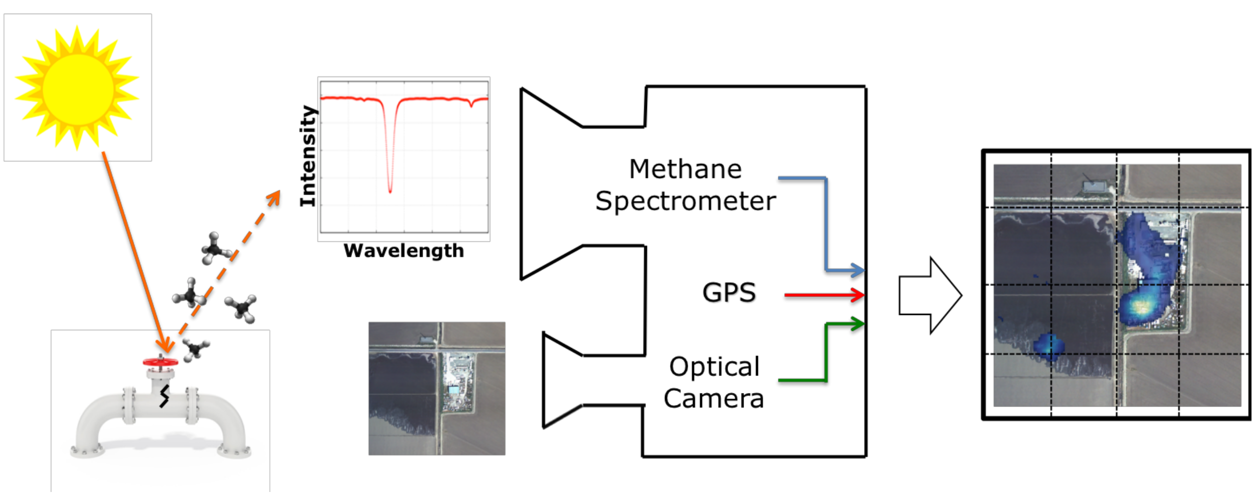
KAIROS AEROSPACE

Kairos Aerospace

Technical White Paper: Methane Detection

Introduction

Kairos Aerospace's LeakSurveyor™ is a light-aircraft mounted, integrated methane imaging system which detects large methane emissions from as much as 100 square miles of oil and gas infrastructure in a single day. LeakSurveyor provides georeferenced methane emissions data combined with real-time optical imagery for accurate methane source attribution. Kairos Aerospace offers methane detection as a service, eliminating customers' need for capital outlays, operator training, raw data analysis, and instrument upkeep. The Kairos Aerospace LeakSurveyor has detected methane over more than 4.75 million acres of oil and gas infrastructure in North America on more than 250 separate flights in the last 2 years. In this way, Kairos Aerospace LeakSurveyor provides customers actionable data on large-scale methane fugitive emissions in a timely and cost-effective offering.



Background

Cost-effective detection of methane plumes, particularly from fugitive methane emissions, has become a high priority for industry and governments alike. There are many challenges to detecting fugitive methane emissions including, but not limited to, the large number of potential emission sources over large geographical areas, the unpredictable and intermittent nature of fugitive emissions, and the large range of leak sizes. Recent research has shown that methane emissions are most likely underestimated in the current inventories[1,2,3]. Zavala-Araiza et al. concluded that total methane emissions correspond to 1.5% of natural gas production[4].

Furthermore, consensus is emerging that a small percentage of leaks account for a disproportionately large percentage of the total volume of gas released ([5], [6] and [7] among many others). For example, Brandt et al. in a review of 15,000 measurements in the literature, showed that 5% of the leaks were responsible for contributing over 50% of the total volume of released methane[5]. Many others have found the same type of distribution; recently Rella et al. surveyed oil and gas producing wells and found that 6% of sites produced 50% of emissions[8] and Yacovitch et al. surveyed a variety of oil and gas infrastructure to find that 7.5% of emitters contributed 60% of the total methane emissions[9]. These largest emissions have been dubbed "super-emitters" and, as Brandt et al.[10] note, "present an opportunity for large mitigation benefits [for] reliable (possibly remote) methods to rapidly identify and fix the small fraction of high-emitting sources." While there is wide agreement on the importance of "super-emitters", it has in the past been difficult to ascertain the distribution of large leaks due to studies having small sample sizes; Kairos data suggests that the distribution is even more heavily weighted towards the large emission sources than previously thought.

