Methane Emissions Quantification

Kenneth Branson, Brian B. Jones, Elena S.F. Berman,
Kairos Aerospace, Mountain View, CA

Overview

Kairos Aerospace uses sensors mounted on light aircraft to detect the presence of elevated levels of methane in the air below the plane. By combining infrared spectroscopic data with optical images of the ground, GPS location, and inertial orientation data, Kairos creates maps showing the location of detected methane emissions. In addition, Kairos' technology quantifies the emission rate – how much gas is being emitted – so that operators can prioritize ground follow-up and measure the effectiveness of their emission management programs. This document explains how that quantification is computed and provides data showing the accuracy of quantification for data from controlled methane releases.

Background

Traditionally, two approaches have been taken to estimating emission rates. The most accurate approach is to fit a flow meter to the source of emissions and measure the actual rate of gas flow. If the percentage of methane in the gas is known, this can result in a highly accurate measurement of the emission rate of methane from a source. Unfortunately, there are practical problems with flow meters. Even if budget exists to take the metering equipment out to each emission source, the actual leak may not be amenable to measurement. Sometimes the emission is in an unsafe or inaccessible location. Often the operational equipment simply doesn't have the clear space necessary to attach a meter so that it captures all of the escaping gas.

Another approach taken by many researchers is to measure the concentration of methane at several locations downwind of the source and then try to use these point measurements to reconstruct the shape of the methane plume. They then create a theoretical plume model, and use that model to estimate the emission rate. This approach has several drawbacks. For example, the models assume smooth Gaussian dispersion of the gas rather than taking into account the turbulent flow that is evident in most real-world plumes. Second, this approach requires samples to be taken from multiple locations at the plume near the ground, rather than being able to measure the plume remotely, requiring significant time and instrumentation to collect the data. As a consequence of the difficulty of both of these quantification methods, methane emissions quantification is usually only attempted during research studies.

Based on feedback from oil and gas companies, Kairos has found that leak detection and repair (LDAR) teams and repair crews may provide qualitative feedback about the size of leaks that are found and repaired but rarely any quantitative estimates of the emission rates. Many teams use an optical gas imaging camera (OGI) to find leaks. These cameras make it apparent that there is methane coming from a tank hatch, but provide very little information about the size of the leak. Because plume brightness is based on the temperature difference between the escaping gas and the background air, environmental conditions can make large plumes look small, and small plumes look large. Usually, there are no numbers upon which someone using the OGI could base an estimate of the concentration of the gas or the speed at which is it moving in order to quantify the emission rate. Handheld methane detectors (sometimes called RMLDs) can provide a numerical measure of the path concentration (ppm-meters) of methane through one cross-section of a plume, but in a study done jointly between Kairos and a client oil producer, we found almost no correlation between the measurements taken by the RMLD and the known emission rates, even under tightly controlled study conditions. As a result, oil & gas companies have generally not been able to collect good data about the size of the emissions sources that they find and fix. By providing a quantification estimate for each methane source detected, Kairos aims to fill in this gap in data so that companies have a better understanding of the amount of their emissions, can use that information to prioritize investigation and repair efforts, and can quantitatively assess the effectiveness of their LDAR programs in terms of emissions reductions.

General Approach

Kairos' methane data is different from that of the quantification approaches described in the preceding section. By flying over an entire plume of methane and collecting a 2-dimensional set of data points (a sample for each square of ground below the plane), Kairos can simply add up the total quantity of methane in the plume rather than basing our quantification estimates on a small number of point samples or cross-sections of the plume and relying on some kind of plume model to estimate what the whole plume looks like. This provides an unusually accurate view of the shape and quantity of detected methane.

Knowing the total mass of a plume is different from knowing the rate of emission of methane from its source, however. To determine the rate, Kairos analyzes the core section of the plume. If, for example, that section is 10m long (in the direction of the wind) and if the wind is going 1m / sec, then it would take 10 seconds for all of the methane in the core section to move downwind out of the area. If the plume is in a steady state (i.e. the amount of methane in the core section is expected to remain approximately constant over time), then the same amount of methane must be moving *into* the core section from the upwind direction every 10 seconds. Therefore, the release rate from the emission source can be estimated based on the mass of the methane within the core section, the length of the core section, and the speed of the wind.

KAIROS AEROSPACE

Computing Excess Methane in a Plume

Figure 1 shows an example of a methane plume as measured by Kairos' LeakSurveyor. We first determine the point on the map where the methane signal is highest. This is shown in red in Figure 1 and is used as the origin of our coordinate system for measuring the plume. Our next step is to determine the direction that the plume is blowing downwind. We can estimate the direction of the wind by determining the point within the plume that is furthest from the metric peak. Since the methane is spreading out slowly by diffusion but moving downwind much more quickly (unless there is almost no wind at all), the plume will stretch out from its highest concentration, with the concentration decreasing as it goes. Figure 1 shows this "downwind point" in yellow. The direction from the metric peak to the downwind point is the wind direction and is used as the X' axis for our calculations.

