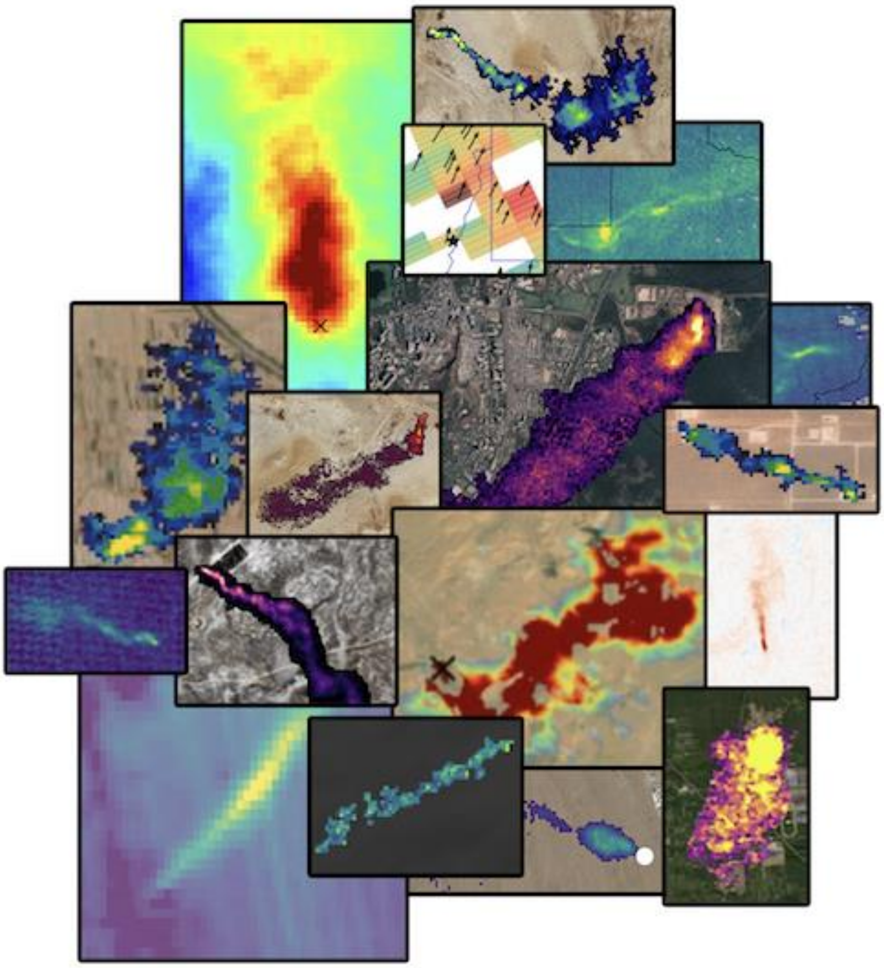
User Requirements Document v2.1

WP110 - Deliverable D1.1



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Change log

Version	Date	Status	Authors	Reason for change
0.1	11/07/2024	Version for review by User Group	see title page	New document
0.2	29/7/2024	Version for review by project lead SRON		Included feedback from User Group (Hugo Denier van der Gon, Sander Houweling)
1.0	04/09/2024	Version submitted to ESA		Included feedback SRON

1.1	26/10/2024	Version submitted to ESA		Include feedback from ESA RID_v1.0
1.2	09/06/2025	Version for review by User Group		Yearly update
2.0	01/10/2025	Version submitted to ESA		Included feedback from User Group
2.1	21/10/2025	Version submitted to ESA		Include feedback from ESA dated 16 October 2025

