Description of Technology

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1 Scientific Theory

The SOOFIE Emissions Monitoring System is a network of point sensors designed to detect, localize, and quantify methane emissions at oil and gas facilities. Each SOOFIE device is equipped with a metal-oxide semiconductor (MOS) sensor that provides high-sensitivity measurements of local methane concentration changes. These measurements are combined with atmospheric data—including wind speed, wind direction and variability, temperature, pressure, and humidity—to identify the most probable location of an on-site leak. Once the leak is localized, its emission rate is estimated using an inverse dispersion model that incorporates source-receptor relationships and wind data. The following sections outline the methodology used to quantify facility-level emissions using the SOOFIE system.

1.1 Methane Detection with the MOS Sensor

1.1.1 Operating Principle

MOS sensors detect gases through changes in electrical resistance driven by surface adsorption and desorption phenomena. In ambient conditions, oxygen molecules adsorb onto the surface of the metal-oxide material, forming a depletion layer that increases the sensor's electrical resistance. When a target gas such as methane interacts with the sensor, it displaces the adsorbed oxygen, altering the surface charge distribution and thereby reducing the resistance (Yamazoe, 1991).

The underlying mechanism involves modulation of the semiconductor's band structure (Figure 1). Adsorbed molecules influence the energy levels of the valence and conduction bands, effectively altering the band gap. This change affects the energy required for electrons to transition across the gap, which is reflected in the sensor's voltage response. Methane and other volatile organic compounds (VOCs) modulate the band gap differently, enabling gas-specific detection when combined with appropriate filtering and modeling techniques (Korotcenkov, 2007).

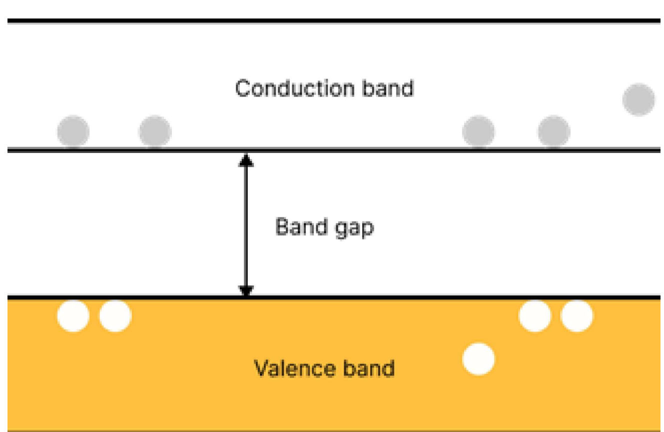

Figure 1. *A cartoon illustrating the band gap between the conduction*

and valance bands. The width of the band gap changes with concentration in methane.

1.1.2 Historical Development and Material Selectivity

MOS sensor technology was first developed in the 1970s for general air quality monitoring. Since then, advances in material science have enabled the fabrication of sensors with enhanced selectivity for specific gases. SOOFIE employs MOS sensors engineered with materials and filters that preferentially respond to methane while suppressing cross-sensitivity to other VOCs. This is achieved through:

- Selective sensing layers tailored for methane adsorption.
- Pre-filtration systems that exclude particulates and non-target gases.
- Signal processing algorithms that normalize and calibrate voltage responses to derive methane-specific concentration and emission rates.

1.1.3 Sensor Performance Characteristics

Response Time
The kinetics of gas-surface interactions are temperature-dependent. To accelerate adsorption/desorption dynamics, MOS sensors operate at elevated temperatures (>150 °C), which enhances response and recovery times (Lee and Lee, 2001). In the SOOFIE system, only the sensor element is thermally activated, and it is thermally insulated to ensure safety and environmental compliance. The operating temperature has been optimized specifically for methane detection.

Stability
MOS sensors are subject to gradual degradation due to chemical aging and material fatigue. Long-term stability tests conducted on SOOFIE sensors indicate reliable performance over a five-year operational lifespan. Beyond this period, sensor drift and reduced sensitivity necessitate replacement to maintain data integrity.

Selectivity
Selectivity is achieved through a combination of sensor material choice and physical filtration. The SOOFIE system incorporates filters that block non-target gases and particulates, ensuring that only methane reaches the sensing surface. This design minimizes false positives and enhances the accuracy of leak detection.

Sensitivity
Sensitivity is defined by the differential resistance between ambient air and methane-rich environments. The SOOFIE system quantifies this change and applies calibration models to convert electrical signals into mass emission rates.

2 Description of Physical Instrument

The SOOFIE Emissions Monitoring System consists of a network of SOOFIE devices that collect methane measurements in-situ at different points of a facility. Each network is equipped with at least one two-dimensional ultrasonic anemometer that is connected to a given SOOFIE device. Each SOOFIE device is mounted on a pole and is further connected to an external solar panel for power. Data from each SOOFIE device is transmitted via LTE or on-site Wi-Fi to the cloud. Below, we detail the specific components that make up each device (Figure 2).

