EARTHVIEW

Formal Alternative Test Method

3 February 2025

Contents

1 Scope and Application

This alternative test method outlines the procedures for periodic screening of site-level methane emissions at oil and natural gas production facilities using the Earthview BluBird gas monitoring system. As applied here, the continuous monitoring observations obtained by the BluBird system provide periodic surveys of site emissions defined in OOOOb §60.5398b(b) and §60.5398b(d).

This alternative test method applies to sites of any size and equipment configuration, including single- and multi-wellhead sites, compressor stations, and production facilities. This method provides detection and quantification of methane emissions at the facility level. The system measures emissions from the facility for a period of time necessary to survey all equipment locations on the facility. This period is typically less than 24 hours, depending on wind conditions and BluBird node distribution. Screenings are done quarterly or semiannually as defined in tables 1 and 2 of the OOOOb regulations based on a Minimum Detection Threshold of 15 kg/hr.

The method serves as an alternative to the required fugitive emissions monitoring and monitoring and inspection of covers and closed vent systems under Title 40 CFR part 60, subparts OOOOa, OOOOb and OOOOc.

1.1 Analyte List, CAS Numbers, Matrices

Table 1: *Analyte List, CAS Numbers, Matrices*

Compound Name	**CAS number**	**Matrices**
Methane	74-82-8	Air/gas emissions

1.2 Method Sensitivity

Table 2: *Method Sensitivity*

Mass Sensitivity (Minimum detection level)	≤5 kg/hr methane
Detection Sensitivity	At least 0.4 kg/hr methane

Concentration Sensitivity	0.5 ppm methane
Sampling Temporal Resolution	Once per 30 seconds

Sensitivities quoted here are based primarily on single-blind testing in field conditions. See Section 13 for details.

2 Summary of Method

The BluBird gas monitoring system consists of the measuring and reporting instrument (the BluBird itself), the cloud-based computations that compute analyte concentrations and emission rates, and the cloud-based tools and human interactions that deliver the information to the customer. The Earthview BluBird system, including its associated cloud data processing and analysis components is installed, maintained, and operated by Earthview. No operator interaction is required. The complete system is available by lease arrangement, with Earthview providing installation, data access, and analyses. In this document, we refer to the field instrument portion of this system as the BluBird, and the cloud-based software as the Gridded Pad Analysis and Quantification System (GPAQS). The "BluBird CMS (Continuous Monitoring System)" refers to the entire system - field sensors, firmware, cloud-based software, and cloud-based data dashboard. A basic part of the processing software is an Earthview-developed virtual model of the MOS sensors that allow Earthview to estimate how various factors affect the MOS measurements using real-time data.

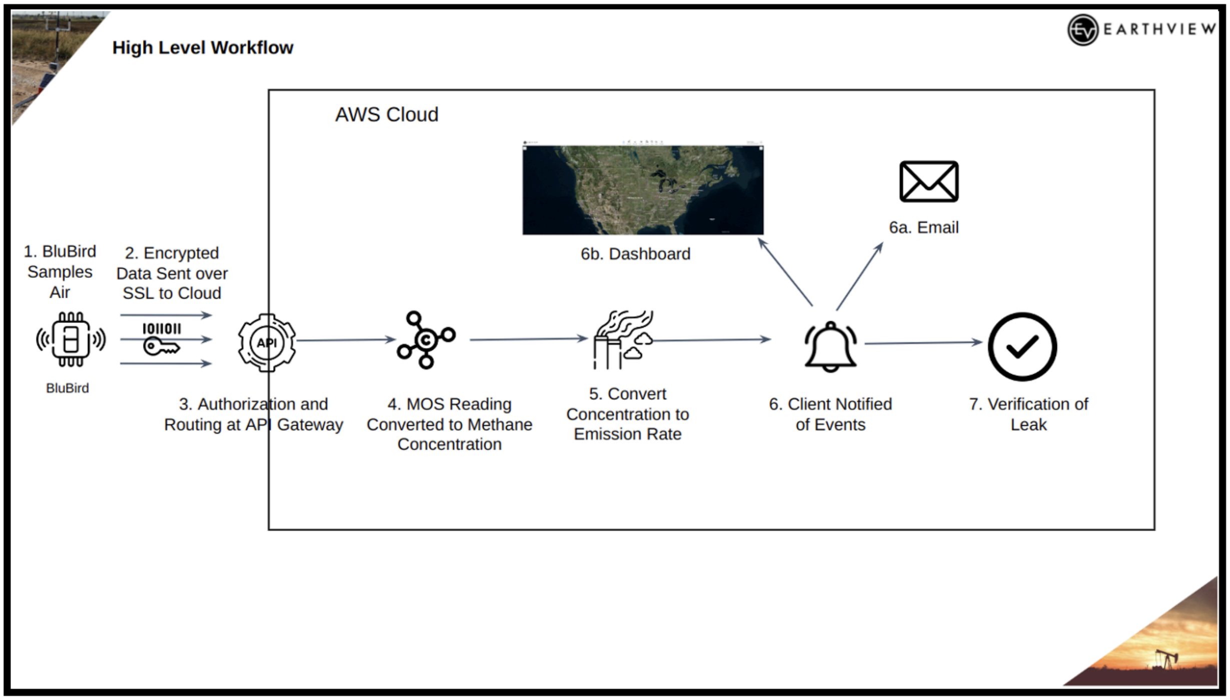


Figure 1*: High level workflow of the BluBird CMS system.*

The BluBird device draws in air from the atmosphere using a pump. This assures that the BluBird sensors are exposed to a consistent volume of air. The pump supplies a consistent air sample of approximately 0.3 liters per measurement cycle. The sample enters a sealed chamber where various measurements are taken. These measurements include humidity, temperature, pressure, and the resistances of several Figaro metal oxide semiconductor (MOS) sensors. These MOS sensors are the primary components responsible for measuring analyte concentrations, as their quantifiable resistance changes with the introduction and cessation of subject gas species.

Methane concentrations are determined by a continuous process that estimates the “clean-air” MOS resistances. A significant difference in the estimated clean-air resistance and the actual measured resistance indicates the presence of analyte species. The other measurements like temperature and humidity are required to estimate this clean-air resistance.

The BluBird system senses methane via transport of gas from the leak source(s) to the BluBird node(s) by winds and/or diffusion processes. Leak rates and source locations are calculated by Earthview using inverse dispersion modeling, consisting of either the standard Gaussian plume model or variants of the Gaussian model optimized for low wind speeds and/or short distances between the leak source and the BluBird nodes. BluBird nodes measure gas concentrations, wind speed, and wind direction at each node, along with other information useful for determining atmospheric stability and gas dispersion conditions. These are determined for each observation within Earthview's cloud-based data processing system (GPAQS). Earthview uses GPAQS to map the production facility onto a grid, with each grid cell defined according to whether it contains a potential leak source, along with additional information about the source (such as equipment type, height, etc.). GPAQS uses this grid-based information to evaluate leak rates from a finite set of potential leak locations. Earthview uses statistical analysis of the aggregated data across multiple sensors deployed at a site to determine the most likely leak source locations. The resulting distance between source and sensor, along with local winds and dispersion conditions, is used to estimate mass emission rates of methane.

3 Definitions of Method

3.1 Air sample refers to the volume of air drawn into the BluBird node and exposed to the BluBird sensors, followed by release of the sample into the outside air.

3.2 Axetris LGD TDLAS refers to a tunable diode laser spectrometer that Earthview uses to provide reference methane concentrations in the field and laboratory.

3.3 BluBird refers to Earthview's combination of field sensor unit (BluBird node) and the companion edge software and cloud-based software that make up the BluBird continuous monitoring system for methane.

3.4 BluBird dashboard is the user interface that allows Earthview staff and customers to display, download, and interact with site data.

3.5 BluBird node is the field instrument portion of the BluBird system that is deployed on site.

3.6 Concentration sensitivity is taken to be the smallest increment of methane concentration that can be reliably determined above the general noise level. Concentration sensitivity of the BluBird system, in terms of a concentration by volume, is estimated to be approximately 0.5 ppm.

3.7 Continuous monitoring defines the nature of the BluBird system, which involves continuous measurement of air samples on a site. Continuous is defined here as operating 24 hours per day, every day, with a sampling rate of once per 30 seconds.

3.8 Data quality indicators refer to the set of checks that Earthview carries out on sensor data and derived parameters.

3.9 Detection limit is defined as the lowest practical limit of a measurement that is repeatable and consistent with other sensor behavior. For BluBird, detection limits are approximately 0.5 ppm of methane concentration or approximately 0.1 kg/hr of methane emissions.

3.10 Dispersion coefficients are key parameters of the Gaussian plume model that define the lateral and vertical spread of methane within a Gaussian plume.

3.11 Earthview is the commercial vendor who created the BluBird system, and which contracts with a site operator to deploy, maintain and operate BluBird.

3.12 Earthview cloud computing center is where BluBird data from the field is transmitted for processing and analysis.

3.13 Emission rate quantification is the series of data processing and analysis steps that Earthview uses to estimate methane emission rates using the BluBird-measured methane concentrations and other site measurements.

3.14 Inverse Gaussian plume modeling refers to the mathematical model used to calculate emission rate from measured methane concentration.

3.15 Mass sensitivity is taken to be generally equivalent to the smallest increment of mass that can be reliably detected above the general noise level. Mass sensitivity of the BluBird system, in terms of a methane emission rate, is estimated to be approximately 0.1 kg/hr.

3.16 Metal oxide semiconductor sensor is the type of sensor used in BluBird to measure methane and volatile organic compound (VOC) content in the air samples.

3.17 Monte Carlo simulation refers to the approach that Earthview uses to assign a range of uncertainty to estimated emission rates.

3.18 MOS sensor refers to metal oxide semiconductor sensor.

3.19 MOS 1/ gas1 refers to one of three MOS sensors contained in the BluBird sensor chamber.

3.20 MOS 2/ gas2 refers to one of three MOS sensors contained in the BluBird sensor chamber.

3.21 MOS 3/ gas3 refers to one of three MOS sensors contained in the BluBird sensor chamber.

3.22 Screening Period refers to the time required for all equipment locations of a site to be sampled by the network of BluBird nodes.

3.23 Sensor chamber is the sealed chamber within a BluBird, where air samples are measured.

4 Interferences

The following are factors that can affect the installation, operation and performance of the method.

4.1 Planning for Interferences

Installation and operation of the method are carried out by Earthview, after consultation with the site operator. Prior to installation, Earthview and the operator review the site characteristics, including access, locations of equipment, and any special situations that might need to be accommodated. The sensor network is simple to install, and can accommodate virtually any site through choice of node placement as well as the optimal number of nodes.

4.2 Site Interferences

4.2.1 Site Access

Installation and operation of the Earthview BluBird gas monitoring system (GMS) do not have any requirements beyond normal access to the site.

4.2.2 Site Configuration

To optimize the ability of the method to measure methane being emitted from different locations on the site, normal practice is to deploy BluBird nodes around the periphery of the site. Earthview personnel in consultation with the site operator will determine optimal locations based on wind patterns and the site layout. Earthview uses climatological wind data and aerial imagery of sites to determine an optimal node deployment pattern. For a typical production pad, 3 to 5 BluBird nodes are usually recommended. This process is described in Section 6.1.7.

Best performance is achieved when nodes can be positioned at least 20 meters from equipment. Structures located between an emission source and a sensor node will affect wind flow during the transport of methane from source to sensor. The added mixing due to turbulence is a factor in the accuracy of emission rate calculations. Rate calculations will be most accurate for relatively open sites.

Placement will also consider the potential for possible obstruction of cellular transmission due to large structures.

The BluBird nodes are self-powered and do not require installation of any cabling, mounting poles, tethers, stakes, etc.

The system is not affected by terrain or setting, other than through any effects these might have on wind transport of the methane plume from source to sensor.

4.2.3 Communications Quality

The method requires that the BluBird nodes be able to upload data to Earthview's cloud computing center in near real-time. This is typically done using cellular communications but can also use the operator's local site Wi-Fi if available. The system can, however, tolerate interruptions in cell connection. In these situations, data continues to be acquired and is stored onboard each node. When cell connection is reestablished, the data is uploaded to the cloud center.

4.2.4 Off-site Emissions

Methane emissions that originate from a location other than the target site itself need to be identified and excluded from emissions calculated for the site. The BluBird system addresses this automatically, using wind direction to determine which node(s) are at the upwind edge of the site. If elevated concentrations are observed at these nodes, this background concentration is subtracted from concentrations measured downwind. More detail is provided in Section 12.1.

4.3 Weather Interferences

The BluBird system operates under a broad range of weather conditions and is tolerant of extreme conditions. Operating ranges are noted in the BluBird specification sheet (Table S.1) included in Section 17.

4.3.1 High Winds

The node mount design and flexible air intake mast (see Section 6.1.5) allow BluBird units to reliably resist winds up to approximately 60 mph, and will typically survive higher winds either unscathed or with minor damage that is repairable in the field.

4.3.2 Effects of Wind Speed, Relative Humidity and Air Temperature on Emissions Calculations

Estimation of emission rates is less reliable when wind speeds, relative humidity, and/or air temperature fall outside certain ranges. Optimal conditions are wind speeds between 0.8 m/s and 8.5 m/s (1.8 mph and 19 mph), relative humidity between 5% and 90%, and air temperatures between -20° C to 40° C (-4° F to 104° F). In cases where humidity or temperature is outside these ranges, accuracy of the temperature/humidity sensor is decreased slightly.

The wind speed range given above was determined using METEC (Advancing Development of Emissions Detection (ADED) 2024 test data (Maslanik et al., 2024). It represents the minimum and maximum wind speeds for single-release experiments that yielded true-positive detections, with estimated emission rates that were within 100% of the reported rates. For humidity and air temperature, the ranges given are the optimal ranges specified for the humidity and temperature sensor used in the BluBird v.2.

4.3.3 Precipitation

A heavy, persistent snow cover may temporarily reduce the effectiveness of the solar panels. Snow or rime buildup on the wind sensors may temporarily affect the wind readings.

4.4 Sensor Performance Interferences

MOS sensors such as those used in the BluBird are known to be highly sensitive, but affected by a variety of factors that can mask this sensitivity (Schutz et al., 2017). Key influencing factors are noted below.

4.4.1 Humidity

Moisture content of the air sample influences the response of the gas sensors used (e.g., Abdullah et al., 2020; Wang and Zhou, 2022), and so must be addressed as part of data processing. The approach used for this is outlined in Section 11.1.

4.4.2 Cross-Sensitivity to Other Gases

While MOS sensors are engineered to respond most strongly to specific gases, they are affected by other gases that have similar interactions with the MOS sensing material (e.g., Dahl et al., 2021). Earthview addresses this by choosing sensors that are less likely to show cross sensitivity, by using a set of MOS sensors that each have different cross-sensitivity characteristics, by including a filter-equipped sensor, by testing the effects of different gas combinations (see Section 13.1.4), by calculating VOC concentrations in addition to methane concentrations, and by choosing sensor response functions (equations to convert from sensor measurements to methane concentrations) that help account for gas mixtures.

4.4.3 Sensor Drift

MOS sensors tend to experience drift in their baseline resistance over a long period of operation, which can affect their sensitivity (Isaac et al., 2022). However, they are generally considered to be stable over 2 to 3 years (Figure 2; Dhall et al., 2022), and have a longer lifetime than other gas sensor technologies (Chai et al., 2023). Earthview's data processing methodology minimizes the effects of sensor drift and response characteristics (see Section 11.1). Earthview's computing center monitors sensor data automatically (see Section 9), including continuous checks to verify that the MOS resistance readings are within an acceptable range. An Earthview-proprietary test to check for decreases in MOS sensitivity is also applied. Sensors that exhibit a greater than 20% reduction in sensitivity are flagged for maintenance by Earthview.

