GHGMap: Detection of Fugitive Methane Leaks from Natural Gas Pipelines, British Columbia and Alberta

M.J. Whiticar, University of Victoria and Geochemical Analytic Services Corporation, Victoria, BC
whiticar@uvic.ca

L.E. Christensen, NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, US

C.J. Salas, Geoscience BC, Vancouver, BC

P. Reece, InDro Robotics Corp., Salt Spring Island, BC

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Introduction

GHGMap is a research and development project focusing on developing and testing new instrumentation and approaches to measure atmospheric greenhouse gases (GHG). The new consortium of Geoscience BC, Geochemical Analytic Services Corporation, NASA/Jet Propulsion Laboratory (JPL) and InDro Robotics Corp. has developed the capability to provide detailed, unmanned, aerial, regional and site surveys of GHG.

The consortium has developed a system that uses the combined technologies of a state-of-the-art open-path laser spectrometer (OPLS), developed by NASA/JPL (Christensen, 2014), deployed on a specialized small unmanned aerial vehicle (UAV; Figure 1; Whiticar et al., 2018). This OPLS/UAV platform can measure trace levels of GHG in the atmosphere, including methane, ethane and carbon dioxide. This system is ideal for the detection, quantification and source differentiation of GHG emissions and budgets because of the extreme detection sensitivity of the OPLS (parts per billion); the high measurement frequency (10 Hz) of the sensor; the small size, weight and low power consumption of the sensor; and the precise operation and navigation of the UAV.

This novel monitoring capability permits verifiable identification, control and quantitation of emissions (e.g., well and/or pipeline integrity, landfills, feedlots, etc.) and monitoring of mitigation operations. The initial program focuses on major GHG emitters in western Canada (i.e., British Columbia, Alberta, Saskatchewan; Whiticar et al., 2018), but is expanding to private sector enterprise both nationally and internationally.

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A critical exclusive feature of the OPLS/UAV platform is that it can fly close to (<1 m) and hover over identified anomalies, with real-time flight-path and navigation capabilities (Figure 2). In concert with the methane (CH_4) measurements, simultaneous wind direction and speed measurements can also be made by sonic anemometry.

The data collected is stored on the OPLS and sent in real-time to the receiver station for the drone control (Whiticar et al., 2018). The high precision navigation on the drone allows repeatable positioning of the UAV within 50 cm and extremely reduced flying altitude (~1–10 m) in contrast to helicopter or fixed-wing aircraft surveys (>150 m). These high precision, close proximity measurements by the OPLS/UAV platform combined with the low flight velocities (1–3 m/s) permit increased and precise detection capabilities (Figure 2). These are unparalleled by other methods, such as handheld monitors, land-vehicle–mounted mobile sensors, manned aircraft or satellites.

The OPLS/UAV platform is now mature and has been deployed over a wide range of methane emitters (Whiticar et

Figure 1. GHGMap's open-path laser spectrometer (OPLS) on a small unmanned aerial vehicle (UAV).

al., 2018). In 2016 and 2017, initial OPLS/UAV test surveys were successfully conducted over several natural gas distribution and pumping facilities, gas well sites, a landfill and a sewage treatment plant. A summary of the basic technology and these results has been published in Whiticar et al. (2018). This paper discusses a further application of the OPLS/UAV platform, namely the ability to detect leaks from surficial and buried natural gas pipelines.

Pipeline Survey Demonstration Locations

With the generous support of AltaGas Utilities Inc. (AltaGas), the GHGMap team was invited to demonstrate the OPLS/UAV technology along their high pressure natural gas pipeline in Alberta (Figure 3). The tests were conducted in November 2017 with temperatures at approximately –5°C. The first test involved a small, short, controlled release of natural gas on the AltaGas property. AltaGas then chose two segments of their buried high pressure natural gas pipeline for further testing (Figure 4). At a point along each of the two segments, there was a controlled natural gas release point established by AltaGas. The GHGMap team did not know the locations of these two releases beforehand. The natural gas is predominantly CH_4 (>95%), so the test was well-suited to the OPLS CH_4 sensor. The launch points and approximated survey path are indicated in Figure 4. Although the OPLS/UAV platform could fly for greater than 2 km (~15 min) in these cold temperatures, the flights were set to approximately 10 min or ~1 km total flight distance (out and back). In warmer temperatures (approx. >5°C), the flight time increases to ~45 min.

Figure 2. GHGMap's open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform surveying at a gas distribution plant, Victoria region, British Columbia.

Pre-Survey Calibration Release Test

As an initial, pre-survey check, AltaGas set-up a small, controlled release of natural gas on their Alberta property. This limited, surface release test was to calibrate the UAV navigation and verify that the OPLS could detect CH_4 prior to the fieldwork. This successful test is illustrated in Figure 5, which is a time series plot of the UAV altitude (red line) and the OPLS CH_4 concentration (black line). For the first half of this test (38 090–38 190 s), the drone was stationary, as indicated by the altimetry, and approximately 50 m from the point of the small CH_4 release. During this time the CH_4 concentrations measured by the OPLS were generally low. However, there were some minor kicks of elevated CH_4 concentrations during this time period, suggesting the presence of a gas leak in the vicinity. The detection of these CH_4 concentrations that were higher than background levels likely depended on the wind direction and strength. At approximately 38 190 s (Figure 5), the UAV rose to ~150–350 cm above the ground as it traversed across the AltaGas property. As the UAV passed the controlled emission point on the two transects (approx. 38 230 and 38 300 s, Figure 5), the CH_4 spiked to values up to 15 ppm, which is approximately 10 times the tropospheric CH_4 background levels. This controlled natural gas release demonstrated that the OPLS/UAV system could readily detect and localize a small surficial gas leak.