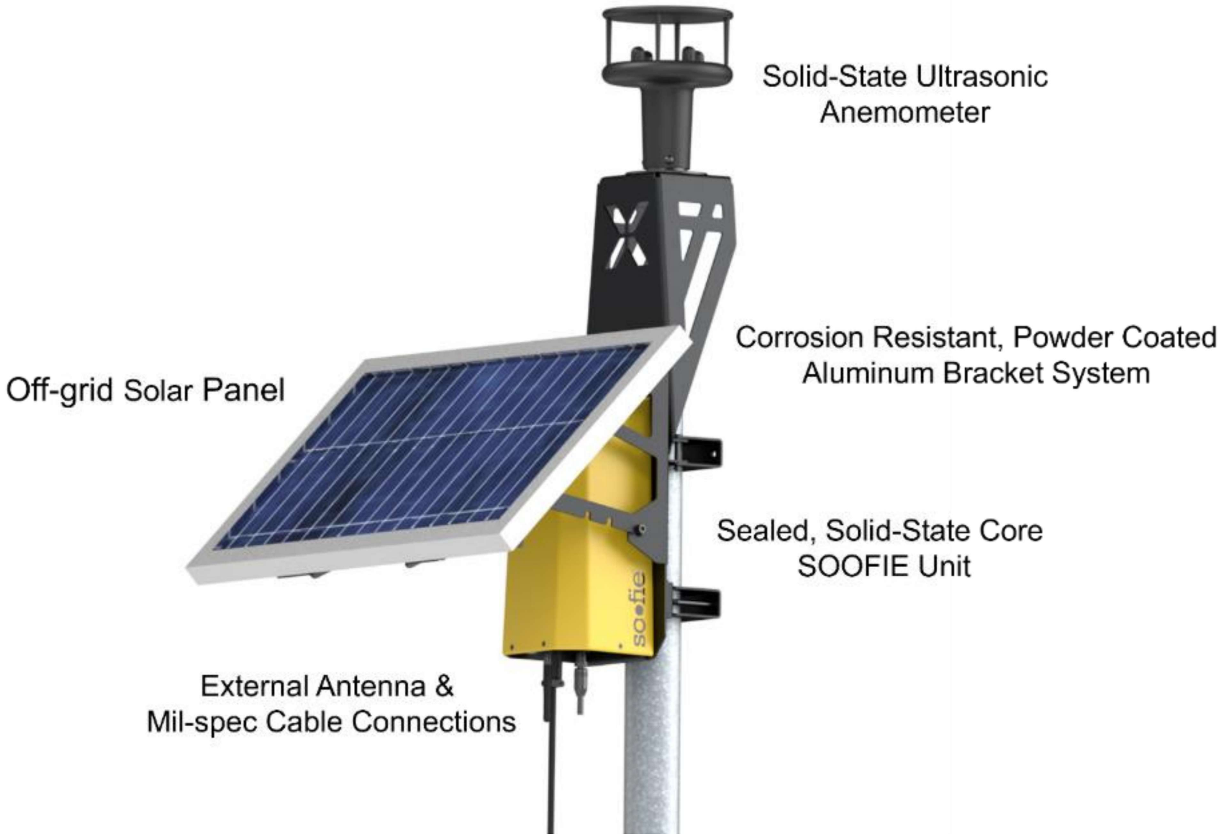

Figure 2. *A rendering of a pole-mounted SOOFIE device, shown here with a connected 2-dimensional ultrasonic anemometer. The device includes a solar panel, bracket system, external antenna and cable connections, as well as housing to contain sensors and electronics.*

2.1 Sonic Anemometer

The installed sonic anemometer is used in to determine wind direction, wind variability, and wind speed at a site. The sensor provides a wind direction resolution of 1° with an accuracy of ± 2°, and a wind speed resolution of 0.01 m/s with a ± 2% accuracy. Sonic anemometers are designed to work at temperatures -35-70 °C. Each wind sensor must be installed 1.5-2.5 m above ground level. Wind speeds must be greater than or equal to 0.4 m/s and below 7 m/s, and wind direction variability (quantified as the wind direction standard deviation) must be below 45 degrees for data from the SOOFIE emissions monitoring system to be used.

2.2 MOS Sensor

The MOS sensor is used to measure methane in the air at the sensor's location. Operating conditions of the MOS sensors fall between -40-70 °C and 2-99% RH. SLB-based laboratory testing has determined that the MOS instrumental has a resolution of < 85 ppb, accuracy of ± 0.79 ppm, and a signal drift of < 1%/year, SLB's proprietary calibration and QAQC methods verify sensor performance throughout the Screening Period.