In terms of both driving operational efficiency and environmental benefit, fugitive emission monitoring systems that give equal weight to identifying very small leaks and larger ones are ineffective. Kairos Aerospace has rethought the value proposition of a fugitive emissions monitoring program to focus exclusively on identifying medium and large leaks as quickly as possible. Given the outsized effect that super-emitters have on methane emissions, the timely detection of large methane leaks is the most cost-effective way to reduce total methane emissions, thereby reducing environmental impact, enhancing safety, and reducing lost revenue.

Kairos Aerospace Integrated Methane Imaging System

Approach

Based on this current research, Kairos Aerospace's LeakSurveyor has been intentionally designed to detect medium and large methane emission sources over expansive geographical areas cost-effectively. The LeakSurveyor instrument is easily mounted on widely-available, light aircraft and flown at standard general aviation altitudes of 3,000 ft above ground level (AGL), making it faster and safer than both helicopters and low-flying aircraft. It can fly longer and farther than commercially available drones, which rarely have battery lives of more than 30 minutes, limiting their flight range and increasing their cost. Drones are also subject to complex and shifting state regulatory requirements. The LeakSurveyor instrument is faster and less expensive than a ground crew, particularly over the large geographical areas typically covered by oil and gas infrastructure (Figure 1). Ground crews spend the majority of their time driving between sites,

Figure 1: LeakSurveyor covers orders of magnitude more area than a ground crew, covering hundreds of assets in a single day and allowing frequent revisits. Small yellow squares indicate gas wells or facilities.

and surveying sites with no significant emissions; this is time that could be spent verifying, and fixing, the most critical emissions.

LeakSurveyor can monitor thousands of facilities or hundreds of miles of linear pipeline infrastructure in a single day, quickly determining which assets need attention and allowing frequent retesting of sites. LeakSurveyor can thus serve as the foundation in a tiered emissions detection strategy that combines frequent aerial monitoring for large emissions with ground teams for verification and repairs.

In addition, Kairos Aerospace operates LeakSurveyor as a service to our customers; Kairos performs all the data collection and processing, providing customers with only actionable information about assets surveyed. Customers require no capital outlays for equipment like aircraft and sensors, no training of personnel, no instrument calibration, maintenance, or repairs, and no complicated data analysis. Kairos eliminates the possibility of operator error or variation as all protocols, from pre-survey calibration to post-survey data quality assurance, are performed by highly trained Kairos-employed engineers.

Instrumentation:

The Kairos Aerospace LeakSurveyor instrument consists of three integrated measurement capabilities: 1) a patented spectrometer system that detects methane; 2) GPS and inertial monitoring units (IMU) to record precise position; and, 3) an optical camera for visual verification of sites. When reflected sunlight passes through a plume of gas, the gas molecules absorb certain wavelengths in the infrared. Each type of gas molecule absorbs specific wavelengths of light while letting others pass, as shown in Figure 2 for methane, water, carbon dioxide, and ethane.

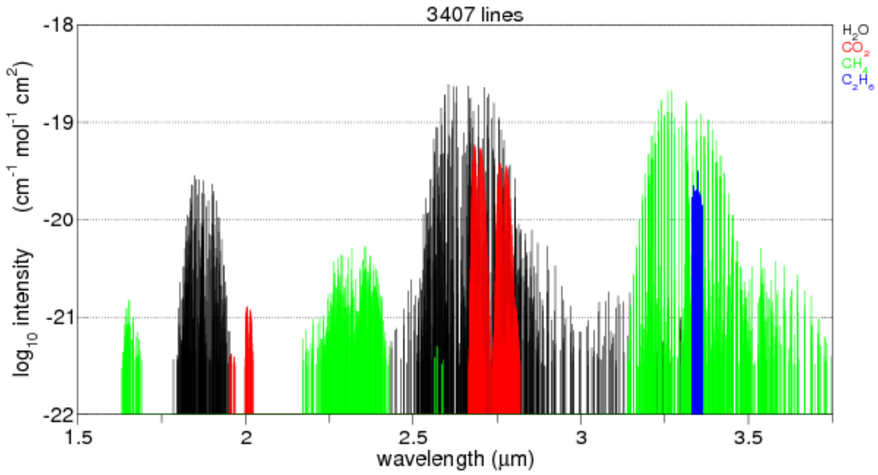


Figure 2: Absorption spectrum of methane (green), water (black), carbon dioxide (red), and ethane (blue) in the infrared region of the electromagnetic spectrum. Plot courtesy of Spectralcalc.