List of Acronyms

- CAL/VAL – Calibration and Validation
- CAMS – Copernicus Atmosphere Monitoring Service
- CEOS – Committee on Earth Observation Satellites
- CLDP – Commercial Law Development Program
- CO2MVS – Copernicus CO_2 Monitoring and Verification Support
- EC – European Commission
- ECMWF – European Centre for Medium-Range Weather Forecasts
- ESA – European Space Agency
- IG3IS – Integrated Global Greenhouse Gas Information System
- IGO – Intergovernmental Organizations
- IEA – International Energy Agency
- IMEO – International Methane Emissions Observatory
- LDAR – Leak Detection and Repair
- MARS – Methane Alert and Response System
- MEDUSA – Methane Emissions Detection Using Satellites Assessment
- MRV – Measurement, Reporting, and Verification
- NDC – Nationally Determined Contributions
- NGO – Non-Governmental Organization
- NIST – National Institute of Standards and Technology
- POD – Probability of Detection
- RMI – Rocky Mountain Institute
- SPECT – Satellite Point Source Emissions Completeness Tool
- SWIR – Short-Wave Infrared
- TNO – Dutch Organisation for Applied Scientific Research
- TROPOMI – Tropospheric Monitoring Instrument
- UKSA – United Kingdom Space Agency
- UNEP – United Nations Environment Programme
- UNFCCC – United Nations Framework Convention on Climate Change
- WMO – World Meteorological Organization

Table of Contents

1. Executive summary

The MEDUSA, Methane Emissions Detection Using Satellites Assessment, project is focusing on intercomparing and validating the detection of methane plume hot spots and their emissions quantifications across the various existing satellites.
To assist different users in utilizing this rapidly expanding and powerful satellite data, this document lists the main use cases of methane hotspot data, along with the requirements of the various users associated with each use case. These requirements are not qualitative evaluations of current capabilities, but practical specifications that indicate what information, processing steps, or metadata should be included in the satellite data products to enable their smooth integration into users' workflows and decision-making processes.

The users included in this project are ECMWF/CAMS, The European Commission (EC), IEA, IG3IS/WMO, IMEO-MARS, and TNO. Through individual sessions with the users, it was determined that the users' applications can currently be described by the following four different use cases:

- The detection & attribution of super-emitters (here defined as localized sources emitting above 100 kg/hr) enabling mitigation actions
- The quantification of emissions from the detected super-emitters
- Derive yearly emissions from super-emitter data at the country-level
- Incorporate super-emitter data into (facility-level) emission inventories

It should be noted that use-cases 3 and 4 do not describe total methane emissions. Rather, they focus on emissions from super-emitters (events) and are intended to complement existing inventories that account for non-super-emitting sources.

The following table below summarizes the link between the users and the use-cases.

Users / **Use-cases**	IMEO-MARS	IEA	ECMWF-CAMS	TNO	IG3IS	EC
1. Super-emitter detection	x	(x)	x			x
2. Super-emitter quantification	x	(x)	x		x	x
3. Aggregation analysis of super emitters	(x)	x	x	x	x	
4. Inventory at the facility-level	(x)		x	x	x	

(x)Lower priority

User requirements across various use cases exhibit significant similarities, particularly in validation and interoperability. Validation consistently relies on validated instruments, data products and documented methodologies. While interoperability requirements share common metadata, they also demand precise, use case-specific metadata unique to each context. Harmonization requirements are minimal, but adherence to timeliness varies according to the specific needs of each use case.

2. Introduction

The MEDUSA, *Methane Emissions Detection Using Satellites Assessment*, project is focusing on intercomparing and validating the detection of methane plume hot spots and their emissions quantifications across the various existing satellites.

The users included in this project are:

- ECMWF/CAMS represented by Richard Engelen, is responsible for developing the Monitoring and Verification Support (CO2MVS) capacity for anthropogenic CO2 and CH4 emissions, as part of its overall portfolio. CO2MVS will assist the European Commission (EC) in conducting the global stocktake by utilizing ground-based measurements, Earth observation data, and advanced modeling techniques. It will also support the EC and EU member states in implementing the EU Methane Strategy and the Global Methane Pledge by enabling the detection and monitoring of global super-emitters. Additionally, CAMS will contribute to international coordination efforts for monitoring greenhouse gas concentrations and fluxes, such as the Global Greenhouse Gas Watch led by the World Meteorological Organization and the UNEP International Methane Emissions Observatory. CAMS now has a methane hotspot tracker operational and plans to integrate data from additional satellite constellations (from the Copernicus Contributing Missions) to enhance its monitoring capabilities (CAMS, 2025, https://apps.atmosphere.copernicus.eu/methane-explorer). As such, CAMS is engaged in all four use cases. However, its top priority regarding methane plumes and hotspots is the global detection and quantification of emissions from methane super-emitters to support its ongoing initiative. On the other hand, CAMS has a growing interest in use-cases 3 and 4, although CAMS is currently more advanced in CO2 monitoring with regards to these topics (personal communication, CAMS representative at ECMWF).
- The European Commission (EC) represented by Brendan Devlin, Henry Winckle, and Leona Kolberg from its Directorate-general for Energy, is interested in using satellite-based methane plume hot spot data as one of the tools/datasets to support the new EU Regulation on methane emissions reduction in the energy sector. This data is expected to be an important component of the EC's methane transparency database, providing real-time, publicly accessible information on methane emissions. The EC also intends to use this information for the Regulation's rapid reaction mechanism, enabling swift notification and responses to significant methane emissions events within and outside the European Union. This dual approach aims to enhance

