realSens™ Airborne Pipeline Leak Detection Field Operations Results

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ABSTRACT

Detecting natural gas leaks from the worlds nearly 5 million kilometers of underground pipelines is a difficult and costly problem. Existing technologies are limited to ground deployment and have a number of limitations such as slow response, false leak readings and high costs. Various remote sensing solutions have been proposed in the past and a few are currently being developed. This paper starts by describing the remote sensing concept and then will focus on a new technology called **realSens™**. This airborne instrument is a passive Gas Filter Correlation Radiometer that is tuned to measure ethane and methane in the 3.3 microns near-infrared band. Theoretical plumes derived from the AFTOX model are compared with actual field measurements taken with the **realSens™** instrument. The paper concludes with a description of the service which Synodon is offering to the transmission and distribution pipeline operators using the **realSens™** technology.

Keywords: remote sensing, airborne pipeline leak detection

1. REMOTE SENSING

Remote sensing refers to the technique of measuring the properties of an object from a distance, without physically sampling the object, by detecting the interactions of the object with an electromagnetic field. When applied to the detection of natural gas leaks from underground pipelines, this inspection method presents a number of benefits over other techniques. The measurement does not have to be performed inside the plume which eliminates pipeline access and landowner issues as well as the need to know how the wind and atmospheric dynamics is likely to disperse the gas to create the plume. Also, since the deployment of remote sensing solutions is normally done by aircraft, the dramatic increase in productivity can have the effect of lowering the cost per inspected mile for the pipeline owner.

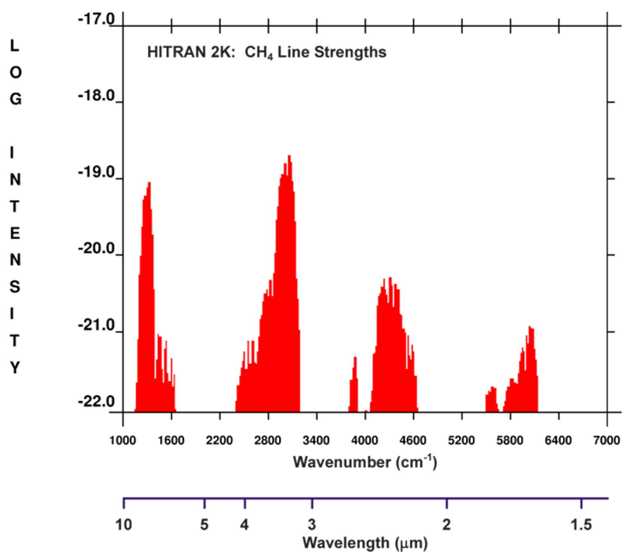

Figure 1: Methane Spectral Absorption Bands

If one examines the infrared spectra of most hydrocarbon gases (as an example, methane is presented in Figure 1) it would be noticed that there are four areas centered around 1.6, 2.4, 3.3 and 7 microns where there are significant spectral absorption features present. These areas present potential measurement bands for remotely sensing these gases. Each band is very different however in the type and source of infrared energy available. At 1.6 microns the majority of the infrared energy is provided by the sun while at 3.3 microns only half the energy is due to the sun while the other half is thermal radiation from the earth. At 7 microns all the available energy is thermal radiation.

There are two main classifications of remote sensing techniques, active and passive sensing. Active sensing involves illuminating the scene with an EM radiation source (usually a laser) and detecting the absorption of the target gas. Passive sensing involves detecting either the emission of radiation by the gas, or the absorption of a background radiation field by the gas. Both classes of remote sensors observe a change in the detected radiation field due to the presence of a gas in the instrument's field-of-view (FOV), relative to a measurement made without the gas in the FOV. Also, both require a radiative contrast between the background and the gas. For passive sensing, this contrast is dependent on a difference between the temperature of the background and the gas, and the emissivity of the background. Therefore, if the leaked methane is the same temperature as the radiation source, then no methane can be detected.

Passive remote sensing of methane using backscattered solar near-infrared radiation in the 1.6, 2.4 or 3.3 micron bands, gets around the requirement of a temperature contrast, as the backscattered energy of the Sun is much larger than the emission of the gas or surface. The solar energy component provides the required radiative contrast.

2. REALSENS™ TECHNOLOGY

Gas-Filter Correlation Radiometry (GFCR) was employed in some of the first remote sensing measurements made from satellites, and continues to be used today to measure atmospheric temperature and composition. An example of such an instrument is the Canadian-made MOPITT (Measurement Of Pollution In The Troposphere) instrument. MOPITT, which is current operating on NASA's Terra satellite, measures atmospheric carbon monoxide (CO) and methane (CH_4).

