Methane Alternative Test Method 2 (MATM-002): Aerial LiDAR Survey for Fugitive Methane Emission Monitoring

1 Scope and Application

1.1 Scope

1.1.1 This method is applicable for demonstrating compliance with the procedures in 40 CFR §60.5398b for fugitive emissions components affected facilities and compliance with periodic inspection and monitoring requirements for covers and closed vent systems, specifically demonstrating compliance through periodic screening in 40 CFR 60.5398b(b), as approved, per 40 CFR §60.5398b(d). Affected facilities could include but are not limited to single wellhead only sites, small well sites, multi-wellhead sites, well sites with major production and processing equipment, centralized production facilities, and compressor stations.

1.1.2 This method details a standard set of protocols to monitor emissions when using Gas Mapping LIDAR™ (GML) airborne remote sensing technology. In addition, this method defines what emissions detection data ("Deliverables") result from the method implementation, and what additional information ("Auxiliary Data") may be provided to support objectives of the implementing program including investigating emissions causes and tracking emissions mitigation.

1.2 Application

1.2.1 The application of this technology is per the Environmental Protection Agency's 40 CFR part 60 New Source Performance Standards (NSPS): Subparts OOOO, OOOOa, and OOOOb and Emissions Guidelines (EG): OOOOc, for the Oil and Natural Gas Source Category.

1.2.2 The test method is applicable to methane (CH_4, CAS #: 74-82-8) emissions monitoring, and monitoring for other pollutants, including volatile organic compounds (VOC), that may be co-emitted with methane, in which case methane provides a surrogate for the detection of these pollutants. This method is broadly applicable across the oil and natural and gas sector, and it may be implemented within other applicable sectors.

1.2.3 This method can be used, as approved by the Administrator, in lieu of the applicable fugitive monitoring requirements in either §60.5397a or §60.5397b and inspection and monitoring of covers and closed vent systems in either §60.5416a or §60.5416b. This test method may be used for fugitive monitoring requirements in §60.5397c and monitoring of covers and closed vent systems under §60.5416c when a state, local, or tribal authority incorporates the model rule (i.e., OOOOc) for the emission guidelines as part of their State Implementation Plan (SIP) or elsewhere approved as applicable (e.g., within state VOC and methane monitoring rules and permit operating plans).

1.2.4 The test method is a performance-based method to determine whether area-level emissions remain below prescribed thresholds.

1.3 Method Sensitivity

This method provides an average detection sensitivity of ≤ 1, 2, 3, 5, 10, or 15 kg/hr methane with 90% probability of detection (POD), with the specific threshold identified within the implementing program.

1.4 Data Quality Objectives

The objective of this method is to provide a 90% POD at the specified emission rate for each “Emission Source”, which is the source of a methane release within a defined scanned spatial region (“Target Area”) with an emission rate that exceeds the specified threshold; to accurately locate the origin of the Emission Source; and, optionally, to confirm if methane release from an Emission Source is ongoing (“Persistent Emission Source”). The protocols in this method ensure that GML technology is deployed to reproducibly meet the performance metrics (Section 2.2) that support the method’s objectives.

2 Summary of Method

2.1 Overview

This method is based on using aerially-deployed, laser-based, beam-scanning Gas Mapping LiDAR remote sensing instruments (“GML Instrument”) to scan Target Areas for emissions (see Figure 1, left) and generate georegistered imagery of “Methane Plumes”, which are regions of anomalously elevated methane gas. This imagery constitutes part of the Deliverables when Methane Plumes correspond to Emission Sources or Persistent Emission Sources within Target Areas. Secondary Scans may be performed for locations where preliminary data acquisition and processing indicates a release event to confirm Persistent Emission Sources. Instrument operations include ranging LiDAR measurements, concomitant with methane sensing LiDAR measurements, that are combined with navigational data to georeference measurement data and to provide distance measurements for background methane subtraction. Aerial photographs are concurrently acquired for contextual information.

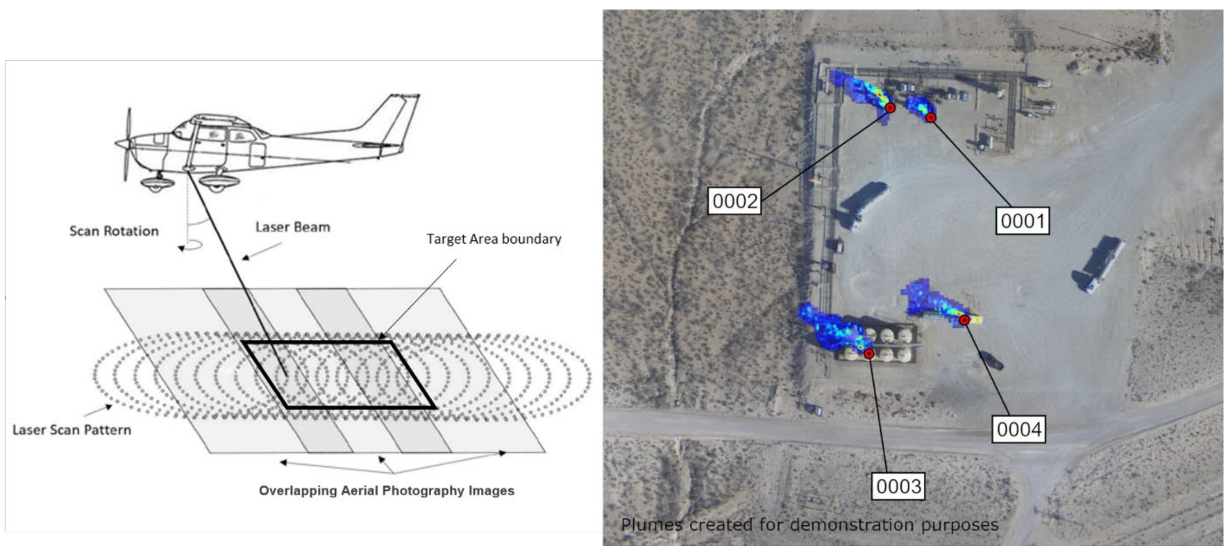

Figure 1. Left: Conceptual diagram showing laser beam scanning, Target Area, and overlapping camera images. Right: Example data showing Methane Plumes, Emission Sources, and aerial photography.