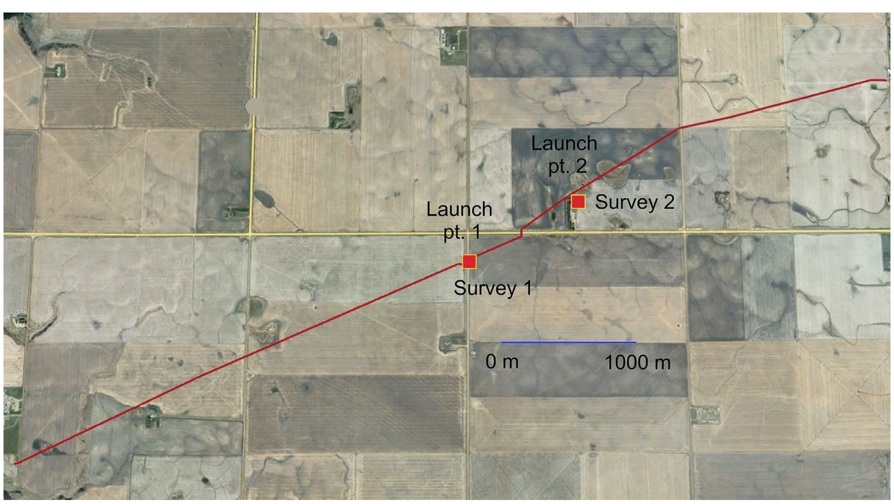

Figure 3. Survey map of AltaGas Utilities Inc. pipeline testing area, Alberta. The red line shows the location of the buried, high-pressure gas pipeline. The red squares show the two launch points of the open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform for the test surveys. Abbreviation: pt, point.

Natural Gas Pipeline Release Surveys

Four individual flights were made by the OPLS/UAV platform at the two AltaGas buried pipeline locations and a total of 23 445 discrete methane (CH_4) measurements were taken (Table 1). The weather was approximately –4°C, with clear conditions and firm winds predominantly from the west (0–4.7 m/s, mean = 1.57 m/s; Figure 6). A detailed map of the actual flight paths flown by the OPLS/UAV at each of the locations 01 and 02 is shown in Figure 7. Two flight segments were made at each of the locations.

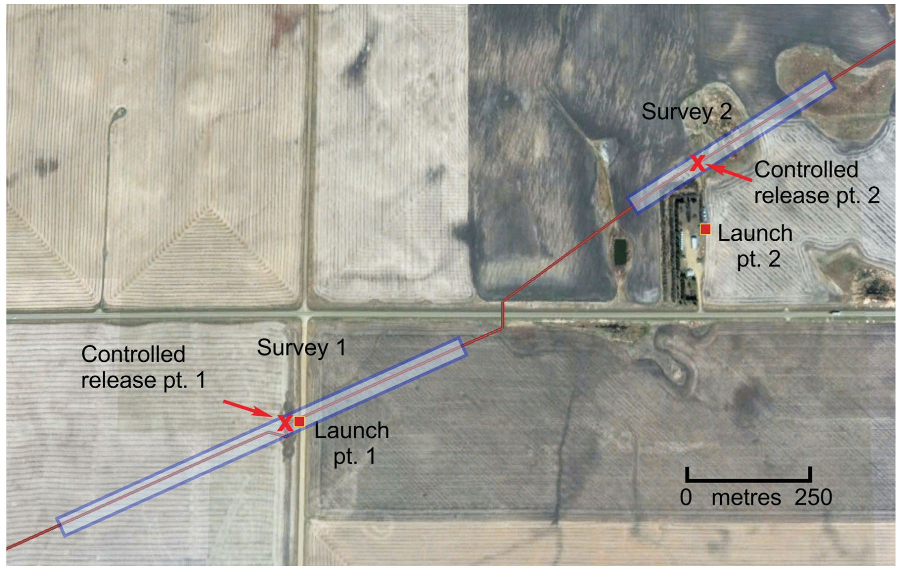

Figure 4. Detailed locations of two AltaGas Utilities Inc. (AltaGas) pipeline test leak detection surveys, Alberta. The red line shows the location of the buried, high-pressure gas pipeline. The red squares show the two launch points of the open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform for the test surveys. The two controlled natural gas release points set by AltaGas are marked by X. Abbreviation: pt, point.

The minimum CH_4 value measured was 1.58 ppm and the highest was 25.8 ppm, which is more than 16 times higher than normal tropospheric CH_4 background levels (Table 1). The mean CH_4 concentration was 2.61 ppm with a standard deviation of 0.95 ppm. As anticipated, the vast majority of the CH_4 measurements revealed concentrations that were at, or close to, the expected background tropospheric CH_4 level of ~1.8 ppm. This is illustrated in Figure 8a and b with the histograms of measured CH_4 concentrations (1.5–4 ppm and 4–30 ppm). Table 1 also reveals a strong skewness and kurtosis to the CH_4 distributions at the two locations. The strong skewness is also evident in the unidirectional tails of CH_4 concentration in the histograms. Similarly, the probability plot (Figure 8c) clearly shows the single-ended tailing of methane to higher concentrations.