The patent-pending Kairos spectrometer system collects reflected sunlight and measures the absorption of infrared light (Figure 3). The spectrometer detects the specific pattern of methane absorption at high spectral resolution, avoiding signal confusion from other gases like carbon dioxide, water vapor, and ethane. LeakSurveyor measures the total concentration of methane along the path of the light coming into the instrument and determines the amount of methane in excess of the standard atmospheric methane concentration. Excess methane concentration is driven by both methane release rate and the speed of wind that dissipates the methane plume.

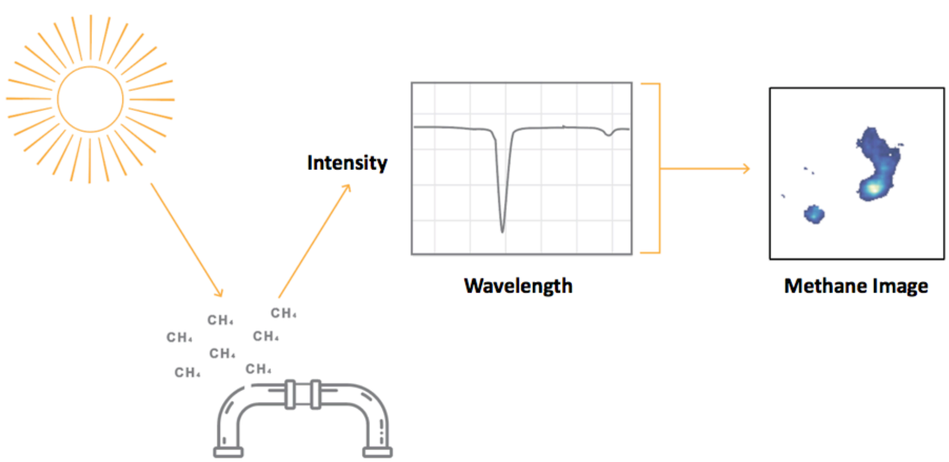


Figure 3: Sunlight reflects off the ground and passes through methane molecules in a plume, which absorb certain frequencies of the infrared light while letting others pass through. LeakSurveyor translates these absorption features into an image of detected methane.

Raw spectral data is automatically processed using proprietary, innovative data analytics including atmospheric retrieval techniques and advanced chemometric routines. This automated data pipeline converts raw spectral data into a set of signals: sunlight illumination, confidence metrics, and images of detected methane plumes. Kairos engineers then review the data to identify high-confidence methane plumes. The data is combined with the precise location information provided by the GPS and IMU instrumentation. Finally, the geolocated methane images are superimposed on optical images that were collected at the same time as the methane data (Figure 4). This combination of methane detection, precise geolocation that can feed into customers' in-house mapping tools, and optical data allows the customer to determine the location and likely source of the methane plume.

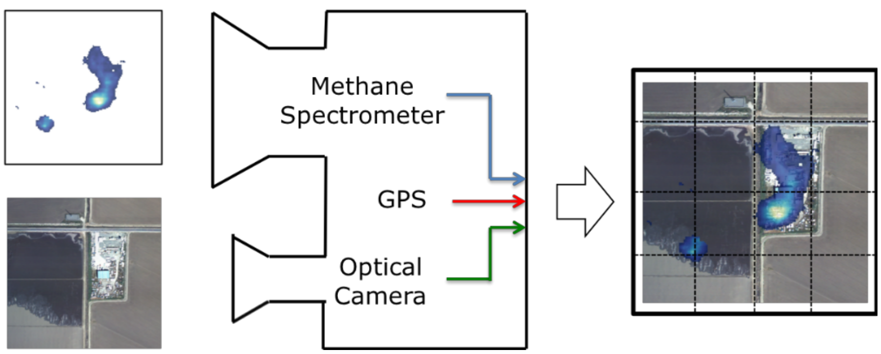


Figure 4: Conceptual diagram (with actual field imagery) of the LeakSurveyor instrument, which synthesizes data from a methane spectrometer, GPS and IMU instrumentation, and an optical camera to create a single georeferenced image of a methane plume superimposed on an optical image.

Performance

The Kairos Aerospace LeakSurveyor has inspected for methane emissions over 4.75 million acres of oil and gas infrastructure in North America on more than 250 separate flights in the last 2 years. In a subset of flights for which we have accurate asset counts, 1.2% of production sites (a mix of wells, tank batteries, separation units, etc.) were found to be medium or large methane emission sources. Figure 5 shows false-color images of example methane plumes detected by LeakSurveyor over working oil and gas facilities; these methane emissions were detected emanating from an underground gas storage facility, an underground gas gathering pipeline, a compressor station, and a well pad.