As its name suggests, a GFCR uses a sample of a gas as a spectral filter for the gas. The principle of the GFCR being developed is shown in Figure 2.

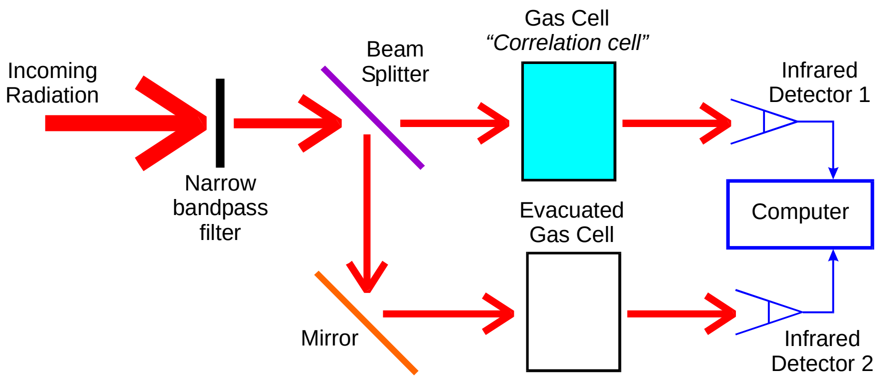

Figure 2: GFCR Conceptual Diagram

Incoming radiation is first passed through a narrow band-pass filter (as is the case in any typical radiometer). The beam is then split along two paths; one path containing a gas cell filled with the gas of interest (known as the correlation cell) and the other path containing no gas. The correlation cell acts as a spectral filter, removing energy from the incoming beam at the wavelengths corresponding to the absorption lines of the gas. The radiant fluxes in each path are then measured by infrared detectors, and the signals are analyzed.

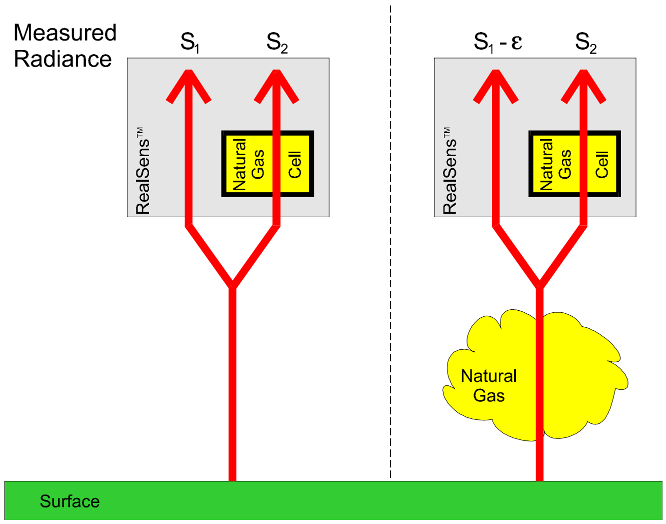

Figure 3: GFCR Measurement Principle

The detection of a cloud of "leaked" natural gas by a GFCR is show schematically in Figure 3. The instrument detects two signals, S1 and S2 respectively. If a cloud of leaked natural gas is in the field-of-view, the signal in channel 1 will be reduced due to the absorption of methane, (S1 - ε). However, since channel 2 already has the wavelengths of energy absorbed by methane removed, the signal does not change.

The choice of a GFCR to measure the natural gas leaks was made for a number of reasons. The advantages of GFCRs include:

- Large radiative grasp greatly increase the signal-to-noise of the measurement;
- High spectral selectivity greatly increases the sensitivity to methane, over that of a conventional radiometer;
- Can be operated in an imaging mode, to provide images of the leak;
- Not necessary to understand the spectrum, thus simplifying the data analysis;
- Robust and sturdy instrument with no moving parts
- Simplicity makes the instrument easy to operate;
- GFCRs have over two decades of history in satellite remote sensing.

realSens™ is a helicopter mounted GFCR that is tuned to detect the main constituent of natural gas, namely methane (CH_4) in the solar near-infrared region of the spectrum. The reasons for choosing this configuration include all the advantages of a GFCR (as described in the previous section), plus:

- The instrument is not affected by variations in the aircraft height above the surface;
- By measuring in the near-infrared, detection of leaked natural gas does not require that the gas be a different temperature than the surface;
- **realSens™** measures the leaked natural gas in the entire column of air between the helicopter and the ground (see Figure 4). The aircraft does not have to fly through the plume of the leak;