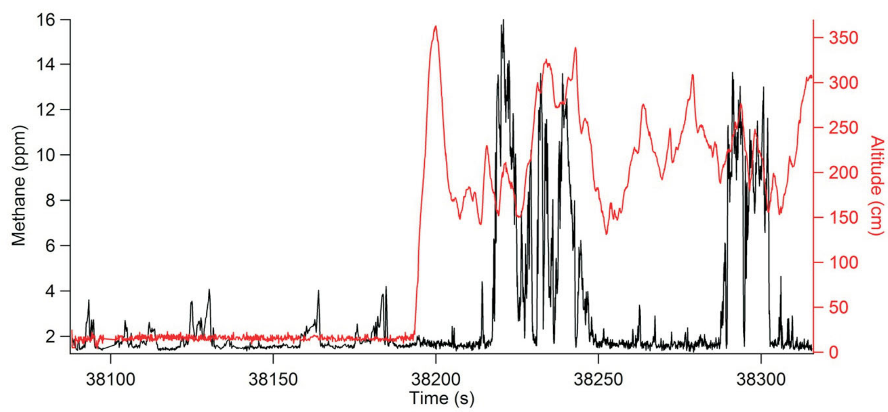

Figure 5. Small, controlled natural gas release at AltaGas Utilities Inc., Alberta. The red line is the altitude of the unmanned aerial vehicle (UAV). The black line is the methane concentration detected in real-time by the open-path laser spectrometer (OPLS).

The importance of elucidating the CH_4 distributions is to determine thresholds for the classification and delineation of background and anomalous CH_4 values. Using this information, the following categories for CH_4 concentration were defined:

1) background, 1.6 to <2.5 ppm CH_4 (blue colour);
2) elevated, 2.5 to <4.0 ppm CH_4 (green colour);
3) anomalous, 4.0 to <10.0 ppm CH_4 (orange colour);
4) highly anomalous, ≥10.0 ppm CH_4 (red colour).

Table 1. Statistics of methane concentration measurements for locations 01, 02 and all four flights combined, at AltaGas Utilities Inc., Alberta.

Parameter	Location 01	Location 02	Combined
Minimum (ppm)	1.58	1.58	1.58
Maximum (ppm)	25.8	25.4	25.8
Number of measurement points	11 479	11 970	23 445
Mean (ppm)	2.64	2.59	2.61
Median (ppm)	2.54	2.43	2.48
Standard deviation (ppm)	0.913	0.976	0.95
Variance	0.833	0.952	0.89
Standard error	0.0085	0.00892	0.0062
Skewness	10.79	10.42	10.61
Kurtosis	168	166	168

Pipeline Release Location 01 (Flights 01, 02)

The location 01 surveys were conducted over an open harvested grain field. The ground was frozen and had a light snow cover (Figures 9, 10). As illustrated in Figure 6, the wind during flights 01 and 02 was firm and steady from the west and southwest at up to 5 m/s (18 km/h). The highest gusts were approaching the operational limits of a light UAV.

The 11 479 discrete CH_4 measurements by OPLS at location 01 generally had low concentrations, i.e., <4.0 ppm CH_4, with a mean value of 2.64 ppm CH_4 and a standard deviation of 0.913 ppm (Table 1). Figure 11 shows that the two flights (01 and 02), for the most part, revealed background levels of CH_4. However, at the location of the controlled natural gas release, significantly elevated levels of CH_4 were detected, up to 26 ppm. The moderately high values directly to the north of the release point reflect the strong winds (Figure 6) that rapidly dispersed the CH_4 plume.

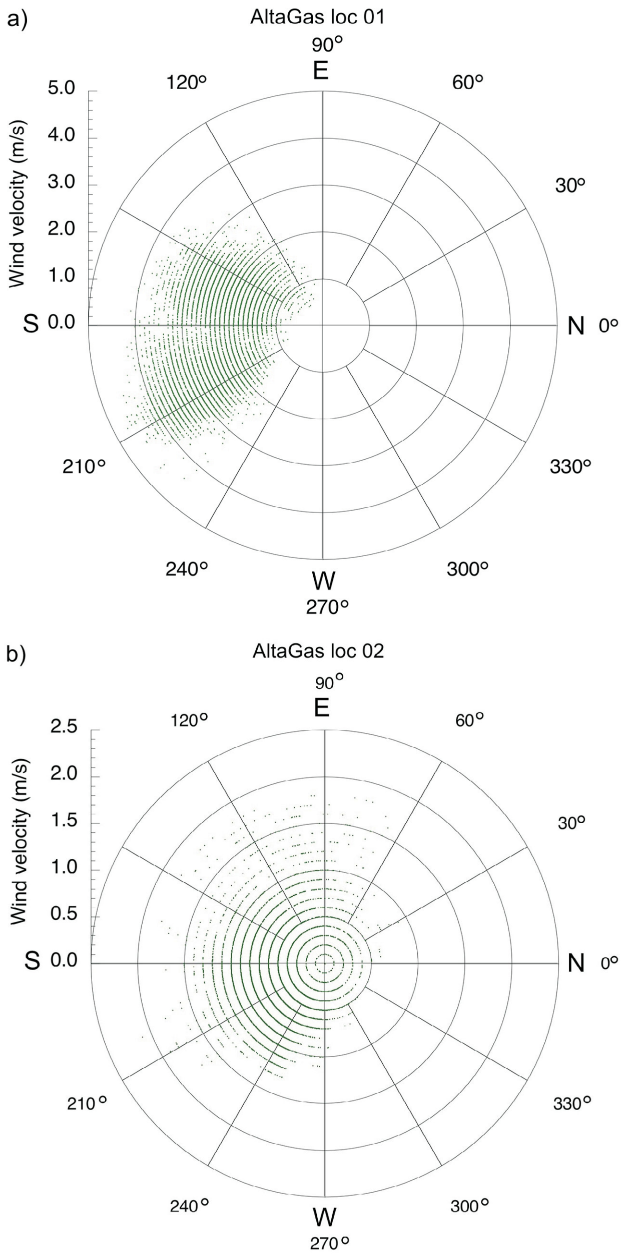

Figure 6. Windroses of wind directions and velocities at **a)** location (loc) 01 and **b)** location 02, at AltaGas Utilities Inc. (AltaGas), Alberta. The data refer to the direction the wind blows from, i.e., predominantly from the west.

