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Workshop Report: Methane Super-Emitter Consensus Standards workshop

Terminology and Taxonomy, January 2024

Annmarie Eldering
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This publication is intended to capture external perspectives related to NIST standards, measurement, and testing-related efforts. These external perspectives can come from industry, academia, government, and other organizations. This report was prepared as an account of a workshop; it is intended to document external perspectives, and does not represent official NIST positions.

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Abstract

A workshop in methane super emitter and consensus standards was held in January 2024. This workshop brought together measurement teams, regulators, and representatives from a wide range of federal agencies. The use of remote sensing measurement systems on drones, aircraft, and satellites to detect large methane emissions from oil and gas, landfills, and manure management is expanding rapidly. To increase the utility and trust in this data, consensus on the terminology and best practices needs to be developed and documented. This report briefly captures the presentation and discussion topics from this first workshop. The focus was on discussing current status and planning next steps, no recommendations and findings were recorded.

Keywords

Methane, remote sensing, super-emitters.

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Executive Summary

Methane has become a focal point of efforts to reduce greenhouse gases, and emissions from energy exploitation and waste (landfills) are seen to be an opportunity for significant reductions at low-to-no cost. At the same time, there has been rapid growth and advancement in technologies for remote sensing of methane plumes from aircraft and space. These new capabilities have great potential for enabling targeted reduction in atmospheric methane through the identification of the largest emission sources, known as "super-emitters," but enabling maximum impact of data from these sources requires consensus among stakeholders regarding definitions and methodologies.

The absence of consistent definitions, best practices, and protocols for plume identification, data quality control, emissions analysis, and independent validation are sources of confusion that pose a threat to widespread adoption and use of these data. Trust in the accuracy and authenticity of these data sets by operators, regulators and civil society is the foundation for effective accounting and mitigation. There is an urgent need and opportunity to establish consistent best practices and taxonomy in this field – initially focused on super-emitter detection, attribution, and reporting challenges.

In light of these needs, a group of practitioners, regulators, and interested federal agencies were gathered in a workshop to begin discussions of terminology and best practices for the use of such remote sensing data and detecting methane super emitters. This report summarizes the elements of the workshop, including describing consensus standards, setting the regulatory context, and describing existing validation approaches. The report also captures key points from presentations of measurement analysis workflows, challenges, issues and concerns identified by the measurement teams, and a brief discussion of definitions.

This document is a snapshot of the state of affairs at the time of the workshop. Since the meeting, additional discussions and writing sessions have been held to advance the work on writing down definitions and key terminology. Documentation of best practices is also underway. Readers are encouraged to search for more recent material on the topic from NIST, for example by visiting www.nist.gov/spo/greenhouse-gas-measurements-program.

1. Background

Methane has become a focal point of efforts to reduce greenhouse gases emissions (GHGs). Unexpected emissions from industrial processes are particularly seen to be an opportunity for significant reductions in methane emissions at low to no cost. At the same time, there has been rapid growth and advancement in technologies for remote sensing of methane plumes from aircraft and space. Many of these new measurements are coming from commercial and philanthropic entities, a departure from the historical dominance of government satellites for remote sensing of atmospheric composition.

Specifically, in early 2024, new US federal and state regulations for oil and gas (O&G) methane emissions are set to go into effect that will levy requirements on the detection, notification, and response for high emission point sources (also referred to as super-emitters). These programs may leverage advanced remote sensing observations over large areas to identify potential fugitive emissions at facility or component scale for expedited mitigation action. However, success is not assured given the current lack of agreement on common definitions, terminology, and methodologies that describe and attribute super-emitter detection and geolocation of a facility/operator that can translate to false alarms and divergent findings. The absence of consistent definitions, best practices, and protocols for plume identification, data quality control, emissions analysis, and independent validation are sources of confusion that pose a threat to widespread adoption and use of these data. Trust in the accuracy and authenticity of these data sets by operators, regulators, and civil society is the foundation for effective accounting and mitigation. There is an urgent need and opportunity to establish consistent best practices and taxonomy in this field – initially focused on super-emitter detection, attribution, and reporting challenges.

In light of these rapid new developments, a group of practitioners, regulators, and representatives from interested federal agencies were gathered to begin discussions of terminology and best practices for the use of such remote sensing data and detecting methane super-emitters. Once a sound, broadly recognized taxonomy is established, attention can then be turned to the related topics of super-emitter emissions quantification and uncertainty analysis.