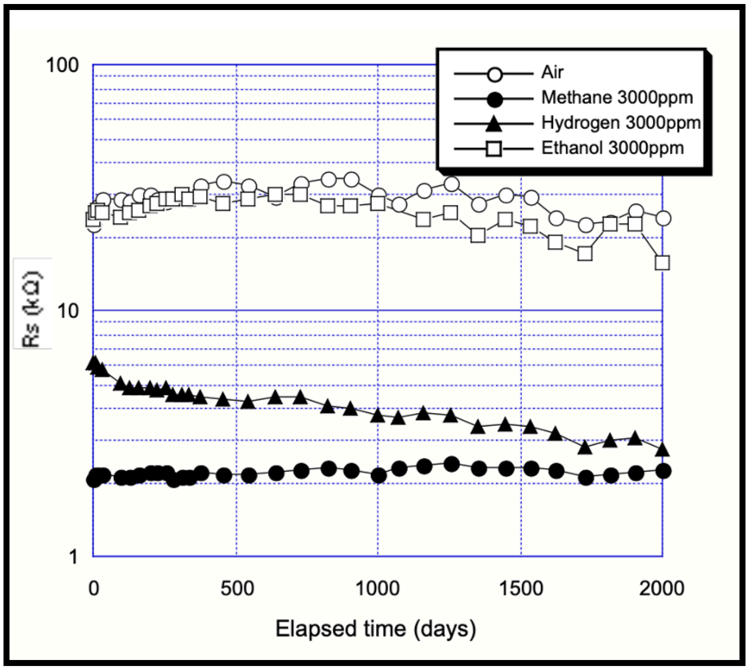


Figure 2. *Long-term stability of MOS sensor 3 under continuous operation (from manufacturer's data sheet). The y axis shows sensor resistance. The test was done using constant exposure to 5000 ppm of methane, 3000 ppm of hydrogen, and 3000 ppm of ethanol.*

4.4.4 Sensor Poisoning

MOS sensors are long-lasting and resistant to contamination. However, exposure to high concentrations of certain gases or contaminants can permanently alter the sensor surface, reducing its sensitivity. These include substances containing silicone (which can be found in some lubricants, desiccants, and hydraulic fluids, for example), and prolonged exposure to high concentrations of sulfur-containing gases, including hydrogen sulfide and sulfur dioxide. However, prolonged exposures to levels sufficient to cause poisoning are very unlikely in an open setting such as well pads.

5 Safety

5.1 Site Safety

The sensor nodes operate autonomously. Earthview personnel are only required on site for network installation, occasional maintenance and removal. Earthview personnel undergo any specialized training needed for site access. Standard safety practices are followed. In most cases, maintenance can be done by the operator's staff, with instructions provided by Earthview.

5.2 Precautions

When installing a node's fiberglass air intake mast, attention should be taken to not contact any overhead structures or wires. Earthview technicians are well trained professionals with years of experience working in the oil and gas industry. Our system requires no staking, drilling or digging of any kind, eliminating the potential to strike underground pipes or other hazards.

6 Equipment and Supplies

The following equipment and supplies are required for installation, and are provided by Earthview. Other capabilities such as data processing and analyses are provided by Earthview's cloud computing system, with no extra requirements for specific equipment and supplies needed to interact with that system.

6.1 BluBird Sensor Node

BluBird sensor nodes (Figure 3) will be supplied by Earthview for installation on site. Each of these nodes consists of the main components listed in Figure 3. The number of nodes used per site, and their positioning, are determined by Earthview and the customer (see Section 6.1.7).

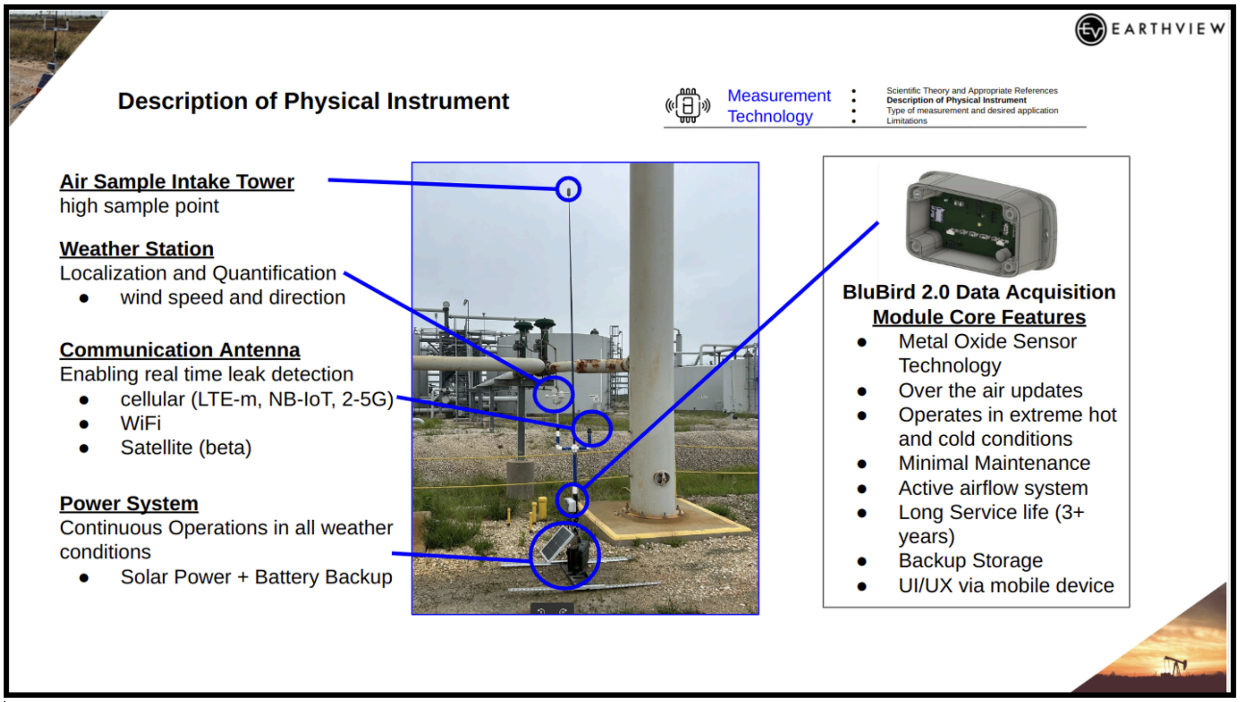


Figure 3*. Earthview BluBird sensor. Consists of a folding stand, solar panel, backup battery, instrument case, cellular antenna, wind sensors, and adjustable mast with air intake.*

6.1.1 Air Sample Mast and Intake

The air intake uses a custom-designed intake mounted onto a fiberglass mast. Teflon tubing extends from the intake, through the inside of the mast, into a connection on the BluBird enclosure. The mast height is adjustable up to a maximum of 20 feet. The standard installation height is 15 feet. Alternatively, a height of 20 feet may be used if installing near tall structures such as storage tanks while a lower height may be used if installing near lower structures. The height used is recorded for each node and taken into account during emission rate calculations.

6.1.2 Weather Station

Wind speed and wind direction are measured and reported by each BluBird device on a site. The standard BluBird installation uses a wind vane and cup anemometer installed at each device.

6.1.3 Communication Antenna

The BluBird has a small communications antenna that has both cellular and Wi-Fi capabilities. The default option is to use cellular to connect to the internet. The site’s Wi-Fi can be used if the customer desires. Data packet sizes have been minimized to the lowest byte size possible to minimize data transmission costs. Different antennas are used depending on cell transmission quality, with a typical example shown in Figure 4.

Figure 4*. Communication Antenna. Sends local measurements to Earthview cloud servers.*

6.1.4 Power System

Each BluBird node is equipped with its own power system, consisting of a solar panel and backup battery supply. A custom-designed Maximum Power Point Tracking (MPPT)-type solar charge circuit is contained in the main electronics enclosure and is used to regulate charging of the included 12V battery (Figure 5).

Figure 5: *BluBird power supply system: solar panel and backup battery.*

The devices can operate for about 7 days without needing a solar charge. Earthview's cloud processing continually monitors battery voltage and solar charge current. (Figure 6 displays a healthy battery voltage pattern.) In a scenario where the battery voltage drops below 8V, the system switches into an under-voltage lockout mode to protect itself from draining the battery. Once the battery is sufficiently recharged to 11V, the system restarts its normal sampling procedure. The Earthview cloud processing system tracks such “no data” periods and includes them in the overall determination of system downtime.

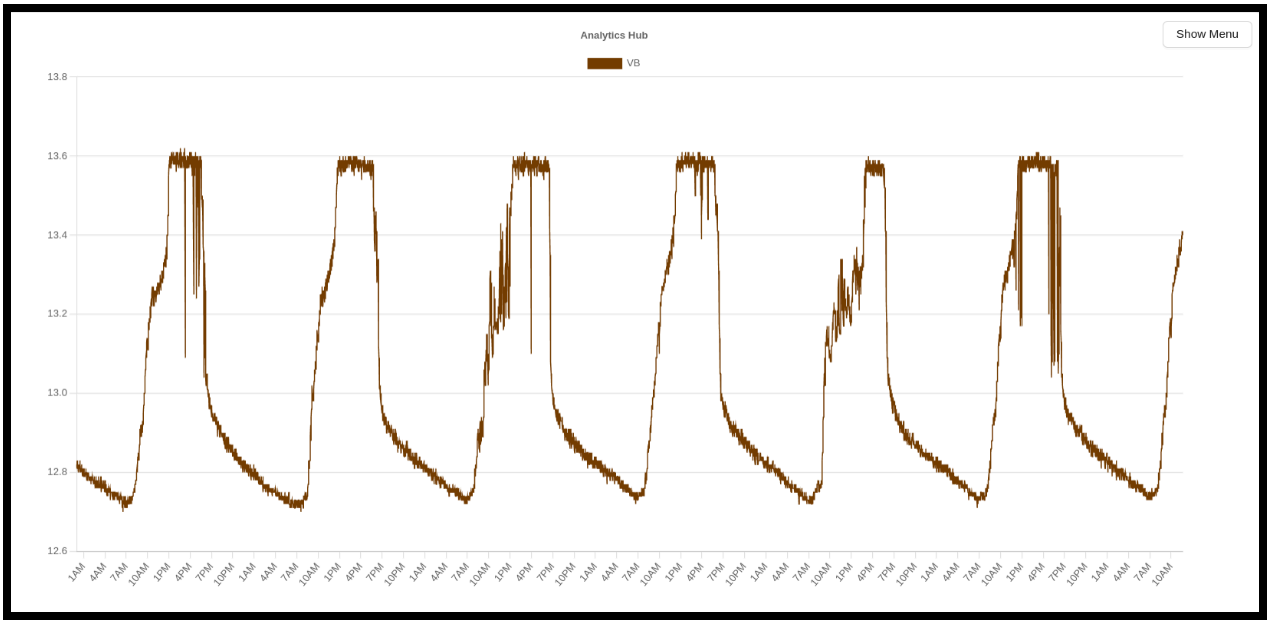


Figure 6*: A typical healthy battery voltage over a seven day period. Battery voltage quickly increases to full between sunrise and around 10AM. Battery voltage plateaus during the day at around 13.6 V. Battery voltage slowly discharges at night after sunset before repeating the cycle at sunrise.*

6.1.5 BluBird Stand

The Earthview BluBird gas monitoring system is mounted on a lightweight, "H" bracket stand (Figure 7). Earthview's field-operations engineers anchor the stand with sandbags to prevent the system from blowing over or moving during high winds.

Figure 7*: Support base.*

6.1.6 Data Acquisition Module

The data acquisition subsystem is housed in a water- and dust-resistant enclosure that mounts onto the support base (Figure 8). This enclosure encompasses the sensors that measure air samples, the air pump to draw in the air samples, and the system electronics that control operations, data transmission, onboard storage, power management, and data transmission.

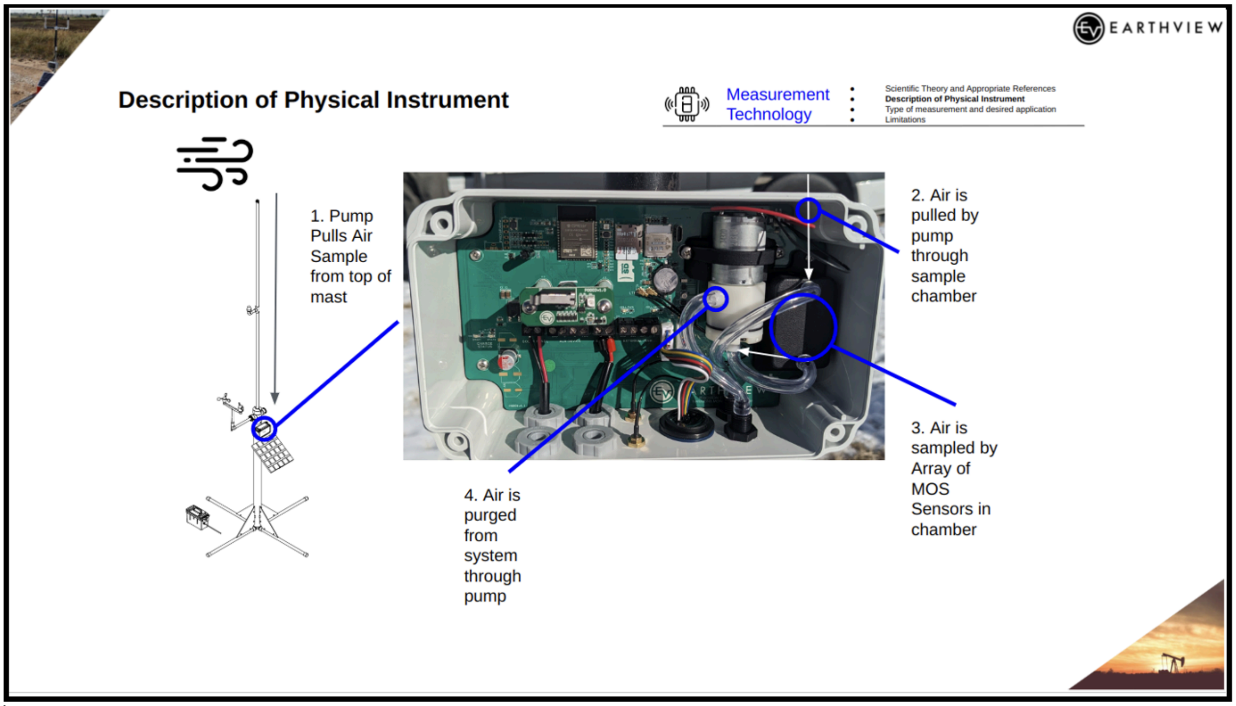


Figure 8*: BluBird air flow system.*

6.1.6.1 Communications, time tagging, and positioning

The underlying driver of the communications, time tagging, and positioning subsystem is that all data collected must be readily transmitted to the Earthview cloud processing center, augmented with necessary information including sample time stamps and device position. This is achieved by using a cellular modem equipped with GPS, along with Wi-Fi capability. A common modem integrated circuit (IC) is used that is capable of handling a variety of protocols, including non-U.S. providers. This IC includes a GPS which provides time and position independent of cell connectivity.

This subsystem also includes the cellular antenna, as noted in Section 6.1.3. The BluBird installation provides different options for cellular antenna mounting positions as well as antenna type. These choices are made based on the quality of cell coverage at a particular site.

6.1.6.2 Onboard Data Storage

Each BluBird unit includes a micro SD card to store data and to provide a backup to the cellular/Wi-Fi data transmission. If the cellular or Wi-Fi connection is interrupted, measurement data continues to be stored on the card. When Wi-Fi or cell coverage eventually returns, the data is then transmitted to ensure continuous sampling. If an SD card becomes filled, the oldest data are overwritten.

6.1.6.3 Air Temperature and Humidity Measurement

As noted in Section 4.4, MOS sensors are highly affected by humidity. The BluBird system uses a separate sensor to provide air temperatures and humidity of air samples as they pass through the sensor chamber. The temperature and humidity sensor data are internally corrected and compensated to provide consistent accuracy over a large range of temperatures and humidities without the need for calibration. An additional temperature and humidity sensor is used to monitor overall conditions within the BluBird enclosure but outside of the sensor chamber.

6.1.6.4 Server Firmware Communications

The physical hardware is equipped with Earthview proprietary firmware that instructs the hardware how to function. The firmware has a wide range of functionality besides sampling for methane that aids in device health checks and ensuring a streamlined system. Firmware updates are carried out via cellular, so no maintenance visits are required to change operating modes or to add functionality.

Earthview uses encrypted Transport Layer Security (TLS) to communicate with devices in the field. This architecture is outlined in Figure 9.

