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Development of a highly repeatable and auditable, cost-effective monitoring system to locate and quantify emissions via small unmanned aerial systems (sUASs)

Final Report – June 2018

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Executive Summary

Researchers from SAIT and NASA's Jet Propulsion Laboratory (JPL) have been involved in a study looking at the use of NASA's Open Path Laser Spectrometer (OPLS) mounted on an Unmanned Aerial Vehicle (UAV) for detecting fugitive emissions of methane in an active oil and gas production facility, located in the Drayton Valley area of Alberta

Researchers visited the study site in August 2017, October 2017, and March 2018, and carried out a series of flights for leak detection and emissions quantification on all three dates. The first field campaign took place on August the 30th, 2017. A total of four science flights were carried out, with the OPLS being flown on a DJI M600 UAV platform. The first two flights were used for leak detection, and were able to isolate the two major onsite leaks, which originated from storage tanks at the southern end of the site. The third flight was used for flux quantification, and involved flying back and forth at 5 m altitude increments to define a flux plane. The aggregate flux for both leaks was estimated to be 12.5 $\pm$ 6.5 cubic metres per hour (CMH). The final flight was used to test the range of detection. Significantly elevated levels of methane were detected at over 250 m from the source.

The second field campaign took place on the 19th of October, with five scientific flights being carried out. The OPLS was mounted on a DJI M200 UAV platform. The first four flights were designed to look for methane leaks, with investigations focusing on the storage tanks, and on the outbuildings to the north of the tanks. The same two leaks from the storage tanks were once again quickly identified from the third flight, in which the UAV was flown downwind of the tanks at multiple elevations. The second and fourth flights focused on the outbuildings to the north of the tanks. Three small leaks were detected from different buildings, and these were verified by the representative of the Alberta Energy Regulator (AER). The final flight was used for flux quantification, with the UAV being flown back and forth at 5 m altitude increments to define a flux plane. The aggregate flux on this occasion was determined to be 13.2 $\pm$ 4.9 CMH, which is similar to the estimate from the August survey.

The third field campaign took place on the 20th of March, and used the OPLS mounted on a DJI M600 platform. Temperatures were cool, but remained above freezing throughout the day, averaging 3.5°C, with snow on the ground. A total of five surveys were carried out, with the initial flight providing little in the way of useful information, due to light and variable wind conditions. The second flight was a reconnaissance flight to identify where the main leaks were located. Attempts to complete a flux quantification during flight 3 were unsuccessful, due to poor wind conditions. The fourth survey involved carrying the OPLS around the site to investigate potential leak locations in more detail. A number of small leaks were identified in the outbuildings to the north of the storage tanks. These were confirmed by the representative of the AER. The final flight investigated emissions from the flare stack, while it was active. Methane spikes, believed to be due to flaring were identified during this flight.

The results from this study are promising and suggest that combination of using the OPLS, mounted on a UAV, has the potential to be an effective tool for detecting fugitive methane emissions from oil and gas facilities. The study also highlighted the important role that weather conditions play in successful leak detection and flux determination. This was particularly evident during the March 2018 campaign, when light and variable winds prevented flux estimations from being made.

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1 Introduction

With carbon pricing soon to become a reality for oil and gas producers in Alberta, there is considerable interest in technologies which can allow sources of fugitive emissions to be identified. Most of the current effort is focused on reducing methane emissions. Methane is estimated to be 25 times more potent as a Greenhouse Gas (GHG) than CO_2 over a 100 year period (EDF, Pembina Institute, 2015), and reduction of methane emissions is seen as being the most cost-effective way to help meet industry, provincial, and federal goals in the short to medium term.

This report presents the results of a joint project carried out between researchers from NASA's Jet Propulsion Laboratory (JPL) and SAIT, who have been investigating the utility of NASA's Open Path Laser Spectrometer (OPLS) sensor mounted on an Unmanned Aerial Vehicle (UAV) for the detection of leaks and determination of flux rates for methane leaks from conventional oil and gas production facilities in the Drayton Valley area. Over the course of a year, three separate field surveys were carried out, in August, October, and March. The study was designed to test the efficacy of the OPLS sensor under different atmospheric and temperature conditions, and to identify optimal conditions and flight patterns for successful leak detection.