1.1. Objectives

1.1.1. Meeting Objectives

Detailed objectives of the meeting were to:

1. bring together key communities to start the discussion on consensus standards, terms, and taxonomy around remote sensing of methane super-emitters,
2. maintain a limited scope in this first meeting to allow for progress,
3. invite the practitioners to share summaries of their analysis processes, lessons learned, and challenges ahead,

4. discuss current methods to assess performance of the remote sensing technologies with controlled-release testing,
5. discuss and reach consensus on key terms and definitions, and
6. identify next steps and plan future meetings.

1.1.2. Longer-Term Objectives

As an organizing structure, three pillars were proposed by the meeting conveners as potential elements of a longer-term strategy for improving confidence in remote-sensing of methane super-emitters:

1. Methodological consistency (observational strategies, data analysis, and quality control).

   In the initial meeting, January 2024, the emphasis was on engaging the community of technology and data providers with established experience in remote-sensing of methane super-emitters who could contribute to the development of consensus standards and best practices with the goal of establishing documentary standards such as those recognized nationally by the American National Standards Institute, ANSI, and internationally by the International Organization for Standardization, ISO.

2. Independent evaluation (controlled-release testing and other ground-truthing).

   Additionally, discussions centered on the need for independent evaluation of detection limits and accuracy of individual emission estimates. University labs with experience performing controlled releases to the atmosphere shared lessons learned and considerations for scaling up such efforts to address the unique aspects of satellite observations.

3. Enhanced transparency (enabling further intercomparison and repeatability).

   An add-on meeting was convened by the US GHG Center (https://earth.gov/ghgcenter) immediately following the January 2024 gathering for an initial discussion of the challenges of intercomparing data and methods from a diverse set of public and private-sector data providers. The discussions explored possibilities for the GHG Center establishing an “enhanced transparency portal”: analytic methods, algorithms, calibration/validation data, and/or exemplar/benchmark data sets to improve confidence in data accuracy and trust.

2. Participants and Perspectives

The meeting participants spanned a wide range of methane remote-sensing companies, non-profits, Federal and State agencies, international organizations, and university researchers. There were about 30 participants in person and the number of virtual attendees ranged from a few to about 25. Appendix A provides a list of attendees' organizations.

The January 2024 meeting included a critical mass of organizations with extensive experience performing measurements and/or analysis to identify atmospheric methane plumes and in most cases attribute them to specific emission sources and estimate emission rates. Participants came from groups performing research, non-profits, for-profit businesses, and regulatory and non-regulatory federal agencies. The range of groups is important for several reasons:

The for-profit companies focus on providing a set of services to companies and governments, so the performance characteristics they need are specific and known. They are focused on high-confidence measurements and plumes with known origins. Commercial entities generally are not interested in sharing low-level data but are willing to participate in comparisons of high-level products (plume locations and emissions).

The non-profit groups have broader open data policies.

The academic research groups are typically interested in exploring capabilities – how is the sensitivity impacted by different approaches and what can be extracted from a wide range of instruments? These groups may be exploring the range of conditions and sensitivities that are possible and may be more willing to share detached plumes and plume complexes without identifiable origins. They use measurement systems that range from those specifically designed for plume mapping to geostationary weather sensors. The detection sensitivities and spatial resolution of the measurements are wide ranging.

Engaging a diverse set of groups is important to ensure that this effort includes a range of perspectives that spans differing priorities and constraints that could translate to different approaches for data quality control, source attribution, emission estimation, and uncertainty quantification as well as varying abilities or appetite to engage in regulatory programs and data publication.

3. Concept of Consensus Standards

The United States uses a voluntary, consensus standards process. Standards in this context are descriptive documents that set terminology, definitions, references, and procedures and fall into two general categories: management and technical standards. Documentary standards development in the U.S. is done by several hundred standards development organizations (SDOs) ranging from those that develop documentary standards across broad groups of interest, e.g., ASTM International (formerly the American Society for Testing Materials), or by professional organizations where standards are of intrinsic interest to their membership, e.g., the Institute of Electrical and Electronic Engineers (IEEE) or the American Society of Mechanical Engineers (ASME). Industrial groups at times have need of specific requirements for uniformity related to product, process, or system needs and use industry-led organizations to establish standards for uniformity in operations and/or processes across an industrial sector, e.g., the American Gas Association (AGA), the Interstate Natural Gas Association of America (INGAA), or the American Concrete Pipe Association (ACPA).