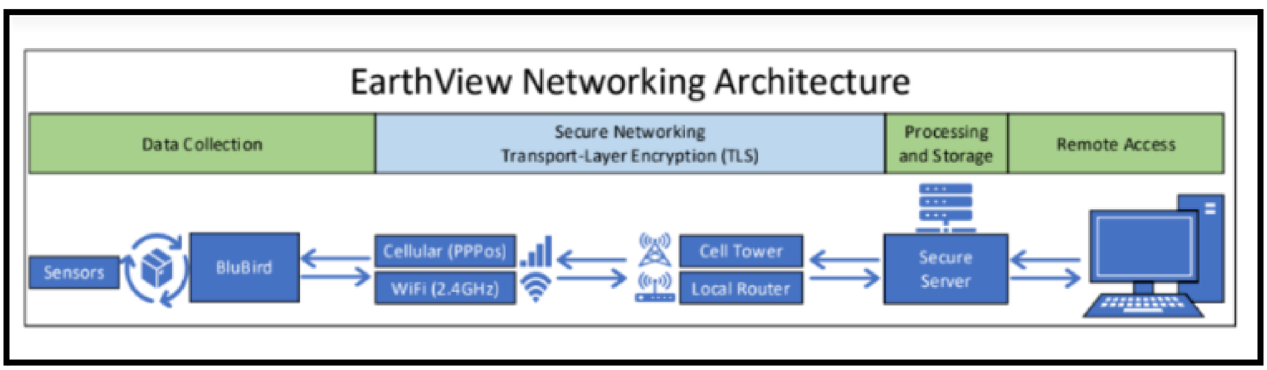


Figure 9. *Earthview networking architecture. Uses Secure Networking with Transport Layer Encryption.*

As mentioned, BluBirds communicate via cellular or Wi-Fi protocols. The device initiates a connection to the Earthview server and engages in a handshake process to establish cryptographic keys to encrypt and decrypt data sent between the two parties. A description of HTTPS TLS Communication is provided below (Figure 10).

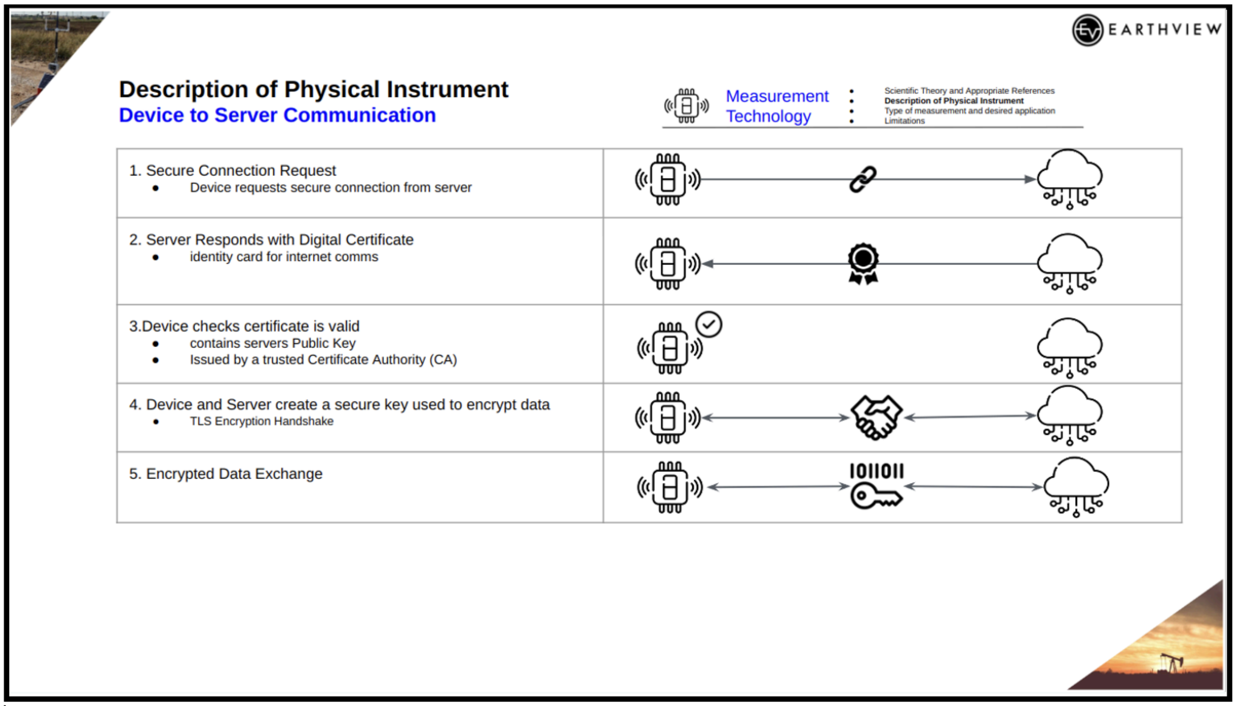


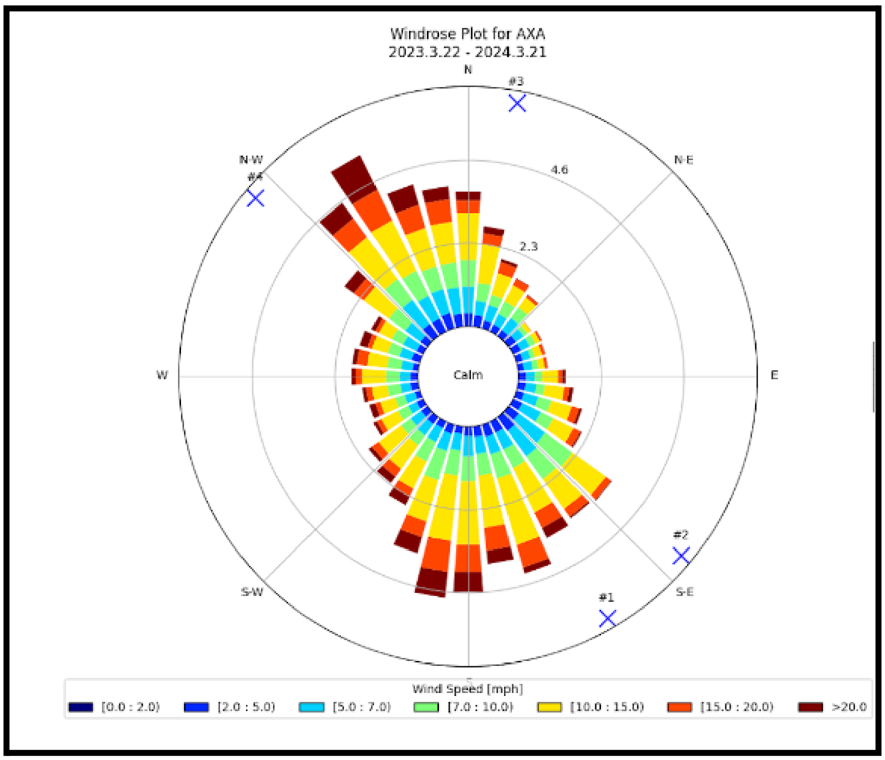
Figure 10*. HTTPS TLS communication with devices and Earthview servers.*

6.1.7 Sensor Node Placement

Sensor nodes are installed at a site by an Earthview field technician at locations that are optimized to take advantage of wind patterns while avoiding interference with site operations. As discussed in Section 13.2, for periodic screening applications, the number and positioning of BluBird nodes should be arranged such that all potential emission sources are less than approximately 125m from a node.

Gas monitoring systems of this type are influenced significantly by wind speed (through plume transport and dispersion), wind direction (which dictates path of travel between source and sensor), the size of the pad, and the location of oil and gas production equipment. For continuous monitoring to be most effective, devices should be placed downwind from production equipment. To best account for these factors, Earthview uses an algorithm to determine the optimal number and placement of devices at a location.

When Earthview plans a site installation, the first step is gathering wind data from the nearest weather station. The latitude and longitude of the target site are used to identify the closest weather station. Once identified, the previous year's wind data from the station is retrieved and organized into a wind rose graph (Figure 11). This data is sourced from publicly available records. Earthview uses a proprietary algorithm that optimizes node positioning as a function of wind direction variability and locations of potential leak sources on the site. This analysis is done individually for each site. The result of this process is shown in Figure 11.



label	node % coverage	total % coverage
1	27	27
2	22	31
3	12	44
4	24	67

Figure 11*: Result of device placement algorithm. Optimal device positions (blue Xs) are positioned to observe the greatest amount of wind while covering a majority of the pad.*

Several obstacles may prevent a device from being placed where the optimizing algorithm suggests. The Earthview field technician is provided with a site diagram (Figure 12) which outlines the placement algorithm results as a guideline. The field technician makes the final recommendation on positioning based on where devices can be safely placed and not interfere with day-to-day operations on the site.

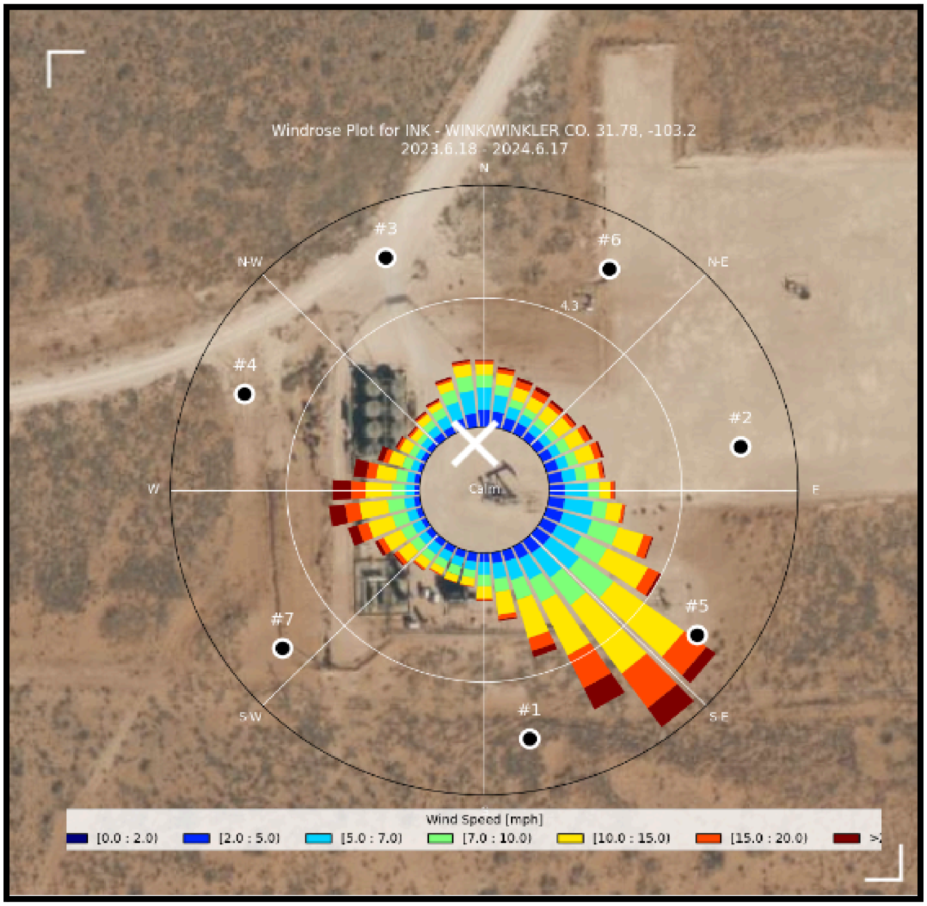


Figure 12*: Device optimization overlaid over site diagrams*

7 Reagents and Standards

[Reserved]

8 Sample Collection, Preservation and Storage

Air samples are continuously collected, analyzed and released back into the atmosphere. The BluBird device pulls air into its sampling chamber using a pump. After sensor measurements are obtained, the air is cleared from the device so there are no residual effects on the subsequent sample. This cycle is configurable with typical settings using a 30s clearing rate.

The data from the samples is recorded and the samples themselves are neither preserved nor stored.

9 Quality Control

9.1 Hardware

Before a device can be packaged and sent to the field, it is tested at Earthview and the measurements submitted to the server. This verifies that all sensors are working as expected and prevents issues that can occur from installing underperforming devices in the field.

9.2 Server Communication

After the initial bench test, the hardware-to-software communication is tested (Table 3). A successful test screen is shown in Figure 13.

Table 3. *Initial hardware to software tests to validate communication between the device and the server. Here "Node" refers to one of the BluBird devices.*

Check	Description
1. Node Created	Device was created in the cloud server database.
2. Location	Node is sending GPS coordinates and the last GPS check-in was within an acceptable range of the Dallas Earthview Assembly Location.
3. Getting Reads	Node is sending methane sampling payloads to the server.
4. Reporting Regularly	Node has been running for at least 15

	minutes and there are no gaps over 90 seconds between reads.
5. Read Validation	Sample reads being sent to the server are passing validation.
6. Hardware Test	A valid bench test has been sent and is recorded in the system.
7. Firmware Test	Node is on the most recent version of the firmware.

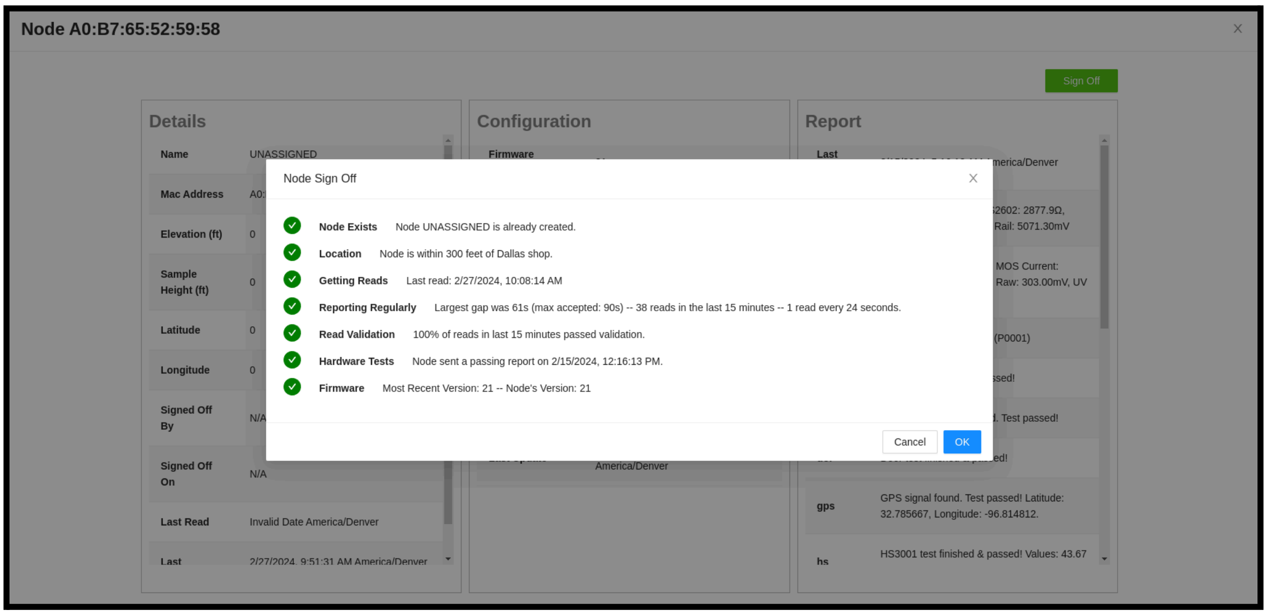


Figure 13: *automatic sign off of server firmware communication in the Earthview dashboard.*

9.3 Sample Validation

All reads from a device are validated before they are converted to a methane concentration. If a read fails validation, it is stored in the database for record keeping but will not be converted to a methane concentration (invalid wind values can be replaced by other sources and do not invalidate methane concentration analysis). If a device in the field is continuously failing validation, it will be flagged for repair by the field operations team in the 6-hour automatic status reports (see Section 9.4).

9.4 Six-Hour Status Checks

The system runs a series of health checks for all devices twice per 6-hour block. These status checks help field operators be aware of necessary maintenance. Table 4 describes these status checks.

Table *4. Twice per six-hour device status checks.*
** Local airport data is used in place of invalid wind measurements, so this check alerts operators to problematic wind instruments separately.*
*** The humidity sensor reporting erroneous 100%+ humidity values typically indicates damaged sensor(s).*

Status Check Name	Description
Online	Did the device send any data in the last time period?
Connection	Is network signal quality above minimum acceptable threshold at least 80% of the time?
Validation	Did at least 80% of measurements pass validations?
Battery Voltage	Is the battery voltage at least 1V above 10V under voltage lockout threshold at least 80% of the time?
Battery Charging	Did the device's battery charge?
Wind Speed Validation	Are at least 50% of wind speed measurements valid? *
Wind Direction Validation	Are at least 50% of wind direction measurements valid? *
Read Frequency	Did the device send at least 80% of the expected number reads?
Internal Humidity	Was the internal relative humidity measurement ever above 100%? **

9.5 Additional Data Quality and System Status Checks

Numerous additional checks of data quality and system status are carried out by Earthview automatically and in real time, for all units. These checks are listed in Tables S.2-S.3 in Section 17.

10 Calibration and Standardization

The BluBird system does not require calibration. Adjustments in sensor behavior are carried out automatically in real-time within Earthview's cloud computing system using an Earthview-patented method that involves creation of a machine-learning based representation of each individual MOS sensor using real-time and time history data at each location. This model calculates the expected sensor resistance under observed conditions, thereby compensating for atmospheric effects and sensor changes (see Section 11.1). No additional field calibration is required. The processing results in a MOS resistance ratio that is standardized across BluBird units.

