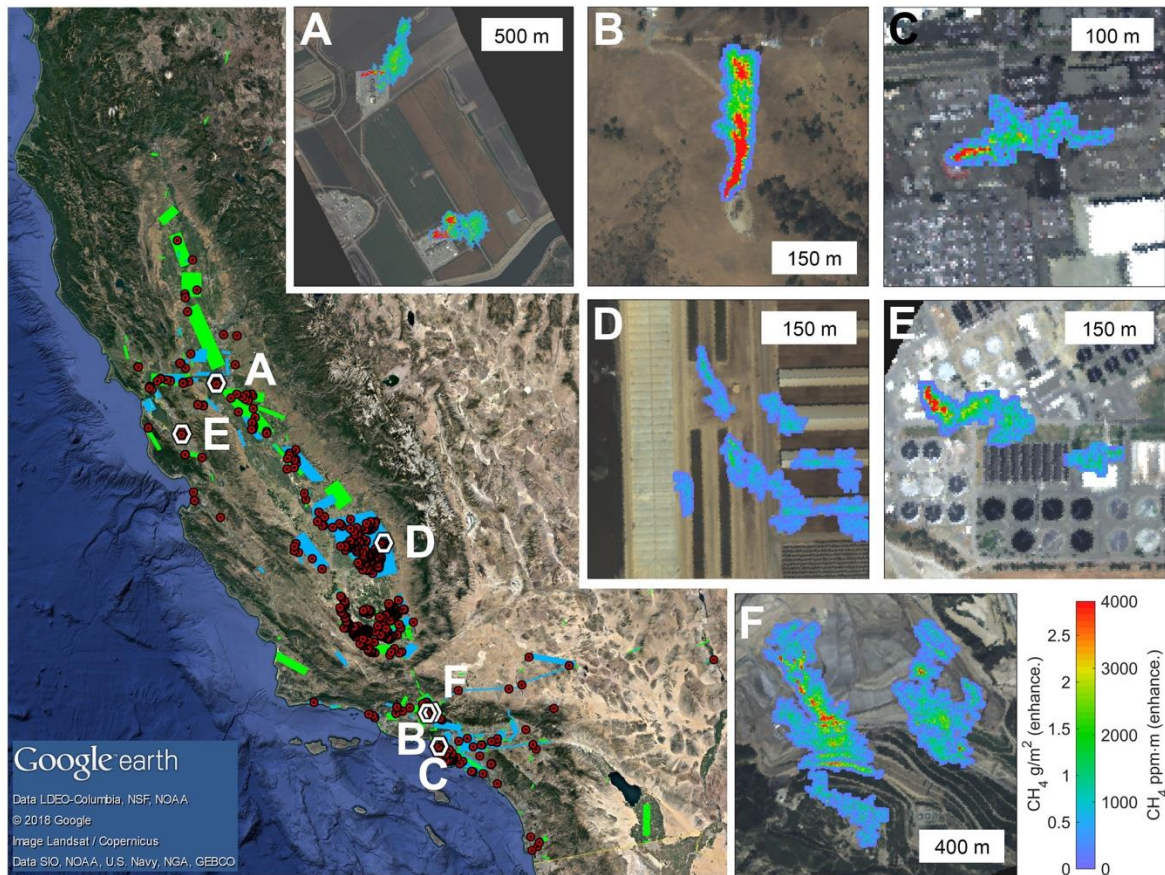


Figure 1: Methane super-emitters detected with NASA remote sensing aircraft during the California Methane Survey. Main figure shows 2,000 individual flight lines from 2016 (blue) and 2017 (green) that covered more than 272,000 individual facilities and infrastructure elements. Detected methane sources are indicated by red points, with the densest clusters seen in the San Joaquin Valley (dairies and oil fields). The inset images show examples of representative methane plumes from different sectors: a, compressor stations at a natural gas storage facility; b, oil well; c, tank of liquefied natural gas; d, dairy manure management; e, wastewater-treatment plant; f, landfill. The color scales indicate the methane concentration enhancement (the mass of methane in a plume relative to background air) in each pixel in units of parts per million-meter (ppm-m). [source: Duren *et al.* 2019]