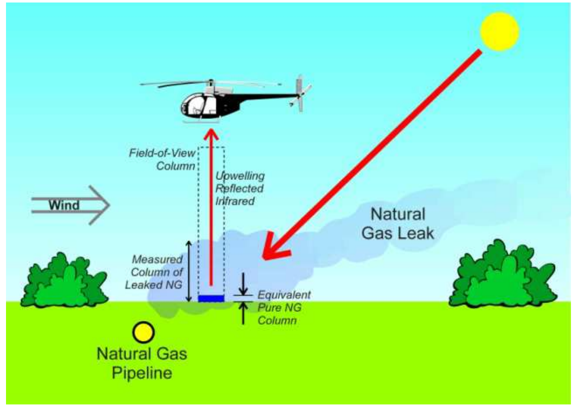

Figure 4: realSens™ Operation

Unlike sampling instruments which measure a relative concentration of CH_4 in a sample of air (i.e. mixing ratio or ppmv), the **realsens™** instrument will measure the absolute amount of natural gas in the column of air below the aircraft (see Figure 4). This can be expressed as the thickness of a column of natural gas if all the gas in the column was brought to the surface at STP (standard temperature and pressure, 0°C and 101.325 kPa). The detection limit of **realsens™** to leaked natural gas is roughly 500 µm of gas [(1)] in practical field applications.

3. THERORETICAL PLUME ANALYSIS

Leaks that develop from underground pipeline networks present a significant safety issue and are difficult to accurately quantify. The primary method in use today involves walking surveys using handheld technologies such as Flame Ionization Detectors. These instruments are measuring the mixing ratio of natural gas in air and express it as ppmv values. These readings are affected by a wide variety of factors such as leak rate, diffusion area, wind and atmospheric conditions, distance from leak site, etc. The pipeline operator is also more interested in the amount of gas that is leaked (the leak rate) rather than the natural gas concentration in air (unless explosive limits are reached). In this regard, the integrated column measurement that **realsens™** performs is much better correlated with the actual leak rate to the point where rough leak rates can be extracted from the data.

To assess the capabilities of **realsens™** at detecting various leak rates (rather than concentrations), a significant amount of effort was dedicated to modeling typical plume dynamics and the resulting column thicknesses and correlating the results with field measurements.

The first step in this process was focused on understanding the three dimensional characteristic of a theoretical plume calculated with a dispersion model called AFTOX. AFTOX is a Gaussian dispersion model that was developed by the US Air Force to calculate toxic corridors in case of accidental releases and was selected since it is an appropriate fit for simulating natural gas plumes in air. The AFTOX model has been developed based on actual field plume measurements and has been extensively validated since its inception in the late 80's. However, since plume point concentrations can vary quite significantly due to entrained air, plume meander and other effects the AFTOX model uses a rather long integration time (60 seconds or more). The simulation results represent the average plume concentration over this time period and shorter integration times will yield different results.

Since the model could not simulate natural gas directly, all the runs were completed using methane, a gas which represents about 95% of a typical natural gas mixture. The results presented in this note are therefore expected to be reasonably representative of the behaviour of a natural gas plume.

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[1] This could be thought of roughly as being equivalent to 50 ppm-m, a unit of measure currently in use by the gas industry for path integrated measurements. However, the ppm-m unit is dependent on the path length while an integrated column thickness is not.

Figure 5 shows the concentration contour lines (set at 10, 3 and 1 mg/m^3 for this example) at ground level resulting from a simulated underground leak with a rate of 0.01 kg/min (or 8.8 cuft/hr). The wind was set at 1 m/s (3.6 km/hr or 2.25 miles/hr). These numbers were chosen since they are characteristic to some of the smallest leaks that low pressure distribution networks might experience.

The plume has been superimposed (to scale) over a typical suburban neighborhood image and shows the 10 mg/m^3 [2] concentration contour extend roughly 10 meters (30 feet) downwind from the leak.

Figure 5: Plume simulation contours

The graph in Figure 6 outlines the centerline downwind concentration of this plume at 6 different heights above the ground. Two characteristics are worth highlighting from this data:

- At 0.5 meters above ground, the highest concentration will be recorded roughly 3 meters downwind from the leak source and will measure about 80 mg/m^3.
- At 1.5 meters above ground, the highest concentration will barely reach 10 mg/m^3 at any point downwind.

These results show the tendency of the gas to stay close to the ground as it travels downwind from the leak source and it takes significant atmospheric turbulence or object interference to mix it into higher altitudes. This has been confirmed by various plume imaging cameras as well as reported by experienced field staff and it also explains why detecting small leak rates from a sampling sensor mounted on a low flying helicopter is so difficult.