The OPLS was originally developed by NASA for use on the Mars lander. The sensor is compact and lightweight and is extremely sensitive, with the capability of measuring methane concentrations of a few parts per billion (ppb) in the atmosphere. These characteristics also make it ideal for mounting on a small UAV. By combining these two technologies, this project aims to develop a versatile system which can be used to carry out inspections of oil and gas production facilities, with a view to detecting methane leaks and providing quantitative estimates of flux rates. Such a system has the potential to be a key part of an operational methane monitoring program for Alberta's oil and gas production facilities.

2 Site Description

The study site comprises an active oil and gas facility, located in the Drayton Valley area of western Alberta. The facility was selected from a shortlist of sites provided by the representatives of the Alberta Energy Regulator (AER), and was specifically chosen because it had a number of known methane leaks present. The site is approximately four hectares in extent and comprises five storage tanks, approximately eight outbuildings including a mobile office, as well as a flare stack and three pump jacks. For reference purposes, an image of the site is provided in Figure 1. This image is based on a UAV photographic survey carried out during the August 30th visit. However, the precise location of the site and the name of the site operator are not being released for operational and privacy reasons. To facilitate feature identification and comparison, all overhead diagrams provided make use of the same image backdrop. The coordinate system used throughout this report is based on Universal Transverse Mercator zone 11, with only the last three digits provided.