Figure 2 This false color scene shows a typical collection of methane plumes detected by the Global Airborne Observatory (overlaid on Google Earth imagery) from an altitude of 17,500 ft (~5.3 km) in Fall 2019 over the Permian oil and gas basin. The red plumes indicate methane emissions from oil & gas infrastructure: wells, tank batteries, compressor stations, gathering lines, etc. The plumes are all aligned with the prevailing wind. We have detected over 3,000 such plumes so far in the Permian basin with our airborne surveys. The area shown here is a small fraction of a single Carbon Mapper satellite observation. [source: Carbon Mapper, University of Arizona, NASA Jet Propulsion Laboratory, Arizona State University; Cusworth *et al.*, 2021a]

Meanwhile, nearly 60% of global CO₂ emissions from coal power plants occur in regions that lack facility level emissions monitoring and reporting programs. We are now demonstrating with aircraft and satellite observations the ability to independently detect, pinpoint, and quantify CO₂ emissions from large coal and gas fired power plants (Cusworth *et al.*, 2021a). High costs of monitoring systems and incomplete data accessibility and transparency are barriers to diagnosing and mitigating anomalous point sources for geographically dispersed infrastructure.

Remote sensing, in principle, is capable of contributing data that can help fill gaps in current methane and CO₂ accounting systems and even enable direct action by facility operators and regulators. In practice, the ultimate mitigation impact of such data depends on the degree of completeness (or what fraction of emissions can be identified and quantified) which is a function of detection limit, spatial coverage and sample frequency. The latter is particularly critical given the intrinsic variability in many methane and CO₂ point source emissions.

Carbon Mapper: a Public-Private Partnership for Operational GHG Monitoring

In recent years, a growing number of public- and private-sector actors have signaled an interest in reducing their methane and CO₂ emissions including ambitious decarbonization targets by some of the world's largest economies and major oil and gas companies (e.g., [Oil and Gas Methane Partnership](#)). This, when combined with the aforementioned summary of methane

super-emitter activity, suggests potential “low hanging fruit” for near-term mitigation progress. A high-fidelity constellation of satellites could offer daily, facility scale methane monitoring over key regions globally to alert operators and regulators of leaks for more timely and cost-effective repairs.

However, deploying such an observing system means confronting both technical and institutional barriers. No single organization today has the mandate, resources or culture to field this kind of decision support system – at least not quickly or affordably. In this case,

- The necessary remote-sensing technology is unavailable outside NASA
- NASA itself lacks the capacity to launch constellations of satellites
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To confront these challenges we founded a new nonprofit organization called [Carbon Mapper](#) and a public-private partnership that includes

- *Remote sensing technology transfer from NASA JPL*
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We plan to launch the first two Carbon Mapper satellites in 2023 followed by a larger constellation starting in 2025 by our commercial partner Planet that will offer daily to weekly monitoring of methane and CO₂ point source emissions at facility-scale in key regions globally. Teaming JPL and Planet together created a unique solution: a high sensitivity, moderate resolution payload and agile satellite platform that can deliver the required precision (detection limit), spatial coverage, and temporal sampling. By persistently tracking and pinpointing point source emissions at individual facilities, Carbon Mapper is designed to complement other observing systems that are capable of quantifying net regional emissions and the largest point sources. We will accomplish this observing strategy by tasking our satellites to acquire data over priority areas based on a combination of prior knowledge of infrastructure locations and follow-up based on “tips” from other satellites designed for wider area monitoring (for example the Sentinel-5P, EDF’s MethaneSAT or NASA’s OCO-2 and OCO-3 missions). Figure 3 provides a notional map of Carbon Mapper sampling areas in the US and Canada; there are similar patterns in other parts of the world. This is similar to the existing tasking approach used by Planet’s constellation of Skysat satellites and is enabled by the moderate field of view provided by NASA JPL’s spectrometer technology. The system includes other observing modes: glint mode for tracking methane emissions from offshore oil and gas platforms and pushbroom mapping for larger area coverage on land.