The American National Standards Institute (ANSI) is a private, non-profit organization that administers and coordinates the U.S. voluntary standards and conformity assessment system. ANSI is the sole U.S. representative to the International Organization for Standardization (ISO) working closely with SDOs in their development of U.S. national standards. ANSI promotes the use of U.S. standards internationally, advocates for U.S. policy and technical positions in international and regional standards organizations, and encourages the adoption of international standards as national standards where they meet the needs of the user community.

4. Regulatory and Application Context

4.1. Context

The development of remote-sensing methane measurement techniques and the regulatory context are rapidly evolving. Potential regulatory applications include multiple EPA regulations of the oil and gas industry, leak detection and repair (LDAR) screening, and super-emitter reporting. The California Air Resources Board (CARB) amended the state oil and gas rule (see below), and additional regulations are currently in development. In the January 2024 meeting, specific applications of remote sensing data were discussed by CARB and the State of Colorado. The recently finalized methane rules of the U.S. EPA were also presented and discussed.

LDAR screening has existed for a wide range of gases and industries for more than 20 years, driven by Federal regulations of the EPA as well as state regulations. LDAR programs typically require direct detection of emissions using portable systems (e.g., optical gas imaging or EPA Method 21), on-site, by workers. In most cases, the emission rate of emitters is not measured, but when it is measured, direct-source measurement techniques are typically used, including high-flow sampling, flow meters, and similar techniques.

Recently, additional on-site methods have been developed. These include fence line sensing systems, fixed gas-imaging cameras, and open-path laser systems. While recent EPA regulations provide a path for these systems to become formally compliant with LDAR programs, most systems have not yet been approved as alternative methods. Multiple aircraft remote-sensing systems are currently capable of routine screening across large facilities or regions with spatial resolutions ranging from centimeters to several meters.

4.1.1. State Regulations

CARB recently amended the state’s Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities (the Oil and Gas Methane Regulation or the Regulation) to add a provision that requires owners or operators to respond to remotely detected methane plumes reported to them by CARB. The required actions include on-the-ground investigations to find the emission source (or alternatively reporting of an activity-based venting emission source), repair of the emission source depending the type of source found, and reporting on the outcomes of these inspections and repairs. These changes are an important element of programs to find and mitigate large emission sources, which often make up a disproportionate share of total emissions. These rules take effect on April 1, 2024.

The State of Colorado has developed new regulations on oil and gas, with key legislation in 2021 and 2023. The goal of these regulations is to accurately measure emissions from oil and gas operations to ensure that the industry is meeting its regulatory obligations to reduce greenhouse gas emissions through compliance with new intensity standards. The term “intensity” refers to the ratio of a facility’s amount of greenhouse gas emissions over the amount of oil and gas it produces.

More specifically, this rule functionally sets a requirement for both the state and operators to develop measurement-informed inventories of their methane emissions from the upstream segment (midstream is not applicable).[1] There are two pathways for compliance with this rule – the first path is that operators can develop their own 'Operator-Specific Program' to deploy different types of direct measurement technologies to improve the quantification of their emissions in the inventories. Should operators not wish to follow that path, they can utilize the 'State default factor,' which will apply a scaling factor to increase all of their reported emissions to match observations. The scaling factors are being developed by meta-analysis of multiple measurement campaigns to quantify upstream O&G sector emissions throughout the State.

The State is exploring how they can use super-emitter data from platforms like Carbon Mapper and MethaneSat in other contexts of improving the State's inventory for non-O&G sources and assessing rule compliance. They are utilizing all available technologies and methodologies to improve understanding of O&G sector emissions (mass balance, tower inversions, satellite inversions, point-source surveys).

4.1.2. Recent EPA regulation changes

In rules that were adopted by the EPA in November 2023 (published March 8, 2024, at 89 FR 16820), several important changes were made in the regulation of methane. The final rules include New Source Performance Standards for methane and volatile organic compounds, which apply to new, modified, or reconstructed sources and for the first time, Emission Guidelines, which set procedures for States to follow as they develop plans to limit methane from existing sources. A second change is that owners and operators can choose to use approved advanced methane detection technologies (e.g., aerial surveys) as an alternative option to meet the requirements for fugitive emissions detection and repair. This is also referred to as the Advanced Methane Detection Technology Work Practice.