11 Procedure

This section outlines the procedure used by Earthview to calculate methane concentrations from the BluBird sensor readings. Conversion of the methane concentrations to emission rates is described in Section 12. As with all the other elements of the BluBird system, these steps are carried out by Earthview and do not require any involvement on the part of the customer.

Converting a BluBird sensor reading to a methane concentration in ppm involves multiple analysis steps, which are necessary to address factors such as effects of humidity, temperature, sensor differences, and sensor drift. All of these steps are carried out by Earthview's cloud processing system - no action is required of the customer. As noted earlier, this processing is how Earthview exploits the inherent high sensitivity of MOS sensors while minimizing the factors that can mask this sensitivity.

At a high level, this conversion can be described in the following steps, shown visually in Figure 14.

1. Validate sensor data (see Section 9.3)
2. Predict a clean-air MOS resistance based on machine learning (see Section 11.1)
3. Calculate methane concentration from the ratio of observed to predicted MOS resistance using a response function that captures the relationship between resistances and methane concentrations

4. Convert the derived methane concentrations into methane emission rates (see Section 12.0).

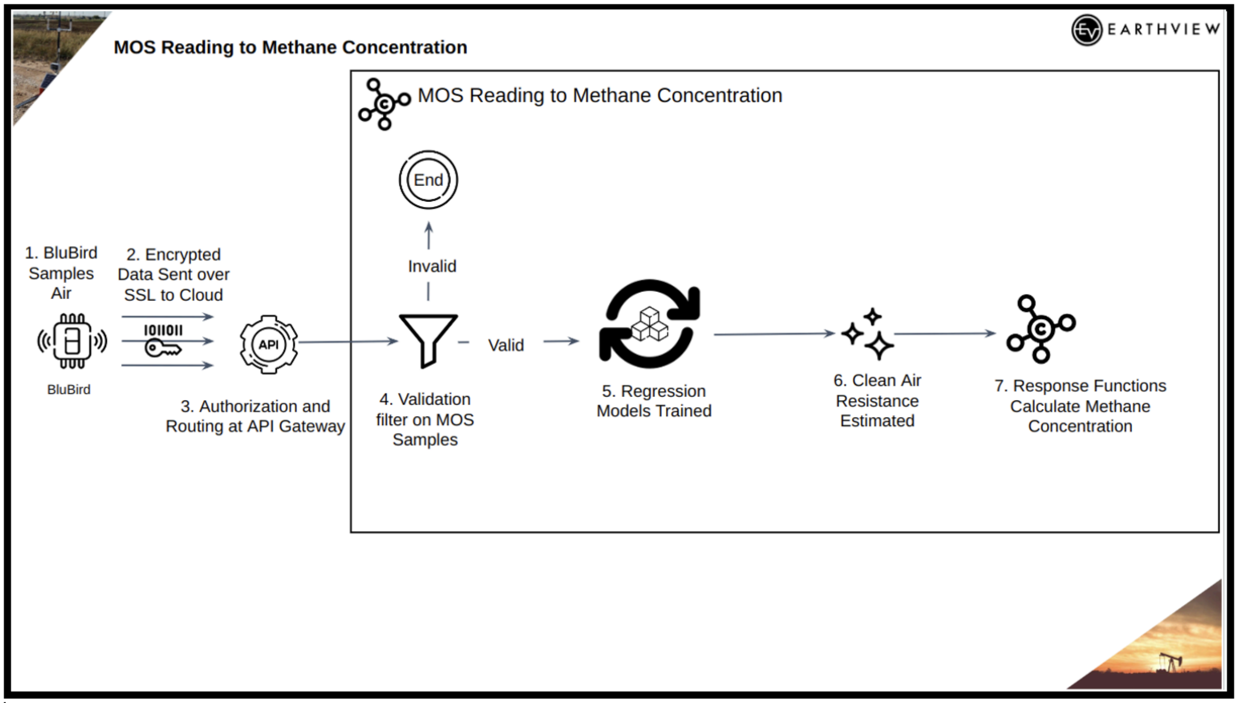


Figure 14*: Conceptual workflow of MOS Sample to methane concentration calculation.*

11.1 Machine-Learning Based Sensor Model

The estimation of a “clean air” background resistance, Ro, is critical to the operation of the BluBird system. This resistance represents the expected MOS resistance if the air sample contained only a background level of methane. Earthview’s patented approach builds a digital model individually for each individual MOS sensor using real-time data, allowing the model to evolve, incorporating changes in sensor behavior.

11.2 Response Functions

The predicted resistance provided by the sensor model along with the observed resistance is used to calculate the concentration of gas in the sample, where the clean-air resistance is determined as described in Section 11.1. The resulting ratio of observed and predicted resistance (Rs/Ro) is used to estimate methane concentration using selected response functions. A variety of data sets have been used by Earthview to develop these functions, including results in published literature, lab experiments with calibration gases, co-located field measurements with research-grade air monitoring instruments. These response functions are quite consistent between different BluBird units.

12 Data Analysis and Calculations

The result of the steps outlined in Section 11 is methane concentration (in units of ppm). These concentrations are then passed to the subsequent analysis steps listed below.

12.1 Background Methane Concentrations

As pointed out in Section 4.2.4, it is necessary to calculate what the methane concentration is, for air traveling into the domain of the monitoring site. The detection system calculates this “background” methane concentration based on wind direction, device placement, and methane readings over a 10 minute sampling period. For example, consider the image in Figure 15. The white circles represent BluBird devices, where the arrows point in the direction of where the wind is blowing to. In the example, the southeastern and northeastern devices have no upwind production equipment. These devices are therefore identified as seeing exclusively offsite methane concentrations. When quantifying emissions rates, the background methane concentration is set to the average methane concentration observed by these exclusively offsite devices.

This automated process of identifying exclusively offsite methane concentrations is repeated every 10-minute sampling period to determine the background methane concentration. When performing quantification, we consider the difference between the background methane concentration and the methane concentration observed by individual devices on the site that have winds favorable to sampling production equipment. The example in Figure 15 shows that the southeastern device is recording the highest methane concentration, so emissions calculations would report no methane emissions during this snapshot since all other devices are measuring below that offsite methane concentration.

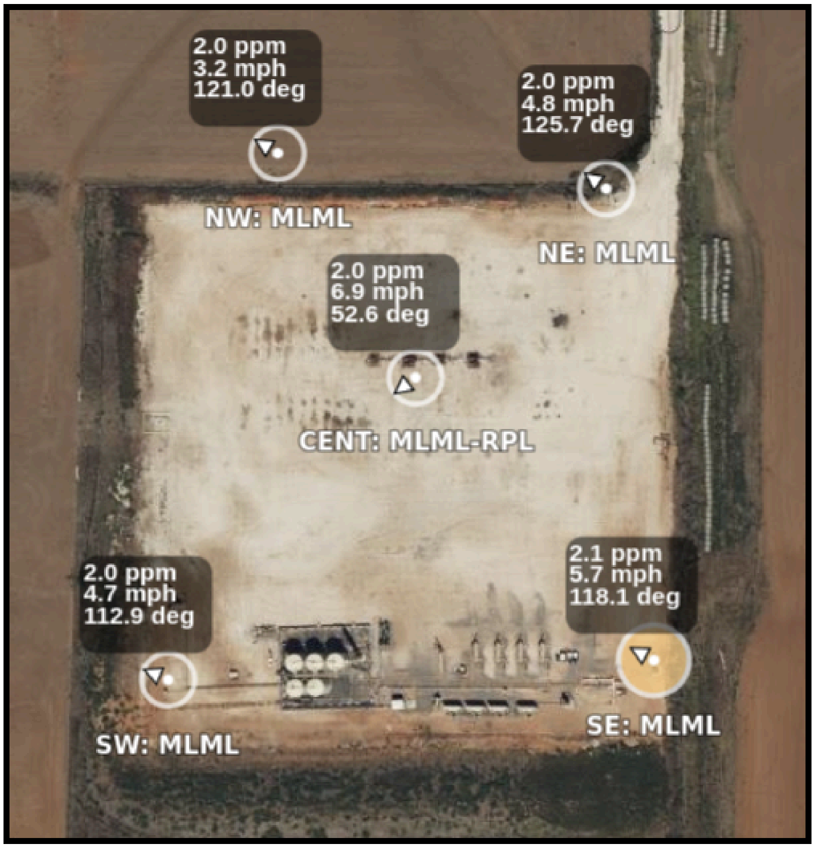


Figure 15. *Production facility with 5 sensors deployed.*

12.2 "High concentration" check and alert

Once the methane concentrations are calculated, they are used in real time to see if the concentrations exceed a pre-defined threshold. If so, the event is recorded in Earthview's data analysis dashboard, and an automated alert email is sent to the customer and to Earthview staff within seconds of the measurement time. The alert message contains the estimated concentrations, site information, and the identifier of the node reporting the high concentration. This step therefore provides a nearly immediate alert to potential high emissions on a site, and can draw attention to conditions that might not be readily obvious in the emission rate estimates discussed below.

12.3 Emission Rate Calculation

Calculation of emission rate makes use of plume dispersion modeling, applied using information extracted from “localization” steps that determine the most likely emission source based on a time series of data. These steps are contained within Earthview’s Gridded Pad Analysis and Quantification System (GPAQS). Details of GPAQS analysis and calculation steps are provided below.

12.3.1 Plume Dispersion Modeling

Plume dispersion modeling is used to convert the methane concentrations into emission rates. Earthview uses an inverse version of the standard Gaussian plume model (e.g., Hanna et al., 1982), along with modifications to address special conditions. The main aspects of the models are outlined below.

The parts per million methane concentration can be converted to a grams per cubic meter concentration via the following equation, which takes the measured pressure and temperature into account:

$$\begin{array}{ll} c : \text{methane concentration} & [g/m^3] \\ c_{\text{ppm}} : \text{methane concentration (parts per million)} & [1] \\ P : \text{atmospheric pressure} & [Pa] \\ T : \text{chamber temperature} & [K] \\ R : \text{ideal gas constant} & [J/K \cdot mol] \\ M : \text{molar mass of methane} & [g/mol] \end{array}$$

$$c = \frac{c_{\text{ppm}} P M}{10^6 R T}$$

Equation 1. Methane *parts per million concentration to grams per cubic meter concentration conversion.*

Here, we describe the exact formulations used for calculation.

q : emission rate	$[g/s]$
c : methane concentration	$[g/m^3]$
w : wind speed	$[m/s]$
h : vertical distance between sensor and leak source	$[m]$
x : horizontal distance between sensor and leak source	$[m]$
y : horizontal distance from plume center	$[m]$
z : vertical distance from plume center	$[m]$
A_y, B_y : y direction dispersion coefficients	$[1]$
A_z, B_z : z direction dispersion coefficients	$[1]$

$$q = \frac{2\pi c w \sigma_y \sigma_z}{f(y, \sigma_y)\left[f(z+h, \sigma_z) + f(z-h, \sigma_z)\right]}$$
$$\sigma_y = A_y x + B_y;\ \ \sigma_z = A_z x + B_z$$
$$f(r, \sigma) = \exp\left[-\frac{r^2}{2\sigma^2}\right]$$

Equation 2. *Gaussian plume dispersion model.*

Plume dispersion modeling depends greatly on the choice of dispersion coefficients (e.g., Carrascal et al., 1993; Irwin et al., 2005; Finn et al., 2016), and many options for estimating the coefficients have been described in the literature (e.g., Korsakissok and Mallet, 2009). In our case, we use the dispersion coefficients provided in tables A-1 and A-2 in U.S. EPA (2013), as consistent with the OTM-33A approach. Using the data in the two tables, linear equations were fit to predict sigma y and sigma z as functions of distance between source and sensor. Individual equations were generated for each stability class. A and B in Equation 2 are the slope and intercept for each of the equations. Currently, our approach uses the Pasquill stability class definitions as given in Table 5 (Pasquill, 1961).

Table 5. *Surface layer stability classes, as defined by Pasquill (1961).*

Surface wind speed (m/s)	Daytime incoming solar radiation			Daytime / Nighttime cloud cover	Nighttime cloud cover	
	Strong	Moderate	Slight	8 - 10	Upper sky layer 5 – 10, Middle / Lower sky layer 5 - 7	0 - 4
< 2	A	A - B	B	D	G	G
2 – 3	A - B	B	C	D	E	F
3 – 4	B	B - C	C	D	D	E
4 – 6	C	C-D	D	D	D	D
> 6	C	D	D	D	D	D

12.3.2 Modification to Plume Modeling for Short Distances and for Low Wind Speeds

To help mitigate limitations of the standard Gaussian plume model for short plume travel distances and/or low wind speed conditions, Earthview applies alternative models more suited to these conditions. The low wind speed model is applied when measured wind speeds are less than 2 m/s. The short distance transport model is applied when the estimated distance between source and sensor is less than 20m.

12.3.3 Leak Rate Quantification

The detection system calculates emissions rates every 10 minutes. At this stage the system is not attempting to determine a source location. The system receives the quality-controlled measurements for each device and determines what emission rate from any potential location would produce the concentrations observed on each device. For each device, the average of the quality-controlled measurements is input into the relevant plume dispersion model for that period. This leak rate calculation is performed for every location that is within range of a given sensor. A location is considered in range if it lies within a 70° cone centered on the wind direction, see Figure 16. The distance between the sensor and a grid cell is determined using the Haversine formula (Equation 3), where the latitude and longitude of a grid cell represent the cell's center.

$$\phi : \text{latitude}$$
$$\lambda : \text{longitude}$$
$$R : \text{radius of Earth in meters}$$
$$a = \sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_1)\cos(\phi_2)\sin^2\left(\frac{\Delta\lambda}{2}\right)$$
$$c = 2\arctan 2\left(\sqrt{a},\ \sqrt{1-a}\right)$$
$$\text{distance} = R \cdot a$$

Equation 3. *Haversine formula for finding the great-circle distance between two points on a sphere given their longitude and latitudes.*

The result is an emission rate for each in-range grid cell, representing the calculated leak rate as if that grid cell was the leak source. This process is repeated for each sensor independently.

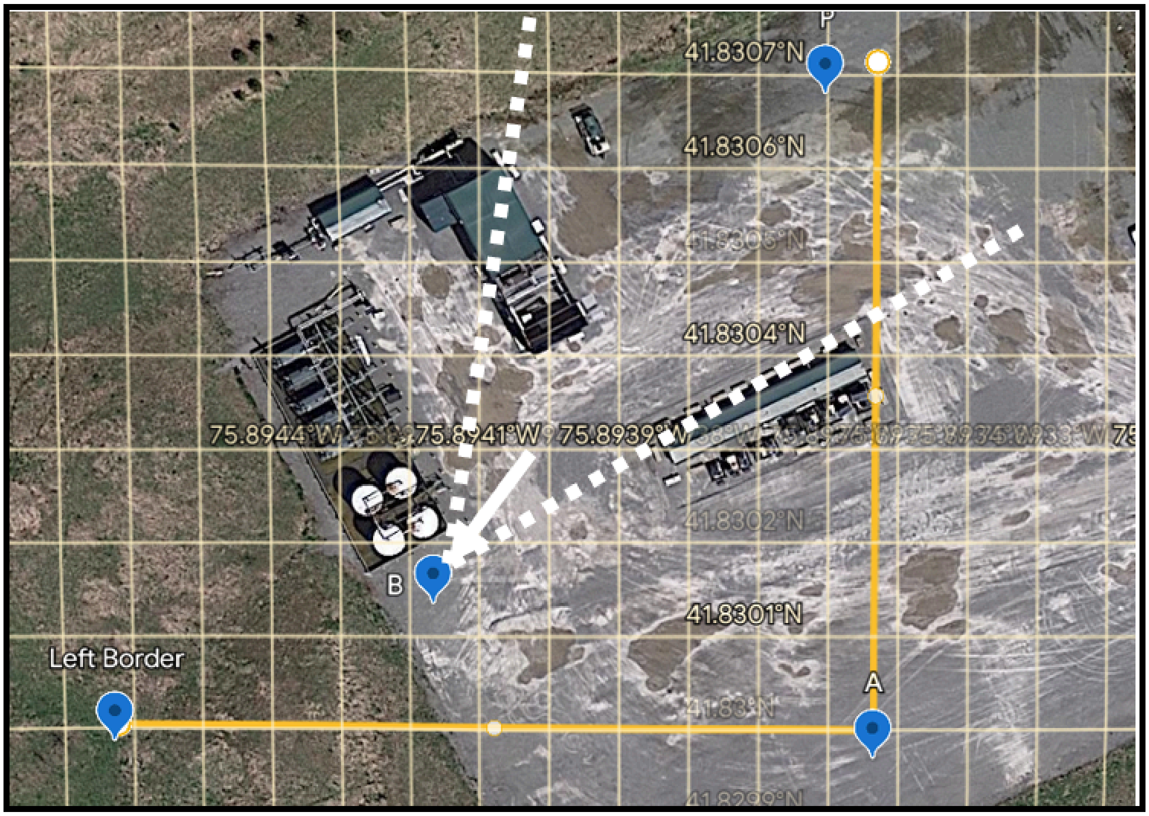


Figure 16*. Sensor cone of visibility. Each sensor (blue pin) has a 70° "cone of visibility" (dotted white line) that opens into the current wind direction (white arrow).*

12.3.4 Localization

GPAQS divides the area of potential leak locations into a grid of equally sized cells, typically 10m x 10m (Figure 17). In the grid layout, green cells indicate a potential leak location and gray cells indicate locations without any known equipment.