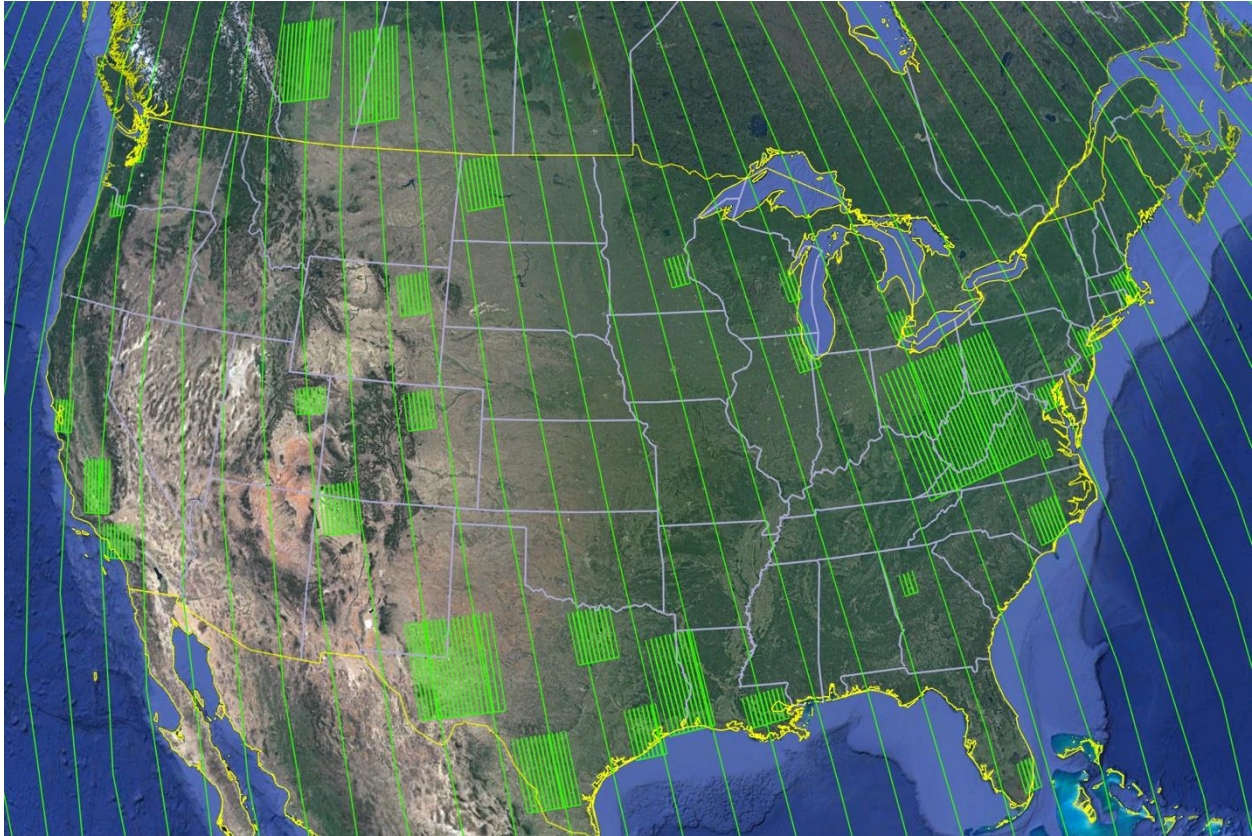


Figure 3: Green boxes indicating notional priority regions for persistent Carbon Mapper observations of methane and CO₂ point source emissions in the US and Canada. The system will likely have similar sampling patterns in other regions and has the flexibility to sample the entire landmass with slower reduced revisit time. [Source: Carbon Mapper]

A unique aspect of this program is the role of Planet's commercial space operation in offering sustained data delivery in support of Carbon Mapper's public good mission beyond the time horizon of traditional research driven satellites. This dual-use potential is enabled by the NASA imaging spectrometer technology which spans the visible to shortwave infrared wavelengths (380-2510 nm) which in addition to Carbon Mapper's focus on methane and CO₂, offers 25 other land and ocean environmental indicators that can generate commercial revenue to sustain our public-good mission. This provides a degree of continuity and stability that is often difficult to attain with federal research satellites.