2.2 Method Performance Metrics

This method provides the following performance metrics: (a) identification of Emission Sources with an average detection sensitivity of no greater than the value specified within the implementing program (e.g., ≤ 1 kg/hr with a 90% POD) (“Detection Sensitivity Metric”), (b) determination of a Emission Source geodetic coordinates on average within 2 m from the true Emission Source geodetic coordinates, and with a standard deviation less than 2 m (“Localization Metric”), and (c) quantification of an Emission Source emission rate with an average ratio of the rate estimated by GML for controlled releases relative to the metered rates (“Relative Error Ratio”) of between 0.7 and 1.4 (“Quantification Metric”).

2.3 Method Deliverables

Deliverables are the results of the test method implementation and correspond to each “Screening Event”, which is the collection of all scans of a Target Area within a monitoring interval (e.g., within a given quarter). These Deliverables comprise data for identified Persistent Emission Sources and include: (a) geo-referenced Methane Plume imagery, (b) Measured Coordinates of identified Emission Sources, (c) time and date that identifiable Emission Sources were detected on the final scan. If a Secondary Scan is not performed, then the Deliverables pertain to Emission Sources identified in the initial scan of the Target Area. Deliverables may incorporate multiple documents in different file formats and may be transmitted using varying mechanisms. Example Deliverables, including Methane Plumes and Emission Sources, are shown in Figure 1 (right), which are accompanied by tabular data with geodetic coordinates and time/date of detection.

2.4 Auxiliary Data

Auxiliary Data may also be provided under this method to assist in determining the Emission Source type (e.g., fugitive emission or normal process emission and regulated or nonregulated emission source type), aid in causal or investigative analysis, track emissions mitigation, or support other objectives of the implementing program. Auxiliary data may include geo-referenced and orthorectified aerial photography or satellite imagery, equipment attributed to identified Emission Sources, persistence of identified Emission Sources, emission rate quantification, height estimate of Emission Sources, historical data indicating previous identification of an Emission Source, supervisory control and data acquisition data, information from other methane monitoring technologies, or other information.

3 Definitions of Method

3.1 Definitions

3.1.1 Auxiliary Data

Information other than the Deliverables used to assist in determining the Emission Source type (e.g., fugitive emission or normal process emission and regulated or nonregulated emission source type), aid in causal or investigative analysis, track emissions mitigation, or support other objectives of the implementing program.

3.1.2 Causal Analysis

Low levels of ranging and atmospheric laser light return in captured data are investigated to determine the underlying reason (E.g., physical or environmental conditions, flight events, or instrument performance). Implementing programs may have a different causal analysis definition.

3.1.3 Deliverables

The resulting processed emissions detection data compiled and delivered from use of this method.

3.1.4 Detection Sensitivity Metric

The specified method average emission rate for which 90% POD is achieved. This metric is based on demonstrated performance and ensured by adhering to method protocols.

3.1.5 Detection Sensitivity Model

Parametric model for emission rate POD performance that is developed using and validated against controlled release tests under diverse deployment conditions.

3.1.6 Emission Source

The identifiable spatial location within a Target Area from which a Methane Plume originates.

3.1.7 GML Instrument

The laser-based, beam-scanning, remote sensor instrument used to scan an area for the purpose of detecting, localizing, and quantifying sources of methane emissions in addition to providing other contextual information on the emissions.

3.1.8 P-Concentration

Path-integrated methane gas concentration.

3.1.9 Localization Metric

The method Emission Source localization uncertainty. This metric is based on demonstrated performance and ensured by adhering to method protocols.

3.1.10 Methane Plumes

Regions of identified anomalous P-Concentrations that exceed the nominal ambient background amounts of methane gas concentrations.

3.1.11 Persistent Emission Source

The same Emission Source identified throughout initial and Secondary Scans.

3.1.12 Quantification Metric

The method boundaries for average quantification bias. This metric is based on demonstrated performance and ensured by adhering to method protocols.

3.1.13 Relative Error Ratio

The emission rate estimate from GML technology for a controlled release divided by the metered emission rate for that release.

3.1.14 Scan Swath

The geospatial region of the ground surface within which measurements are acquired during a single GML Instrument pass.

3.1.15 Screening Event

The collection of scans within a monitoring interval (e.g., within a given quarter) for a given Target Area. A Screening Event may include either just initial scan, or both initial and Secondary Scan. The Screening Event for a given Target Area is completed after all scans of that Target Area are completed.

3.1.16 Secondary Scan

GML Instrument scan of those locations where preliminary data and analysis indicates identification of one or more Emission Sources. These scans may be used to determine if an Emission Source is a Persistent Emission Source. If this method is being performed within the context of 40 CFR 60.5398b, then the use of Secondary Scans must be specified within the implementing program monitoring plan and the scan must occur no more than five days after the initial scan is complete. The same GML Instrument deployment and processing parameters are used during initial and Secondary Scans.

3.1.17 Target Area

The defined geographic area containing possible methane Emission Sources, which is scanned by the GML Instrument during method implementation.

3.2 Acronyms

FAA – United States Federal Aviation Administration

GML – Gas Mapping LiDAR™ (GML)

GPS – Global Positioning System

LiDAR – Light Detection and Ranging

POD – Probability of Detection

RPM – Revolutions Per Minute

4 Interferences and Envelope of Operation

GML technology has zero or negligible interference from species other than methane that were tested due to their similar chemical structure or prevalent co-occurrence with methane at emission sources.[1] Certain operational and environmental conditions impact detection sensitivity and may require defined operating windows or other control measures to manage their impact as detailed in Table 1.