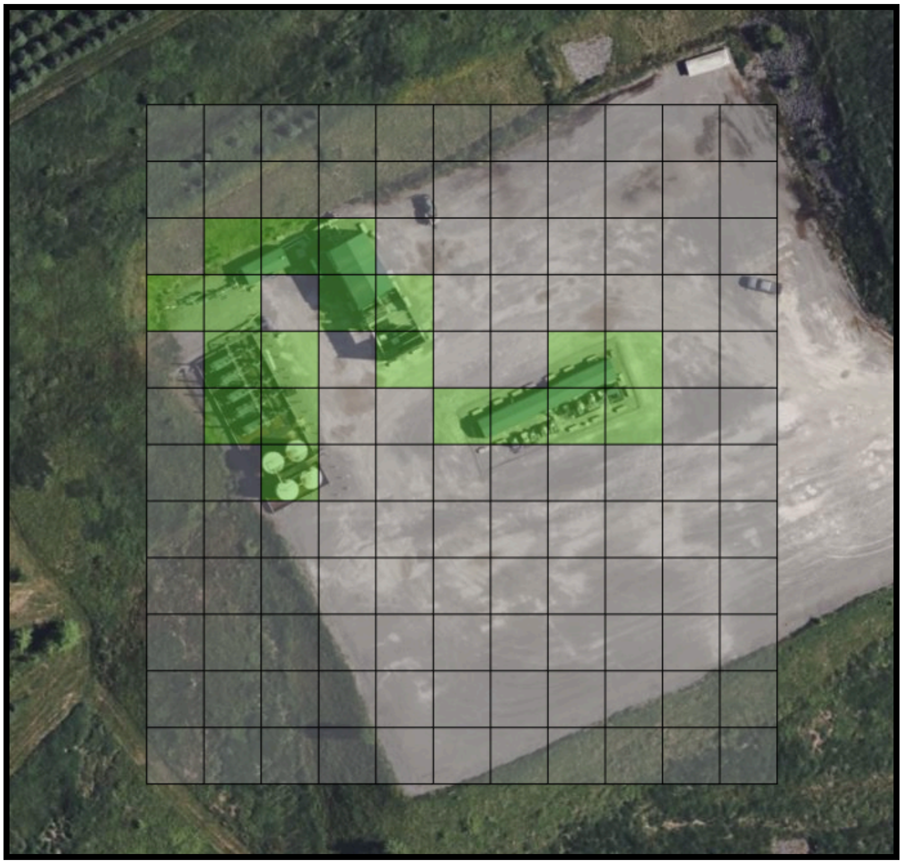


Figure 17*: Grid layout over potential leak locations. Green cells indicate a potential leak location, gray cells indicate locations without any known equipment.*

To determine the most likely leak source, we compare upwind devices and then each grid cell is ranked based on two statistics: the coefficient of variation among the sensors and our confidence evaluation for each potential leak location.

12.3.4.1 Comparing Upwind Devices

It is often advantageous to place a device in the center of the pad in order to further narrow down the location of the source. A central device will typically be positioned in-between production equipment which gives additional information on the potential leak source. Consider Figure 18, with a central device positioned in a given wind field. In this example with winds blowing from the southeast, the northwestern and central devices will both have the separators on the southeastern side of the pad in range. If the upwind central device saw low levels of methane during the sampling period and the downwind northwestern device saw elevated methane readings, using geometry, we can safely eliminate the southeastern portion of the pad as a potential source and most likely the source was a wellhead location just north of the central node.

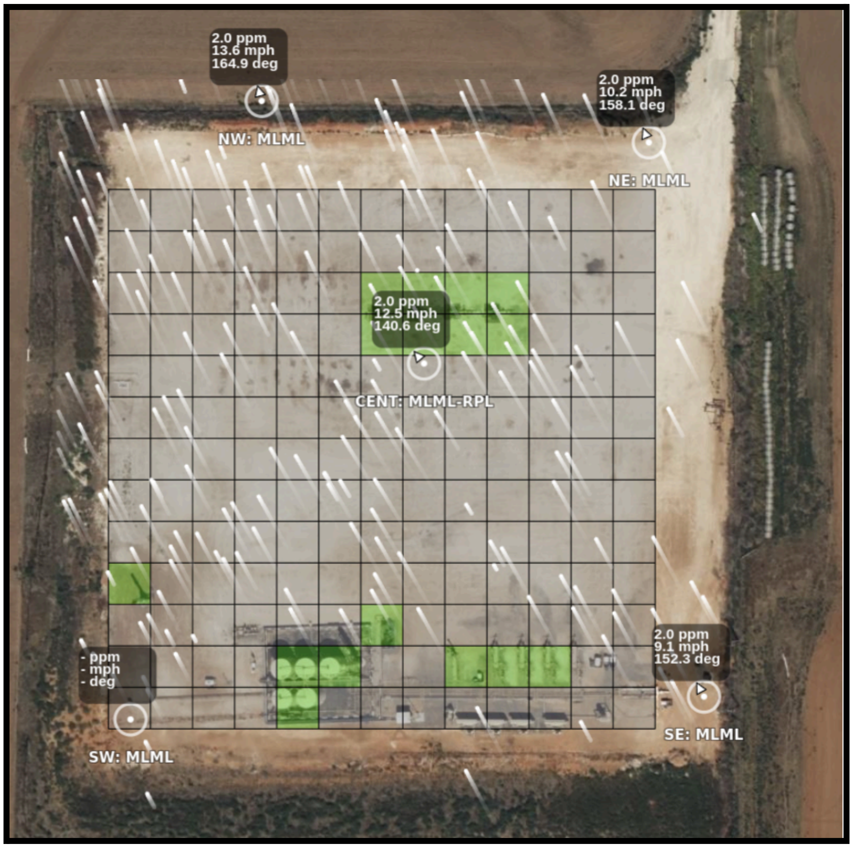


Figure 18. *Example comparing upwind and downwind sources when there is a central device on a pad. The figure is oriented so that North is up. The separators are in the southeastern part of the pad directly East of the node labeled SE. Wellheads are directly north of the central node labeled CENT.*

12.3.4.2 Confidence Checks

The confidence score evaluates the likelihood of a leak based on an extensive set of considerations. For example, a larger emission rate increases the confidence in the event, which means an increased overall confidence for that location. The overall confidence of a leak emanating from a particular grid cell is the sum of each confidence check multiplied by a weight of the importance of the check. The weights are determined experimentally.

The confidence checks and coefficient of variation are both expressed as a percentage. The coefficient of variation (CoV) is close to zero with minimal variance and larger with more variance, so we convert it to a percent with $CoV_{\%} = 100 \cdot (1 - CoV)$. The “total score” is then the average of the confidence percentage and the coefficient of variation percentage. Finally, the most likely location for the leak is the one with the highest total score. It follows that the next most likely location is the next highest score, etc.

12.4 Emission Action-Level Analysis for Periodic Screening

Periodic screening per 40 CFR §60.5398b(b) requires that all portions of the site be observed during a screening survey. To achieve this, Earthview's system measures site emissions for enough time to allow every grid cell on the site to be "seen" by at least one BluBird node. Here, this is defined as the wind direction aligning such that a vector drawn from a grid cell intersects a node. Once all parts of the site portions of the site have been sampled in this manner, the average emission rate for the site as measured over the survey period is calculated and checked to see if target emission thresholds have been exceeded. The survey results are provided to the operator within 24 hours of completion of the survey period.

The above screening procedure is designed to mimic as closely as possible an "emissions snapshot" of the site; comparable to that provided by an aircraft overpass. However, since the BluBird system calculates emissions continuously, there are variations of the above procedure that could be applied if EPA modifies or further defines the survey requirements for periodic screening using continuous monitoring data. For example, emission rates could be averaged over a longer time period, or rather than using an average, the maximum emission rate over the survey period could be determined. Another option would be to use identified emissions events or emissions above an emissions baseline for the site.

One survey is to be done in this manner quarterly for well sites, centralized production facilities, and compressor stations subject to AVO inspections with quarterly OGI or EPA Method 21 monitoring, or semiannually for well sites and centralized production facilities subject semiannual OGI or Method 21 monitoring.

EPA's guidelines in Subpart OOOOb of Part 60, tables 1 and 2 are based on the monitoring technology's minimum detection threshold, as defined by the emission level that is demonstrably detectable 90% of the time by the screening technology. This is typically referred to as the 90% Probability of Detection (POD) level. The proposed ATM's cited 90% POD levels are based primarily on Colorado State University METEC Advancing Development of Emissions Detection (ADED) testing. Therefore, the BluBird node installations should provide comparable sampling capability. To achieve this, potential sources of emissions should be within approximately 125m of a node. This is dictated by the range of methane concentrations expected to be encountered under typical weather conditions for an emission rate of at least 15 kg/hr.

12.4.3 Data in Support of Action-Level Investigative Analysis

If periodic screening survey detects confirmed emissions above the relevant thresholds listed in Part 60 tables 1 and 2, the operator is required to investigate the emissions as described in 40 CFR 60.5398b(b)(5). The ATM system supports this in various ways that can be useful to the operator. For example, daily emission estimates can be provided, which the operator can use to monitor progress of repairs and to document that requirements have been met.

12.5 Measurement Uncertainty

To quantify the uncertainty in emission rate calculations, we need to consider the individual uncertainties inherent in the measurement equipment and data sets. These calculations involve multiple inputs and relatively complex nonlinear equations, which make the mathematical determination of propagated uncertainty difficult. Therefore, we use the Monte Carlo simulation method to estimate uncertainty, as discussed by (Possolo et al. 2019;, Farrance and Frenkel, 2014; Papadopoulos and Yeung, 2001). The simulations incorporate expected ranges of uncertainties in the emission modeling.

12.6 Emission Source Verification

The Earthview dashboard provides a variety of tools to assist operators. When the system issues an alert, operators receive an email alert and report indicating the two most likely sources. These are linked directly to the operator’s site page on the Earthview dashboard. An example email is displayed in Figure 19 and an image of the likely leak sources is displayed in Figure 20. The customer can respond to the event and verify that a leak was a true positive or false negative. In the true positive case the customer can triage in the dashboard where the leak originated from and Earthview can back calculate what the emissions rate was with the known source for the most accurate emissions estimate possible. Furthermore, users can classify events into one of three categories, maintenance, operational and fugitive. An example of the diagnostics information available to the customer is given in Figure 21.

- Methane Alert

* At least **3** measurements, **3** standard deviation(s) above **0.016 MCFH | 0.318 kg/hr** site average

* Coordinates

Location Estimates

1. Central Tanks	$0.108 \pm^{0.02}_{0.01}$ MCFH $2.192 \pm^{0.39}_{0.30}$ kg/hr (Red)
2. East Separators	$0.074 \pm^{0.01}_{0.01}$ MCFH $1.502 \pm^{0.22}_{0.18}$ kg/hr (Orange)

Leak Statistics

Start Time	2024-06-28 13:10:00 CST
End Time	new

Site Wide Rolling Averages

Duration	Average	Standard Deviation
7-Day	0.014 MCFH | 0.282 kg/hr	0.010 MCFH | 0.205 kg/hr
30-Day	0.016 MCFH | 0.318 kg/hr	0.010 MCFH | 0.206 kg/hr
90-Day	0.016 MCFH | 0.318 kg/hr	0.010 MCFH | 0.206 kg/hr

See attached image for localization.

For additional information please see dashboard.earthview.io.

Figure 19. *Example email notification that goes out to the customer when the event is detected.*

Figure 20. Example localization estimates sent in event notifications that are sent out to customers.

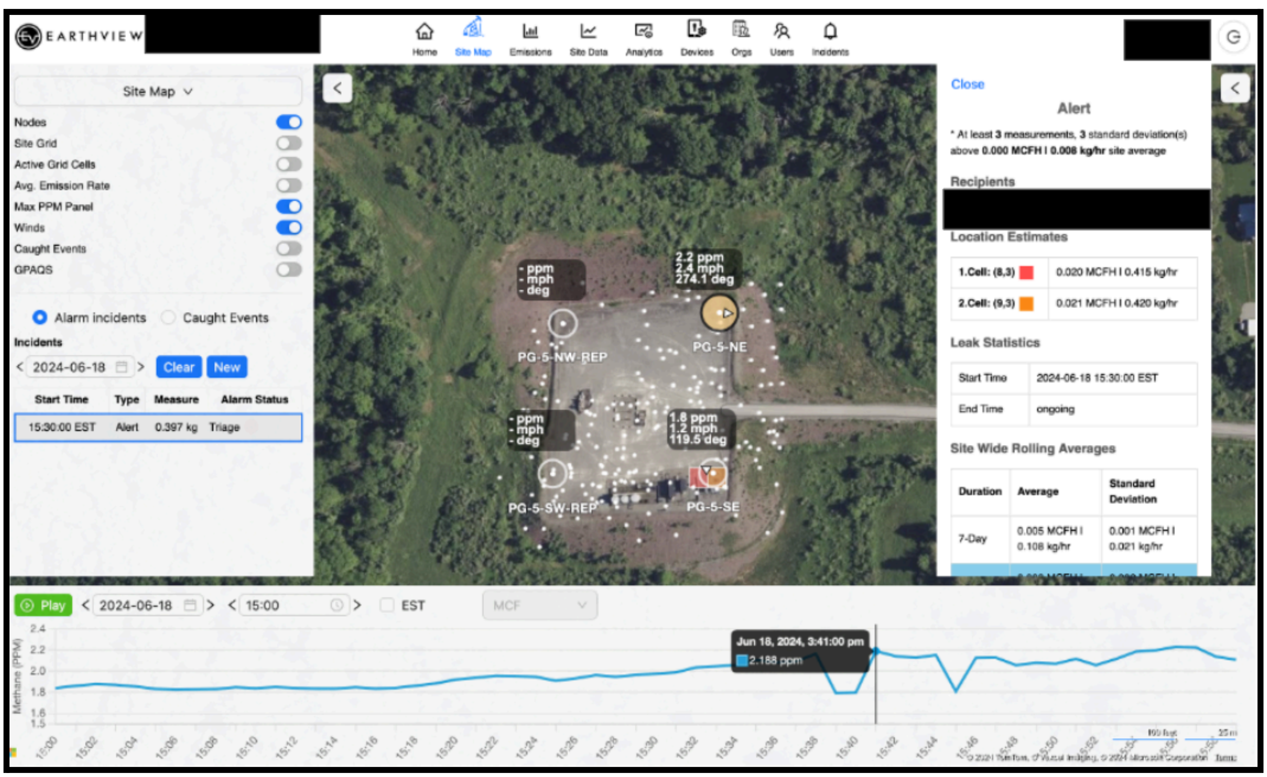


Figure 21. Example of diagnostic information associated with the detection, localization and quantification of a small emission rate (0.415 kg/hr), showing one of the Earthview dashboard's emission diagnostics pages.

13 Method Performance

13.1 Methane Concentration Accuracy

Below, we provide some examples documenting the sensitivity and accuracy of methane concentration estimates using data obtained in single-blind tests under field conditions. This includes testing done at a realistic oil and gas pad setting (Colorado State University's METEC facility during ADED testing (e.g., Ilonze et al. 2024) and at an outdoors EPA facility. The estimated concentrations shown here encompass all of the Earthview processing steps described above. These steps include: (1) raw sensor measurements (Rs), (2) transmission to the Earthview cloud server, (3) real-time estimation of clean-air resistances (Ro), (4) calculation of resistance ratio Rs/Ro, and (5) conversion from Rs/Ro to methane concentration using standard Earthview algorithms. The results shown here are in line with results from other studies using the same brand and model of MOS sensors (e.g., Van den Bossche et al., 2016; Bastviken et al. 2020).