Meanwhile, we're using research aircraft to expand regional methane surveys over more US states and working with facility operators, state and local agencies and other early adopters to ensure maximum impact when the data starts flowing from the satellite constellation. Carbon Mapper will have transparent, open policies for releasing emissions data to expand accessibility and trust for widest possible adoption and impact by governments, businesses, and the general public. This will be further strengthened by the California Air Resources Board that will provide independent ground-truth measurements across the state for comparison with Carbon Mapper data towards increasing confidence in the data in other jurisdictions around the world. By

combining the strengths of diverse institutions Carbon Mapper may suggest a broader model for additional, expanded collaborations between NASA and other non-governmental actors to move quickly to deploy the critical data infrastructure needed to address the diverse environmental challenges confronting our society.

Progress and Gaps in GHG Monitoring

Stakeholder needs for GHG data varies widely which translates to differing requirements on the supporting observations, analysis and estimation frameworks. For example, most countries deliver national GHG inventories that represent their primary method for reporting and tracking emissions. These so-called “bottom-up” inventories apply well-established accounting methods to combine activity data and standard emission factors to estimate annual aggregate emissions for the country organized by gas and economic sector. Some sub-national governments use the same approach to produce inventories for their jurisdiction although regular updates are not universal. The accuracy of these inventories can vary significantly by region (e.g., due to varying availability of activity data) as well as by gas and sector (e.g., methane emission estimates tend to be highly uncertain in most jurisdictions because of emission factors that don’t capture skewed behavior such as the previously described super-emitters).

Over the past decade, scientists have developed methods for independently evaluating GHG emissions including the use of atmospheric measurements that can directly constrain emissions from a given region. Those so-called “top-down” atmospheric methods have historically been limited to continental scale emissions estimates motivated by carbon cycle research however there have been recent strides in resolving country-level emissions, including the use of satellite data (Maasaakkers, *et al.*, 2019). Other teams are using similar methods to detect trends in urban scale emissions with surface measurement networks, although those remain quite sparse and limited to a handful of testbed projects (Yadav *et al.*, 2021). Meanwhile, other scientists have successfully developed space-time resolved fossil fuel CO₂ emission maps using available activity data at sufficiently fine scale to enable independent assessment of fossil fuel CO₂ emissions from individual cities (Gurney *et al.*, 2020). A common feature of all these examples is the current state of the art involves significant latency in publishing data: time lags of 1-3 years are not unusual. ***Data latency remains a core challenge and is a major reason for why more operational, streamlined frameworks are needed to effectively support decision making in the face of rapidly changing economic, political and environmental conditions.***

At the finer scale end of the GHG data spectrum are the needs of facility operators and local regulators to detect, pinpoint and quantify methane leaks from individual facilities and equipment. Building on the Carbon Mapper example described above, there are many technologies available for providing actionable emissions data at facility scale including satellites, aircraft, drones, and surface measurements in cars, handheld sensors or fence-line monitoring systems within or adjacent to facilities. These technologies have widely varying degrees of sensitivity, spatial resolution, area coverage, sample frequency, reliability and cost.