Most relevant to this meeting is EPA's new Super Emitter Program, which leverages third-party data that identifies large emission events and prompts appropriate follow-up actions to investigate, identify, and remedy super-emitter events at regulated sources. The Super Emitter Program defines a super-emitter in the oil and gas source category as a methane emission that is larger than 100 kg/h. Research studies have shown that a relatively small number of super-emitters– many of which occur as highly intermittent and/or variable emissions events – contribute disproportionately to net regional oil and gas emissions. Under the EPA's new Super Emitter Program, third parties that use EPA-approved remote sensing technologies can become EPA-certified notifiers. These “third-party notifiers” are required to use information from remote methane monitoring technology, such as methane observations from satellites and/or aircraft to report super-emitter detections to the EPA. Any independent entities separate from the owners and operators of the facilities being measured may request to become a third-party certifier. This request must include a description of the measurement technology being used, standard operating procedures for processing super-emitter data consistent with the requirements in the rule, data quality management and retention processes, and proof of

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[1] Starting on Page 137 of this document: https://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=11327&fileName=5%20CCR%201001-9

expertise/training on the selected remote sensing technology. When a remote methane monitoring solution provider also wants to become a third-party notifier, EPA would conduct the third-party certification in conjunction with their review of the technology. EPA will review these qualifications and when the minimum standards are met, EPA will provide the third party with certification and access to a portal to provide EPA information on super-emitters. These certifications are effective 30 days after award and could be revoked if the notifiers use unapproved remote sensing technology, persistently submit data with significant errors, and/or engage in illegal activity during the assessment of a super-emitter event (e.g., trespassing).

Third-party notifiers must submit notifications to the EPA within 15 calendar days after a confirmed detection of a super-emitter event. An extensive set of information must be submitted to the EPA's Super Emitter Program Portal (see appendix). The EPA then evaluates the information, and if found to be complete and accurate, the EPA notifies the owner(s)/operator(s). The owner(s) or operator(s) must initiate an investigation within 5 days and report the results to the EPA within 15 days of notification. There is a process for the EPA to revoke certification of third parties for several reasons, include the failure to submit accurate data, or persistent submission of data with significant errors.

Additionally, the Inflation Reduction Act (IRA) was signed into law in August 2022, amending the Clean Air Act (CAA) to direct the EPA to impose and collect a charge on methane emissions that exceed statutorily specified waste emissions thresholds from petroleum and natural gas systems facilities that report to Subpart W of the Greenhouse Gas Reporting Rule. The CAA was further amended by the IRA to require that the EPA revise the requirements of Subpart W to ensure that the reporting (and corresponding waste emissions charge) is based on empirical data, accurately reflects the total methane emissions (and waste emissions) from applicable facilities, and allows owners and operators of applicable facilities to submit empirical emissions data to demonstrate the extent to which a charge is owed. In August 2023, the EPA proposed revisions to Subpart W consistent with these IRA directives. These revisions included adding a new source category referred to as "other large release events" to capture large emission events that are not accurately accounted for using existing methods in Subpart W. Under the proposed Subpart W revisions, data from some top-down approaches, including data derived from monitoring using advanced screening methods in accordance with the New Source Performance Standards or Emission Guidelines discussed above, in combination with other empirical data, could be used by reporters to calculate the total emissions from these events and/or estimate the duration of such an event. The proposed Subpart W revisions further required that owners or operators evaluate releases identified in notifications received under the EPA's Super Emitter Program and, if appropriate, report those releases as Other Large Release Events.

4.1.3. Barriers to acceptance of methane super-emitter remote sensing quantification

Given the new opportunity in the EPA Super Emitter Program, and the new attention and awareness of remote sensing measurements of methane in the news and events such as COP28, it is beneficial to consider the consistency of the information provided by the community of practitioners.

There are many organizations that provide methane plume information. As discussed below, there can be different quantification of emissions from the different organizations, which feeds skepticism about the validity of this measurement and quantification approach.

Specifically, two types of issues have been observed. Given differences in spatial resolutions, detection limits, approaches for attribution and quantification of emissions, sample frequency, the intermittent nature of some emissions, and the uncertainty of measurement and interpretation, different instruments may make measurements over the same source location and report different emissions.