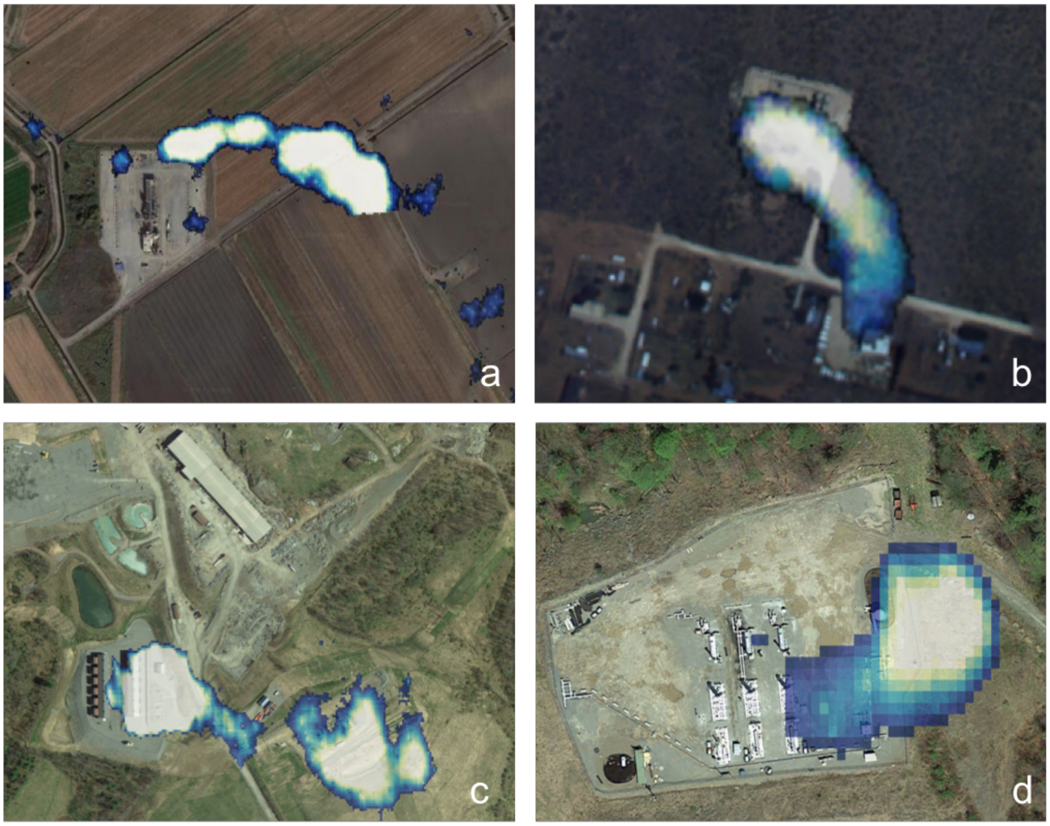


Figure 5: False color methane plume images collected by LeakSurveyor in the field over a working underground storage facility (a), an underground gathering pipeline (b), a compressor station (c), and a well pad (d).

Kairos has a robust set of calibration and validation procedures designed to provide consistent results to our customers across many flights and over time. Sixty-three (63) automated data quality checks are performed on each flight data set to ensure optimal data quality. These include checks on flight operations, hardware performance, and data integrity. Furthermore, Kairos engineers inspect and interpret the results from each flight prior to delivery to the customer.

Some leak detection technologies are sensitive to false positive results due to dust in the area of investigation. Kairos has conducted on-the-ground tests of dust interference and has detected no methane signal from dust plumes. As can be seen in Figure 6, while methane is clearly detected at the site of methane release, no methane signal is detectable over the dust plume created by farming equipment.

Figure 6: Dust clouds created by equipment (left) create no detectable interference to the methane signal produced by LeakSurveyor instrumentation (right, no methane signal observable at dust cloud, orange arrow). Methane signal is clearly observable over the release site (right).