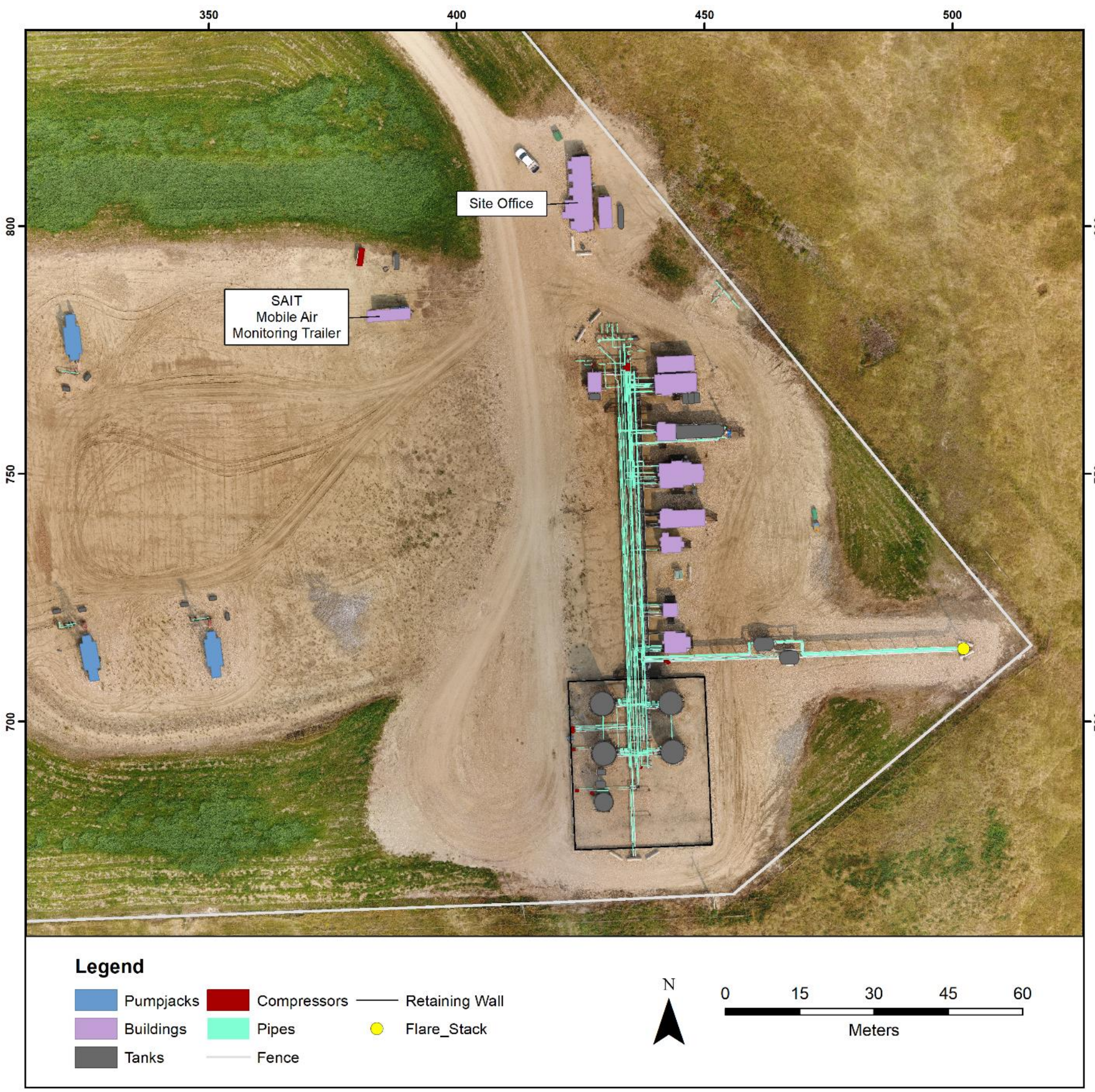


***Figure 1**: Layout of site.*

3 Equipment Used

3.1 Open Path Laser Spectrometer

The key component of each of the surveys is the OPLS instrument. This instrument was developed by Dr. Lance Christensen of NASA / JPL, and consists of an open-path multi-pass Herriott cell optical head, custom electronics boards, and room-temperature-operating semiconductor laser and detector. The instrument's sensitivity towards methane is 10 ppb/s, and it has a signal-to-noise of 200 at background atmospheric pressure. The operating range is from 0 – 1% methane concentration, for measurements made at 1 Hz. The optical head and electronics weigh about 150 g. Depending on housing configuration (e.g. fixed-wing versus quadcopter UAV), the total instrument can vary from 250 to 350 g.

The optical head employs two gold-coated confocal mirrors, spaced 15 cm apart. An off-axis hole in the front mirror permits entry of the laser beam and an off-axis hole in the back mirror allows light to impinge on a detector. Total optical path length is 430 cm.

The OPLS response time is based on the time it takes air to clear out the analysis region. A quick residence time is useful for characterizing the spatial extent of methane plume filaments that are often interwoven in relatively clean air. The sharpness of the filaments can inform the user how far the methane indication has traveled from its source to the sensor. Long distances will be characterized by a relatively smooth time series whereas short distances have rapidly changing signal. A short residence time is also important for correlating methane concentrations with air-stream eddies for eddy covariance flux measurements.

3.2 Equipment used in Field Campaign 1

3.2.1 DJI M600

For the August 2017 survey, a DJI M600 UAV platform was chosen. The M600 is a heavy lift multirotor platform, which is capable of lifting payloads of up to 5 kg. While this could potentially be seen as overkill, the OPLS sensor was initially an unknown quantity. It was therefore decided to play it safe, and ensure that the UAV platform chosen was more than capable of carrying the equipment required. The M600 is also known for its stability and predictable performance characteristics. The GPS system for the M600 was a triple redundancy system, capable of delivering 1 m accuracy in X, Y, and Z. The full configuration used in the first field campaign is shown in Figure 2.

3.2.2 Sonic Anemometer

A Trisonica sonic anemometer was added to the UAV platform to capture wind speed and direction during the flight. Since the UAV flight direction and speed are logged several times a second, these values could be subtracted to derive the ambient wind conditions at the sensor. To ensure that this instrument would not be affected by turbulence from the rotors, it was mounted over the centre of the UAV platform, on top of a 1 m high mast, as can be seen in Figure 2.

3.2.3 Custom Mounting Assembly

One of the major tasks in preparation for the first field campaign was developing a mounting system for the OPLS sensor. In order to ensure that the sensor remained clear of the rotor wash from the UAV platform, it was necessary to mount it almost 1 m out from the centre. The M600 is a large platform, and this offset will generally be shorter for other UAV platforms, such as the M200 used in the second campaign. Because it is very important to maintain balance for a UAV platform, a counterweight needed to be placed at an equal and opposite distance from the UAV centre. In this case the sensor battery was used to balance the system, as shown in Figure 2. The mounting assembly also accommodated a Lidar-Lite v3 range-finder, to provide accurate measurements of the height of the UAV above the ground. Telemetry was provided for the OPLS data via an XBee 2.4 GHz system, with data from other onboard sensors being written to an SD card.