13.1.1 Results from Natural Gas Releases in Outdoors Conditions - Concentration Estimates

Earthview conducted testing in 2021 using an array of 6 BluBird v.1 instruments positioned outdoors, downwind of a natural gas source released at 1.1 kg/hr, with wind speeds ranging from 0.8 m/s to 2.0 m/s (Maslanik and Givhan, 2021). In this experiment, the BluBird system proved to be able to detect the 1.1 kg/hr emission of natural gas under light winds and at distances of 38m (the longest distance tested) and closer. The derived concentrations were reasonable as compared to expected concentrations for these conditions, and the measurements are consistent between the 6 units. When the results are used to estimate a likely emission rate that would yield the BluBird-measured concentrations, the derived rates fall within the range of model uncertainty.

13.1.2 Results from METEC ADED 2024

These data were collected at the CSU METEC site in spring 2024, coincident with the Advanced Development of Emissions Detection (ADED) test program. They consist of the standard BluBird data reported to the cloud, combined with coincident methane concentrations measured by connecting the LGD TDLAS instrument to the air outflow from BluBirds. (These TDLAS data were not used as part of the ADED testing, and were obtained for comparison purposes only.) Figure 22 compares the LGD and BluBird concentrations for a 6-hour period on 25 April 2024. The LGD and BluBird data are significantly correlated at the > 99% level, with coefficient of determination (R2) values around 0.5. Figures 23 and 24 demonstrate the level of sensitivity of the BluBird measurements versus those from the TDLAS. BluBird shows responses corresponding to changes in CH4 concentration of less than 1 ppm. Again, it is important to note that this sensitivity was achieved using data collected under field conditions and is the same type of data supplied to customers.

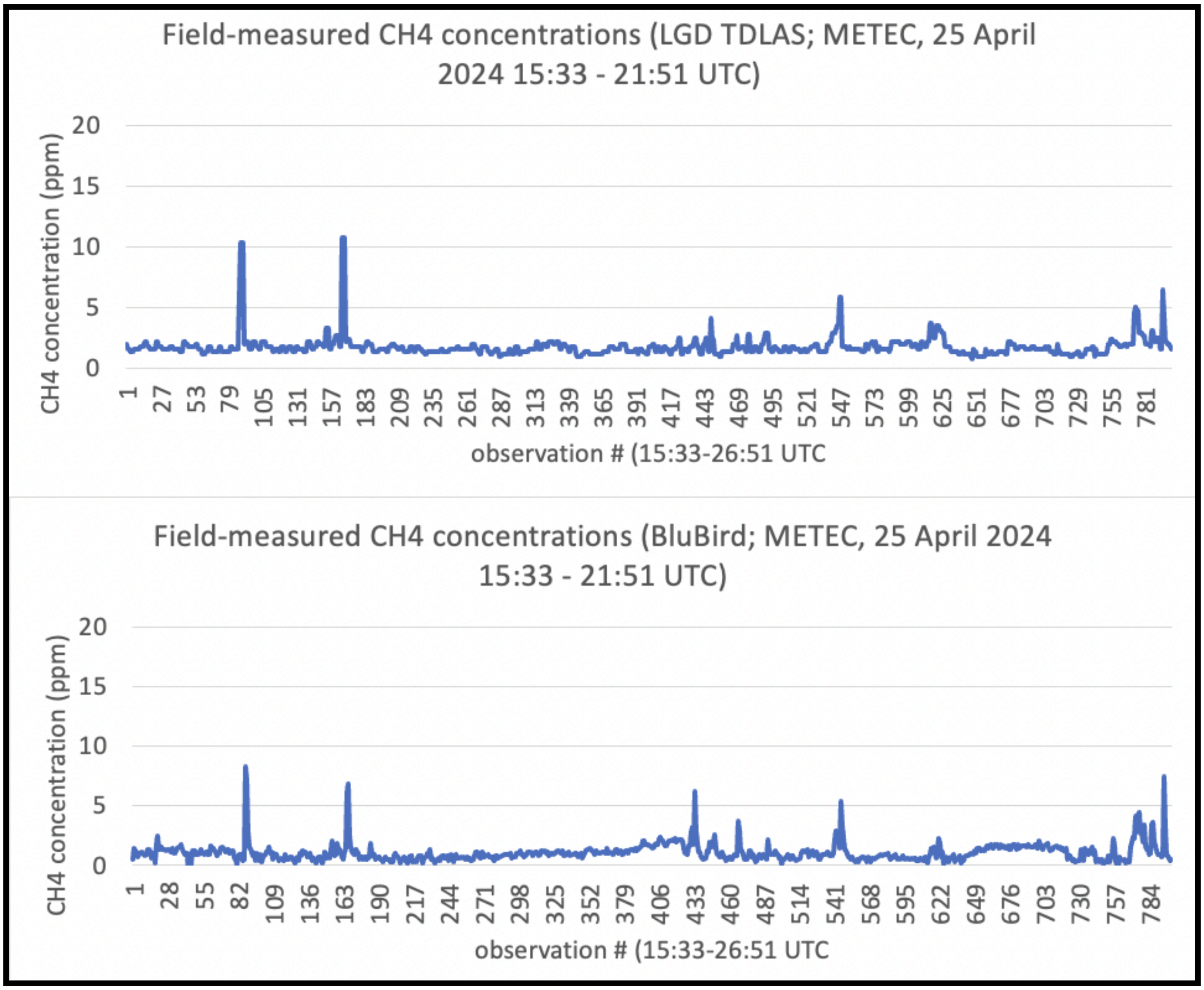


Figure 22*. Coincident measurements of CH4 during a portion of the METEC ADED testing in April 2024.*

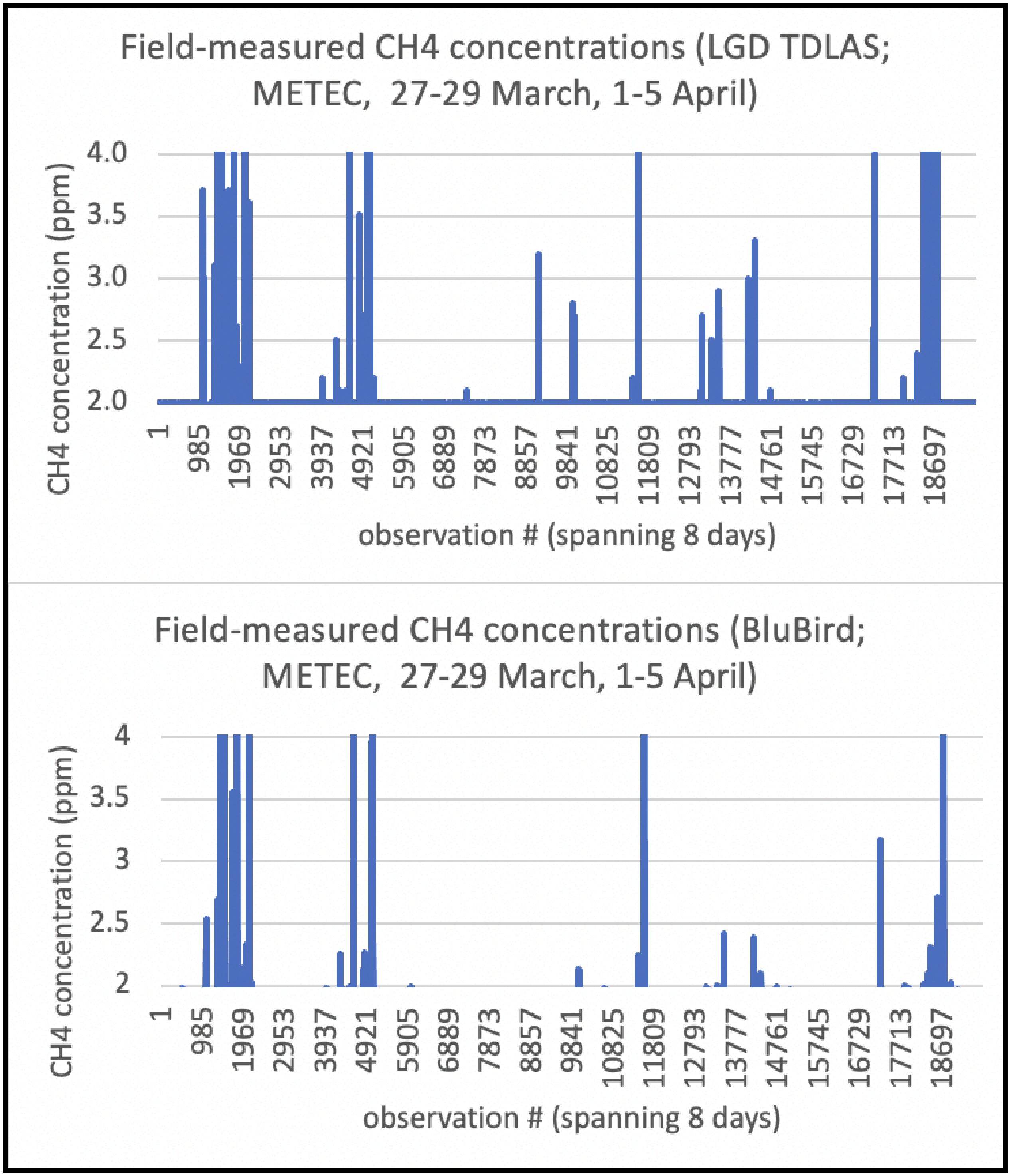


Figure 23*. Coincident measurements of CH4 over 8 days of the METEC ADED testing in March - April 2024. The y axis range is reduced to highlight small variations in CH4.*

13.1.3 EPA CEMM Testing

In single-blind testing carried out by the EPA Center for Environmental Measurement and Modeling (CEMM) using 100% methane, an Earthview BluBird instrument detected methane released at rates of less than 0.1 kg/h in a field setting. BluBird-estimated concentrations agreed well with a reference-grade LiCOR Li-7700 open-path laser instrument over the range of LiCOR-measured concentrations of approximately 2 ppm to 45 ppm, with the ability to resolve changes of at least 1 ppm and to detect changes in release rates between 0, 0.08 and 0.3 kg/h

13.1.4 Bench Testing Using Calibration Gas Mixtures

The results below were obtained by Earthview using methane calibration gas at different concentrations, obtained by mixing air zero gas with 1000 ppm methane to provide a range of known concentrations from near zero to 900 ppm. The BluBird measurements showed high correlation with the actual concentrations and good overall accuracy. Average error was 9% over a concentration range from 0-20 ppm, and 16% over a range from 0-900 ppm.

Figure 24 shows how BluBird responds to different concentrations of methane, using calibration gas mixtures and an Axetris LGD TDLAS for reference, with the airflow exiting the BluBird's sensor chamber routed into the LGD.

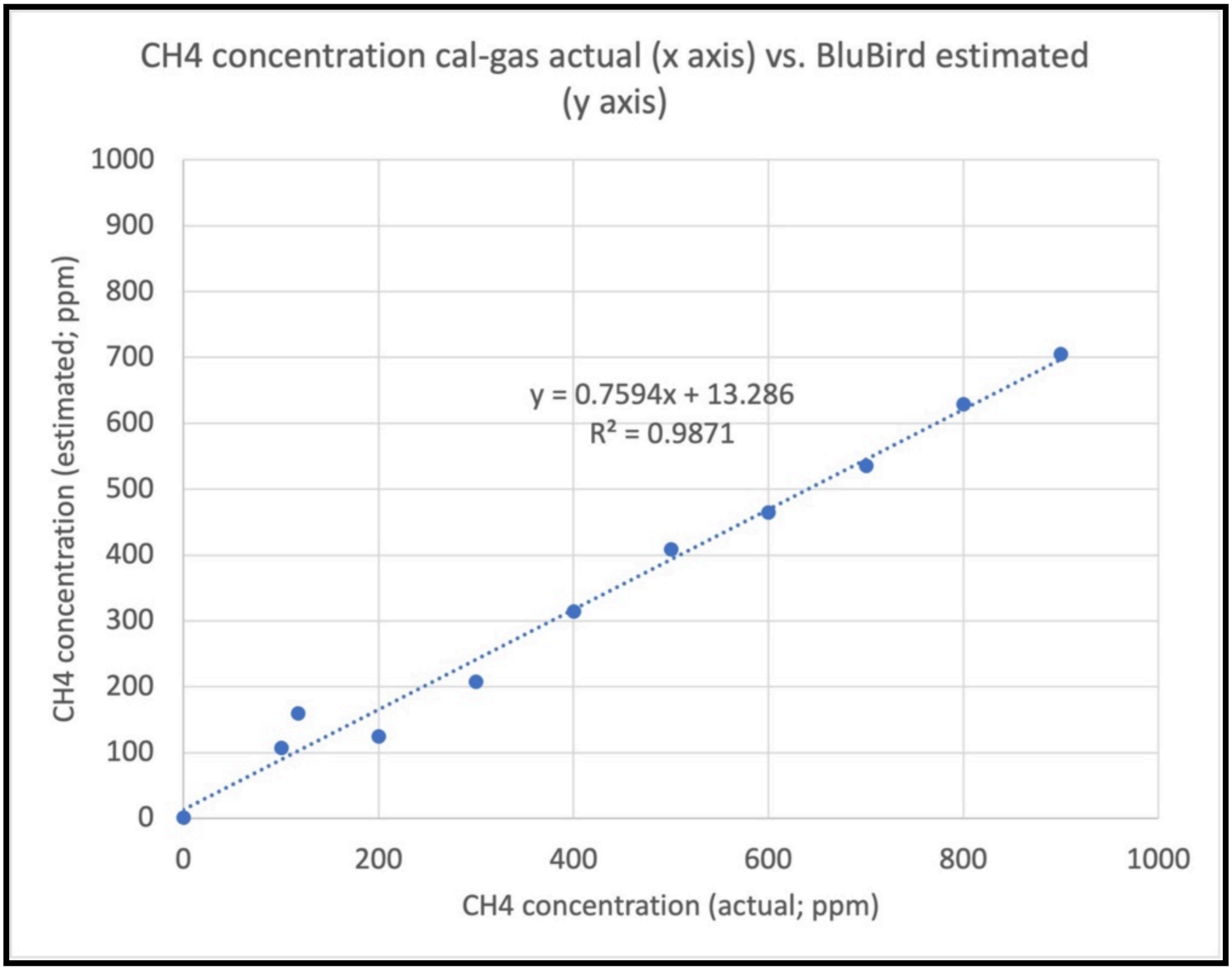


Figure 24a: *Comparison of calibration gas CH4 concentrations with BluBird-estimated CH4 concentrations over a range from 0 to 700 ppm.*

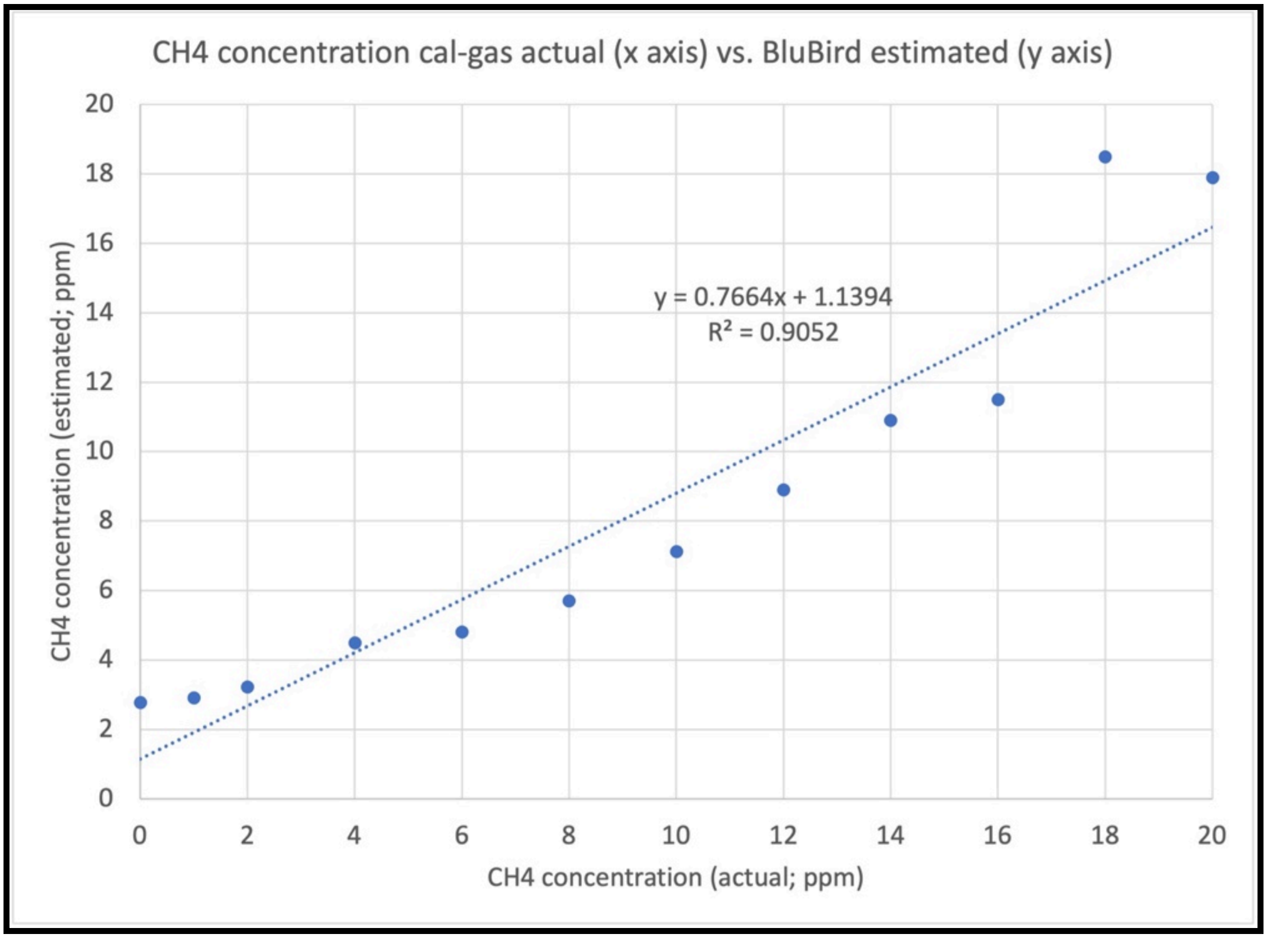


Figure 24b: *Comparison of calibration gas CH4 concentrations with BluBird-estimated CH4 concentrations over a range from 0 to 20 ppm.*

13.1.5 Co-located Measurements at an Air Quality Monitoring Site

The BlueBird sensor package was deployed in the field in conjunction with research-grade instrumentation operated by Boulder A.I.R. LLC at two locations in Colorado (Broomfield Soaring Eagle Park and Boulder Reservoir; https://bouldair.com/). Methane is measured by Boulder A.I.R. using a Picarro G-2401 Cavity Ring Down Spectrometer. Figure 25 presents a comparison of Picarro and BluBird data for a 10-hour period. These results highlight the ability of the BluBird instrument to resolve small changes in concentration.