transparency, ensure regulatory compliance, and facilitate timely mitigation across the EU's energy supply chain. The EC would also use this data in support of engagement with third countries, encouraging them to also directly use the data and integrate it into or use it to create domestic monitoring, all in support of meeting the 30% by 2030 Global Methane Pledge target and thereby broader climate goals.

- IEA represented by Tomás Bredariol and Courtney Turich is focused on obtaining yearly estimates of total super-emitter emissions at country level. This data will be used to analyze trends in methane emissions, allowing the IEA to assess the effectiveness of mitigation efforts and identify emerging patterns. By tracking super-emitter emissions over time, the IEA aims to support policy development, promote best practices, and guide international efforts to reduce methane emissions in the energy sector. The IEA recently launched a new initiative focused on the accountability of companies, specifically comparing reported versus measured emissions, where they use a mix of satellite data and other sources (IEA, 2024). This would fall under use cases 1 and 2, keeping in mind this is of secondary priority for IEA.IG3IS/WMO, represented by Sander Houweling, is focused on supporting countries in using super-emitter data to enhance their national greenhouse gas inventories and evaluate their Nationally Determined Contributions (NDCs) under the Paris Agreement. While IG3IS/WMO does not directly integrate super-emitter data into national inventories, it plays a key role in formulating good practice guidelines. These guidelines help countries understand how to utilize atmospheric data, including satellite datasets, to improve methane emission reporting and ensure transparency. By doing so, IG3IS/WMO aims to empower countries to assess their emissions with scientifically sound methods, ensuring independent and traceable data flows. A key area of interest for IG3IS/WMO lies in the intersection of use-cases 3 and 4, specifically targeting urban-scale emissions where there is a strong potential in leveraging super-emitter data to refine high-resolution inventories in urban environments.
- UNEP's MARS represented by Itziar Irakulis Loitxate, Manuel Montesino San Martin and Cynthia Randles (formerly with IMEO), Yasjka Meijer from CEOS joined the telecon with MARS in 2024. MARS is the Methane Alert Response System managed by UNEP's International Methane Emissions Observatory (IMEO), which is developed to support companies and governments to reduce their methane emissions in support of the Global Methane Pledge. MARS is leveraging satellite-based super-emitter detections and source attribution to notify oil and gas operators and government stakeholders of ongoing methane

emissions and encourage prompt mitigation actions. By providing operators with near real-time data on large events, UNEP's MARS aims to drive rapid responses and reduce methane leaks in the oil and gas sector. MARS also plans to expand the notification process to the coal and waste sector in the near future (UNEP, 2024), although with lower notification latency due to the higher complexity to rapidly mitigate the emissions from these sectors. After some time, the data is also provided on the public IMEO's Eye on Methane data platform for transparency. As such, use cases 1 and 2 are the prime focus for MARS. However, there is a growing interest in use-case 3, as MARS users are increasingly requesting estimates of total emissions at national or regional scales.

- TNO represented by Hugo Denier van der Gon and Emma Schoenmakers, is interested in using super-emitter data to improve their gridded emission inventories at the facility level. By incorporating super-emitter estimates, TNO aims also to improve the accuracy of methane emissions reporting and refine country-level total emission estimates on an annual basis. This data will also help distinguish between point source and diffuse emissions more accurately. This approach will provide more detailed and reliable data for tracking methane emissions, supporting both national and international climate goals through better-informed bottom-up emission inventories. Next to this, large accidental releases (super emitter events) are not covered in a regular inventory or reporting scheme. Therefore, having the quantification of these events as an "add-on" to the regular TNO products (e.g. under CAMS) would be valuable (personal communication, TNO representative).