Figure 12 shows an aerial view of the OPLS/UAV platform survey tracks (black line) for location 01, flight 02, proximal to and directly at the controlled release point. The CH_4 concentrations during the survey are represented by the coloured points in the figure, with cooler colours representing higher concentrations. The figure also shows the anemometry wind vectors to the anomalous CH_4 concentration (i.e., above CH_4 background levels) points in flight 02. These vectors show the wind directions and speeds at the time of the CH_4 measurement. The real-time measurement combination of the wind direction and strength with the CH_4 concentration permits a back-trajectory calculation of the natural gas plume anomaly to the source.

Time series plots of the CH_4 concentrations and the flight altitude of the OPLS/UAV platform for location 01, flight 02, are shown in Figure 13. The strongly delineated points of higher CH_4 concentrations clearly demonstrate the ability of the OPLS/UAV platform to make precise and spatially focused measurements in real time. The figure also illustrates a critical advantage of the drone-based measurement strategy. By flying the OPLS/UAV platform at different altitudes, not only can the horizontal distribution and footprint of CH_4 plumes be surveyed, but also the vertical distribution. Figure 13 indicates that the anomalous CH_4 concentrations measured at close to ground level (~1–2 m) are not observed at higher altitudes, up to 20 m. This indicates that the anomalous CH_4 plume is essentially

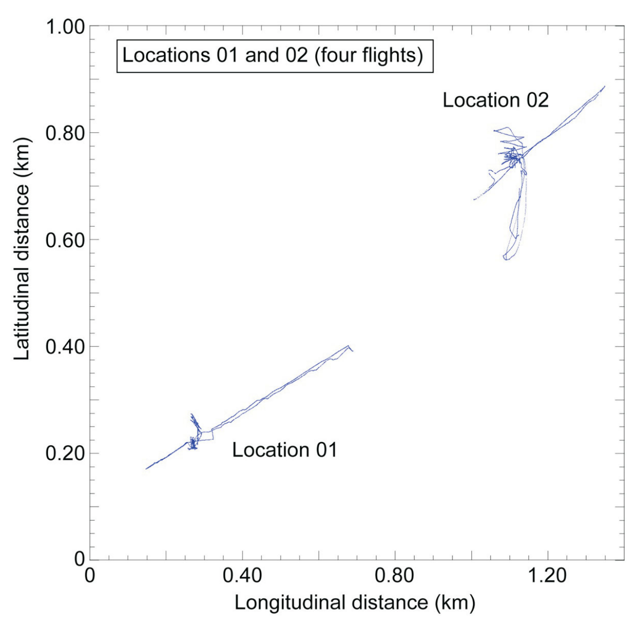

Figure 7. Detailed flight location paths of four pipeline test leak detection flights at locations 01 and 02, at AltaGas Utilities Inc., Alberta.

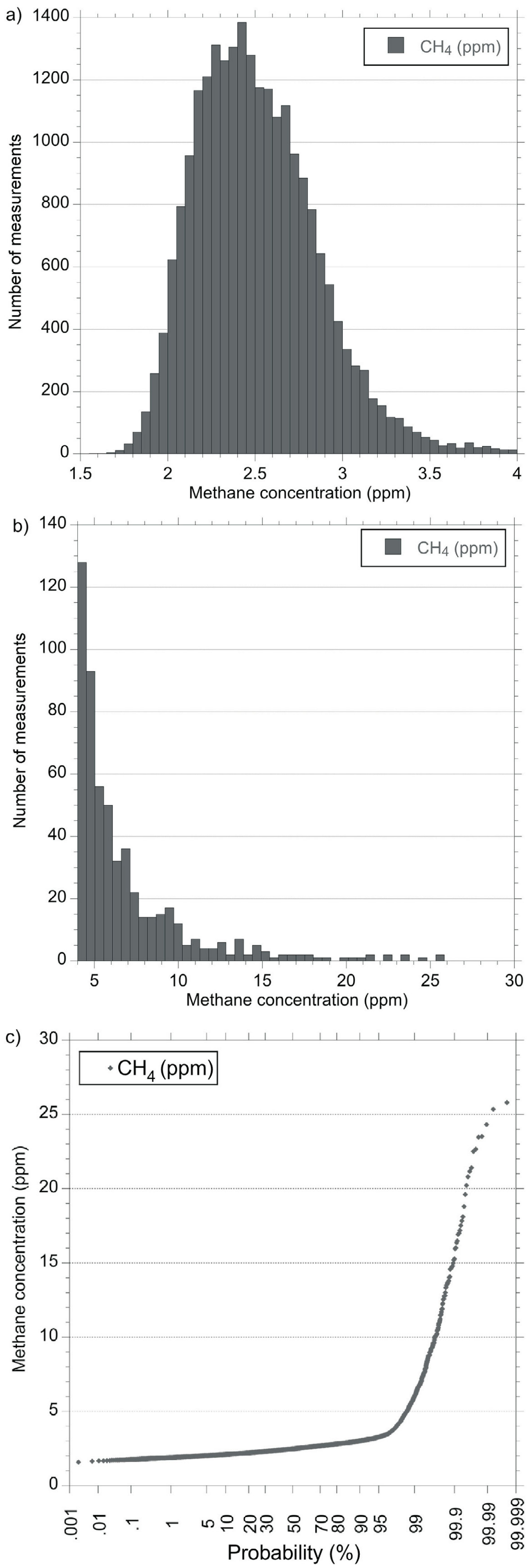

Figure 8. Measured methane (CH_4) concentrations at locations 01 and 02 (combined), at AltaGas Utilities Inc., Alberta: **a)** histogram of 1.5–4 ppm range, **b)** histogram of 4–30 ppm range and **c)** probability plot .