In addition, in some cases the same measurement datasets are analyzed by several groups. As seen in Sherwin et al. (2023), the analysis of the same radiance measurement data by different groups can result in emissions estimates that vary by a factor of two or more. More recent work by several of the measurement and analysis teams, not yet published, shows that plume identification, source attribution, and emissions quantification based on the Earth Surface Mineral Dust Source Investigation (EMIT) data can vary substantially depending on analysis and quality control protocols.

These discrepancies need to be understood and addressed to build confidence and usability of remote sensing methane plume quantification. We want to start by discussing the terms and taxonomy, and eventually understand issues around quantification of single plumes. In the longer run, community discussion and consensus around how to use such measurements along with sampling statistics to understand trends in time on the facility and regional scale is needed.

5. Controlled-Release Experiments

To date, controlled releases of methane have been a key method for assessing the performance of methane plume sensing systems both in terms of detection limits and single measurement quantification accuracy. This is in part because the class of sensors used for point-source imaging generally lacks the higher precision of regional atmospheric sounders. These regional sounders can detect smaller gradients in column-averaged mole fractions and validate with surface-based solar tracking sensors such as NASA's TCCON network. Controlled-release experiments have been performed for aircraft instruments as well as satellites, which has the benefit of directly assessing the performance of emissions quantification. Key papers describing these experiments are:

- Sherwin, ED, et al. 2021. Single-blind test of airplane-based hyperspectral methane detection via controlled releases. Elem Sci Anth, 9: 1. DOI: https://doi.org/10.1525/elementa.2021.00063
- Sherwin, E. D., Rutherford, J. S., Chen, Y., Aminfard, S., Kort, E. A., Jackson, R. B., & Brandt, A. R. (2023). Single-blind validation of space-based point-source detection and quantification of onshore methane emissions. Scientific Reports, 13(1), 3836.
- Bell, C, et al. 2022. Single-blind determination of methane detection limits and quantification accuracy using aircraft-based LiDAR. Elem Sci Anth, 10: 1. DOI: https://doi.org/10.1525/elementa.2022.00080
- El Abbadi et al., 2024, Comprehensive evaluation of aircraft-based methane sensing for greenhouse gas mitigation, https://eartharxiv.org/repository/view/5569/

At this workshop, we invited two of the groups that perform controlled-release experiments to briefly review their past work and then share some information about future directions and the challenges ahead as the community of measurement practitioners expands.

Adam Brandt discussed the controlled-release program that he runs at Stanford University. This program has worked with drone, aircraft, and satellite data providers and created methane releases that range from 2 kg/h to 2000 kg/h of methane. There are many published papers showing results of the controlled-release testing. Overall, there has been extensive testing with aircraft systems, with hundreds of plumes detected by multiple aircraft. For satellite testing, the extent of testing is more limited, as overflight coordination is more difficult and release rates need to be large. The current focus for satellite testing is on baseline cases – uncomplicated albedo, cloud-free scenes, where operators know the location of the release. This is an important first step to baseline capabilities. Future experiments are being designed to perform releases in more complex environments (albedo variations, background clutter) and a wider range of environmental conditions such as temperature and humidity.

Dan Zimmerle presented the controlled-release work at Colorado State University/ Methane Emissions Technology Evaluation Center (CSU/METEC). They also have worked with both aircraft systems and satellites. Like Stanford, he reported that aircraft experiments can generally be completed in a week, while capturing a range of conditions with satellite system can take months. METEC has run the Colorado Coordinated Campaign, in which rather than controlled releases they work with industrial partners to get emissions information, install ground measurements, and have other aircraft overhead. In an experiment like this, they observed 123 plumes from oil and gas equipment. They were able to relate about a quarter to maintenance operations while 20% of estimated emissions could not be connected to a facility (likely due to low wind conditions).

6. Discussion/ Working Towards Consensus

To begin our discussion of consensus standards, we asked each of the measurement groups to make a short presentation that addressed the following questions.

- Slide1: describe your measurement technology including key parameters such as altitude, swath, ground sampling distance, etc, observational/sampling strategies, and key data products
- Slide 2: summarize your workflow for detecting, attributing, quantifying, and reporting super-emitters
- Slide 3: summarize your protocols for calibration, validation, quality control screening, and uncertainty quantification
- Slide 4: top issues, concerns, and lessons-learned from field experiences, including feedback from users
- Slide 5: what you'd like to see/recommendations regarding best practices and standards for super-emitter detection

In this workshop report, rather than provide detailed information about the inputs from every group, we will highlight the key messages, discuss common approaches and assessments, and then note where there are significant differences between the teams.