[2] The volume mixing ratio units used in this simulation were mg/m^3. To convert from this unit to ppmv one has to multiply the mg/m^3 figure by 1.47.

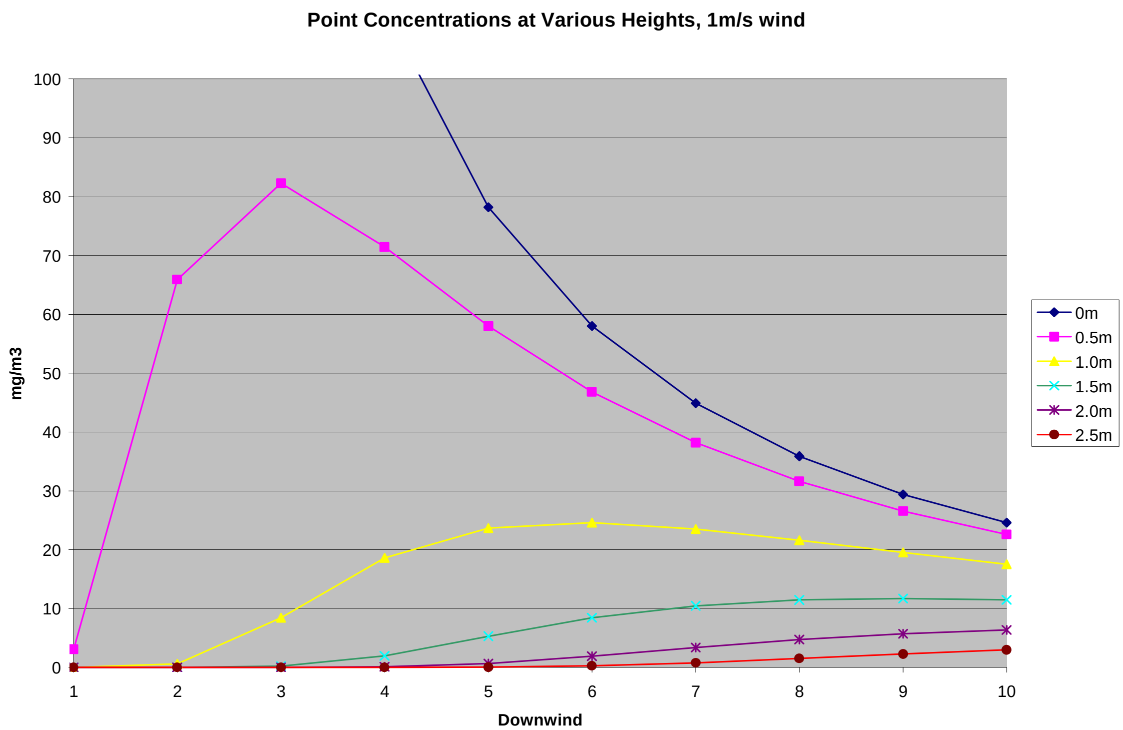

Figure 6: Centerline downwind concentrations at various heights

The second step was to derive theoretical integrated column values expressed in µm of natural gas, the measurement unit for the **realsens™** instrument (these units were described earlier in this paper). As can be seen from Figure 7, for the 1 m/s wind case the integrated column thickness at the 1 meter downwind position is 310 µm decreasing to 50 µm at 10 meters. A secondary dataset representing column values for a 2.5 m/s (9 km/hr or 5.6 miles/hr) wind case was added to this graph also. These values are roughly 2.38 times lower than in the previous wind condition indicating that the column thickness scales roughly proportional with the wind speed.