Figure 9. Photograph of survey field containing the buried, high-pressure natural gas pipeline at location 01, at AltaGas Utilities Inc., Alberta.

Figure 10. Photograph of open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform at location 01 survey site, at AltaGas Utilities Inc., Alberta.

restricted to ground level and dissipates very rapidly at higher elevations.

This altitude dependence of the CH_4 concentration anomaly is clearly observed in Figure 14. Most of the elevated CH_4 values are at ground level. The small number of hits at 5 and 8 m were measured downstream of the plume release point.

Pipeline Release Location 02 (Flights 03, 04)

Analogous to location 01, the location 02 test survey consisted of two flights (03 and 04) over frozen fields with a light snow cover (Figure 15).The winds during flights 03 and 04 were <2.5 m/s (<10 km/h), which is substantially lower than at location 01 (Figure 6). The dominant wind direction was still from the west, but there was considerably more directional variability than at location 01.

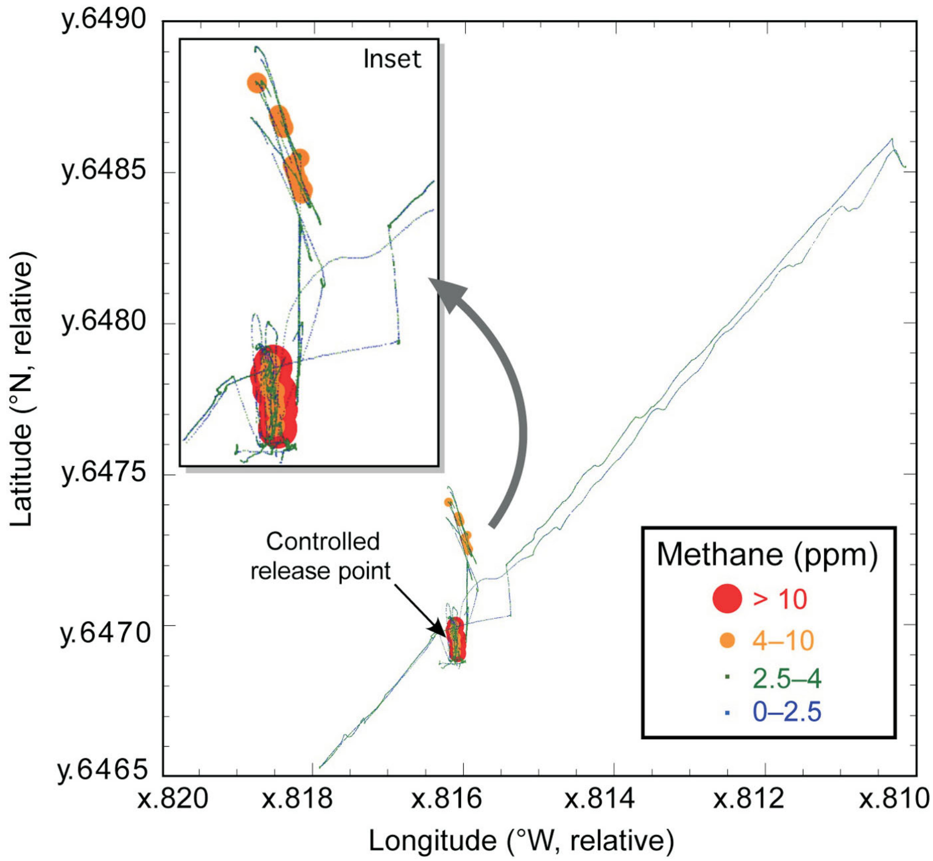

Figure 11. Overview of methane concentrations for location 01, flights 01 and 02, at AltaGas Utilities Inc., Alberta. The warmer (orange/red) colours indicate anomalously higher methane concentrations (significantly above background levels for methane).