2.3 Temperature, Pressure, and Humidity Sensors

The temperature, pressure, and humidity sensors operate within a temperature range of -40-85 °C, and relative humidity between 0-100% RH. The temperature sensor reports temperature at a resolution of 0.01 °C at an accuracy of ± 5 °C. The humidity sensor reports relative humidity at a resolution of 0.1% at an accuracy of ± 5% RH. The pressure sensor reports pressure at a resolution of 0.13 mbar at an accuracy of ± 2.5 mbar.

2.4 Printed Circuit Boards

A SOOFIE device is outfitted with two printed circuit boards and several microchips mounted on them, including a telecommunications chip, accelerometer (SOOFIE V2), GNSS (Global Navigation Satellite Sensor) sensor (SOOFIE V2), power supply, and sealed switch. The MOS sensor and antenna used for SOOFIE devices are also connected to this printed circuit board.

2.5 Solar Panel

The solar panel provides power to the SOOFIE device without being connected to the grid. It is attached to the mounting pole through a support bracket. 30-watts is the minimum power rating used for one SOOFIE device; 65-watts is the maximum power rating compatible with system.

2.6 Battery

The SOOFIE device's battery stores power during low solar irradiance at night or during extended periods of heavy overcast weather.

2.7 Antenna

The antenna enables SOOFIE devices to communicate with the SLB servers through cell towers or local Wi-Fi networks.

2.8 Housing

The housing of SOOFIE devices protects sensitive electronics and equipment from the environment. A proprietary adsorbent filter material is used in its housing to eliminate the influence of interference gases (e.g., alcohols), resulting in a highly selective response to methane.

2.9 Mounting Pole and Stand

SLB provides the customer with a variety of stand options based on the application of the SOOFIE emissions monitoring system and site uses. A mounting pole with a height of approximately 1.5-2 m is fastened to the stand. The SOOFIE device and solar panel are attached to the pole through a custom mounting bracket.

2.10 Clamps, brackets, and other support equipment

SOOFIE devices require several clamps and other equipment to be installed on a vertical post. The brackets holding the SOOFIE device and the solar panel are corrosion resistant.

2.11 Tablet/Phone

During installation, operators must have access to either the SOOFIE app or document the precise source and sensor locations to a SLB Customer Service Representative. Coordinates are within 2.5 m of actual location (CEP-50 with 24-hr static condition and open sky) and reported to nine decimal points.

3 Initial Equipment Location Setup

To guide an owner/operator on the recommended quantities and locations of SOOFIE devices at a site, we employ a proprietary Siting Tool. This tool incorporates site-specific information (unique site shape and size, site-specific equipment layout, proximity to potential off-site methane sources) with local wind statistics to determine expected detection capabilities for a given quantity of sensors.

3.1 Siting Tool Workflow

3.1.1 Detailed Siting Tool Workflow

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3.1.2 General Siting Tool Workflow

1) *Site/File Setup and Site Image Upload:*
The user enters the site name and the site operator name. The algorithm also asks the user to upload a

georectified site image of the site.

2) *Draw Site Boundary:*
The user is asked to interactively draw the site boundaries of the site to aid the algorithm in identifying the areas where sensors can potentially be placed.

3) *Incorporate Site Equipment Information:*
The user is asked to draw the site equipment on the site imagery and include site-specific information (i.e., site perimeter, geographic site location, source locations, and placement of roads and buildings). This aids the algorithm to identify potential sources and the height of the potential leak.

4) *Bring in Wind Data:*
The user is requested to either upload their own wind data or to search for nearby data. If the user selects the latter option, the algorithm will automatically search data from open-source weather stations or anonymously use data from a nearby SOOFIE Emissions Monitoring System. A minimum of one year's worth of data is required, so that the placement algorithm incorporates seasonal and monthly wind variability.

5) *Run Simulations*:
After incorporating numerous site-specific information (i.e., wind data, component location, and leak likelihood), the client can choose between fenceline or internal site placement. Next, simulations are run to determine the 'Probability of Detection' of any on-site releases at identified sources.

6) *Process Placement to Maximize Source Coverage:*
The algorithm incorporates the results from the previous step to determine the optimal placement and amount of SOOFIE devices needed to obtain at least 90% POD across the site.

7) *Export Results and Recommended Placements:*
The user is informed how the quantity and location of sensor placement can impact site-wide sensor performance. We recognize that the 'Probability of Detection' is a function of both the length of the emission as well as the wind variability with time. As a result, the output of the Siting Tool is an estimated 'Probability of Detection' across a given user-defined time frame (1-hr, 4-hr, 12-hr, etc.) (Figure B-1). Unless a user-selected range of devices are considered, the Siting Tool will also provide the operator with the recommended number of devices for a given site and time to detection.