Table 1. Method limitations and conditions of operation to mitigate performance reductions.

Condition	Summary	Mitigation
High ground wind speed	High wind may disperse methane, reducing the probability of detecting emissions.	Deployment is limited to ≤ 15 m/s forecasted average wind speed for typical operations. An alternative wind speed limit may be set according to the deployment planning procedures at Section 8.2.1.

Condition	Summary	Mitigation
Standing water	The GML Instrument's laser light typically reflects off standing water in a single direction away from the GML Instrument.	This method is not applicable to portions of Target Areas comprising oceans, lakes, ponds, flooded regions. Equipment may be used as an alternative backscatter surface for applications including offshore platforms
Low ground reflectance	Low ground reflectance can inhibit scattered laser light from returning to the GML Instrument. Effects are most pronounced for certain snow crystal grain sizes and snow water content.	Because LiDAR detection sensitivity is multiparametric (impacted by optical configuration, flight altitude, flight speed, and wind speeds) and often convoluted with the impact of these factors, there is not a specific numerical value for ground reflectance. To achieve the Detection Sensitivity Metric, deployment decisions are made based on prior data collected and analyzed using the parametric Detection Sensitivity Model described herein. In addition, the planning procedures at Section 8.2.1. may avoid deployment on days with deleterious snow crystal grain sizes and snow water content. QA/QC procedures include checking for light returned to the GML Instrument (Table 5).
Low visibility to ground	Heavy smoke or other atmospheric conditions may limit the GML Instrument's laser light from reaching surfaces on the ground.	GML is not deployed in heavy smoke or when other atmospheric conditions prevent safe flight. QA/QC procedures include checking for light returned to the GML Instrument (Table 5).

Condition	Summary	Mitigation
High flight altitude	High flight altitude reduces laser light received by the GML Instrument and decreases LiDAR data point density in the Target Area.	Flight altitude boundaries are used within each deployment according to the deployment planning procedures at Section 8.2.1. QA/QC procedures include checking for light returned to the GML Instrument (Table 5).
Unacceptable ambient temperature	Extreme high and low ambient temperatures reduce GML Instrument performance.	Flight planning may avoid GML Instrument deployment during periods of extreme high or low temperatures. The instrument functionality parameters described in Table 4 inform the operations team if the instrument performance is compromised due to temperature. In addition, the QA/QC procedures in Table 5 check for compromised data.

5 Safety

5.1 <u>General Safety Considerations</u>

This method may not address all potential safety scenarios associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to performing this test method. The subject method requires activities governed by other categories of regulations, including requirements of the Occupational Safety and Health Administration and the Federal Aviation Administration (FAA). Applicable requirements and regulations from these, and other relevant jurisdictional administrative authorities, must be followed to properly conduct this method. Because this method may be adopted by a variety of industries, site-specific hazards may be identified, understood, and accounted for prior to conducting this method.

5.2 <u>Flight Safety</u>

Flight providers operating the aircraft to which the GML Instrument is attached have rules, regulations, and safety policies and procedures which must be followed for internal and general aviation compliance. The aircraft operator therefore has complete authority to cease or limit flight operations for safety purposes. The GML Instrument must be secured to the aircraft by an FAA supplemental type certificate mount or certified by a designated engineering representative. Notwithstanding the broad discretion concerning safety granted to the aircraft operator, unidentified general aviation flight hazards may still exist.

5.3 Laser Safety

Each GML Instrument used within this method must comply with all applicable United States Federal Drug Administration regulations, including those regulating the maximum amount of laser light that may reach the ground surface in order to protect human eyesight.

6 Equipment and Supplies

6.1 GML Instrument

The subject method requires the use of GML Instruments to detect and image Methane Plumes. An onboard methane gas reference cell, and temperature and pressure sensors are used for P-concentration measurements. The instrument incorporates a navigation subsystem that includes a global positioning system (GPS) antenna to measure and record the coordinates of the GML Instrument and an inertial measurement unit to determine the GML Instrument orientation.

6.2 GML Instrument Mount

The GML Instrument is attached to the aircraft by a mount that complies with FAA regulations. All external mounts to the aircraft must be certified by an FAA supplemental type certificate or a designated engineering representative, and the GML Instrument must be installed by an FAA-certified mechanic.

6.3 Computer Programs

Computer software and GML Instrument firmware are used to acquire and process data in this method.

7 Reagents and Standards

[Reserved]

8 Data Collection and Method Input Sourcing

8.1 Method Data Inputs

This method makes use of the data inputs provided in Table 2.

Table 2. Test method data inputs.

Instrument/Source	Variables	Use
GML Instrument	Georeferenced P-concentration data, aerial photography, and other remote sensing data.	Identify methane plumes and provide contextual information.
GPS Satellites	GML Instrument latitude and longitude.	Georeferencing GML data.

Instrument/Source	Variables	Use
Meteorological Model(s)	Local wind speed data and adverse weather conditions.	Used (a) in preflight planning to limit Target Area scans to acceptable ground wind speeds and to identify safe flight conditions, (b) to calculate emission rates, and (c) to evaluate detection sensitivity in the Detection Sensitivity Model.
Anemometer(s)	Local wind speed data.	Used to (a) calculate emission rates, and (b) evaluate detection sensitivity in the Detection Sensitivity Model.