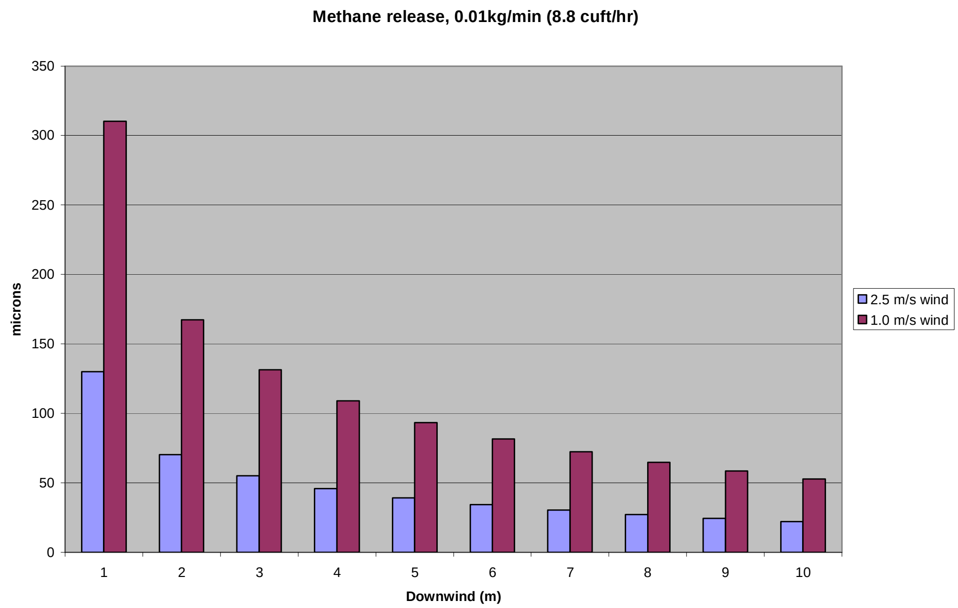

Figure 7: Integrated column thicknesses (in µm)

Using this newly developed methodology, a 2-dimensional view of a simulated 110 scfhr methane leak was created and is presented in Figure 8. The plume was superimposed to scale on an image acquired over a pipeline ROW during one of the field tests and shows the extent of the column thickness for the 500 to 5000 µm range.

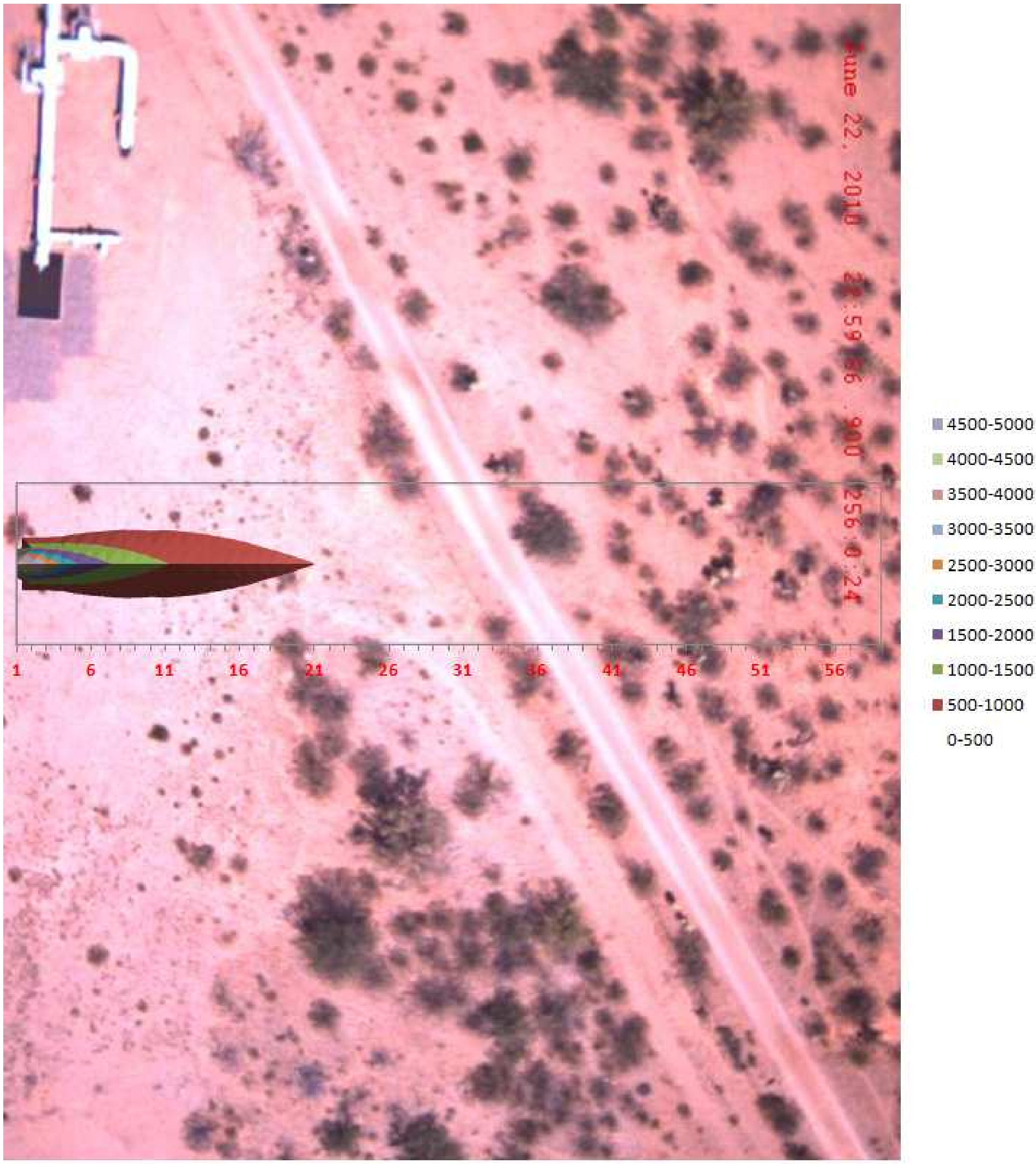

Figure 8: 2D plume image with integrated column thicknesses (in µm)