3.2 Siting Tool Evaluation

Evaluation of the Siting Tool using METEC ADED controlled release data showed strong performance of the Siting Tool. As shown in Figure 3, the Siting Tool's predicted Percent of Detection consistently fell within 10% of the actual results, and, at ≥3 SOOFIE devices, had an average error of 7%.

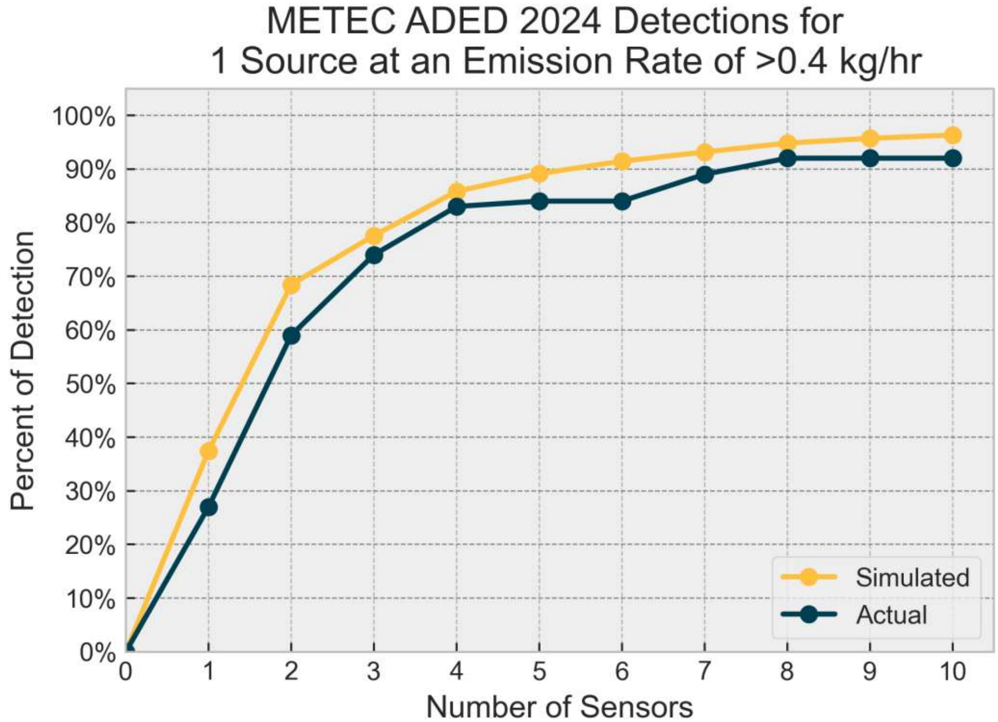

Figure 3. *A comparison of simulated sensor placement performance versus the actual on-site detection capabilities at METEC ADED during two months of controlled releases.*

4 Potential Limitations

4.1 Device Placement Limitations

The SOOFIE devices are not intended to be used in hazardous areas. They have a general safety rating and must be kept away from hazardous locations, and at least 1 m away from on-site sources. As a general guideline, however, SOOFIE devices are placed at a distance of at least 1.5 times the source height away from each probable source. SOOFIE devices are not intrinsically safe and do not carry any certifications for use when an explosive atmosphere may be present; such as ATEX, IECEx, Class/Div.

4.2 SOOFIE Network Environmental Limitations

Although SOOFIE devices are designed to work in rugged and environments, the internal components of the devices operate under a specified range of environmental conditions. In addition, point sensors require methane particles to travel from source to the receptor (e.g., SOOFIE device) for methane detection and quantification. It follows that certain wind conditions need to be achieved for successful particle transport and detection by the sensor. As a result, the SOOFIE Emissions Monitoring System requires the following conditions for a given 5-min period for successful operation and quantification:

- The average wind speed must be between 0.4-7 m/s.
- Humidity levels must be between 2-100%.
- Temperatures must be between -20-70 °C.
- Pressure must reflect a value that can be found on the Earth's surface (i.e., between 800-1,200 mbar).
- The presence of around 21% oxygen.

5 Mass Emission Rate Calculation Procedure

5.1 Sensor Measurement

Each SOOFIE device is equipped with numerous sensors and logs sensor-specific data at 1-minute frequencies. Environmental data collected includes ambient temperature (°C), barometric pressure (mbar), relative humidity (%), wind speed (m/s), wind direction (°), and the standard deviation in wind direction (°).

5.2 Methane Conversion to Concentration Values

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5.3 AI Event Detection

All one-minute methane concentration measurements collected across the SOOFIE sensor network are processed through a proprietary AI-based Event Detection algorithm. This algorithm evaluates temporal and concentration-based patterns in the data to classify each reading as either part- or outside of a methane emission event. The output is a binary indicator assigned to each data point, denoting its inclusion within or outside of an event window. The methodology used to differentiate emission events from non-events is detailed in the accompanying CBI document.