To simulate real-world operational conditions, Kairos routinely flies LeakSurveyor instrumentation above controlled methane releases of known release rate in order to characterize the detection sensitivity of our spectrometers. Methane is released from a point source at varying well-controlled rates and detected using LeakSurveyor instrumentation with Kairos' standard practice of measuring each plume at least twice. Figure 7 shows the measured probability of detecting emissions of various sizes over multiple flights, in multiple geographic regions, and measured using three different LeakSurveyor instruments in our fleet. A best fit curve to the data shows that the 50% probability of detection occurs at 5.5 MCF/day per mph of wind and is similar between instruments and different geographical locations. Wind speed is an important factor in all emissions detection methodologies including ground-based optical gas imaging; wind will naturally dissipate any methane that is released and should be considered whenever one assesses methane detection technology. For this reason, we quote our detection probabilities with reference to wind speed and closely monitor wind and other environmental conditions for all flights in order to ensure the highest data quality.

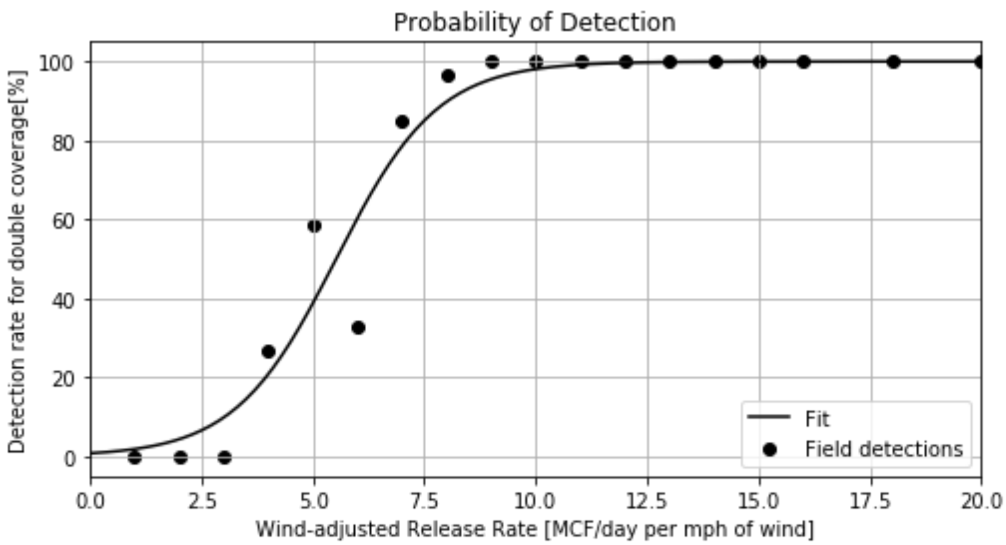


Figure 7: Aerial methane imaging probability of detection as a function of methane emission size and wind speed. The fit shows that the 50% probability of detection after two passes over a methane plume occurs at 5.5 MCF/day per mph of wind. Data taken on five different occasions in three different locations using three different LeakSurveyor instruments in our fleet.

Figure 8 shows a controlled methane release where methane emissions were simultaneously monitored using LeakSurveyor from an airplane flying at 3,000 ft. AGL, a FLIR GasFinder 320 IR camera pointed at the release valve from 50 ft. away, and a Method 21 analyzer held 20 ft. from the valve. As the figure shows, the relative brightness of the methane plume in the LeakSurveyor images reflects the rate of methane release under similar wind and lighting conditions.