The practical application of this analysis is in the evaluation of the ability of a certain technology (with a known integrated column thickness sensitivity and spatial imaging resolution) to detect a given leak rate. In the example illustrated in Figure 8, an instrument with a minimum sensitivity of 1000 µm should be able to image a plume roughly 10 meters long (the green level in Figure 8) while one with a sensitivity larger than 5000 µm would not be able to see the gas plume at all.

4. FIELD PLUME MEASUREMENTS

The theoretical release models discussed in the previous section use a long integration time (60 seconds in this case) to calculate the average shape and concentration of a plume. In practice, technologies that image plumes from a moving airborne platform will take a snapshot of it in a much shorter period of time and as such will look quite different. The important thing to remember however is that, although the spatial distribution of the gas in the instrument field of view will be different than that indicated by the model, *the total amount of gas will be the same*.

During the last 2 years, Synodon has collected a significant amount of field data with its **realsens™** instrument by flying over a variety of leak rates under differing environmental conditions. This section will present the results from two such tests as well as two plume images from this collection ahead of a discussion on how the real world results relate to the model predictions.

Two extensive, third party controlled leak detection tests were performed in 2011 and 2012. The first one was located in Central California while the second one in the Canadian Arctic. The setup for both was similar in that a large number of varying leak rate releases were created from compressed natural gas cylinders while **realsens™** was flown overhead. To fairly determine the performance of a remote sensing technology, the performance in different wind speed regimes must be considered. One way this can be accomplished is by categorizing the detection performance using different wind speed ranges. This method however requires an arbitrary selection of wind speed ranges which can impact the results presentation. To circumvent this issue, Synodon has introduced a new performance metric which normalizes the leak rates with wind speed resulting in SCFH/mph units (or (m^3/min)/(m/s)) . By using the wind normalized performance methodology, where the leak rate is divided by the wind speed, **realSens™** has demonstrated a 100% detection success for normalized leak rates larger than 75 SCFH/mph (0.075 (m^3/min)/(m/s)) and a 50% detection success for normalized leak rates of 25 SCFH/mph (0.025 (m^3/min)/(m/s)).

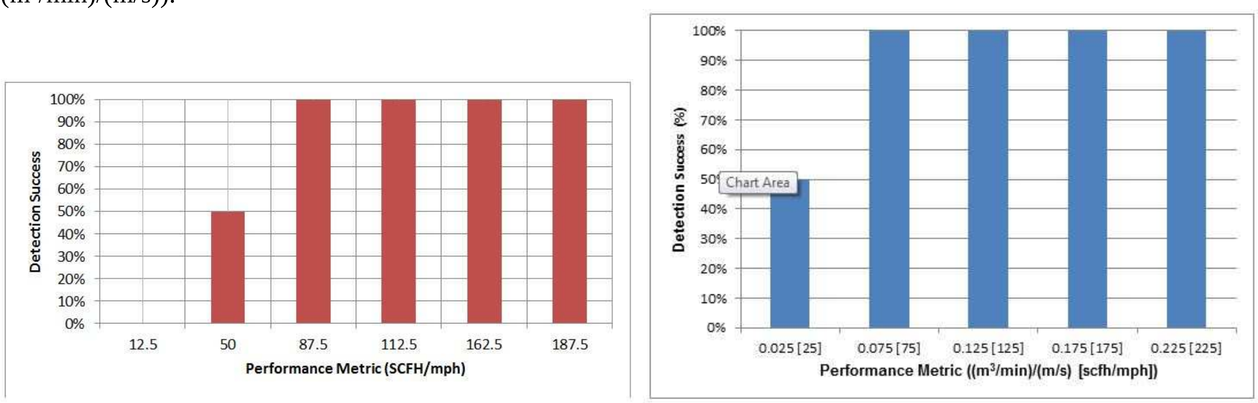

Figure 9: Blind test results for California test (left graph) and Canadian Arctic (right graph)

Figure 10 shows the plume image of a controlled 1100 scfhr leak. The release location was just west of the white truck parked in the open field and the winds were from the northwest (upper left hand corner of the image) gusting between 5 – 10 miles/hour. From this image it can be clearly seen that the plume disperses downwind (in a southeasterly direction) but due to the variable gusts it is quite broken up and is not forming a perfect, contiguous shape.