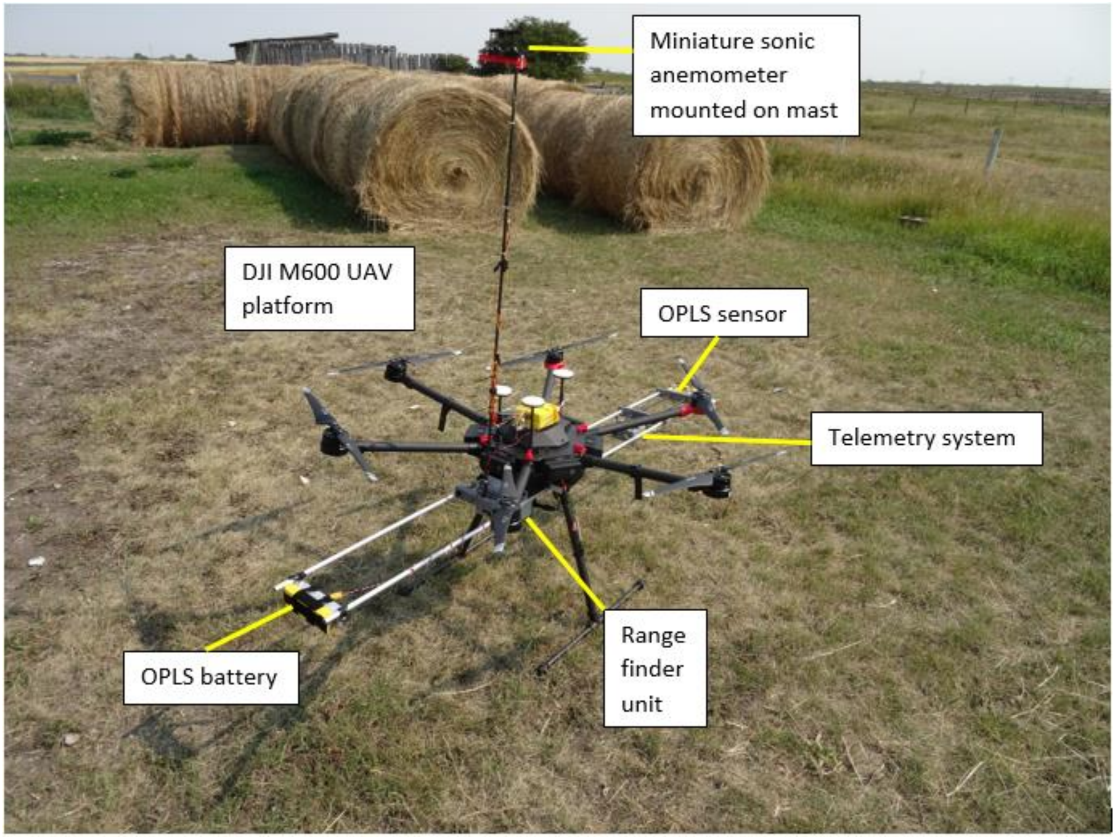


Figure 2: *OPLS system mounted on M600 platform.*

3.2.4 SAIT Monitoring Trailer

For the initial campaign, a specially-equipped monitoring trailer was used to provide details of ambient weather and temperature conditions, as well as measurements of background methane concentrations. The trailer comprised a full meteorological station, which was equipped with a sonic anemometer, as well as temperature, pressure, and precipitation sensors, and is shown in Figure 3, below. In addition, precise measurements were made of the background concentration of methane using a ThermoFisher Scientific Direct Methane and Non-Methane Hydrocarbon Analyzer (model 55i), which had been calibrated against a government standard the previous week. This instrument has an operating range of between 0 and 20 parts per million (ppm).