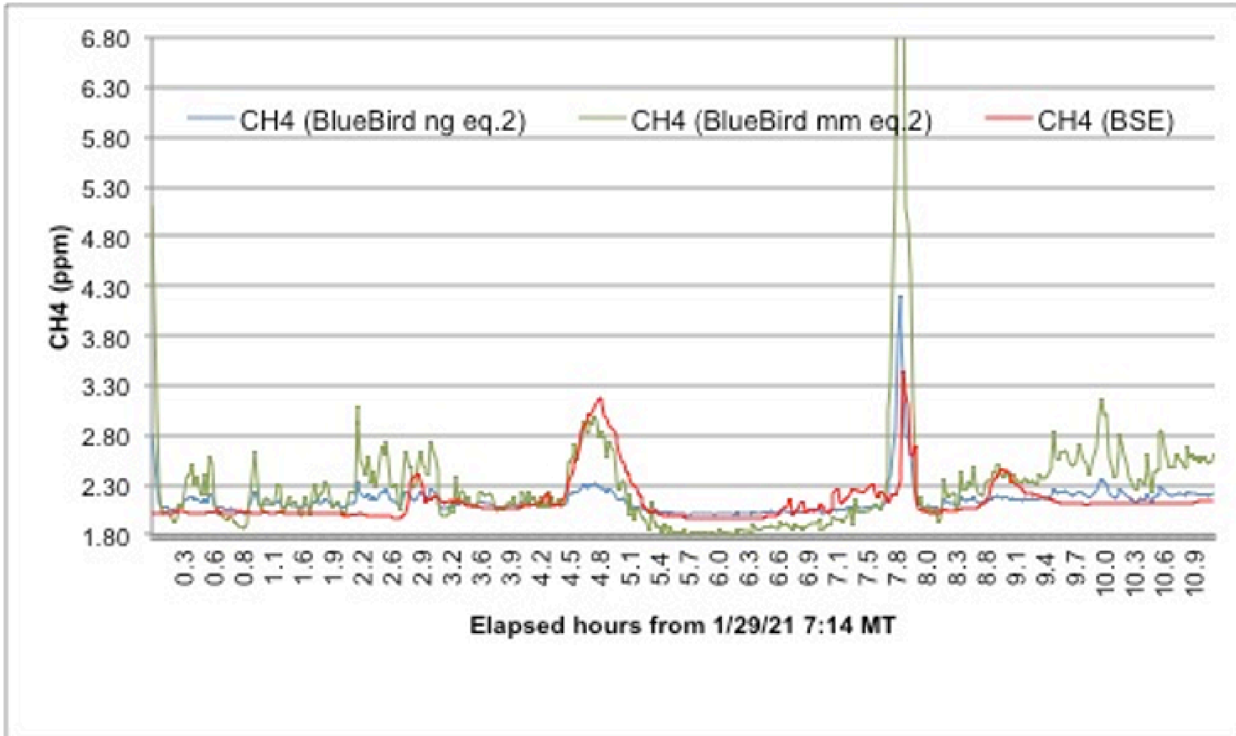


Figure 25. Methane concentrations measured by the Picarro G-2401 (red) and methane concentrations estimated from BlueBird data.

13.2 Emissions Performance Metrics

Much of the following information is based on Earthview results achieved during single-blind testing at the The Colorado State University Methane Emission Technology and Evaluation Center (METEC) facility as part of the Advancing Development of Emissions Detection (ADED) program, which was carried out during February - April 2024 (METEC, 2024; Maslanik et al., 2024 [white paper WP-2022-3 in Supplemental Materials]),

13.2.1. Probability of Detection

As described below, the Earthview BluBird GMS has demonstrated the ability to detect 15 kg/hr at a 90% POD. METEC's standard method of assessing leak detection performance during previous ADED experiments (e.g., Ilonzi et al., 2024) uses a methodology that arguably is not well suited to assessing continuous monitoring solutions. METEC has since developed a new testing and grading protocol that will be used for future ADED experiments from 2025 onward

(METEC, 2025). The results presented below are from an analysis of Earthview BluBird ADED 2024 performance using grading criteria that are consistent with this ADED 2.0 protocol (E. Levin, pers. comm.). Specifically, a detection report that significantly overlaps a METEC release is classified as a successful detection, and any detection of one or more leaks during a multi-release experiment is considered as a successful site-level detection.

In terms of total event (i.e., experiment) detection, using these revised ADED 2.0 criteria, 98% (343 of 349) of METEC's site-level events were automatically detected and reported. Ninety-three percent (53 of 57) of site-level events of less than 0.4 kg/hr were detected, with a minimum detection level of 0.04 kg/hr. (For cases with more than one release per experiment, the maximum release rate was used for analysis). Leak event duration was accurately determined, with average durations of 229 minutes versus METEC's average of 224 minutes (Maslanik et al., 2024b; WP2022_3.pdf in Supplemental Materials).

A commonly applied method for defining POD uses binary classification methods such as logistic regression modeling to identify the relationship between whether a leak was detected, as a function of some parameter such as leak rate. Using these criteria, this approach yields a 90% POD for releases of 60 g/hr or greater (Figure 26). The predictive power of the model is relatively weak, suggesting that the BluBird GMS' leak detection rate is not strongly dependent on emission rates. This can be explained by the fact that the BluBird system is quite sensitive, and is able to detect sub-ppm increases in CH4 concentrations. As described in the next section, leak rates greater than around 0.4 kg/hr are likely to yield CH4 increases that are detectable by BluBird under typical field deployments.

Given this ability to detect low concentrations, other factors such as leak duration or total emission during an event are likely to be more relevant for BluBird POD. In fact, the time required for wind direction to align between a leak source and a sensor node is the main control on whether a leak will be detected. This is controlled by variability in wind direction along with the placement and number of nodes. It is important to note that, for the ADED 2024 results presented here, Earthview had deployed 12 nodes. This is more than would be typical for an oil and gas production pad (a typical Earthview deployment ranges from 4 to 10 nodes, depending on site complexity and customer preferences) but is intended to compensate for the fact that METEC's release rates are relatively short, so less time was available for winds to intersect nodes, and that METEC released gas from up to 5 different locations at a time on the test pad.

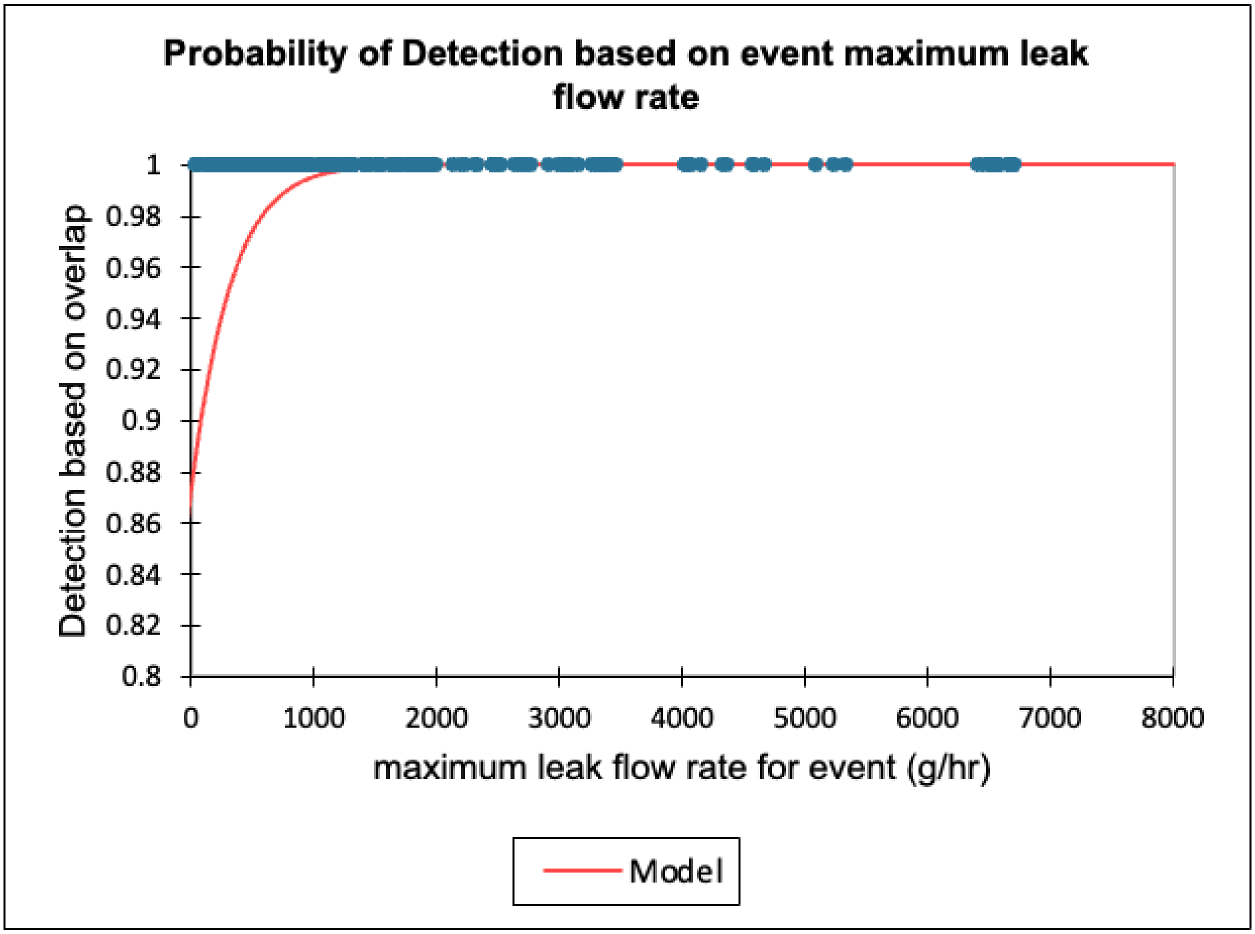


Figure 26. Probability of detection estimation using logistic regression applied to event maximum leak-flow rate (quantitative parameter) with overlap-based detection flag as the response parameter. The POD reaches 90% at a leak flow rate of 90 g/hr.

Using the same "overlapping detection" criterion, BluBird's POD was 97% (100 of 103) for single-release events. For these single-release events, the statistical POD is above 90% for the full range of event release rates (Figure 27).

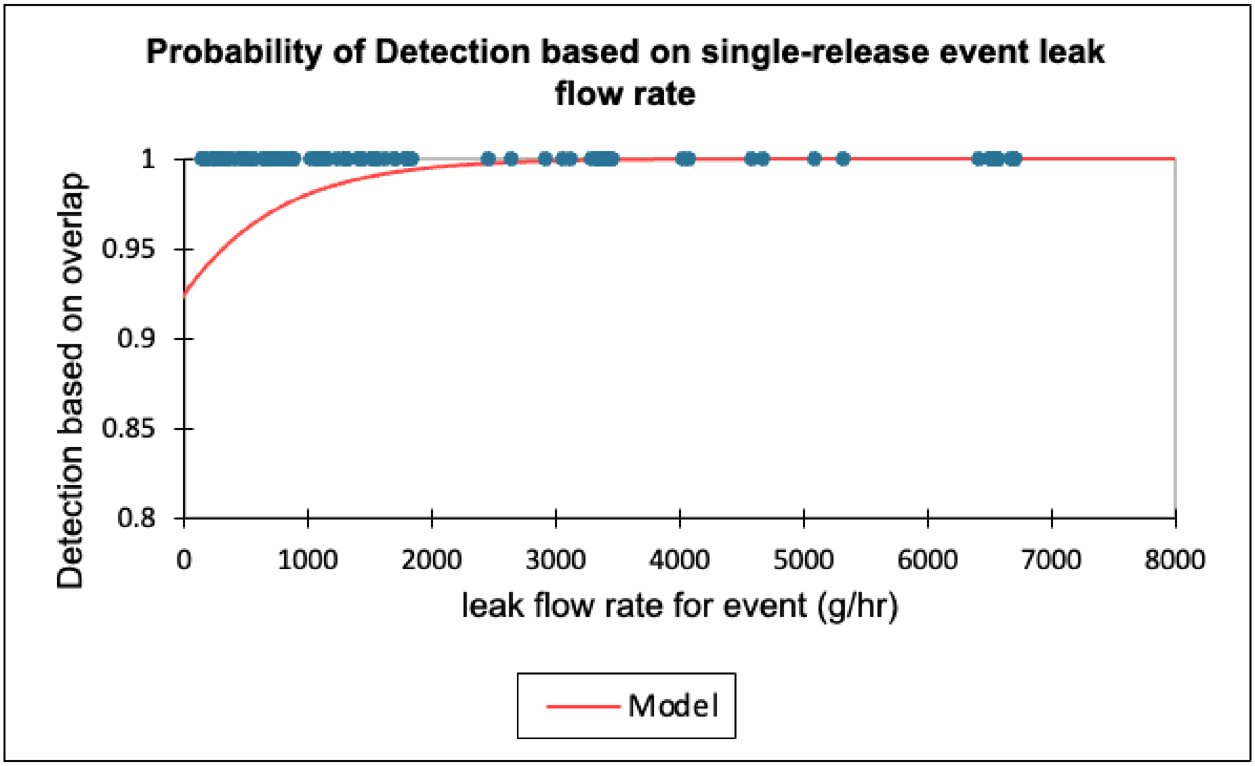


Figure 27. Probability of detection estimation using logistic regression applied to single-release event leakflow rate (quantitative parameter) with overlap-based detection flag as the response parameter. The POD is above 90% for the full range of event release rates.

While METEC ADED testing focuses on detection rate as a function of leak rates, for point sensors such as BluBird that have a high sensitivity, the detection rate is controlled mostly by the time it takes for wind direction to align with the leak source and a sensor node. Therefore, POD is affected both by release rate and by leak duration. One way to represent this is by calculating the total gas release during experiments (e.g., release rate multiplied by release duration). This relationship is depicted in Figure 28. This POD plot suggests that a leak yielding at least 3800 grams should be detectable at the 90% level under conditions comparable to the ADED testing. In other words, at a leak rate of 1 kg/h, the leak might be expected to be detected within a maximum of 4 hours.