To ensure the accuracy and relevance of the information presented, the former paragraph has been updated based on insights gathered during informational interviews with key stakeholders.

This document draws upon existing literature and feedback gathered from individual sessions with each member of the User Group during May and June 2024 to list the main use cases of methane hotspot data (e.g. supporting mitigation activities and improving reporting under the UNFCCC Paris Agreement), along with the requirements of the various users associated with each use case. As this field is new and rapidly evolving with emerging use cases, this document will undergo annual updates.

The User Group will also assess the extent to which the MEDUSA project meets these requirements at the project's midpoint and conclusion as part of WP610.

3. Review of existing documentation

Methane has become an important focus for various communities that are deeply invested in detecting and mitigating its emissions. The monitoring of methane from space offers valuable information for a wide array of end users, each with specific goals, responsibilities, and decision-making needs. The following communities have shown particular interest in this technology for measuring methane plumes and emission hot spots:

- Legislative bodies and policymakers are interested in using satellite data to inform policy decisions, enforce regulations, and track progress towards emission reduction goals
- Regulatory compliance bodies use satellite-based methane detection to monitor compliance with emission regulations and verify reported emissions data
- Researchers aim to utilize these satellite-based Data to improve the detection and quantification of methane plumes.
- NGOs, IGOs and think tanks interpret satellite data to provide actionable insights for various end users, bridging the gap between complex data and practical applications
- Operators use methane data for leak detection and repair, emissions reduction efforts and to comply with environmental regulations
- Investors and financial institutions are looking for satellite-derived methane emissions data to assess climate-related risks and inform investment decisions.
- Intermediaries such as IMEO MARS and CAMS that provide actionable information to, for example policymakers, or to governments and companies.

Each of these user communities has requirements for methane detection from space, driven by their specific goals. Currently, there is limited detailed documentation outlining the various user requirements associated with the use of methane super-emitter data. Efforts in this regard can be categorized into two main streams.

The first category revolves around requirements, exemplified by CEOS/IMEO's initiative in 2023, which organized a workshop (June’23, Harvard) followed by separate telecons addressing themes such as Observability, Data Integration, Use Cases, Roadmap, and Cal/Val/Testing. The objective was to craft a concise 'charter' for each working group, comprising the problem statement, methods for addressing it, and short- and long-term goals, needs, or deliverables.

The second category focuses on Methane standards. Two events have delved into this realm:

1. The NIST workshop in January 2024, associated with the forthcoming EPA super-emitter program, aimed to establish a consensus on definitions, draft standards, and best practices for point source detection, geolocation, and attribution. It also aimed to explore frameworks for data intercomparison, enhance transparency, and discuss protocols for reconciling discrepancies among data producers, particularly in response to public inquiries. Following the workshop, NIST released a summary report (Eldering A., 2024) that captured the key presentations and discussions from the event. The document served mainly as a record of the current state of efforts and preliminary planning for future work, rather than offering formal recommendations or conclusions. Since then, a change in the U.S. administration has shifted federal priorities, and further progress by NIST on this topic have slowed.
2. The NPL workshop, supported by the UKSA, in 26-28 February 2024, centered on "Towards an Internationally Recognized Standard in Methane Monitoring from Space." This event notably discussed the standardization of methodologies for super-emitter detection and quantification. While the workshop itself did not result in a dedicated report describing requirements, its discussions and outcomes contributed to a broader CEOS publication on common practices in satellite-based methane monitoring. This report is discussed in the following paragraph.