8.2 Data Collection Procedures

8.2.1 GML Instruments deployment parameters are set to ensure the Detection Sensitivity Metric. Parameters include flight altitude boundaries, flight speed, ground wind speed limits, and GML Instrument selection. Prior region-specific performance analysis is used to guide parameter decisions and accounts for terrain reflectivity. The parametric model for emission rate POD ("Detection Sensitivity Model") described in Section 13.2.3 is used to determine the average emission rate at which 90% POD was previously achieved in the Target Area region or, if there is no data or limited data for a region, a similar region is inspected. Deployment parameter updates are typically made to improve detection sensitivity; conversely, detection sensitivity can be decreased to match the specified Detection Sensitivity Metric through less restrictive deployment parameters or using alternative GML Instrument electro-optical configurations.

8.2.2 Predefined flight plans may be established to ensure that GML Scan Swaths cover Target areas. Multiple flight passes may be required to achieve adequate scan coverage. Secondary Scans may be planned as applicable. When using this method in the context of 40 CFR 60.5398b, the emissions monitoring plans for the implementing program must specify if Secondary Scans will be performed.

8.2.3 Prior to each deployment, flight safety conditions are evaluated alongside adverse environmental conditions that may otherwise inhibit successful method implementation. Flights and scans for the subject method must only be conducted when the aircraft and the flight conditions fall within all pertinent safety regulations, including, for example, visual flight rules or instrument flight rules (14 CFR Part 135 Subpart D).

8.2.4 Target Area scans are completed for the Target Areas specified in the implementing program. Throughout scans, the GML Instrument functionality parameters listed in Table 4 are monitored to ensure successful data acquisition.

9 Quality Control

The following quality control measures are taken to ensure that GML Instruments have adequate performance during commissioning (Table 3), to ensure function correctly during deployment (Table 4), and to validate acquired data (Table 5).

Table 3. GML Instrument qualification tests.

Instrument	QC Procedure	Acceptance Criteria	Frequency of QC Procedure	Corrective Action
GML Instrument	Detection sensitivity testing	Controlled releases (≥ 6) must agree with the Detection Sensitivity Model. False negatives must not have < 10% probability of observation.	During commissioning and after each repair or recalibration	Diagnose, adjust as needed, and retest
GML Instrument	Emission Source localization testing	At least 9 valid measurements with average localization error ≤ 2 m and SD < 2 m	During commissioning and after each repair or recalibration	Diagnose, adjust as needed, and retest
GML Instrument	Emission rate quantification testing	Relative Error Ratio (for ≥ 8 releases > 3 kg/hr) must fall between 0.7 and 1.4	During commissioning and after each repair or recalibration	Diagnose, adjust as needed, and retest

Table 4. GML Instrument functionality parameter monitoring.

Instrument	QC Procedure	Acceptance Criteria	Frequency of QC Procedure	Corrective Action
Beam Scanner	Rotation rate	≤ 400 RPM	Continuous during deployment	Flag dataset for review, repair and rescan if needed
GPS System	Satellite communication and positional uncertainty	≥ 8 satellites, ≤ 2 m uncertainty	Continuous during deployment	Flag dataset for review, repair and rescan if needed

Instrument	QC Procedure	Acceptance Criteria	Frequency of QC Procedure	Corrective Action
Gas Laser	Frequency stability	≤ 200 MHz deviation, logged at ≤ 0.1 s resolution	Continuous during deployment	Flag dataset for review, repair and rescan if needed

Table 5. Data quality validation procedures.

Instrument	QC Procedure	Acceptance Criteria	Frequency of QC Procedure	Corrective Action
GML Instrument	Ranging Laser Light Return	Valid signal return with no anomalous gaps	Post-data acquisition	Causal Analysis and rescan if significant data gaps are found
GML Instrument	Gas Measurement Laser Light Return	Valid signal return with no anomalous gaps	Post-data acquisition	Causal Analysis and rescan if significant data gaps are found
GML Instrument	Flight Altitude Check	Must fall within deployment bounds	Post-data acquisition	Review point density and light return; rescan Target Area as needed

10 Calibration and Standardization

10.1 GML Instruments

To ensure correct operation, each GML Instrument must be properly calibrated and tested by the manufacturer. The parameters in Table 6 are calibrated or verified by the manufacturer for each GML Instrument prior to its first use and repeated no less frequently than once every two years thereafter. The quality control procedures in Section 9 identify as-needed calibration, which is performed by the manufacturer. There are no field calibration requirements.

Table 6. GML Instrument calibration and standardization parameters.

Parameter	Value	Measurement Conditions
Chemical species detected	Methane (CH_4)	Methane spectral absorption line at 1651 nm.
P-Concentration Measurement Uncertainty	≤ 10%	Calibrated in the laboratory using external gas cells containing a calibrated P-Concentration of methane gas. Measured P-Concentrations must agree to calibrated P-Concentration to within ≤ 10%.
LiDAR Range Measurement Uncertainty	< 3 parts in 10^3	Verified by direct comparison with an external range measurement system with < 1 part in 10^3 uncertainty.
Thermal operation range	> 0°C and < 40°C minimum range.	All critical subsystems must operate properly during thermal cycling for no less than 10 minutes at low and high temperature values.
LiDAR Geo-Registration Uncertainty	≤ 2 m	Verified during airborne testing by determination of the discrepancy between GML Instrument-measured and ground-calibrated geodetic coordinates of the same object.
Aerial Photography Geo-Registration Uncertainty	≤ 2 m	Verified by direct comparison with geo-registered 3D topographic LiDAR imagery or Google Earth imagery.

10.2 <u>Training</u>

Prior to completing the procedures in Section 12.1.1, GML data analysts undergo a training program and must pass a testing regime that demonstrates consistent results for processing a data set that includes varying degrees of complexity and multiple geographical locations. There are no training requirements for the receiving entity of method Deliverables.