5.4 Event-Based Data Processing and Validation

Data are processed according to whether they are collected during a detected emission event or outside of one. Regardless of the workflow, each 5-minute data interval is ultimately classified as either *valid* or *invalid*. Valid intervals are associated with an estimated emission rate. The following subsections describe the processing methodology.

5.4.1 Event-Based Data

The AI Event Detection algorithm analyzes all one-minute methane concentration measurements to identify the start and end of emission events. To maximize the accuracy of facility-level quantification, all data collected during an event are used to estimate the emission rate of the corresponding fugitive source.
The initial step involves aggregating methane and environmental data from all sensors active during the event. These data are averaged over 5-minute intervals and subjected to a series of pre-processing steps to ensure input quality for the quantification algorithm. Pre-processing includes:

- Signal thresholding: Retaining only data with a minimum change of 0.5 ppm in methane concentration to eliminate noise.
- Operational envelope filtering: Ensuring data fall within the defined operating parameters of the system.
- Directional filtering: Including only data collected downwind of a probable source at the time of measurement, thereby excluding off-site emissions.

Following pre-processing, each event must contain at least three valid (5-minute average) data points to meet the minimum temporal coverage requirement. If this condition is not met, all data within the event window are marked as *invalid*.
If the temporal coverage criterion is satisfied, the data are processed using SLB's proprietary quantification algorithm—a hybrid model combining machine learning techniques with a Gaussian plume dispersion framework—to estimate emission rates (see Section 5.4.1.1). The current model assumes a single continuous source per event, with future updates planned to accommodate multiple-source scenarios.

5.4.2 Event-Based Quantification

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5.4.3 Data Outside of Events

All data characterized as being outside of an event is processed into 5-minute average periods. For each 5-min period we perform upwind analysis to evaluate whether that data was sampled downwind of a probable source. Only when the data is downwind of a probable source is it marked as 'valid'. Once validated, that period of time will be associated with a 0 kg/hr emission. If no devices are covering a probable source in a 5-min time period, that period will be marked as 'invalid' and data during this time period will not be used for quantification. This step ensures that all non-emission readings reflect data from the site.

At the conclusion of the processing workflow, all data collected during the Screening Period are evaluated in 5-minute increments. Each interval is classified as *valid* or *invalid*, and all *valid* intervals are associated with a quantified emission value

5.5 Method Validation and Performance

The SOOFIE emissions monitoring system has been extensively evaluated in performance across multiple controlled releases. Specifically, it has been applied across three testing campaigns:

1. METEC 2024 ADED: METEC conducted a series of tests from February through April 2024 in an emissions testing campaign known as ADED. Tests ranged in duration from 0.3 to 8 hours, with 1-5 simultaneous sources in an emission event. Total methane rates per source ranged from 0.08 to 6.71 kg/hr, and total facility emissions ranged from 0.2 to 9.4 kg/hr.
2. Desert Release: SLB conducted a series of 16 controlled releases with emission rates between 0.5 and 2.3 kg/hr at an anonymized site in a desert environment. The releases took place on May 27-29, 2025. Temperatures during releases ranged from 27.8 °C to 54.4°C, and winds varied from 0.19 m/s to 10.91 m/s.
3. Permian Release: SLB conducted a controlled release at a Permian facility on May 30, 2024. The 1-hr release of 1.27 kg/hr at brisk wind speeds from 4.1 m/s to 6.4 m/s.

Data from these controlled release campaigns is applied below to evaluate and validate SLB quantification method.

5.5.1 Validation of Method Sensitivity

Data from all three release campaigns were used to evaluate the methane sensitivity of the SOOFIE devices. From this analysis, the Instrumental Percent of Detection can be demonstrated. To isolate the instrumental detection capabilities, first, plume coverage of the SOOFIE emissions monitoring system is ensured. For each release, it was confirmed that the plume dispersed over at least one sensor in the sensor network and detection capabilities were only evaluated if this condition was met. Next, events where the event-wide average wind speed was above 7 m/s (e.g., our operating conditions) were removed. Lastly, whether the SOOFIE network detected an emission (e.g., False Negative or True Positive) was labeled and compared to the total facility-wide release rate.

For this analysis, a logistic regression model was fitted to the data, where *y = 1* represents a True Positive, and *y = 0* indicates a False Negative. To quantify model uncertainty, 200 bootstrap resamples of all controlled release results (344 events) were performed, each generating a logistic model. These bootstrapped fits provide a visual and statistical representation of prediction variability. Based on the fitted model, a 90% POD threshold was identified at approximately 0.6 kg/hr, which is below the reference detection limit of 5 kg/hr (**Figure 4**).