On the other hand, many of the mentioned communities have qualitatively articulated their needs through reports, handbooks or notes. A major contribution to defining these needs comes from CEOS and its GHG Task Team on Emissions Reporting (CEOS, 2023). A workshop aimed at developing a common framework for reporting estimates, uncertainties, and ancillary data related to satellite-based methane detection was organized. By prioritizing transparency, standardization, and rigorous evaluation methods, the CEOS initiative seeks to improve the usability and reliability of methane detection data from satellites, supporting both scientific research and policy-making efforts. Furthering this work, CEOS has also published guidance through the CEOS/WGClimate Common Practices for Quantifying Methane Emissions from Plumes Detected by Remote Sensing (CEOS/WGClimate, 2024). This report outlines a consistent set of practices for estimating methane emissions from localized plume detections and aims to harmonize approaches used across the remote sensing community. It highlights the importance of clear documentation, quality control, and methodological transparency, offering both data producers and users a reference for evaluating the reliability and comparability of emission estimates derived from satellite observations. Likewise, The Rocky Mountain Institute has advanced the technical evaluation of methane monitoring through their analysis of satellite detection capabilities (RMI, 2023). Their report introduces "completeness" as a standardized metric for comparing satellite platforms and presents the Satellite Point source Emissions Completeness Tool (SPECT). This contribution provides stakeholders across industry, policy, and public spheres with a practical framework for evaluating and implementing satellite-based methane detection technologies.

The “An Eye on Methane” reports illustrate the evolving needs of stakeholders as satellite methane detection systems mature. The 2023 edition emphasized the importance of understanding the capabilities, limitations, and validation needs of satellite-based observations, particularly in the context of integrating diverse datasets for consistent and transparent emissions reporting. It laid the groundwork for aligning satellite-derived data with the expectations of both regulatory frameworks and operational decision-making. Building on this foundation, the 2024 report highlights major advancements in the International Methane Emissions Observatory’s Methane Alert and Response System. The system now delivers integrated, validated satellite data directly to governments and companies, significantly enhancing the speed, precision, and operational relevance of methane detection. This evolution, from clarifying technical concepts to enabling real-time response, reflects the growing demand for actionable, high-quality satellite data that can support immediate mitigation efforts while maintaining scientific credibility and usability across sectors. Similarly, Gasim et al. (2023) and Shannon et al. (2025) collectively highlight the importance of understanding the limitations and appropriate scope of satellite-based methane products to effectively leverage them. While Gasim et al. emphasize the uncertainties in satellite-derived GHG estimates, advocating for improved quantification methods and integration into national inventories, Shannon et al. focus on the operational challenges, including environmental conditions like cloud cover, low light, and complex terrain. Both underscore the need for users, ranging from policymakers to NGOs, to critically assess coverage and uncertainty when interpreting satellite data, ensuring its effective and transparent use in emissions monitoring and mitigation.

Policy and regulatory frameworks are also evolving in response to the increasing role of satellite detection. The CLDP handbook for policymakers on methane abatement in the oil and gas sector (CLDP, 2023) provides valuable contextual insights into how governments and regulatory bodies are beginning to incorporate detection capabilities into regulation. It helps translate scientific knowledge and technological advancements, including those derived from satellite-based methane detection, into effective policy instruments. This is exemplified by Canada's proposed methane regulations, which now suggests rapid action for emission events exceeding 100 kg/h and reflect a broader move toward performance-based standards. Although current probability of detection benchmarks (e.g., 90% PoD for ≥1 kg/h) are not yet fully compatible with the capabilities of satellite systems, such policy developments indicate a growing expectation for precise, quantitative, and verifiable monitoring technologies. It is important to note that the amendment to the regulation on methane reduction is still in progress and has not yet been finalized or published in Part II of the Gazette.

Finally, J.P. Morgan Chase has also provided its perspective on leveraging technology for continuous improvement in methane emissions management within the Oil & Gas sector (JPMorgan Chase & Co, 2023). This note offers insights into the requirements and expectations from the financial sector, which plays a crucial role in funding and influencing industry practices. This perspective from a major financial institution adds weight to the importance of developing and implementing effective methane monitoring and abatement strategies, potentially influencing both industry practices and policy decisions.