As described in section 3, the teams that were present have a range of measurement technologies and capabilities. Overall, the teams all had similar descriptions of their workflow and of the key steps of concentration retrievals, plume detection, source attribution, and quantification. For this workshop, we kept the focus on plume detection and associated terminology, with the expectation that later gatherings will complete initial terminology discussions and begin to address quantification topics.

A generalized workflow is captured in Figure 1. Teams that gather their own measurement data begin with collecting raw instrument data and transforming that into a radiance spectrum or power signal trace. For spectrometer-based instruments, these are then transformed into concentration fields using spectral reference data, in this case for methane, using a variety of retrieval approaches. The concentration field is used to estimate the retrieval precision, and from that the minimum detection limit. The plume detection step is another process where the details of each team's approach vary – the method to define the background and to delineate the plume from it is different for nearly every team. This step in the workflow informs plume detection rate and the probability of plume detection. Once a plume is detected, it may be attributed to an origin and source on the Earth's surface if justified by the shape of the plume and ancillary information such as GIS databases and higher resolution visible imagery. If not, the retrieval result is either characterized as a plume without a detectable source or rejected as a false positive. There was not consensus on the utility of publishing "detached plumes," which may be atmospheric enhancements some distance downwind of an actual emission source. Most teams do not publish such data, but some argued that such information is useful. It was clear from the discussion that the range of practices for detection of plumes will benefit from work toward consensus and a deeper understanding of the impact of detection strategies on plume information and quantification. The step of the workflow in which emissions are quantified was not a topic of this workshop, and we anticipate addressing this in future meetings.

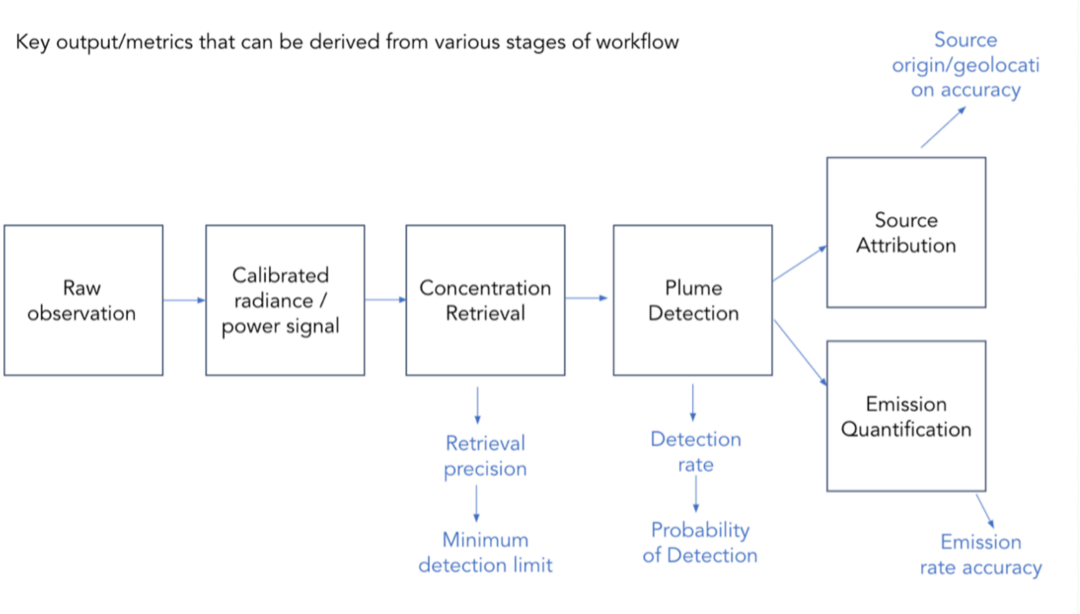

Figure 1: Generalized workflow for plume finding algorithms, courtesy of Dan Cusworth, Carbon Mapper.