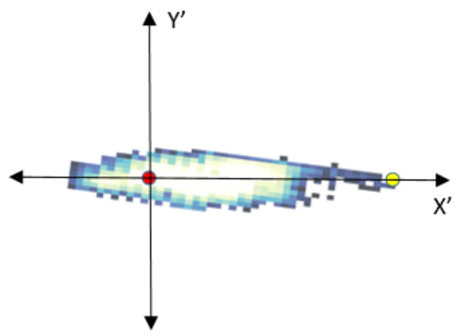

Figure 1: Methane plume with X' axis in downwind direction

At this point, we can choose a core section that we want to measure. Figure 2 shows selecting a core section of length L (in the wind direction) that starts upwind of the metric peak and continues about 50% of the way from the metric peak to the downwind point.

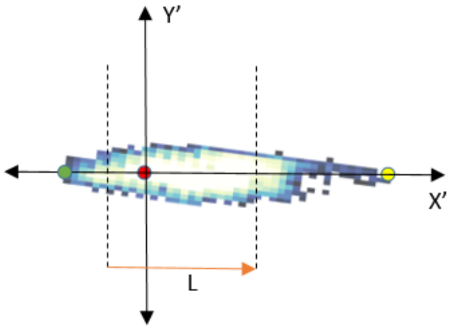

Figure 2: Selecting a sample for the plume

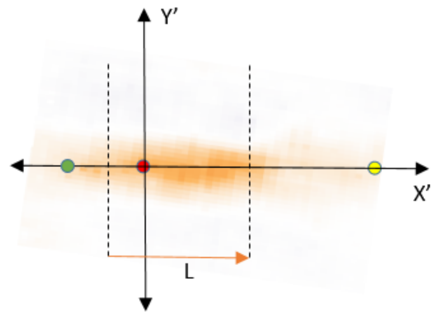

Figure 3: Excess Column Density map for the plume

Figure 3 shows the Excess Column Density map for the same plume with the core section that we identified. This is the area within which we want to measure the amount of excess methane in order to estimate the emission rate for this methane source.

The first step in this calculation is to determine the total mass of methane in the core section by summing over the values for each pixel in our core section:

$$\text{Methane (kg)} = \sum_i \text{Excess Column Density}_i(\text{kg/m}^2) * \text{Area}_i(\text{m}^2) \quad (1)$$

Converting from Total Methane to an Emission Rate

In order to determine an emission rate, we need to make a few simplifying assumptions:

1. The emission rate at the source is constant.
2. The wind speed is constant.
3. The methane is spreading out by diffusion slowly compared to the rate at which it is being blown downwind.

Under these assumptions, we would expect that each cross-section of the plume in the downwind direction contains equal amounts of methane per meter of length. As an example, if the wind is blowing at 1m/s and a plume sample 1m long (in the wind direction) contains 1kg of methane, then the source must be adding 1kg of methane per second in order to keep refilling that 1m sample length (that is being emptied every second by blowing the methane 1m downwind). Hence our emission rate can be estimated as:

$$\text{Rate (kg/s)} = \frac{\text{Methane (kg)}}{\text{Length (m)}} * \text{wind speed (m/s)} \quad (2)$$

By converting units, we can also provide this emission rate in alternative units, including imperial units like thousand cubic feet (MCF):

$$\text{Rate (kg/s)} \rightarrow \text{Rate (kg/hr)} \rightarrow \text{Rate (MCF/day)} \quad (3)$$

Of course, our simplifying assumptions are not exactly true. The emission rate may not be constant, and Kairos will be measuring the average emission rate during the short period of time in which the methane in the measured plume sample was emitted. Wind is usually turbulent, causing eddy currents and shifts in direction, so we would expect some parts of the plume to have more methane (as the plume eddies in the wind) and others to have less. By conservation of mass, however, we'd expect a relatively long sample of the plume to give us a good average concentration of methane per meter of sample length, and we can use that to get an emission rate estimate based on an average wind speed.

One problem with Equation 4 above is that Kairos does not directly measure the wind speed near the ground where the methane plume is. Kairos could measure the wind speed at the altitude of the airplane, but that will, in general, be very different from the near-ground wind conditions. In some cases, Kairos has accurate near-ground wind speed data from separate instrumentation (during a controlled release test, for example), but in most cases there are no wind gauges in the vicinity of emissions detected over real-world facilities. In those cases, there are two choices. First, Kairos can use wind speed data sourced from weather modeling services. We are able to get estimates of historical wind speed and direction for any time and location in North America (based on lat/lon coordinates) from publicly-available weather modeling service. While the public data appears to be reasonably accurate in comparison to the actual wind measurements that we have from a variety of controlled release tests, our calculations indicate that the uncertainty in the true wind speed is the largest contributor to the uncertainty in the emission rate as a whole as calculated using equation (2) above. As an alternative option, Kairos can simply compute a wind-adjusted emission rate that makes no assumption about the wind speed:

$$\text{Wind Adjusted Rate} \left(\frac{\text{kg/s}}{\text{m/s of wind}}\right) = \frac{\text{Methane (kg)}}{\text{Length (m)}} \quad (4)$$

Of course, similar to Equation 3 above, we can convert the Wind Adjusted Rate into alternative units, such as MCF/day per mph of wind.