Except for some isolated applications, there is generally no single one-size-fits-all GHG measurement and estimation technique. A system of systems or “tiered observing system” will likely provide the most optimal performance through thoughtful combination of different methods (see Figure 4). For the methane leak detection example, appropriately equipped satellites and remote-sensing aircraft have the advantage of wide-area coverage and for high emission sources can alert technicians or inspectors on the ground to visit specific sites with surface instruments or drones offering lower detection limits and more precise geolocation – ultimately translating to more efficient location of leaks and potentially, repairs. Another emerging application is the potential adoption of low methane intensity standards for natural gas (e.g., the [MiQ initiative](#)) where independent measurements across global supply chains could help provide certification for suppliers and consumers. Such frameworks will require a combination of measurement techniques including point source tracking and quantification of wider area (e.g., oil and gas production basin) emissions; again, a system of systems. Additionally, for the national and sub-national GHG emission reporting and tracking application, the most accurate and timely estimates will likely involve the integration of top-down and bottom-up methods rather than relying on a single approach. For all of the above cases, ***cooperative systems of systems likely offer more effective, affordable, and timely guidance than monolithic GHG quantification and tracking methods.***

With regards to space based GHG observations, the US, Japan and EU continue to operate research satellites that are providing critical insights into carbon cycle processes at continental to global scales as well as some experimental efforts to estimate regional scale CO₂ and methane emissions (e.g., NASA’s OCO 2 and OCO-3 missions, JAXA’s GOSAT series, and the EU’s Sentinel-5P, respectively). Meanwhile, the Italian and Chinese space agencies have both launched satellites (PRISMA and Gaofen-5, respectively) that have demonstrated the ability to detect and quantify methane and CO₂ emissions at the scale of individual facilities including US power plants and oil & gas infrastructure. The European Commission has signaled an intention to use existing and future satellites in its Copernicus program capable of providing operational methane monitoring ([EU Methane Strategy](#), 2020) as well as CO₂ emissions from cities and large power plants (Kuhlmann *et al.*, 2020). Our own team has used PRISMA and airborne remote-sensing observations to pinpoint and quantify CO₂ emissions from coal power plants in the US and other countries (see Figure 5; Cusworth *et al.*, 2021b).

These developments, along with philanthropically funded programs such Carbon Mapper and our partner mission, EDF’s [MethaneSAT](#), offer promising signs of an emerging global system of systems for monitoring methane and CO₂ emissions relevant to mitigation action. However, they are mostly being deployed independently and so continued efforts to coordinate between the programs as well as integrated analysis of the diverse data sets will be key for success. I’m unaware of any plans by the US government to launch similar satellites like the ones described here with sensitivity to methane or CO₂ emissions from individual facilities. Given US ambitions to provide climate leadership on the global stage, this subcommittee may wish to give some consideration to how the nation’s interests and capabilities align with regards to emissions estimates generated by satellites for industrial facilities around the world.



Figure 4 Conceptual view of a “tiered observing system” (system of systems) for methane monitoring including satellites and aircraft that routinely survey large regions and alert teams on the ground to deploy follow-up surface measurements to high emitting facilities for more cost effective and rapid leak detection and repair. [Source: NASA/JPL-Caltech]

Recommendations for Congress

The recent commitment by President Biden’s administration to reduce US greenhouse gas emissions by 50% by 2030 suggests the need for a whole-of-society approach that is underpinned and guided by the best available US science and technology. The credibility of the expanded US Nationally Determined Contribution could be dramatically strengthened by a bold commitment to operationalizing advanced science-based methods for quantifying and locating greenhouse gas emissions that increases the likelihood that US domestic mitigation policies are successful while enhancing credibility with and galvanizing progress in other countries. In particular, the success of these efforts will critically depend on immediate, focused mitigation of methane and other short-lived climate pollutants (including methane, HFCs, and black carbon) in addition to longer-term decarbonization initiatives. ***The US has developed advanced science-based methods capable of targeting expedited mitigation opportunities and authenticating reported baseline emissions and future reductions for all greenhouse gases,***

including methane and other short-lived climate pollutants, and it should invest in further operationalizing those methods.