11 Analytical Procedure

[Reserved]

12 Detection and Alerting

12.1 <u>Detection</u>

12.1.1 Detections are the identified Emission Sources or Persistent Emissions Sources within the method Deliverables (Section 2.3). Data processing thresholds in combination deployment parameter selection and GML Instrument configurations (Section 8.2.1) may be used to align Deliverables with the Detection Sensitivity Metric.

12.1.2 Processing for collected Target Area data begins with the validation procedures in Table 5 to ensure captured data integrity. Next, algorithms incorporating the spatial distribution of P-Concentration measurements are used to determine the existence, and generate imagery, of Methane Plumes. This step uses automated protocols with manual quality assurance oversight.

12.1.3 Emission Sources are the identifiable spatial location within a Target Area from which a Methane Plume originates. Identification and location of Emission Sources is performed using available inputs which may include P-concentration gradients, Methane Plume shapes, ranging LiDAR data, aerial photography, and other factors. This step is automated and may be supplemented, refined, or replaced by manual processing, and it is performed with manual quality assurance oversight.

12.1.4 The method implementing program may have a different definition of detection (e.g., Emission Sources confirmed as equipment leaks during ground-level follow-up).

12.2 Alerting

An alert comprises delivery of a detection or set of detections for a Target Area scanned according to this test method. Following method completion, the receiving entity is alerted of detections during Deliverable transmission according to the protocols described in Section 15.3. The timeline for transmitting method Deliverables to the receiving entity begins with the completion of Screening Events.

13 Method Performance

13.1 Section Overview

13.1.1 This section describes both semi-blind and fully blind controlled release testing results that demonstrate method performance consistent with the performance metrics in Section 2.2. For semi-blind tests, the sites or locations of controlled releases are known to the party being tested, but not the release rate (including zero release rates). For fully blind testing, the party being tested is unaware of testing activity until after delivering results. The described fully blind testing occurred at various active facilities and provides a robust validation of technology performance because this testing modality prevents artificial performance enhancements. However, because logistical constraints prevent extremely large numbers of fully blind controlled release tests, semi-blind tests were used to evaluate the influence of deployment conditions across a greater parameter space.

13.1.2 A parameter-based Detection Sensitivity Model for emission rate POD was used to evaluate specific performance in areas and under conditions for which controlled release testing has not been completed. This model is used during method implementation to guide GML Instrument deployment parameter settings (Section 8.2.1).

13.2 Detection Sensitivity Performance

13.2.1 Controlled release testing was performed by Carleton University on first-generation GML technology in 2019 and 2020/2021 during actual field operations under both semi-blind and fully blind conditions.[2,3] The key results of the 2020/2021 testing are provided in Figure 2, which plots the metered emission rates against wind speed at time of release.[3] The blue-outlined circles indicate true-positive detections of controlled releases, and red-outlined diamonds represent false-negative detections. While the semi-blind and fully blind false negatives are not distinguishable in this figure, the first-generation GML Instrument detected 120 out of 182 of fully-blind controlled releases that ranged between 0.4 kg/hr to 5.2 kg/hr and; the data also indicate that the first-generation GML had no false negative detections above 4.5 kg/hr for any wind speed experienced during the testing (up to 7.5 m/s).

13.2.2 Using the combined detection data (fully blind and semi-blind) shown in Figure 2, a mathematical model for emission rate POD as a function of windspeed (u) and flight altitude ($\tilde{h}$) was generated (Equation 1).[3] The detection sensitivity observed for the first-generation GML Instrument at the common reference wind speed of 3 m/s and at GML's then-standard operational flight altitude of 175 m was determined to be 2.3 kg/hr with 90% POD. Since these test results, GML Instruments have been updated for improved performance, however, this model shows how more restrictive wind speed conditions and flight altitude boundaries can be used to improve performance.