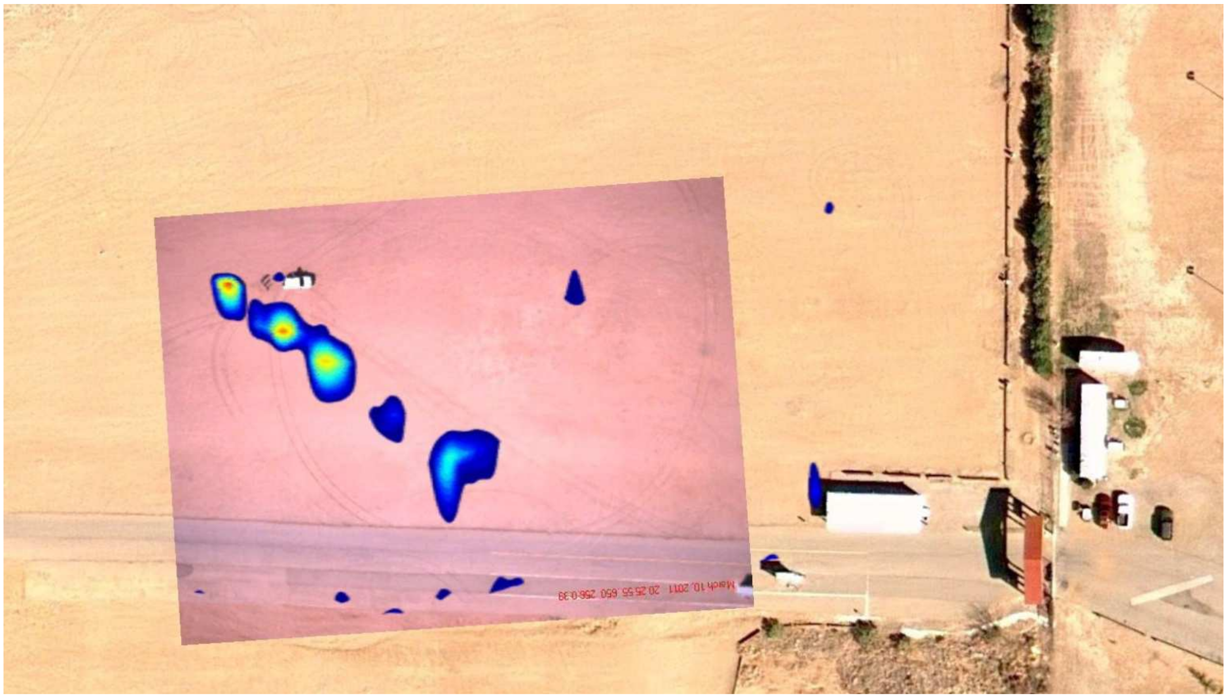

Figure 10: 1100 scfhr plume image under gusty wind conditions

Figure 11 shows the image of a plume taken about 10 minutes later at a second controlled leak location, 500 yards east of the location in Figure 10. The winds had shifted direction towards the south but were also a lot more uniform at roughly 5 miles/hour which resulted in a well defined, contiguous plume (the colour scale superimposed on the image spans the range from 3000 µm (blue) to 10000 µm (red) of integrated methane gas column). The first conclusion that can be drawn from this data is that the plume shape is very similar to the one predicted by the model presented in Figure 8 (narrow and long). At the point where the plume image is clipped at the edge of the **realSens™** instrument field of view, 25 meters away from the leak source, the value of the integrated gas column is roughly 5000 µm (light blue) which is similar to the model (please note that the data in Figure 8 should be multiplied by a factor of 10 to account for the difference in leak rates). And finally, the peak amount of gas in the plume image is not right at the source but rather about 6 meters downwind as the gas has to disperse horizontally far enough to cover a full **realSens™** pixel which is 2 x 2.4 meters.