We did not delve into detailed discussions of the exact methods used for concentration retrievals or plume detection, although we did hear that there are variations – many of which have been published in the open literature. For example, concentration retrievals and radiance analysis approaches that were discussed included matched filter, physics-based retrievals, and comparison to reference scenes. Plume detection approaches mentioned ranged from machine learning, visual analysis/hand drawn, percentile thresholding, and clumping algorithms. Every group reported that a human reviews the plumes before they move to the next step of analysis. Similarly, the source attribution step was described as using this same general approach by many of the groups, but the data available for them to use in that step varied significantly. Some teams rely on high-resolution imagery, others have GIS databases of infrastructure or internal asset databases.

Teams also reported that one to two people review each plume before it is shared or published. The phrases used to describe this analysis step include manual verification, removing double counting, filtering false positives, quality review and check, manual adjustments of plume masks, assessment of plume shape consistency with wind speed and direction, verification of geo-registration, evaluating quality of relationship of plume and point source, operators look for spurious signals and surface reflectance information, and human-supervised validation.

The presentation of approaches for calibration, validation, quality control screening, and uncertainty quantification revealed that all teams engage in pre-flight (for aircraft), pre-launch (for satellites), and on-orbit calibration of instruments. Also, the teams all discussed the use of controlled-release experiments. Some teams use comparison with independent instruments (such as aircraft underflights of satellites) and others use or plan to use comparisons between satellites. Two groups do or will validate their satellite measurements with traditional ground-based measurement systems such as TCCON[2] and/or the Bruker EM-27/SUN Solar Absorption Spectrometer (the instrument of the COCCON network). One team uses the spatial variability of data across plume-free regions as an element of the calibration analysis.

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[2] The Total Carbon Column Observing Network (TCCON) is a network of ground-based Fourier Transform Spectrometers recording direct solar spectra in the near-infrared spectral region.
https://ndacc.larc.nasa.gov/about/cooperating-networks/total-carbon-column-observing-network

7. Challenges, Recommendations, Issues, and Concerns

7.1. Input from teams

Many ideas were shared about lessons learned and recommendations for future directions. The key ideas and phrases as presented in discussion are listed below, grouped by topic. The list below captures topics that were raised, rather than a consensus view. The teams identified many similar areas for improvement.

<u>Communication and need for standardization</u>

- Building trust
- Want to build trust through rigorously vetted and standardized best practice measurement approaches
- Open data and algorithms
- It is imperative that data provenance, models, and assumptions be thoroughly documented
- Proliferation of data portals without standards on methods and reporting
- Reporting frameworks should acknowledge that quick-look results are more uncertain than later/iterated results
- End users can be suspicious and confused when multiple organizations provide different quantifications (emissions estimates), even if they are within uncertainties
- Community should develop agreement on nomenclature, especially around validation (detection limits) and benchmark conditions for validation measurements
- An effort should be made to combine super-emitter data across platforms/sensors

<u>Data product formats</u>

- Would be useful to have community agreed on (consensus) standards for products, especially for higher level products – with agreed upon units and formatting
- Data format heterogeneity makes intercomparisons hard
- Standardization of data products

<u>Sources of error</u>

- Have challenges with dependence on environmental conditions, systematic error, random error.
- Wind speed uncertainty drives plume detection uncertainty. Wind characteristics shape the plume, and highly variable winds can create hard-to-interpret plume shapes. Emissions quantification uncertainty is directly related to wind speed uncertainty.
- Systematic retrieval errors must be included, we can’t assume just random, uncorrelated detector noise
- Intermittency, intermittency, intermittency [point sources are often intermittent, and this makes sampling them and characterizing the emissions over time very challenging] (this relates to interpretation issues beyond the scope of this workshop)

- Wind products and treatment of winds is a big source of uncertainty
- Flow to volume assessment is hard [meaning you know a flow rate, but you don't know duration]
- Sensitivity of detection limit to environmental conditions means that a probability of detection curve is a more informative way to report capabilities.