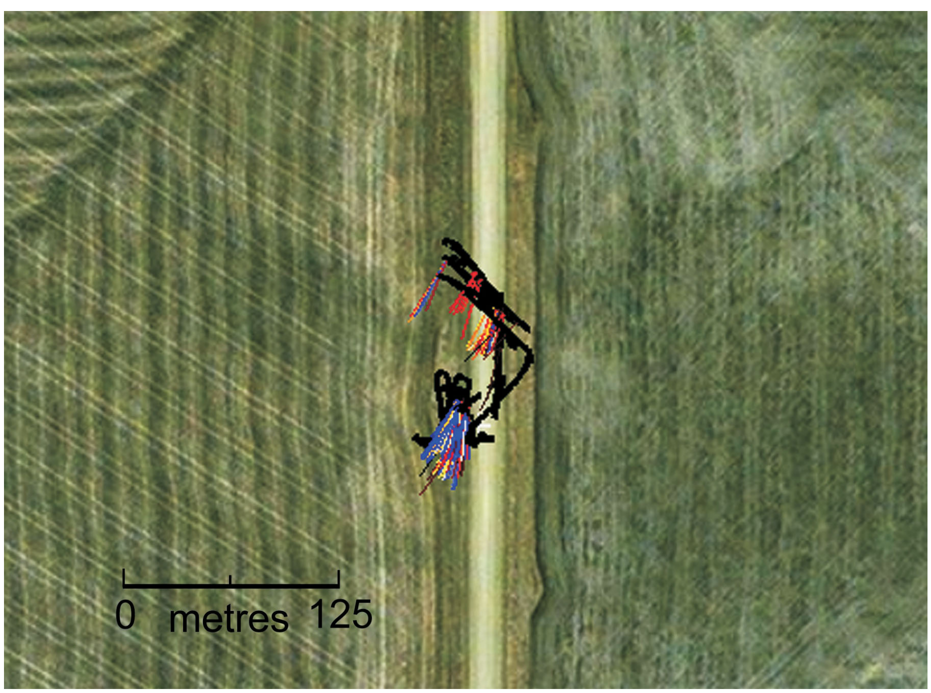

Figure 12. Overview of methane concentrations and wind vectors for location 01, flight 02, at AltaGas Utilities Inc., Alberta. The cooler colours indicate anomalously higher methane concentrations (above background levels for methane). The black line is the open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform survey track.

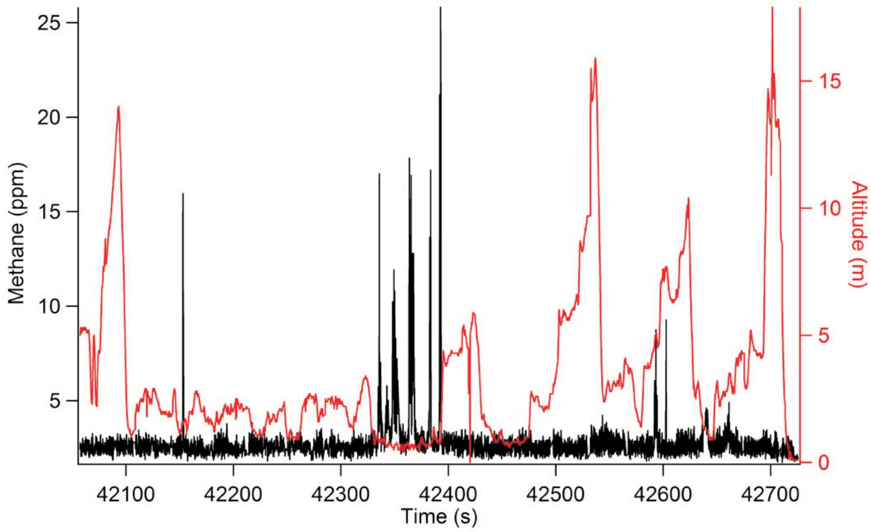

Figure 13. Time series plot of methane concentrations (black line) and open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform altitude (red line) for location 01, flight 02, at AltaGas Utilities Inc., Alberta.

There were 11 970 discrete CH_4 measurements taken during the two flights at location 02 (flights 03, 04). Both flights generally returned low background CH_4 concentrations, <4.0 ppm (Table 1), similar to that measured at location 01. The mean CH_4 value was 2.59 ppm with a standard deviation of 0.976 ppm (Table 1). The mapping of the CH_4 concentrations to the flight track is shown in Figure 16. The two flights 03 and 04 results were dominated by background values for CH_4. However, at the place of the controlled natural gas release, significantly elevated levels of CH_4 were detected, up to 25 ppm, again similar to location 01. The dispersion of the CH_4 plume at location 02 was less pronounced than at location 01.

Figure 17 shows the aerial view of location 02 with the OPLS/UAV platform survey tracks for flight 04, with the CH_4 concentrations overlain at each point. The figure shows the location of the elevated CH_4 concentrations at the controlled release point. The anomalous CH_4 concentrations are flagged by colour, with cooler colours (blue) indicating higher CH_4 concentrations.

Time series plots of the CH_4 concentrations and the flight altitude of the OPLS/UAV platform for location 02, flight 04, are shown in Figure 18. The times when the CH_4 concentrations were substantially higher than the CH_4 background levels can easily be observed. As at location 01, the OPLS/UAV platform can clearly and quickly pinpoint the areas of higher emissions and hence leaks. The higher CH_4 concentration measurements are restricted to lower flight altitudes (<5 m). Vertical profiling, seen in Figure 18, revealed that elevated CH_4 was only observed at close to ground level. This finding of anomalous CH_4 only at or below 5 m is also substantiated by the plot of CH_4 concentration with altitude (Figure 19).

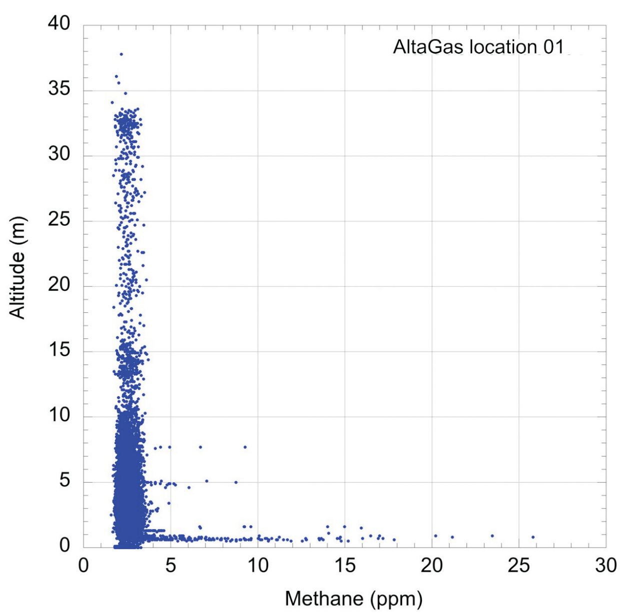

Figure 14. Relationship of methane concentration to the altitude (determined by light detection and ranging [LiDAR] measurements) of the open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform at the time of measurement, location 01, at AltaGas Utilities Inc. (AltaGas), Alberta.