The scientific literature also reflects a growing interest and describes the recent revolutionary advancements in satellite-based methane detection and emission quantification techniques. An extensive overview can be found in the Review State-of-the-art (D1.2). Major game changers in this field - pushed amongst others by scientific developments - have been 1. the capabilities of TROPOMI on Sentinel-5 Precursor for the first time given us a (daily) global view on methane super emitters (e.g. Lauvaux et al., 2022; Schuit et al., 2023); 2. the launch of satellites dedicated to measuring methane at facility-scale resolution (Varon et al., 2019); 3. the realisation that high spatial resolution Earth imagers not designed to measure methane but with SWIR channels can detect the largest emitters under favorable conditions (Varon et al., 2021; Cusworth et al., 2021; Guanter et al., 2022; Jacob et al., 2022); and 4. the use of tip-and-cue combining global flux mapper observations (e.g. from TROPOMI) with the facility scale high resolution satellites providing a very powerful tool to detect super emitters and identify their exact source (e.g. Maasakkers et al., 2022; Irakulis-Loitxate et al., 2022). These developments combined have led to a complex, diverse, and interconnected observing system that provides very valuable information on methane emissions but can be difficult to assess and understand for users. Recent studies have also focused on validation of various satellite systems for methane sensing at facility scale level. The validation efforts highlighted by Sherwin et al. in 2023 and 2024 aim to assess the accuracy and reliability of different satellite platforms in detecting and quantifying methane emissions from point sources. These advancements in remote sensing techniques and their validation are crucial in responding to the early qualitative requirements of end-users. However, the scientific community emphasizes the ongoing need for further refinement of these techniques and continued intercomparison studies to ensure accurate and reliable methane emissions data from space-based sensors. This is the focus of ESA's MEDUSA project.

4. Terminology

Super-emitter: Here defined as a large, urban to facility-scale methane emission source quantified with a flow rate above 100 kg/h. In the oil and gas sector, such events can occur due to equipment malfunctions, pipeline leaks, or improper venting and flaring practices. In the coal industry, methane super emitters are typically associated with ventilation systems in underground mines or coal seam degasification processes. The waste sector sees similar emissions produced from the anaerobic decomposition of organic waste that escape from capture systems or open landfills. The term "super-emitters" has been used with different meanings, originally referring to facilities that both emit a lot and relatively more than similar facilities. Currently, the term is widely used in the satellite community to identify sources that have been found emitting large quantities of methane, even if those emissions are short in duration or are consistent with expected emissions and similar to other facilities.

Threshold requirement: The limit beyond which the data is of no use to a given application.

Breakthrough requirement: The level at which significant improvement in the given application would be achieved.

Goal requirement: The level beyond which further improvement would be of no value for the given application.

Intercomparison: Facilitates performance evaluation and comparison among different satellites/sensors or providers through common evaluation metrics.

Validation: Ensures the reliability and scientific rigor of the approach through independent comparison with "truth" value.

Interoperability: The combined use of super-emitter data from different satellite instruments or different data providers. Standardize data formats and metadata conventions when sharing super-emitter data to enable consistent interpretation by users.

Harmonization: Facilitates the integration and blending of datasets originating from various satellite instruments or providers, accomplished by calibrating and validating them against common reference standards.

5. Use-cases

5.1 Use case-1 Super-emitter detection & attribution leading to mitigation actions

Use-Case - Description

Access super-emitter detections with source attribution to make this data actionable for targeted mitigation actions (LDAR).

Use-Case - Illustration

Access a recent super-emitter detection over a O&G well in Algeria and notify the operator so that they can repair the leak.

Intercomparison Requirements

Detection and reliability indicator of detection (High/Medium/Low)

Allows comparison of detection reliability across different satellites or sensors

Detection threshold of the satellite used under reference conditions

Allows fair comparison of sensitivity, allowing to evaluate whether a non-detection is consistent with a detection by another instrument

Probability of detection curve

Allows fair comparison of sensitivity, allowing to evaluate whether a non-detection is consistent with a detection by another instrument

Spatial resolution of the satellite used (e.g., 20m x 20m)

Allows comparison of the ability to pinpoint emissions sources accurately

Revisit time

Allows comparison of the ability to capture intermittent emissions and to track super-emitter evolution over time

Validation Requirements

Validated instrument and approach with controlled releases or demonstrated consistency with validated instruments (related to detection threshold only)

Ensures the reliability of detected plumes

Quality control process (to filter out false positives)

Ensures overall accuracy and reduces the likelihood of misreporting emissions events

(Peer reviewed) documented methodology for methane detection with versioning

Ensures transparency and reproducibility

Interoperability Requirements

Mask of the plume

Ensures consistent visualization and analysis across different satellites or data providers

Source location, and Uncertainty about the source location (in meters)

If possible: coordinates of the most likely facility nearest to the upwind edge of the plume using public imagery. It is noted that users (such as IMEO-MARS) ultimately need operator information, but this is proprietary data and as such considered out of scope for MEDUSA.