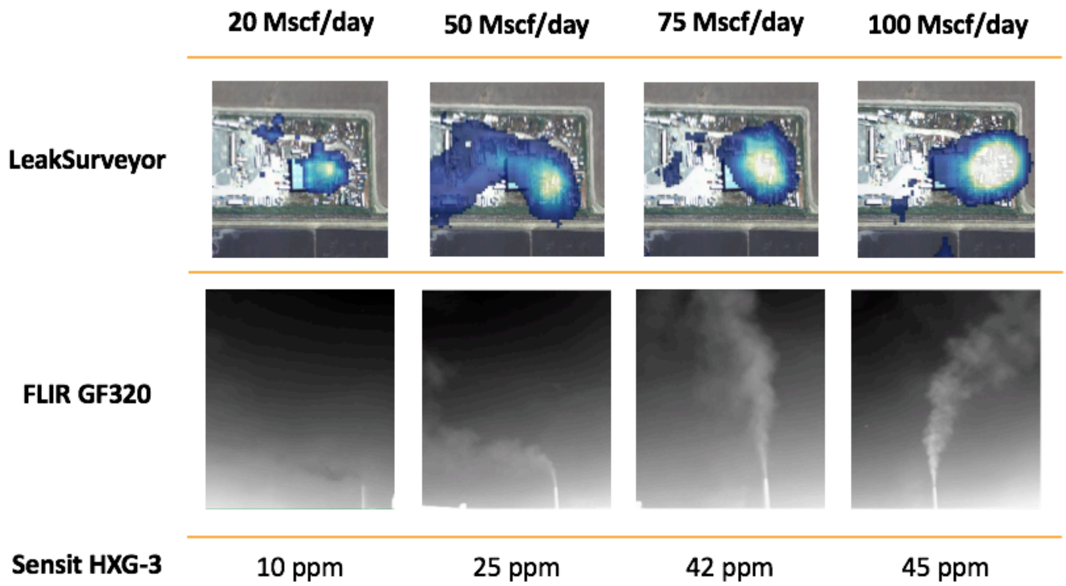


Figure 8: Comparison of emissions monitoring technology results during a controlled methane release. The brightness of the methane plume image reflects differences in the size of the release.

Quantification

In fact, Kairos methane plume data can be used to quantify the rate of methane release. The accuracy of the quantification is demonstrated by comparing the calculated methane release rate per mile per hour of wind compared with the known release rates in the data from the five controlled releases shown above (Figure 7). Figure 9 shows that the best fit line to this data (blue) is in excellent agreement with the line of perfect agreement (black). This indicates that, while individual measurements may show some scatter, aggregate data across a geographical area would be expected to be very accurate. It is important also to note that while accurate quantification relies on accurate measurement of the wind speed, a reasonable estimate of the leak rate can be determined using publicly available weather databases.

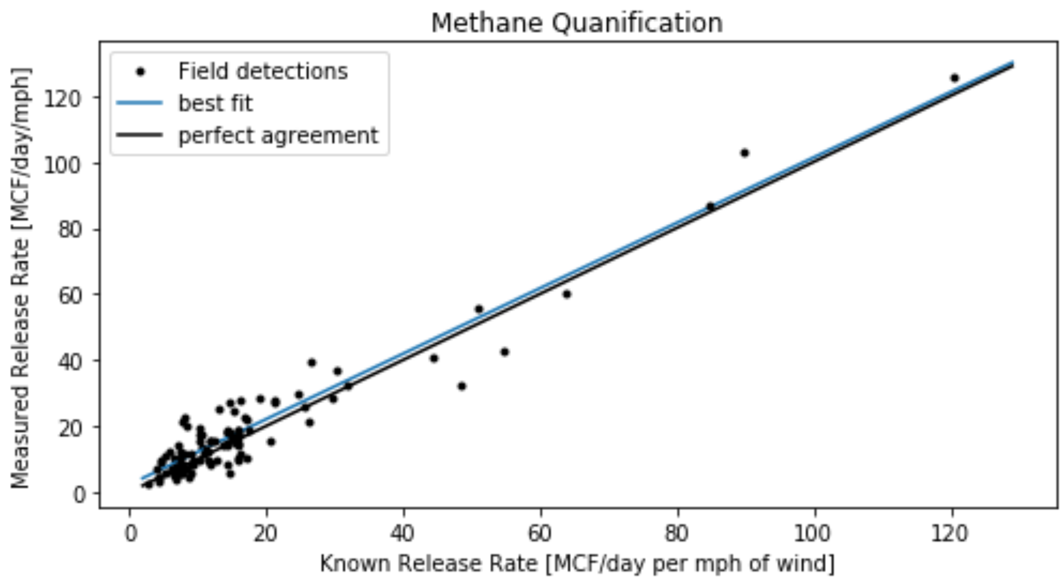


Figure 9: Quantification of methane release rate shown for controlled release data from five different occasions in three different locations and on three different instruments. The best fit line shows excellent agreement with the line of perfect agreement.

Kairos Aerospace is committed to continuously improving both our spectrometers and our data analytics, providing improved data quality and detection thresholds to our customers. This means that each flight is performed with the most up-to-date hardware and software available. In addition, we regularly perform additional flight testing and controlled methane releases to quantify data quality improvements.

Conclusion

The Kairos Aerospace LeakSurveyor detects large methane emissions over expansive geographical areas cost-effectively. LeakSurveyor has scanned for methane emissions over more than 4.75 million acres of oil and gas infrastructure in North America on more than 250 separate flights in the last 2 years. Kairos Aerospace reports methane emissions as georeferenced images of methane plumes superimposed on concurrently-collected optical images of a leak site for accurate methane source attribution. In this way, Kairos Aerospace LeakSurveyor provides customers actionable data on large-scale methane fugitive emissions over a wide geographical area in a timely and cost-effective service offering.

References

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