Figure 15. Photograph of survey field containing the buried, high-pressure natural gas pipeline at location 02 (flights 03 and 04), at AltaGas Utilities Inc., Alberta.

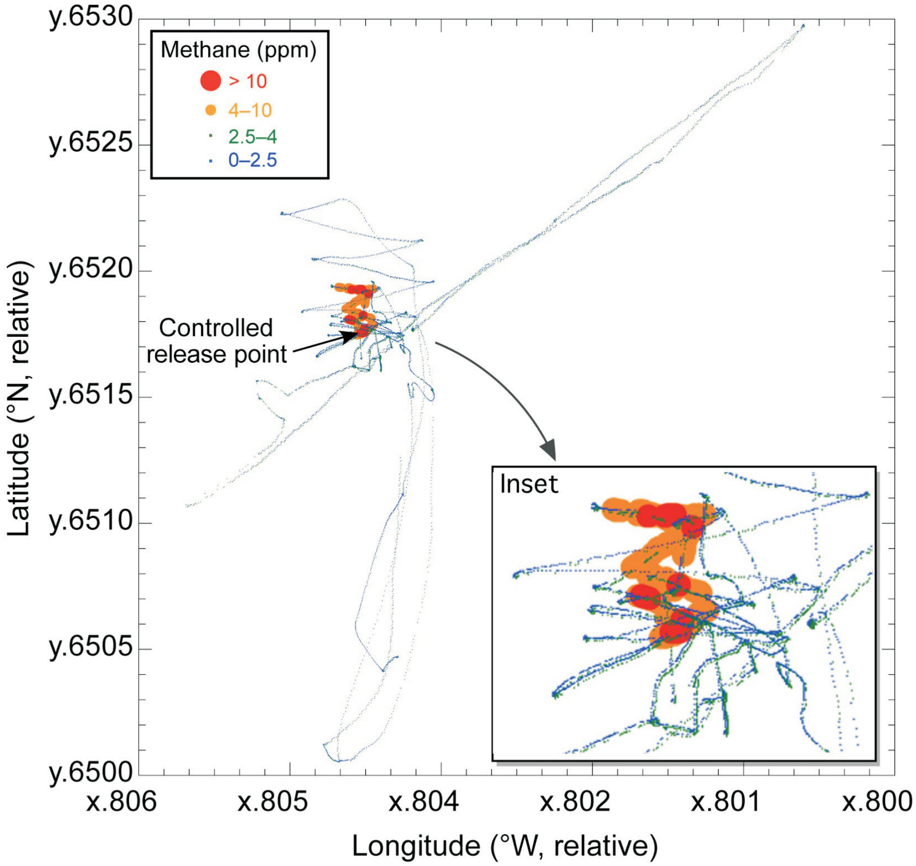

Figure 16. Overview of methane concentrations for location 02, flights 03 and 04, at AltaGas Utilities Inc., Alberta. The warmer (orange/red) colours indicate anomalously higher methane concentrations (significantly above background levels for methane).

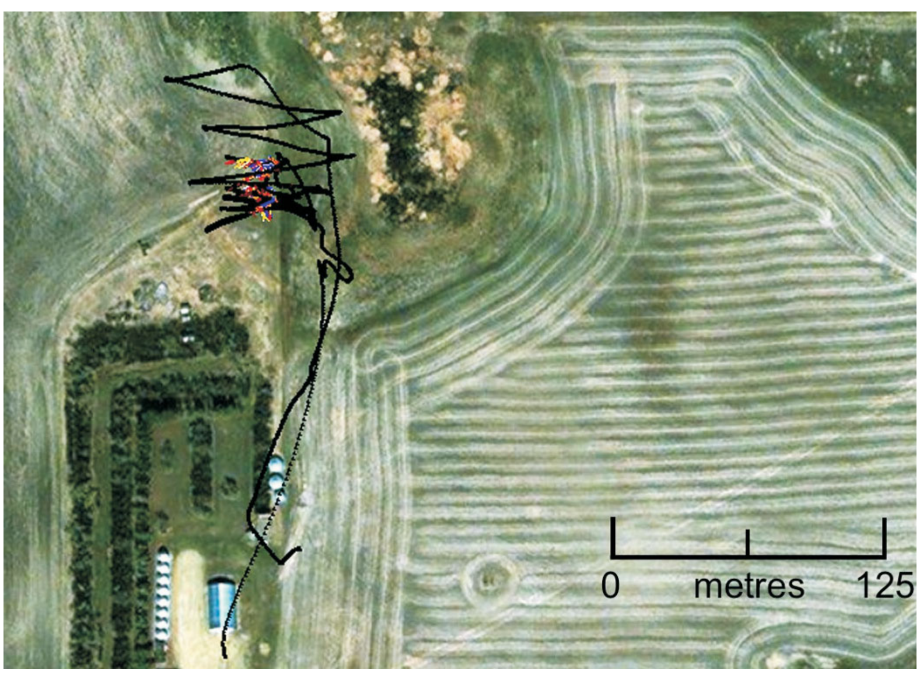

Figure 17. Overview of methane concentrations for location 02, flight 04, at AltaGas Utilities Inc., Alberta. The cooler colours indicate anomalously higher methane concentrations (above background levels for methane). The black line is the open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform survey track.