Figure 3: *SAIT monitoring trailer on site.*

3.3 Equipment used in Field Campaign 2

3.3.1 DJI M200

For the second field campaign, a DJI M200 platform was used. The M200 is smaller and lighter than the M600 and has been designed for industrial inspection work. This platform has a maximum payload weight of around 2 kg, which is sufficient to carry the OPLS and associated hardware. One of the attractive features of this platform is that it has been designed to operate in temperatures as low as minus 20°C. The second field campaign took place on the 19th of October, when there was a distinct possibility of encountering freezing temperatures. The combination of smaller size and ability to work in lower temperatures was the reason for choosing this platform for this phase of the project. The configuration used for the October 19th survey is shown in Figure 4.

3.3.2 Custom Mounting Assembly

A new mounting assembly was fabricated for the M200 platform. The design of this frame was similar to the one developed for the M600, but because of the smaller platform size, the sensor was mounted 60 cm out from the centre of the UAV. The total length of the frame was 1.2 m, compared with 1.9 m for the frame used for the August field campaign. The frame was built out of lightweight aluminum and carried the same components as used in the previous survey, including laser range finder, sonic anemometer, and telemetry system. The mast supporting the anemometer was reduced to 60 cm, which helped to ensure the stability of the platform during operations. The full assembly is shown in Figure 4.

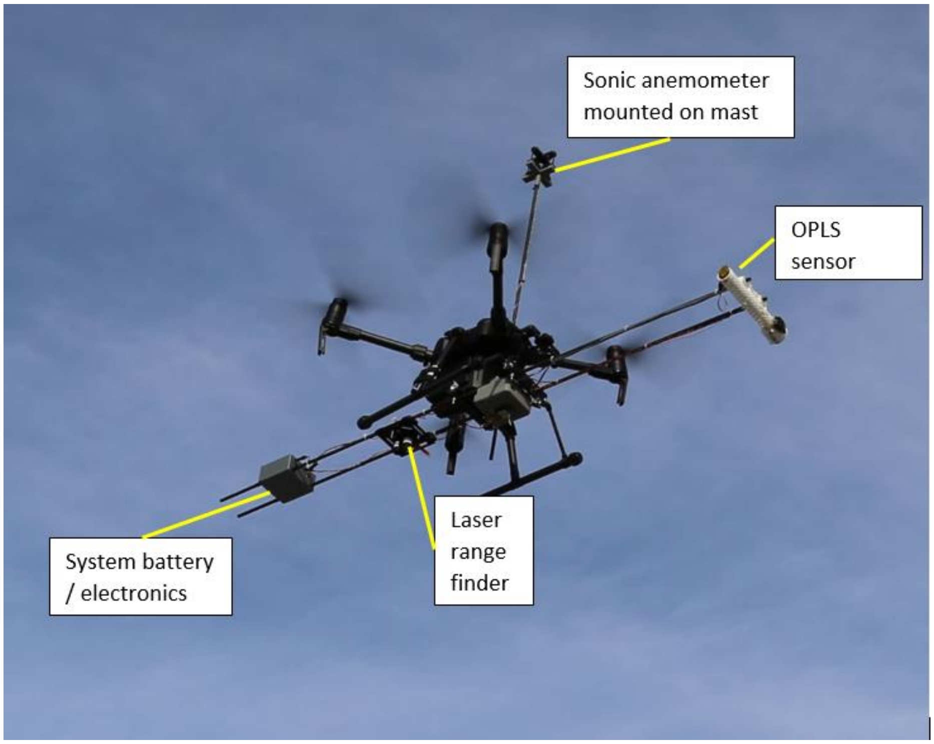


Figure 4: *OPLS system mounted on M200 platform.*

3.3.3 Portable Weather Station

After review of the procedures and results from the first field campaign, the full monitoring trailer was found to be unnecessary, since background wind speed, direction, and temperature were the only variables used in the analysis. For the October campaign, a portable weather station was developed that logged the different weather variables at 10 second intervals. The weather station uses a sonic anemometer to provide detailed measurements of wind speed and direction, and is also equipped with temperature and atmospheric pressure sensors, to provide a complete record of ambient conditions on site. The weather station was deployed for both the October 2017 and March 2018 field campaigns, and is shown deployed during the March campaign in Figure 5.