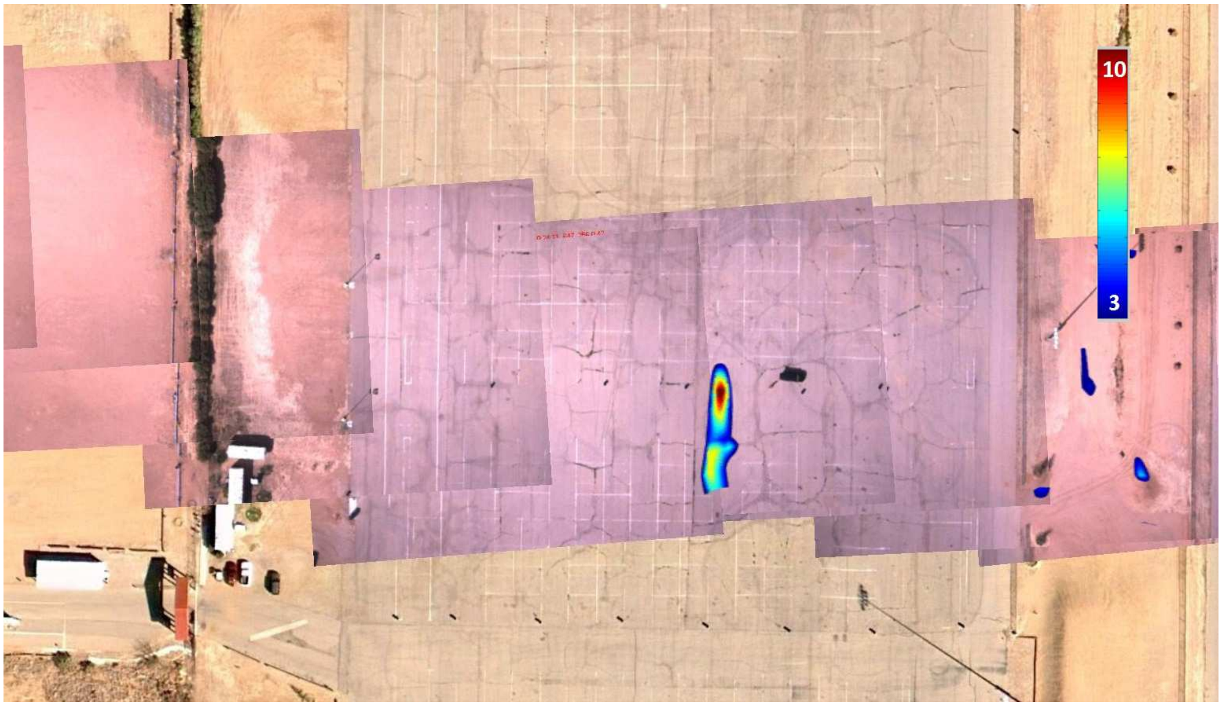

Figure 11: 1100 scfhr plume image with integrated column thicknesses (in mm)

5. CONCLUSIONS

As expected, the instantaneous snapshots of methane gas plumes collected in the field by the **realSens™** instrument are somewhat different from those predicted by the time averaged models, with the main factor affecting this divergence being atmospheric turbulence caused by wind gusts. Beyond this however, the models and field measurements correlate within a reasonable error margin with respect to the expected amount of gas in the plume at various locations downwind (expressed as the amount of gas in the integrated column) and the shape and size of the plume for different leak rates. Based on these results and under appropriate environmental conditions, Synodon has been able to calculate approximate leak rates from plume images acquired by the **realSens™** instrument, typically within a 30-50% error margin.

6. REALSENS™ SERVICE

The **realSens™** instrument is used to provide customers with a complete leak detection service, including all aspects of the leak detection process from route planning through to a field ready report identifying leak locations.

Synodon's service includes any or all of these functions, customized to meet the specific needs of each customer:

- Identification of pipeline area to be surveyed.
- Timing and sequencing of survey areas.
- Training and instruction of helicopter pilots.
- Pre-flight instrument setup.
- Flights over target survey areas.
- Technical analysis of survey data.
- Immediate notification to customer of Class 1 leaks.
- Preliminary classification of all leaks.
- Integration of survey data with GPS and digital imaging.
- Preparation of report of survey results.
- Delivery of survey results via electronic or hard copy.
- Data archiving for subsequent historical analysis.

- Post survey consultation regarding results.

All of these services are bundled together and are offered at a single price. Synodon is committed to offering attractive pricing that will not increase and in most cases will decrease each customer’s cost of leak detection.

Although cost efficiency is the best reason for using **realSens™**, other benefits include:

- Sensitivity: **realSens™** has been demonstrated to detect leaks in the 100 to 500 scfhr.
- Convenience for landowners: No need to enter on landowner’s property. One overhead pass at 1000 feet gives realSens™ all the data it needs.
- Reliability: **realSens™** detects all natural gas emissions in its path with very few interferences
- Coverage: With a 210 foot swath, **realSens™** provides 100% ground coverage in urban areas and ample coverage of transmission line rights of way.
- Ease of use: Synodon will provide a bundled service that includes the entire leak survey function from route planning through to presentation of field ready reports and integration with integrity management systems.