Ensures robust integration of data from different satellites or data providers

Shared Metadata (see end section 5)

Additional Metadata:

- Version of the methodology used (for detection and attribution)
- Visual of the detection with a legend, same unit of concentration
- Most recent high-quality acquisition without any detection (if available)

Harmonization Requirements

None

Use Case Variation - 1: Responsive Monitoring

In certain scenarios, there arises a need to swiftly deploy resources to identify the exact source and monitor a specific event, such as the Nord Stream leak in 2022 or the Oil & Gas well blow-out in Kazakhstan 2023. This rapid response mechanism is essential for gathering extensive data points within a short timeframe, enabling a comprehensive analysis of the emission event.

Use Case Variation - 2: Rapid Detection Mechanism

One of the users identified a potential addition of the use case that emphasizes more rapid detection. This alternative approach aims to achieve quicker identification of relevant events or conditions leading to a rapid reaction, albeit with a trade-off in reliability. However, this may lead to an increased rate of false positives. Users who prioritize speed over accuracy might find this approach beneficial, especially in scenarios where timely detection is critical and occasional false alerts are acceptable. It is important to consider this balance between detection speed and reliability when evaluating the suitability of this use case variation for specific operational contexts. This use case is not implemented today by any user, but this might evolve and could then be considered for future updates of this document.

5.2 Use case-2 Super-emitter quantification

Use-Case - Description

Access quantified super-emitter detections with flow rates for leak detection and repair (LDAR) and methane reporting/verification (MRV) applications.

Use-Case - Illustration

Quantify super-emitter detections over a specific oil and gas site for three months to monitor emissions after a repair intervention.

Intercomparison Requirements

Uncertainty breakdown (wind, product, background)

Enables a more nuanced comparison of quantification accuracy across different satellites or providers

Validation Requirements

Validated instrument and approach with controlled releases or demonstrated consistency with validated instruments

Ensures the reliability of observed resulted emission quantifications

(Peer reviewed) documented methodology for methane quantification and uncertainty

Ensures transparency and reproducibility

Interoperability Requirements

Flow rate (in tons/hour)

Allows a consistent interpretation of the magnitude of an emission

Flow rate uncertainty (in tons/hour)

Allows more trustworthy integration of data from multiple sources for comprehensive analysis

Shared Metadata

Additional Metadata:

- Version of the methodology used (for detection, attribution and emission quantification)
- Visual of the detection with a legend, same unit of concentration (column average mixing ratio)

Harmonization Requirements

None

Use-Case Variation - 1: Responsive monitoring

This use case variation builds upon the variation previously described in the "Super-emitter detection & attribution leading to mitigation actions" use-case. In certain scenarios, there arises a need to swiftly deploy resources to monitor a specific event, such as the Nord Stream leak in 2022 or the Oil & Gas well blow-out in Kazakhstan 2023. This rapid deployment mechanism is crucial for enabling comprehensive monitoring over time, tracking the evolution of the emission, and assessing the effectiveness of any mitigation actions implemented. Such agile responses are essential for timely decision-making and mitigating the impact of methane emissions effectively.

However, this mechanism may affect the previously defined requirements by shortening the necessary timeliness for quantification to occur, and underscores the importance of harmonized, comparable and validated data.

5.3 Use case-3 Aggregation analysis of super-emitters

The requirements in emission integration come on top of earlier defined requirements on detection and quantification.

Use-Case - Description

Access year-over-year comparisons of total methane super-emitter emissions globally and for specific regions/countries with a distinction of persistent and short-term (potentially accidental) emissions if possible.

Use-Case - Illustration

Estimate total detected US super-emitter emissions per sector using TROPOMI detections for the year 2023.