Congress should consider steps to resolve critical data infrastructure gaps and direct federal efforts (with appropriate support from other sectors and partners) to deploy and sustain advanced, science-based quantification and tracking of emissions for all greenhouse gas in the US. In doing so it is recommended that Congress:

- Recognize the limitations of existing federal GHG monitoring programs particularly with regards to measurement continuity given that many of the research driven programs are limited to infrequent or short-duration pilot efforts.
- Leverage established relevant federal pilot programs (e.g., NASA's [Carbon Monitoring System](#) program, [NIST GHG Measurement Program](#), etc.) and emerging nongovernmental programs to build-out and operationalize research-grade observations and analysis frameworks for decision support.
- Explore leveraging other capabilities of federal agencies that traditionally have not been applied to research driven monitoring programs (e.g., systems engineering at NASA) to help provide the necessary system-of-systems design and program management required for truly operational GHG monitoring
- Consider establishing a new interagency program as a companion to the USGCRP but with a mission and resources to deliver operational GHG monitoring and decision support for US federal, state, and local governments, businesses, and civil society
- Expand US agency support for and participation in international and intergovernmental initiatives such as the World Meteorological Organization (WMO)'s [Integrated Global Greenhouse Gas Information System](#) (IG3IS)
- Explore options to support, match and build on the contributions by non-governmental actors including philanthropy and private sector
- Consider establishing a sub-national climate action partnership between the federal government and state and local agencies to facilitate more widespread and actionable GHG monitoring, potentially including federal resources to help build scientific and technical capacity in those sub-national agencies.