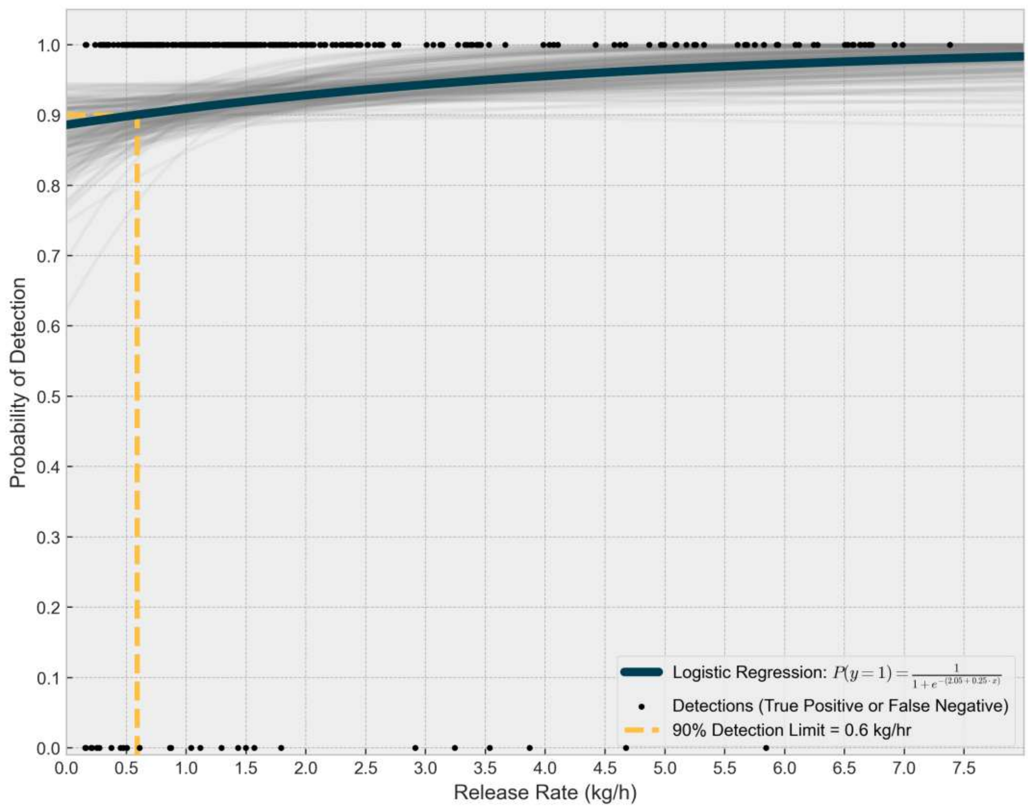

Figure 4. *A comparison of the release rate to the 90% POD. The gray lines show the 500 bootstrapped simulations, and the small black dots represent the raw (True Positive / False Negative) values, where a True Positive is represented by y = 1, and a False Negative is shown by y = 0.*

5.5.2 Evaluation of Method Quantification

To validate the hybrid machine learning and physics-based model, the predicted emission estimates were compared to the actual controlled release rates. A high correlation coefficient (R^2= 0.95) of a direct comparison of the two values shows that the model is effective at predicting release rates on a per-event basis (Figure 5). The coefficients of the line of best fit show that, in general, SOOFIE devices tend to slightly overestimate emissions at low (< 1.5 kg/hr) release rates and marginally underestimate at higher (> 2 kg/hr) emission rates. These findings are further illustrated in an assessment of the absolute quantification with release rate (Figure 6). Figures 5 and 6 demonstrate that, at emission rates < 3 kg/hr, the event duration improves accuracy, whereas duration does not appear to be tied with increased accuracy at higher emission rates. Lastly, the comparison between estimated and actual emission rates on a log-log scale highlights the strong performance of the model.

As shown in Figure 7, 89% of data fell within a quantification accuracy within a factor of two, with only the low-magnitude (< 0.4 kg/hr) emission rates falling outside of the range. This result is highly significant, as achieving agreement within a factor of two is broadly recognized in the atmospheric sciences and environmental engineering literature as a stringent criterion for model-data congruence. This highlights stable model performance, even in the presence of confounding variables such as plume intermittency, meteorological variability, and sensor limitations. The slight divergence at low emission rates is consistent with the signal-to-noise challenges that often constrain precise quantification at the lower bounds of detection.