Intercomparison Requirements

Detection threshold of the satellite used under reference conditions

Allows fair comparison of sensitivity, allowing to evaluate whether a non-detection is consistent with a detection by another instrument

Explanatory note on interpreting the estimates and their limitations

Allows to understand potential biases in aggregated results

Revisit time

Allows to assess the completeness and reliability of aggregated results

Validation Requirements

(Peer reviewed) documented methodology for the quantification approach

Ensures transparency and reproducibility

(Peer reviewed) documented methodology for the summation/upscaling approach accounting for observation coverage and leak duration

Ensures transparency and reproducibility

Interoperability Requirements

Shared Metadata

Number of useful observations over the region

Allows users understand the coverage and frequency of monitoring, evaluate potential gaps and the robustness of the analysis

Number of detections over the region

Allows users to understand the scale of the problem

Average flow-rate per detection

Allows users estimate the potential impact of mitigation efforts

Distribution of flow-rates

Allows users to access more detailed information on the distribution of emissions on top of the average value

Total super-emitters emissions for the region (in Mt)

Allows to interpret the magnitude of the emissions

Uncertainty on the total emissions (in Mt)

Allows a consistent interpretation of the magnitude of the emissions

Harmonization Requirements

Yearly updates using consistent methodology or indicating the impact of changes (e.g., more instruments in orbit)

Ensures consistent and comparable results between years

5.4 Use case-4 Emission inventory at the facility-level

The requirements in emission integration come on top of earlier defined requirements on detection and quantification.

Use-Case - Description

Access yearly estimates of total methane emissions at the facility-level based on super-emitter detection and observability metrics

Use-Case - Illustration

Estimate total methane emissions over a year of a specific compressor station based on several measurements

Intercomparison Requirements

Probability of detection (PoD) curve

Allows to assess the completeness and reliability of aggregated results

Revisit time

Allows to assess the completeness and reliability of aggregated results

Validation Requirements

Validated instrument and approach with controlled releases or demonstrated consistency with validated instruments

Ensures the reliability of observed emission quantifications

(Peer reviewed) documented methodology for methane quantification and uncertainty with versioning

Ensures transparency and reproducibility

(Peer reviewed) documented methodology for the statistical model used to derive total methane emissions from discrete measurements with versioning

Ensures transparency and reproducibility

Interoperability Requirements

Shared Metadata

Number of useful observations over the facility

Allows users to understand the coverage and frequency of monitoring, evaluate potential gaps and the robustness of the analysis

Number of detections over the facility

Allows users to understand the scale of the problem, evaluate potential gaps and the robustness of the analysis

The ratio of number of detections over the facility and number of useful observations over the facility provides the Emission frequency.

This allows users to understand the intermittency of emissions observed by satellites to assess yearly estimates.

Flow rate (in tons/hour)

Allows a consistent interpretation of the magnitude of the emissions

Flow rate uncertainty (in tons/hour)

Allows a scientifically robust estimation

Total emissions for the asset (in Mt)

Allows users to understand the scale of the problem

Uncertainty on the total emissions (in Mt)

Allows a consistent interpretation of the magnitude of the emissions

Location of the detection and uncertainty about the location

Ensures comparison of data from different satellites or data providers

If possible/If sufficient data: Might be interesting to have more frequent than yearly data (ex: quarterly) when there are significant seasonal variations

Harmonization Requirements

Yearly updates using consistent methodology or indicating the impact of changes (e.g., new statistical model)

Ensures consistent and comparable results between years

Shared Metadata

Satellite used (ex: Sentinel-2)

Ensures traceability of the detection and comparison of like with like across different providers or data sources

Product used (ex: L1/L2/etc.) and version (ex: v0.1.1)

Ensures traceability of the detection and comparison of like with like across different providers or data sources

Time of acquisition

Ensures robust temporal analysis and integration

Degree of confidence in the detection: Low/High*

Ensures consistent interpretation of reliability across different systems

Wind Data: Speed and Direction

Ensures a good understanding of the plume dynamics

Source of wind data (ex: ECMWF ERA5)

Ensures traceability of the wind data and robust integration

**High indicates strong confidence in the detection, while Low suggests uncertainty, possibly due to environmental factors or sensor limitations. Further investigation may be needed for low-confidence detections.*

6. References

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