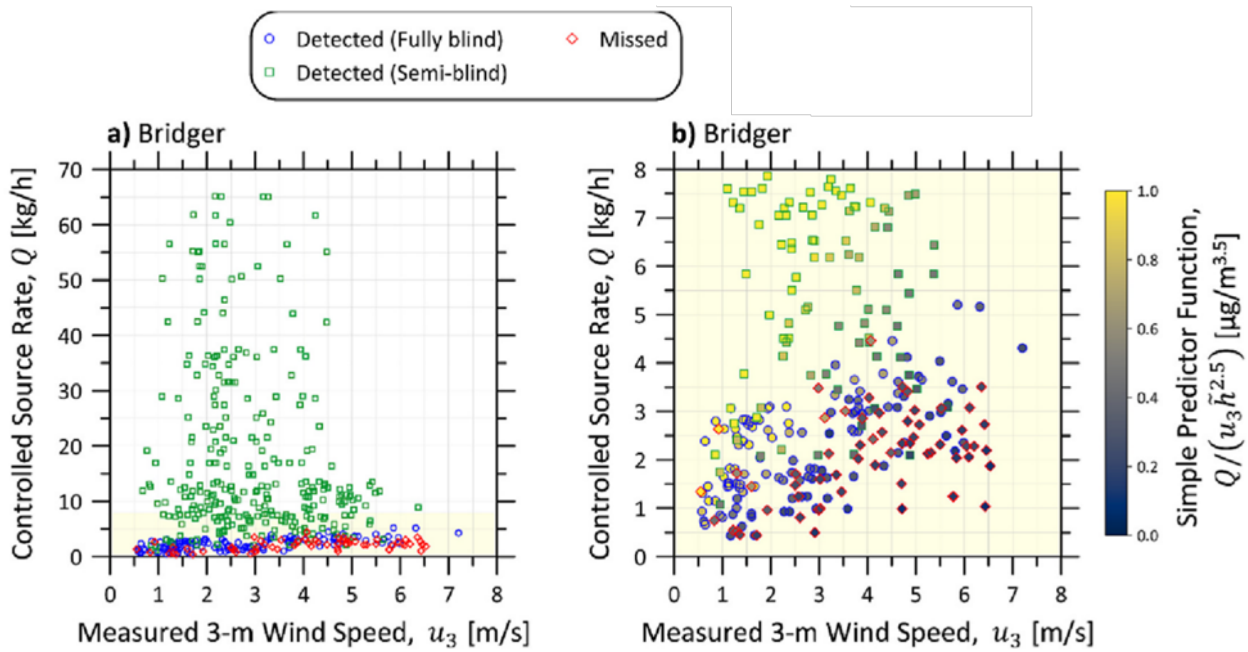

Figure 2. Key results from controlled release testing performed by Carleton University of GML technology (first-generation GML Instruments) taken during field operations in 2020/2021.[3] Blue-outlined circles are true positives, green-outlined squares are semi-blind true positives, and red-outlined diamonds are false negatives. The kg/h units in this figure are equivalent to kg/hr written in this method.

$$\mathrm{POD} = \exp\left(-\left(\frac{0.224\, Q_{[\mathrm{kg/hr}]}^{1.07}}{\left(\frac{\tilde{h}_{[m]}}{1000}\right)^{2.44}\left(u_{3[\mathrm{m/s}]}+2.14\right)^{1.69}}\right)^{-2.53}\right)$$

Equation 1

13.2.3 To account for deployment conditions beyond flight altitude and wind speed, alone, Bridger uses a generalized Detection Sensitivity model. A derivation published in peer-reviewed literature (Reference

4) is expressed as Equation 2 when used to calculate emission rate for a given POD (Q_{POD}). This derivation consolidates all operational and environmental conditions (e.g., wind speed, flight altitude, flight speed, ground reflectivity, measurement point density, etc.) into two measured independent variables: wind speed (u), and gas concentration measurement noise parameter (GCN). The model parameters (α_1, α_2, β_1, β_2, β_3, β_4) are determined by repeated controlled release testing (with automated Methane Plume identification and zero false positive identifications) under varying operational and environmental conditions that may be experienced in the field. The model is validated against further controlled release data and parameter values may be continually refined over time to more accurately represent the GML Instrument fleet performance as additional controlled release testing is performed.

$$Q_{POD} = \left(\left[(1 - POD)^{\frac{-1}{\alpha_2}} - 1 \right]^{\frac{1}{\alpha_1}} \left[\frac{GCN^{\beta_3} u^{\beta_4}}{\beta_1} \right] \right)^{\frac{1}{\beta_2}}$$

Equation 2

13.2.4 Using Equation 2 to evaluate prior performance demonstrates that GML technology can achieve a 90% POD at an average emission rate below 1 kg/hr with appropriate deployment parameters; e.g., GML Instrument optical configurations, flight speed, flight altitude, and average wind speed ceiling. Figure 3 shows a histogram of 90% POD emission rates for Target Areas scanned during standard field operations in the Marcellus production basin, indicating an average detection sensitivity of 0.9 kg/hr (90% POD). Target Areas were not pre-arranged for testing and there was no selection or de-selection of Target Areas to influence the results.

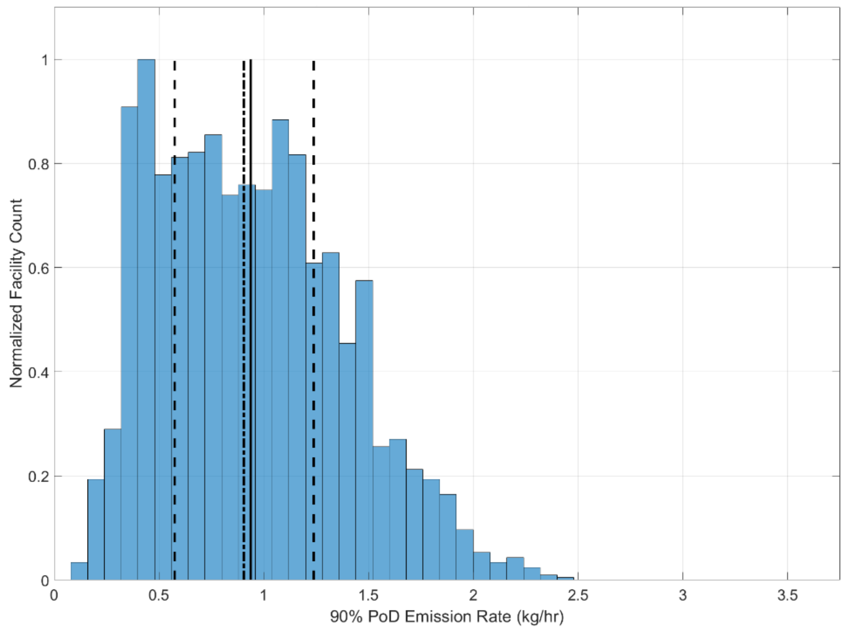

Figure 3. Example histogram of detection sensitivity (90% POD) achieved for numerous Target Areas scanned during field operations in the Marcellus Basin. The dot-dash vertical line represents the median emission rate for 90% POD, and the solid vertical line represents the mean emission rate for 90% POD. The black dashed lines bound the interquartile of the sample set.

13.3 <u>Emission Rate Quantification</u>

Quantification performance has been extensively evaluated by third parties including within the same controlled release tests that demonstrate detection sensitivity performance. The quantification performance for Carleton University semi-blind and fully blind controlled release data is shown in Figure 4. An overall ≅ 8% positive bias of the emission rate estimate by GML is indicated by the distribution mean marker for GML measurement relative error ratios (expressed as the inverse term to that defined in this method). Similar performance is demonstrated in two separate tests administered by Colorado State University (CSU) in Midland, TX in October 2021 and Stanford University in Ehrenberg, AZ in November 2021, with the combined dataset shown in Figure 5. Based on the slope of the linear regression, an 8% positive bias trend in estimated rates is observed. Further analysis shows a positive bias and larger variance for GML estimates for smaller controlled release rates (Figure 5, Bottom).