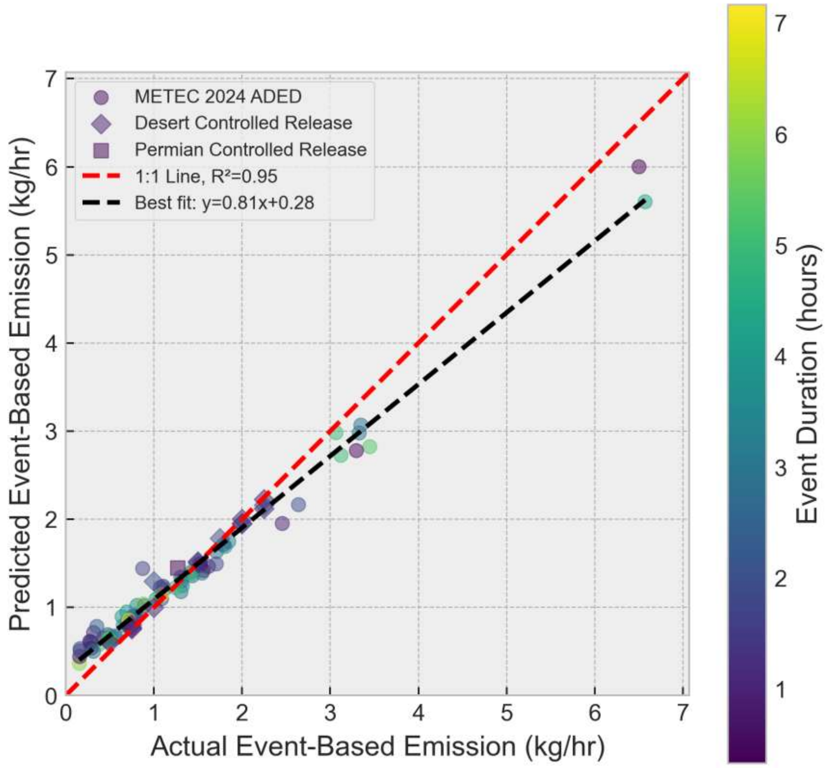

Figure 5. *A direct comparison of the actual event-based emission rates and predicted emission rates from the model. Data from all controlled releases are incorporated into this evaluation.*

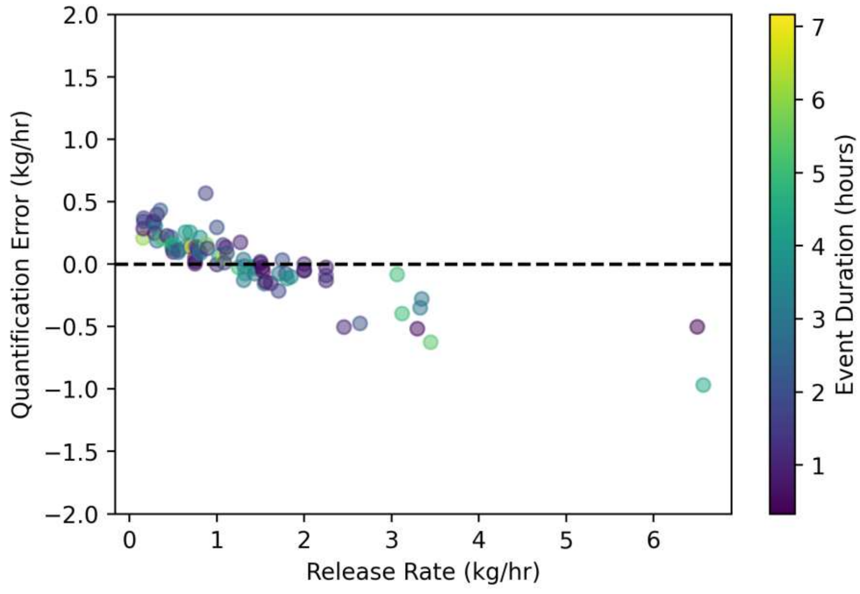

Figure 6. *A comparison of the quantification error with the release rate.*

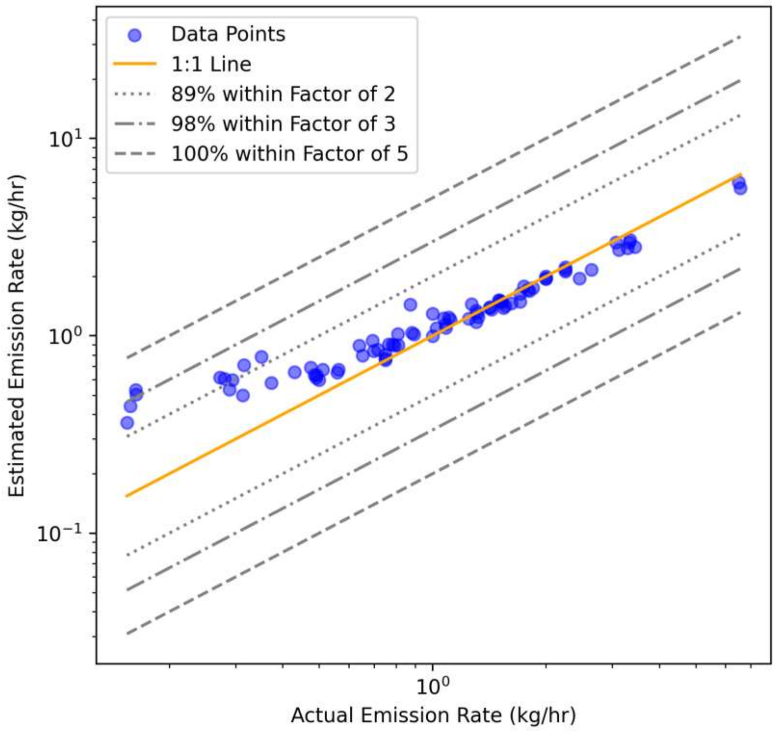

Figure 7. *A direct comparison of the estimated and actual emission rates on a log-log scale.*