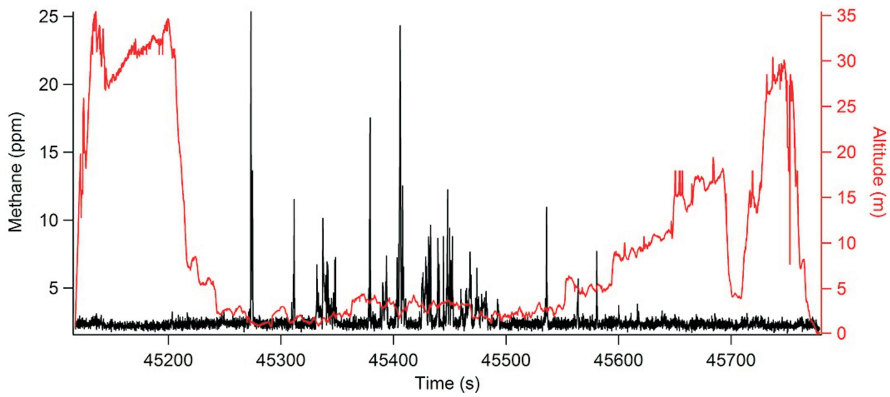

Figure 18. Time series plot of methane concentrations (black line) and open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform altitude (red line) for location 02, flight 04, at AltaGas Utilities Inc., Alberta.

Elevated CH_4 concentrations of up to 26 ppm (location 01, flight 02) were detected by the OPLS/UAV platform at the above-ground release and at both of the buried pipeline locations. Due to the highly constrained vertical dispersion of the CH_4 plumes, due to the windy conditions, it is unlikely that vehicles operating at higher altitudes (e.g., fixed-wing, helicopter, etc.,) would have been successful in detecting the plume under the weather conditions on that day.

This effective measurement method offers high personnel safety as a small UAV surveys the site as opposed to people with monitors. This method also reduces the potential exposure of people to gas leaks as well as hazards associated with activities such as climbing, walking, etc.

Despite the very positive results, it is felt that the OPLS operated at suboptimum levels (noise and detection limits) during the surveys. In comparison with previous calibrations and tests at gas plants and wells, the instrument was somewhat less sensitive. The team identified that the issue is largely due to the cold environmental conditions. As a result, the team changed the OPLS hardware after the survey to allow it to operate as expected at subfreezing temperatures. Changes are also being made to better and permanently integrate the OPLS with the UAV (power, communication, navigation). As a consequence, it is expected that the system will perform better in the future.

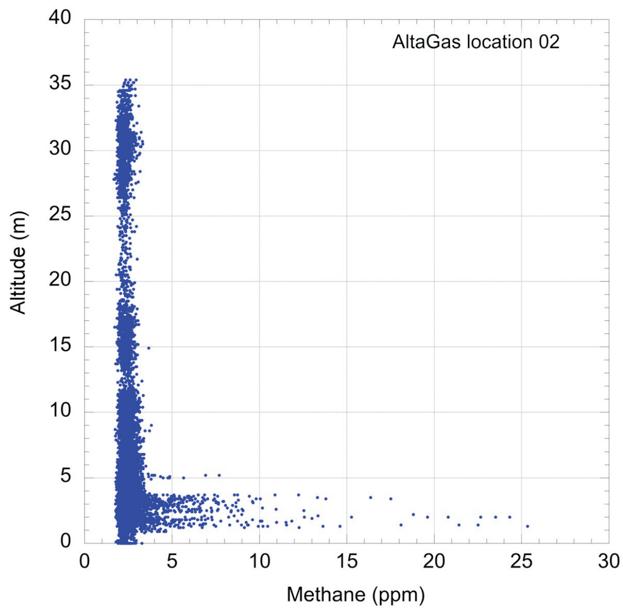

Figure 19. Relationship of methane concentration to the altitude (determined by light detection and ranging [LiDAR] measurements) of the open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform at the time of measurement, location 02, at AltaGas Utilities Inc. (AltaGas), Alberta.

Based on these demonstration results, there is confidence in this new technology and the logistics for deployment. It is anticipated that further testing on pipelines and controlled releases will move ahead quickly. It is also expected that it will be possible to initiate service operations that provide efficient and effective OPLS/UAV platform surveys to clients in the oil and gas industry with fugitive greenhouse gas emission measurement and monitoring needs.

Summary and Conclusions

The GHGMap team was able to conduct a total of five flights at three locations during a single afternoon of testing. A total of 23 445 discrete CH_4 measurements were made at two locations by the novel OPLS, combined with the small UAV platform over the course of the testing. This enormous number of data points coupled with the parts per billion (ppb) sensitivity of the OPLS allows for a high degree of confidence in identifying and reporting anomalous CH_4 concentration levels, which are higher than the atmospheric background levels.

Acknowledgments

The GHGMap team would like to thank AltaGas Utilities Inc. (AltaGas) for their time, effort, expense and enthusiastic support of the open-path laser spectrometer/unmanned aerial vehicle (OPLS/UAV) platform tests at their pipeline. In particular, R. Wintersgill at AltaGas is thanked for his engagement with this emerging technology and for his review of this document.

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