Validation and controlled releases

- In addition to controlled release testing, other methods for ground-truthing (such as independent observations of known persistent emitters) could improve confidence in remote-sensing data
- Coincident aircraft and satellite observations valuable in addition to controlled releases
- Multiple methodologies (controlled release, satellite cross-validation, validation with non-satellite observation) should be used (are useful to) maximize confidence in data
- Controlled releases more informative if different sensors all use the same shared controlled release facilities and participate in blinded studies

Need for automation and timeliness of results

- Rapid analysis and plume reporting after measurement is of the essence
- Different use cases have different requirements for accuracy and latency
- Need more observations, automated data procedures
- Developing effective automated plume detection is first order problem
- Need more automation – for detection and attribution. QC requires significant human in the loop effort
- Automated detection must be evaluated using characterization of false positives, not just true positives
- Non-detects must also be reported
- Automation is essential to manage data volume

Attribution needs

- Plume attribution difficult with just free surface imagery [which may be outdated and/or have coarse resolution]
- Infrastructure data needs to be high quality

7.2. Discussion of taxonomy and terminology

Two breakout groups were formed for more detailed discussion on best practices and terminology. One of the breakout groups focused on concentration retrievals and plume detection. The other breakout was focused on attribution, quantification, and reporting. The aim was to discuss and develop consensus on best practices. Consensus was reached on some terms, but a significant number of open issues remain. The development of consensus terminology will require additional effort.

A brief capture of the results of the breakout discussion is below.

- On the topic of retrieval precision, there is a general consensus with some discussion of the difference between theoretical calculations and what is inferred from actual measurement datasets.
- There was discussion of precision of emission estimates and the group identified that as an area without consensus and some technical topics that need to be addressed.
- We did reach consensus that minimum detection limit is not a useful concept, but we should talk about detection thresholds (or 90% detection threshold) that are tied to precision estimates and observing conditions. Several groups share information about their performance in this way. A concept that was raised but not fully agreed upon is that we should define a set of observing conditions (perhaps a reference observation) and all teams can report detection limit for this observing condition.
- On the topic of plume detection, there was a long discussion and a variety of frameworks that people use in this area. Overall, all the teams detect an enhancement, define a background, and then quantify the enhancement relative to the background.
- Some teams require a certain number of pixels to define a plume, to address concerns of noise being labeled as an ultrasmall plume.
- Many teams discussed the need to examine other data, such as surface reflectance and cloud fields to evaluate whether the apparent plume is an artifact.
- Overall, there was a lot of similarity in approaches to plume detection, although the specifics of the method to differentiate plume from background and to find the plume edges varied significantly.
- The topic of attribution led to a long discussion with several unresolved issues. Most of the groups use visual imagery, databases of infrastructure, etc. in the process of attribution. The plume origin is typically assigned to a concentration hot spot in the plume, and then the nearest plausible piece of infrastructure is assigned as the plume source. But there were a number of unsettled issues. The ability to tie a plume source to a piece of infrastructure also depends on the spatial resolution of the measurement system. Each team appears to have different sources of information about infrastructure locations, and few, if any, teams have complete geospatial information for oil and gas infrastructure.
- Transport and emissions variations may result in a plume that does not have an origin near infrastructure. Most groups found it problematic to report such plumes, although others were advocating that there is value to share these observations. There were varying approaches to how to report or use these, and even what to call them.
- There was some discussion of how to communicate the time that the plume was observed, and that for some technologies, in which measurements are integrated over time, this information needs to be clear.

8. Next Steps

- Develop and distribute this workshop report
- Complete and distribute consensus document of definitions and goals and actions ahead
- Develop consensus document with best practices for workflows
- With the organizing committee, develop agendas for additional needed meetings Topics could include:
    - Attribution and quantification
    - How to use multiple observations to develop regional, quarterly, or annual emissions estimates
    - Intercomparison strategies
    - Landfill and confined animal feeding operation/manure pit detection

Appendix A. Workshop Participant Organizations

A.1. Measurement and Analysis Organizations

Bridger Photonics
Carbon Mapper
GHGSat
Harvard University School of Engineering
EMIT/JPL
Kairos Aerospace
Kayrros
MethaneAir
Netherlands Institute for Space Research (SRON)
The International Methane Observatory

A.2. Federal and State Agencies

Department of Commerce, National Institute of Standards and Technology
Department of Commerce, National Oceanic and Atmospheric Administration
Department of Energy, Fossil Energy and Carbon Management
Department of Justice
Environmental Protection Agency (EPA), Office of Air Quality Planning and Standards (OAQPS)
EPA, Air Quality Assessment Division (AQAD)
EPA, Measurement Technology Group
EPA, Office of Enforcement and Compliance Assurance
EPA, Office of Research and Development (ORD)
National Aeronautics and Space Administration
State of California, Air Resources Board
State of Colorado, Department of Public Health & Environment

A.3. International Organizations

The National Physical Laboratory, United Kingdom

A.4. Academia

The University of Texas