5.6 Calculation of Facility-Wide Mass Emission Rat

As outlined above, the workflow differentiates between event-based and non-event data, validates each 5-minute data packet, and assigns a corresponding emission rate to all validated intervals.
To derive a facility-wide mass emission rate that accurately reflects site-level emissions, SLB defines a quantification window based on the following criteria:

- Minimum duration: At least 48 hours of valid emission estimates must be included.
- Source coverage: Each identified potential source must have a minimum of 30 minutes of valid data coverage.

The quantification window may be extended up to 7 days to satisfy the requirements listed above. Once the quantification window is established, the Site Average Emission Rate Estimate (in kg/hr) is calculated by summing all valid emission estimates (in kilograms) across the quantification window, and dividing the total emissions by the elapsed time (in hours) of the window. This approach ensures that the reported emission rate reflects both temporal consistency and spatial coverage across the facility.

6 Description of Information Delivery

6.1 Screening Report

A screening report will be issued to deliver the results of the periodic screening analysis. This report will produce three main outputs:

- Screening Validity: Whether the periodic screening analysis was *valid* or *invalid*
- Facility-Wide Mass Emission Rate: Provided only for analyses deemed *valid*
- Alert Status: Whether an alert was issued (*yes* or *no*). An alert status is positive (*yes*) if the Facility-Wide Mass Emission Rate is above the applicable Method Detection Threshold

For more detailed information on the content of the screening report, refer to *Appendix A* below.

6.2 Raw Data Accessibility

All one-minute data recorded by the sensors is accessible either through the Dashboard or an API. Data can be interactively viewed (Figure 8), or downloaded as a .csv file.

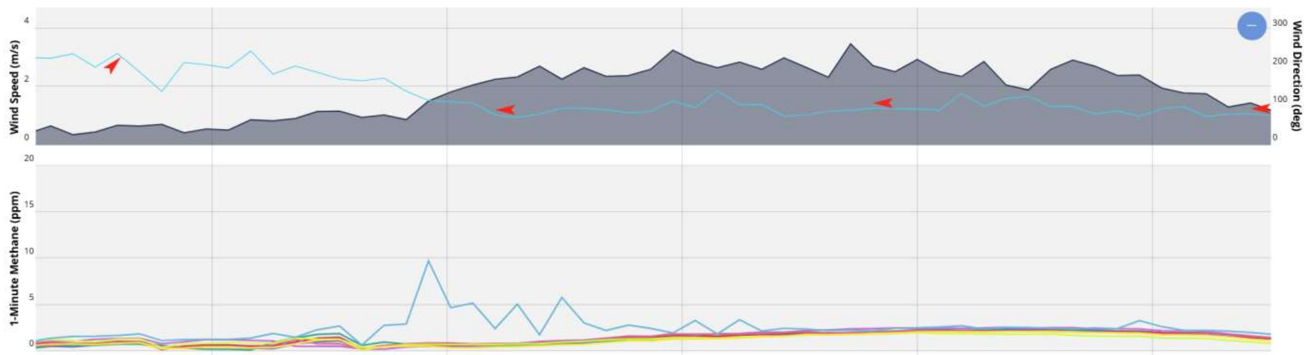

Figure 88. *A screenshot of the SOOFIE dashboard, showing 1-minute resolution methane concentration and wind data.*

7 Data Management and Storage

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Appendix A

SLB will send a periodic screening report to the operator in the format of a .pdf or .xls file (as preferred by the operator) within one week of the end of the assessment. These results are provided with a facility-level spatial resolution. Information contained in the report includes:

- Name of the owner/operator or recipient of report
- Alternative test method and technology used for periodic screening
- Spatial resolution (e.g., facility-level) of the technology used
- Detection threshold of the technology used for periodic screening
- Date that the periodic screening report was created and processed
- Date that the periodic screening report was issued to the owner/operator
- Alerting threshold used for periodic screening assessment
- Periodic Screening Site-Specific Information
    - Name of site analyzed for the report
    - Site type
    - Site location
    - Time period of periodic screening
    - Unique periodic screening report identifier
- Periodic Screening Results:
    - Assessment of 'alert' or 'no alert'
    - Calculated Site Average Emission Rate Estimate