Comparison between retrieved and reported CO₂ emission rates

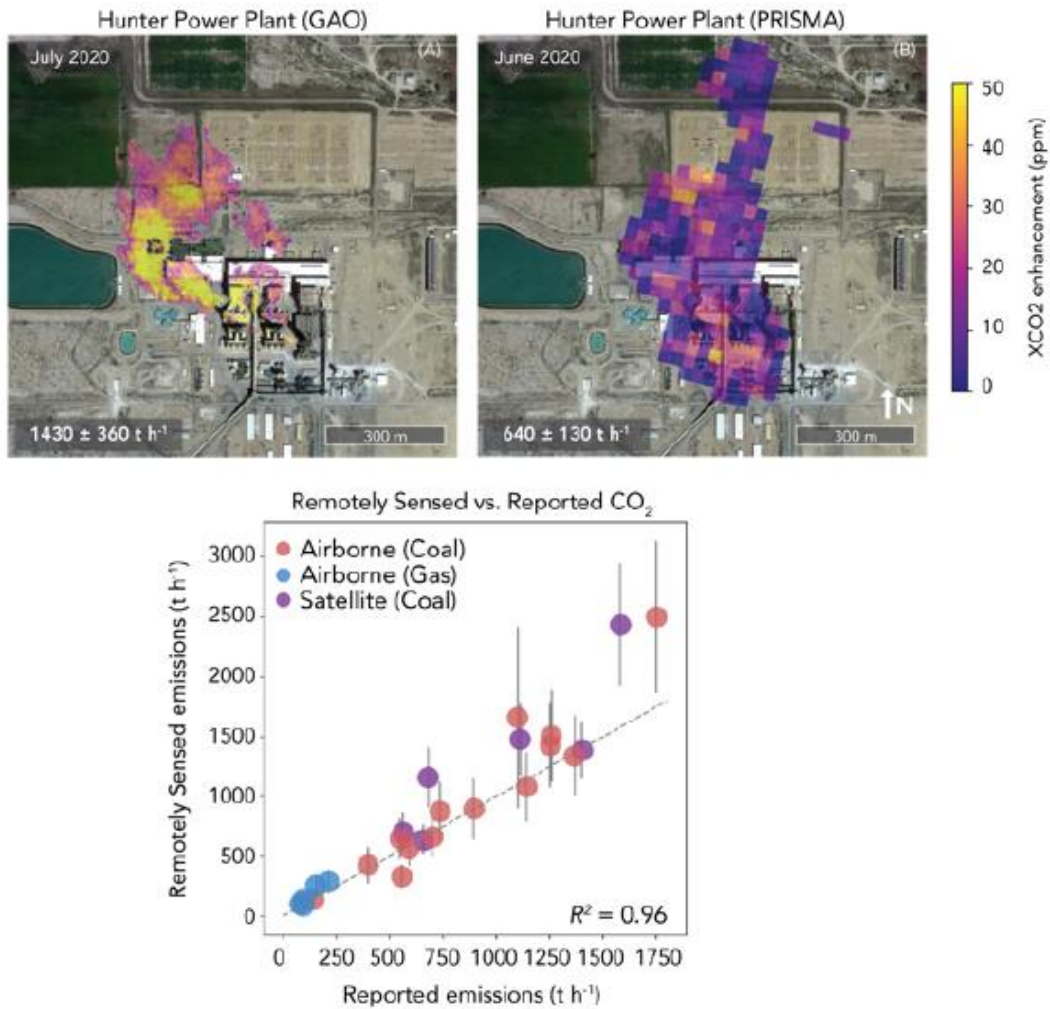


Figure 5. Examples of using satellite and airborne remote sensing to pinpoint and quantify CO₂ emissions from coal and gas fired power plants. Note the variability in emissions in the top panels indicating the need for frequent sampling for accurate estimation. The bottom plot shows mostly good agreement between the remotely sensed emissions in the US and those reported to the Environmental Protection Agency by those facilities using stack monitoring but with some notable outliers. [source: Cusworth *et al.*, 2021b]

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Biography

Riley Duren is a Research Scientist at the University of Arizona and Chief Executive Officer of the Carbon Mapper non-profit organization. He also maintains a part-time appointment as Engineering Fellow at NASA's Jet Propulsion Laboratory, although that work is outside the scope of today's testimony. His career at NASA began with launching space shuttle science payloads from the Kennedy Space Center (1988-1995). He joined JPL in 1996 where he worked at the intersection of science and engineering to deliver earth observing systems and deep space telescopes including the Kepler mission for which he served as Chief Engineer. From 2008-2019 he was the Chief Systems Engineer for JPL's Earth Science and Technology Directorate, with a broad portfolio of satellite and aircraft instruments and missions, research

and analysis, applied science, and technology projects spanning NASA's earth science enterprise.

In 2008 he established a research program that extends the discipline of systems engineering to the challenge of climate change decision support. He has served as Principal Investigator for 10 research projects involving greenhouse gas observing systems and data analysis frameworks. His team combines atmospheric measurements from satellites, aircraft and surface-based observing systems, tracer transport modeling, machine learning, and big data methods to detect, quantify and attribute methane and carbon dioxide emissions. The team also applies considerable energy to engaging with and entraining end users of the data sets produced by these programs towards increasing the data's relevance, adoption and impact. His work has supported programs at NASA, the National Institute of Standards and Technology, the National Oceanographic and Atmospheric Administration, the California Air Resources Board, and California Energy Commission, and multiple non-governmental organizations.

In 2020, Mr. Duren co-founded Carbon Mapper, a new non-profit organization and public-private partnership involving leading philanthropists, the commercial satellite imaging company Planet, JPL, the State of California and two universities, with a public good mission to deploy a constellation of small satellites that will provide globally operational monitoring of methane and carbon dioxide point source emissions at facility scale to help accelerate climate mitigation action. The program also includes expanding airborne methane surveys of key regions to help prepare for and complement the satellites.

Mr. Duren's honors include two NASA Exceptional Achievement Medals, the agency's Systems Engineering Excellence Award, and seven Group Achievement awards. He has served on National Academy of Science and California Council of Science and Technology committees and was a contributing author to the Second State of the Carbon Cycle Report for the US Global Change Research Program. He received a BS degree in Electrical Engineering from Auburn University in 1991. His professional work is partially motivated and inspired by his personal interests in forest conservation and wildlife photography.