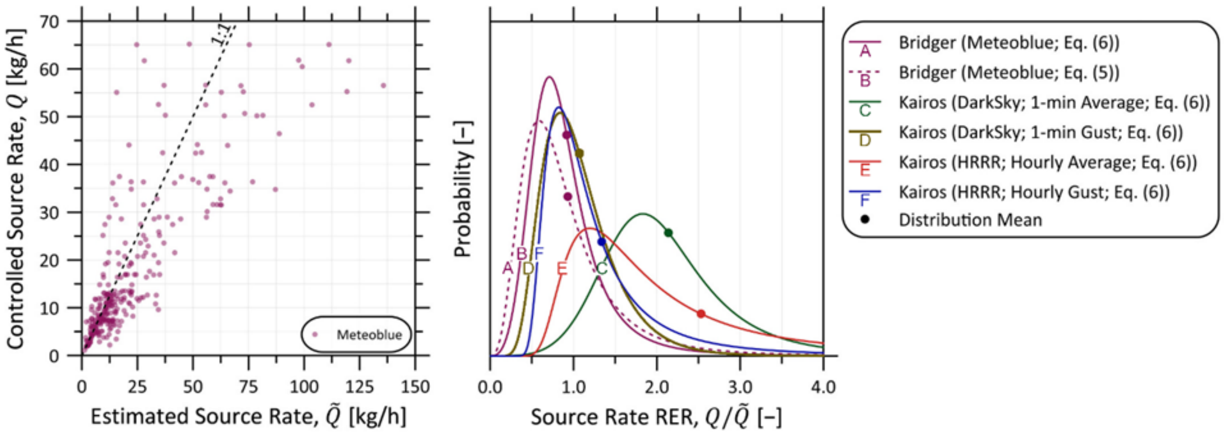

Figure 4. Emission rate quantification results from controlled release testing performed by Carleton University of GML technology (first-generation GML Instruments) taken during field operations in 2020/2021. (Left) Plot of the GML estimated source rate against the controlled release rate for each GML estimated rate (the dashed line indicates 1:1 parity line). (Right) Distributions of the relative error ratio for emission rate estimates analyzed by Carleton University in the study (curves A and B are Bridger GML results). Note that relative error ratio is defined as metered rate divided by estimated rate in the Carleton study whereas it's defined as the inverse term in this method. The kg/h units in this figure are equivalent to kg/hr written in this method.

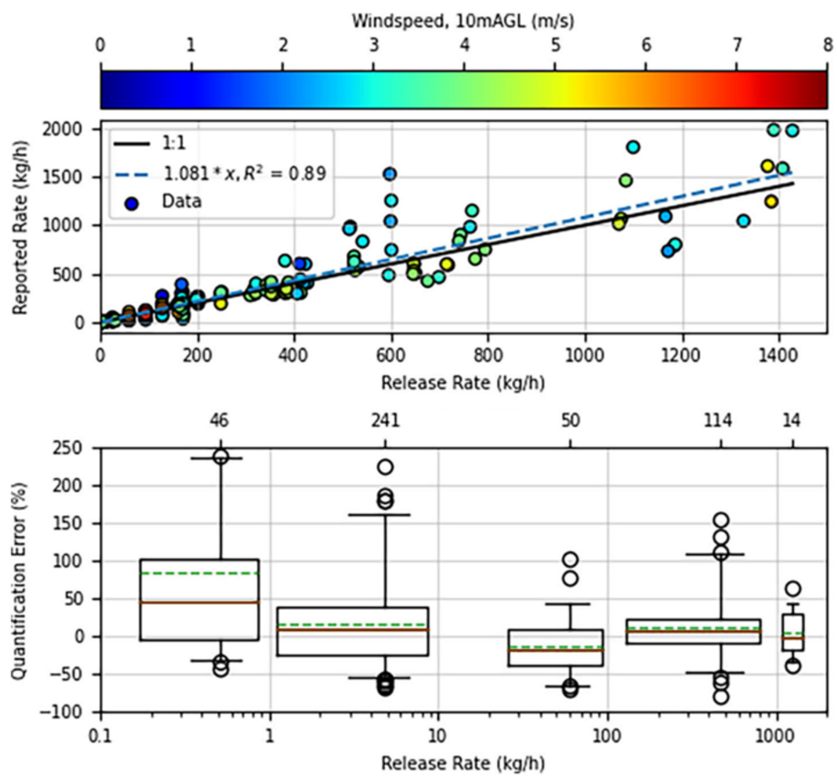

Figure 5. Results from the CSU and Stanford controlled release tests. (Top) Plot of the estimated release rate versus the controlled release rate with the 1:1 parity line (black) and a liner fit of the data (dashed line). (Bottom) Box and whisker plot of the % error defined as estimated rate/metered rate for different metered rate bins. The mean error for each bin is indicated by the solid horizontal line showing a positive bias in the estimated rate for small emission rates. The kg/h units in this figure are equivalent to kg/hr written in this method.