Figure 5: *Portable weather station deployed in the field during March, 2018 field campaign.*

3.4 Equipment used in Field Campaign 3

3.4.1 DJI M600

For field campaign 3, the DJI M600 used in the initial (August) survey was again used. The survey was carried out on March 20th under mild (above freezing) winter conditions, which allowed this platform to be operated within its specified temperature range. The reason for reverting to the M600 was that, prior to the survey there had been a number of incidents reported amongst DJI users, which related to compass errors on the M200, and which caused the platform to occasionally fly in an unpredictable manner. Rather than take a risk with this platform, it was decided to use the M600, which enjoys a reputation for reliability. For the future, it is intended to use the newly-released DJI M210, which is similar in appearance to the M200, but which has a different configuration which is less prone to the system errors of its predecessor. The configuration used during the March field campaign is shown in Figure 6.

3.4.2 Custom Integration and Telemetry System

For this campaign, a new system developed by Automated Aeronautics was used. This system comprised a newly-developed daughterboard, which was used to combine the OPLS measurements with outputs from the onboard GPS, range-finder, and anemometer. This system integrates and resamples all data inputs to produce a single output file for transmission to the ground station. A Holybro 933 MHz telemetry unit emitting under 100 MW was used to communicate the data to a ground station, allowing for greater communication range than in the two previous campaigns.

3.4.3 Custom Mounting Assembly

The mounting assembly used for the third field campaign was similar in size and shape to that used for the initial campaign. However there were a number of improvements made to the system. The frame was redesigned to attach to the legs of the M600. This makes it extremely flexible, since the entire frame forms a payload which can easily be attached and detached from the M600 as a single unit. The M600 used in the third campaign, with the redesigned frame and integrated telemetry system can be seen in Figure 6.

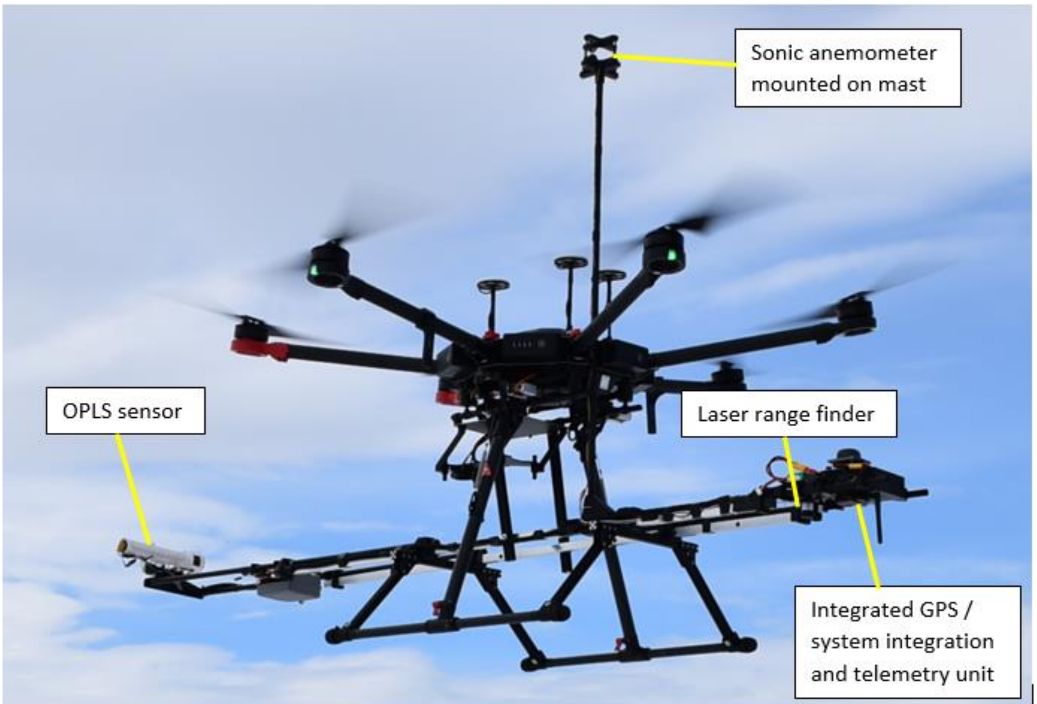


Figure 6: *OPLS and redesigned mount attached to M600 platform, as used in the March field campaign.*