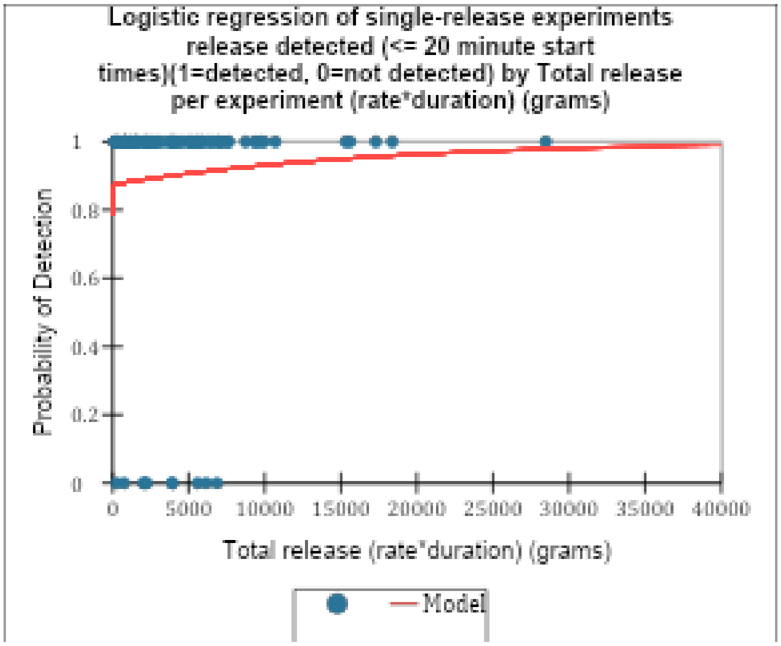


Figure 28. Probability of detection as a function of total natural gas released during experiments. Detection reports meeting the 20-minute start time threshold were included.

13.2.2 Demonstration of Ability to Detect of 0.4 kg/hr Events Above Background

13.2.2.1 Detection of METEC Single-Event Releases that were <=400 g/hr

Using the above-described grading criterion that defines a detection as an automatic BluBird report that overlaps substantially with a METEC release period, BluBird detected 93% (53 of 57) of experiments that had release rates of 0.40 kg/hr or less, across all experiments. BluBird also detected 4 of the 5 releases with a release rate of 100 g/hr or less. The minimum detected emission rate was 0.04 g/hr. (For multiple-release experiments, the maximum release rate for the experiment was used.) Cases where releases were not automatically detected typically were still apparent to the eye in the BluBird CH4 concentrations but did not meet all the requirements to generate an automatic detection report as part of the GPAQS software.

Another way of illustrating the ability to detect emissions at rates of 0.4 kg/hr or less is to examine estimated CH4 concentrations during METEC releases. Figure 29 and Figure 30 show time series of BluBird-derived concentrations measured on 22 March 2024 and 5 April 2024. Each of these cases generated an automatic detection by the BluBird GPAQS system. The highlighted locations are METEC releases at rates of 0.27 kg/h on 22 March (9:35 PM to 10:28 PM) and 0.37 kg/h on 5 April (9:30 AM to 4:15 PM). On 22 March, the estimated concentrations are less than 1 ppm above background, but were still distinct enough to result in an automatic detection and report. The signal is stronger on 5 April. The differences in concentration result from different plume dispersion rates and varying distances from the leak source to the sensors.

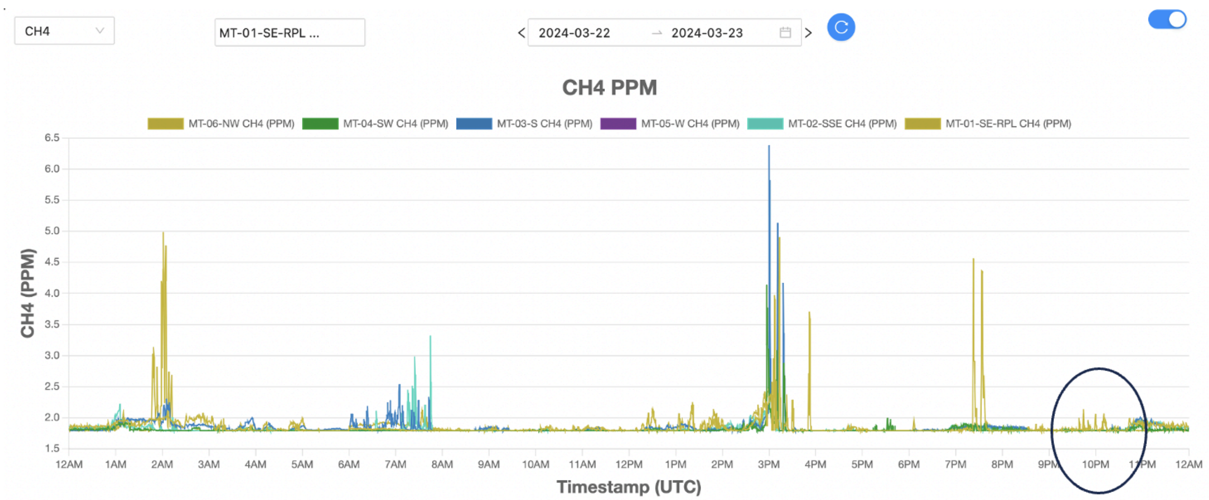


Figure 29. Time series of BluBird-estimated CH4 concentrations for 22 March 2024 during METEC ADED testing. The x axis is time in UTC. The y axis is CH4 concentration in ppm. A METEC release at a rate of 0.27 kg/h is highlighted by the black oval.

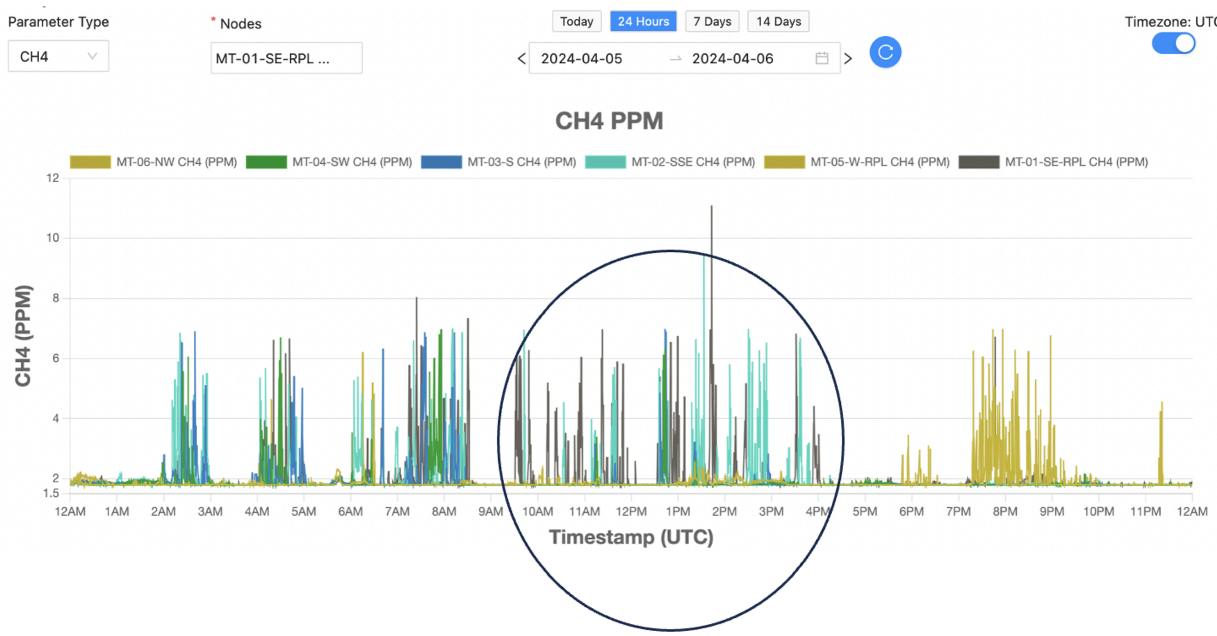


Figure 30. Time series of BluBird-estimated CH4 concentrations for 5 April 2024 during METEC ADED testing. The x axis is time in UTC. The y axis is CH4 concentration in ppm. A METEC release at a rate of 0.37 kg/h is highlighted by the black oval.

13.2.2.2 Detection of Small Changes in Site Emissions

The BluBird gas monitoring system is able to detect if site emissions are deviating significantly above background. This capability is demonstrated in Figure 31. It shows BluBird-measured CH4 concentrations for one of our commercial customer's pads over a 24-hour period. In this time series, the BluBird nodes show typical background concentrations of 2 to 6 ppm for the pad, interspersed by much lower concentrations when the pad production had been shut down for maintenance work.

Figure 31. Detection of emission differences between background pad operations and a pad shut-down period. The x axis is time in UTC. The y axis is CH_4 concentration in ppm.

A more direct example of detecting small changes in emission rates is demonstrated in results of single-blind tests carried out by EPA's Center for Emissions Measurement and Modeling (CEMM) using BluBird units. In these tests, conducted outdoors in a simulated field setting, CEMM used emission rates of methane of between 0.075 kg/hr and 0.3 kg/hr. BluBird was able to detect the differences between these small changes in rate.

13.2.3 Emission Rate Quantification Accuracy

The results given here are taken from Earthview's participation in the above-mentioned 2024 ADED experiment (Maslanik et al., 2024; METEC, 2024). Considering the set of ADED experiments that consisted of single releases, we find that, for all single-release experiments detected, the average error and median error are -0.20 and -0.46 respectively (i.e., -20% and -46%). Eighty-five percent of the estimates are within +/- 100% of the actual rate, 58% are within 70%, 34% are within +/- 50%, and 15% are within +/- 20%. Seventy-five percent of the estimated rates are within one standard deviation of the reported rates.

13.2.4 List of Actual Leak Detections as Confirmed by Customers

Earthview has successfully detected numerous emissions events at our customers' sites, with the large majority of these having been confirmed by the customers during subsequent LDAR inspections. Several of these events were at rates of 1 kg/hr or less. A partial list of these events is available in the **detected_confirmed_emissions_events.pdf table** in Supplemental Materials). Below is an excerpt from this table, which presently lists over 60 such events.

Table 6. Excerpt from Earthview-maintained list of detected and confirmed emission events (see detected_confirmed_emissions_events.pdf table in Supplemental Materials).

Examples of BluBird-detected emission events confirmed by customers within the past 18 months (October 2022 - August 2024). (Entries in quotes are direct statements received from customers. Emissions alerts are typically set at a minimum rate of 0.1 MCFH [~1.8 kg/hr]) or less. (These are only a subset of the detected events.)		
Date and Location	Earthview-Estimated Emission Rate	Operator's Confirmation
8/15/2024; Texas	high concentration alert**	"midstream company purging their line"
8/14/2024; Pennsylvania	1.3 MCFH	maintenance release from separators
7/10/2024; Texas	high concentration alert	"Hung dump valve so dumping gas to tanks"
6/19/2024; Texas	high concentration alert	"Hung dump valve, so was full Gas stream to tank. Discovered with Earthview alert first. Scada caught it but just the way it polls we noticed with Earthview first."
6/18/2024; Texas	0.2 MCFH	"Found a leaking dump control in SW corner."
6/11/2024; Texas	0.03 MCFH	"One of the pneumatic pumps at wellhead pumping chemical had a small constant leak "
5/19/2024; Texas	1.3 MCFH	"hung dump valve on compressor"
5/11/2024; Texas	high concentration alert	"Was a hung dump valve. Had pumper go by early and found it."
5/11/2024; Texas	0.1 MCFH	leaking regulator
4/11/2024; Pennsylvania	1.6 MCFH	"venting on a well"
4/9/2024; Oklahoma	0.7 MCFH	Earthview confirmation***

13.2.5 Device Performance

To address the requirement that the network must operate with at least a 90% uptime, the online statistics have been compiled since September of 2023 when these were first measured. This was determined on a rolling annual basis each month, meaning at the end of each calendar month, the downtime is calculated for the previous 12 months. Table 7 has statistics for each device and for each network. The network is defined as each site monitored, so that if at least one device on a site sent at least one read in a 12-hour block period that is considered a pass with the previous 365 days aggregated. The device column uses the definition that if a single device sent at least one read in a 12-hour block period that is considered a pass with the previous 365 days aggregated.

Table 7. *Annual uptime status checks per device and per site.*

Date	(%) Uptime Per Site - Network
2024/07/01	99.36%
2024/06/01	99.46%
2024/05/01	99.35%
2024/04/01	99.29%
2024/03/01	99.66%
2024/02/01	99.71%
2024/01/01	99.56%
2023/12/01	99.14%
2023/11/01	98.70%
2023/10/01	97.73%
2023/09/01	94.81%

14 Pollution Prevention

[reserved]

15 Waste Management

[reserved]

16 References

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17 Additional Tables, Diagrams, Flowcharts, and Validation Data

Table S.1 Specification Sheet (Earthview BluBird 2.0 hardware) (doc SSv1.2)

Specification Sheet (Earthview BluBird 2.0 hardware) (doc SSv1.2)

Dimensions (electronics unit):	23.0 cm x 8.5 cm x 12.1 cm (9" x 3.25" x 4.75")
Enclosure dust and moisture rating:	IP68
Weight (electronics unit):	0.5 kg (1 lb.)
Power:	12 VDC; 2.5W avg. (AC optional)
Current:	0.21A avg., 0.35A max.
Power Source:	solar + battery
Power Management:	automatic and over-the-air (OTA) selectable, including sleep mode
Measurement Resolution (ppm CH4):	~10% of reading (< 10 ppm),
	~6% of reading (10-100 ppm)
	~10% of reading (100-1000 ppm)
	~20% of reading (1000-5000 ppm)
Measurement Range (CH4):	0.5 - 5000 ppm (readings extend higher but with reduced accuracy)

Measurement Accuracy (CH4):	60% of reading (0-20 ppm); 90% of reading (20-5000 ppm)
Sampling Interval (selectable via remote command):	15 seconds to 1 hour
Communications:	Cellular, Wi-Fi
Firmware Updates:	OTA automatic or on command
Operating Environment (air temperature; recommended):	-20º C to 40º C (-4º F to 104º F) (temperatures outside this range are tolerated)
Operating Environment (winds, humidity; recommended):	max sustained winds 25 m/s (56 mph); 5 - 95% relative humidity
Operating Environment (moisture; rain, snow):	Highly weather resistant; deep snow can affect solar charging
Day/Night/Cloud Limitations:	None (operates 24/7)
Installation:	Movable stand with mast; no posts, holes or wiring needed
Data Management:	cloud dashboard with API access

Table S.2: *Initial Sensor Tests*

Check	**Description**
1. Node Created	Device was created in the Server
2. Location	Node is sending GPS coordinates and the last GPS check-in was within at least 300ft of

	the Dallas Earthview Assembly Shop
3. Getting Reads	Node is sending Methane sampling payloads to the server
4. Reporting Regularly	Node has been running for at least 15 minutes and there are no gaps over 90 seconds between reads
5. Read Validation	Sample reads being sent to the server are passing validation. For validation rules see ___
6. Hardware Test	A valid bench test has been sent and is recorded in the system
7. Firmware Test	Node is on the most recent version of the firmware

Table S.3*: Twice daily device status checks.*

** Local airport data is used in place of invalid wind measurements, so this check alerts operators to problematic wind instruments separately.*

*** Water-logged instruments can cause the humidity sensor to report erroneous 100%+ humidity values, a common occurrence in wet regions.*

Status Check Name	**Description**
Online	Did the device send any data in the last 12 hours?
Connection	Is network signal quality above minimum acceptable threshold at least 80% of the time?
Validation	Did at least 80% of measurements pass validations?
Battery Voltage	Is the battery voltage at least 1V above 10V sleep threshold at least 80% of the time?
Battery Charging	Did the device's battery charge at least once

	in the last 12 hours?
Wind Speed Validation	Are at least 50% of wind speed measurements valid? *
Wind Direction Validation	Are at least 50% of wind direction measurements valid? *
Tier 1 Read Frequency	Did the device send at least 80% of the expected number of tier 1 reads?
Tier 2 Read Frequency	Did the device send at least 80% of the expected number of tier 2 reads?
Internal Humidity	Was the internal relative humidity measurement ever above 100%? **

Table S.4*: Automatic validation checks done on sensor reads from the field. When wind measurements fail validation, they are replaced by the nearest device at the closest point in time. If there is no replacement value available, the wind measurement is taken from the nearest weather station.*

Device Read	Description	Low Range	High Range	Failed Validation Prevents Methane Analysis
M2	The Resistance from MOS_2 chamber. VOC measurement (Ohms)	1000	120000	Yes
M0	The Resistance from MOS_1 chamber. Methane measurement for low concentrations. (Ohms)	1000	120000	Yes

M1	The Resistance from the MOS_3 chamber. Methane measurement for high concentrations (Ohms)	1000	120000	Yes
P1	Pressure of chamber (PSI)	7.25	17.4	Yes
H3	Relative Humidity of chamber (%)	0.1	110.0	Yes
T4	Temperature of chamber (Celsius)	0.0	240.0	Yes
VM	The voltage of the 5V rail figaro sensor (V)	4.8	5.5	Yes
*WD	The direction of the wind. (degrees)	0	360	No
*WS	The speed of the wind. (km/h)	0	240	No