13.4 Emission Source Localization

13.4.1 Bridger published peer-reviewed emission source localization performance results for controlled release tests on 11 GML Instruments (Figure 6).[5] Each instrument localized emission sources with an uncertainty of ≤ 2 m (1 σ). The translation of localization performance testing results into the ability of ground crews to attribute causes at operational oil and gas infrastructure is demonstrated in a field study, wherein crews using OGI cameras were able to attribute causes to 192 out 195 emission sources identified by GML, with the follow-up for the remaining three detections being hindered by lack of familiarity with sites and difficulty locating onsite positions relative aerial imagery or by high winds during onsite follow-up.[6]

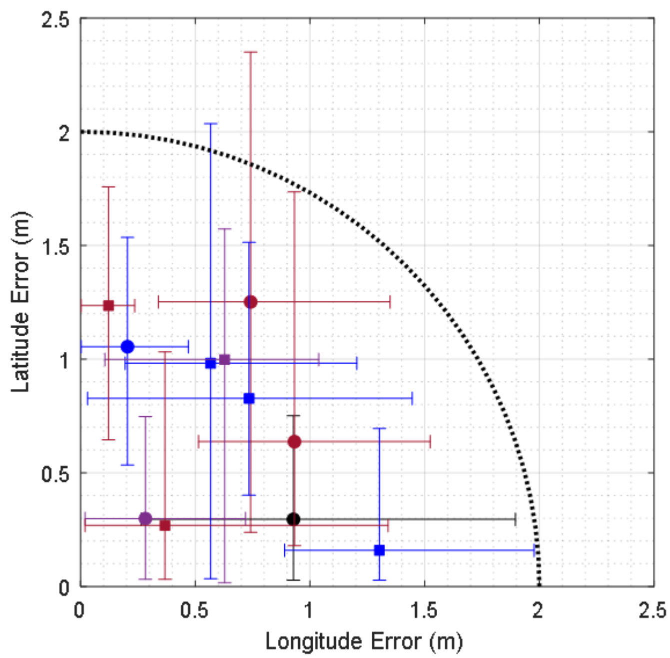

Figure 6. Mean absolute error and absolute error ranges for 321 emission source localization tests across 11 GML Instruments. Each marker represents results for an individual GML Instrument, and the error bars are the range of absolute error in latitude and longitude. The dashed arc represents a 2-m error threshold.

14 Pollution Prevention

[Reserved]

15 Data Management and Recordkeeping

15.1 Pre-deployment records

Instrument calibration (Section 10) and qualification testing (Section 9, Table 3) is performed by the manufacturer prior to GML Instrument deployment (Figure 7). Records are held by the manufacturer and are available on request.

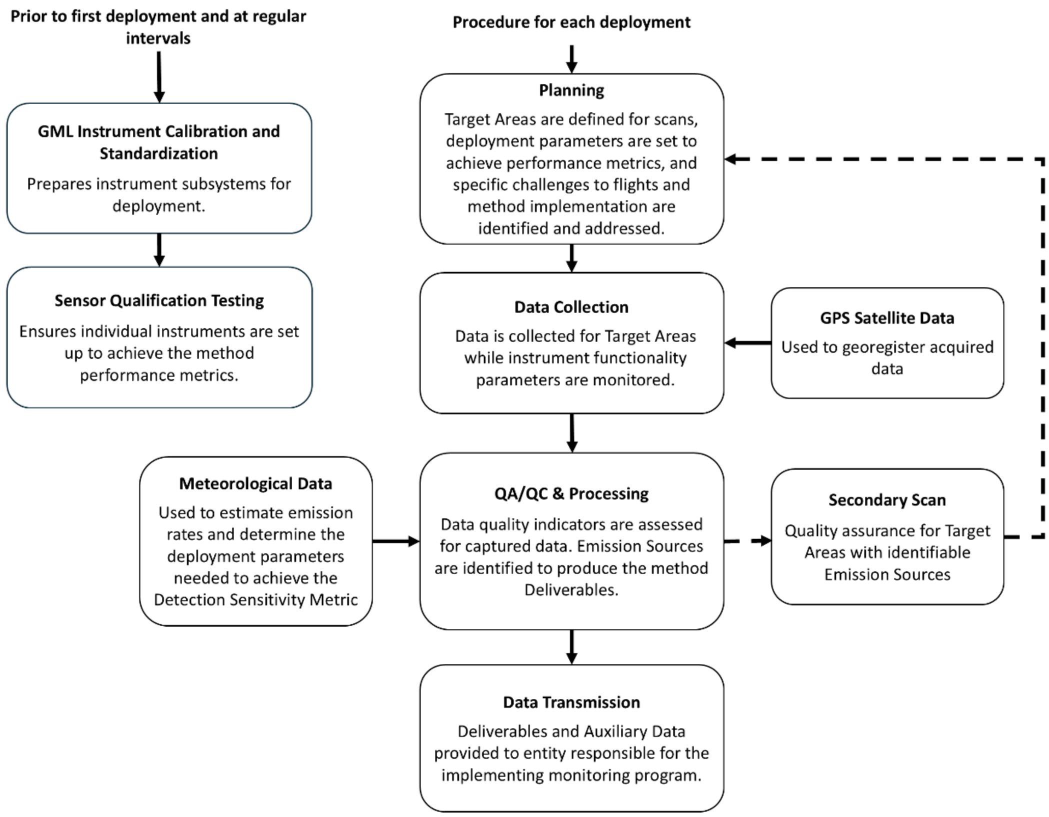

Figure 7. Method procedures and data flow scheme.

15.2 Data Management During Deployments

15.2.1 During each deployment, the data in Table 2 (Section 9) is collected and used to produce the method Deliverables. Data is stored either onboard the GML Instrument, or on an external data storage system. Data may be partially (or fully) processed onboard the GML Instrument firmware in real time. Additional processing may occur following data transfer to an external database.

15.3 Data Transmission and Detection Records

15.3.1 Deliverables and any Auxiliary Data are transmitted through varying mechanisms, i.e., via email, file transfer protocol, file hosting services, web/app interface, application programming interface, or other means. Deliverables may be batched for a collection of Target Areas or they may be transmitted incrementally. Deliverables and Auxiliary Data may be represented in varying documents and file formats (e.g., .pdf, .xls, .kml, .kmz, web/app interface).

15.3.2 Deliverables may be subject to recordkeeping requirements within the implementing program (e.g., 40 CFR 60.5424b(c)(6)).

16 References

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