The advantage of a Wind Adjusted Rate is that it is based on values that Kairos can measure directly, and that is useful in some situations, such as calibrating Kairos' algorithms without introducing noise from an uncertain wind speed or when customers have their own accurate wind speed measurements.

Assessing the Accuracy of Kairos' Emission Rate Quantification

Kairos periodically conducts in-house controlled release tests (where methane is released at known rates while our equipment is inspecting the release area) in order to test and calibrate the equipment. In addition, Kairos' technology was independently verified in single-blind controlled release tests by Stanford University researchers in October 2019. During all tests, the site is instrumented with a wind gauge in order to capture the probability of detection at a variety of release rates and wind conditions. Using this data, we can compare the known wind-adjusted release rate (MCF/day per mph of wind) with the wind-adjusted rates calculated from the Kairos measurements according to Equation 4 above. Figure 4 below shows the results of that analysis.

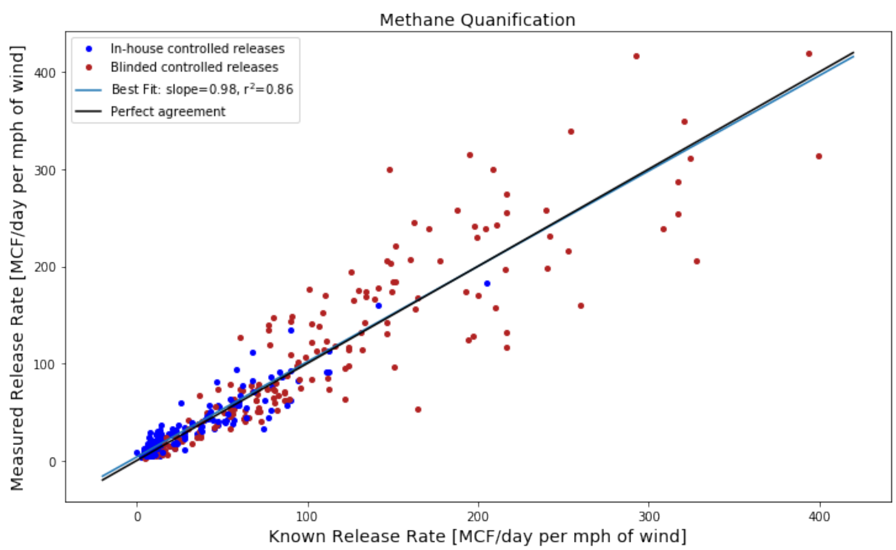

Figure 4: Quantification of methane release rate shown for controlled release data from twelve different occasions in three different locations and on five different instruments. The best fit line shows excellent agreement with the line of perfect agreement.

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 show some scatter, aggregate data across a geographical area would be expected to be very accurate.

The biggest source of uncertainty in individual emission rate estimates is the lack of local wind-speed measurements and a reliance on historical weather model data for wind speed estimates. We have no reason to believe that these weather models are biased high or low, so we would expect wind data to increase the variance in the resulting emission rate estimates but not alter the mean. In other words, inaccuracy in the wind speed data will make individual plume emission rates less accurate, but we believe the aggregate numbers (or averages) will still be quite accurate across a wide range of plumes, such as when inspecting all the facilities within a basin for a client.

One important caveat to the accuracy of these emission rate calculations is that the approach described here assumes that the methane is coming from something close to a point source and that the plume is spreading downwind from that source in a way that allows us to measure a core section of it. There are other situations, such as landfills, where the methane may be seeping up from underground in a much more diffuse manner. It is not clear how that would impact the accuracy of the quantification approach described in this document, but we assume that the computed emission rate in such situations would be less accurate.

Conclusions

Kairos estimates the rate of methane release from emission sources that are detected during surveys of oil and gas production areas or other suspected sources of methane emissions, such as refineries, landfills, and gas storage facilities. While other methods exist to quantify methane emissions, they are often time-consuming or entirely impractical and, in many cases (involving naïve plume models), they do not provide very accurate results. As a result, facility operators often can only guess at what their emissions are, and they record only qualitative assessments of the leaks that are fixed. The emission rate Kairos computes for an *individual* plume does, of course, contain some uncertainty. Test data demonstrates that, in the aggregate, these computed emission rates are very consistent with ground truth. Having accurate estimates of emission rates is valuable for prioritizing the largest emission sources for immediate attention and for understanding total emissions detected and fixed in the aggregate.