3.5 Processing of Data

Methane data obtained during each of the three surveys was sent to the ground station in near real time, to enable methane spikes to be identified during flight operations. This meant that in all three field campaigns, areas with high level of methane could be identified as the survey was in progress, and the flight could be modified to investigate them in more detail. The ground station comprised a laptop which was carried by the data analyst, following behind the UAV. A visual representation of methane concentration was displayed as a graph on the screen in near real time, enabling the analyst to direct the pilot to focus on the areas with the highest concentrations. All data from onboard sensors and the OPLS were also recorded on onboard SD cards, for more detailed post processing. For the first two field surveys, integrating the data proved to be challenging, since it came from different sources and had different sampling rates. This lead to a delay of several hours to produce a file in which all data outputs were integrated. The third field campaign used a unit which integrated inputs from the OPLS and all other onboard systems into a single data file, prior to transmission.

By having a near real time indication of methane spikes, it is possible to identify leaks quickly and easily in the field. However, estimating flux is more complex, and for each survey it required analysis of the data at NASA / JPL, with a consequent delay of several days. This is an area where improvements will need to be made if the system is to be used operationally, and is a priority for follow up work. Software to allow automated flux estimation in the field will need to be developed and tested.

3.6 Expected Future State (three year time frame)

All equipment used in this study is evolving rapidly. While it is impossible to know what the state of technology will be in two to three years' time, current trends can provide some direction. UAV platforms are constantly improving. The successor to the DJI M200, the M210, appears similar to its predecessor in many ways, but represents a considerable improvement in its capabilities. The compass issues which plagued the M200 have been resolved, and the platform has the capability of employing Real Time Kinematic (RTK) GPS, which can provide centimeter level positional accuracy. In the coming years, UAV technology will doubtless continue to improve, with increased range and payload capacity, and reduced platform size (for this application) almost certain to provide increased capability. Costs are also expected to continue dropping over time, in line with current trends.

The OPLS system is also expected to change. A commercial version of this sensor is currently in development by San-Francisco based RKI-Instruments. This will most likely be smaller and lighter than the current prototype. It is expected that within a year, research will transition to using the commercial version of the sensor. NASA / JPL have also recently developed a modified version of the OPLS which is capable of detecting ethane. Ethane is a significant component of natural gas, and is not associated with methane from background sources, such as cattle feedlots and wetlands. By adding the capability for detecting ethane, it will be possible to attribute emissions uniquely to oil and gas production activities, and rule out methane from background sources.

Changes to both the UAV platforms and sensors will mean that the mounting systems and internal electronics of the system will need to evolve constantly, in order to ensure that they are able to integrate with both the platform and the payload optimally. Over time, this likely means that the entire platform and payload will become smaller, lighter, and more maneuverable, with prices for all components expected to drop considerably. Telemetry is also expected to become more reliable, with improved system range. It can be expected that these changes will allow site assessments and flux measurements to be carried out in much shorter timeframes than is currently possible.

In terms of regulatory changes, it is quite possible that routine Beyond Visual Line of Site (BVLOS) operation will become a reality in the coming years. This is an exciting development, which will definitely have implications for methane detection. However, BVLOS will likely be most effective for rapid assessment, making it possible to cover several production facilities in a single flight. The OPLS is most effective for detailed surveys of specific facilities, and as a tool for flux estimation. As such, it is likely that BVLOS operations will not significantly impact the deployment of this technology over the short to medium term.

4 Field Campaign 1: August 30th 2017

4.1 Site Conditions and Flight Overview

The first field campaign was carried out on the 30th of August, 2017, under late summer conditions. Conditions were hazy, due to smoke in the air which persisted through the day, with temperatures rising from the mid-teens to a maximum of 28°C by the middle of the afternoon. Winds were light to moderate through the day, initially blowing from the south, but shifting to an east / northeast direction by mid-morning. Flights were conducted by Automated Aeronautics (Calgary, Alberta, CA).

Preliminary observations made using the OPLS measured methane concentrations of greater than 3 parts per million (ppm) in front of the office trailer near the north fence when the wind was blowing from the south, and upwind observations made with the sensor prior to the first flight suggested that the emissions originated from the storage tanks located at the southern end of the site. By the time the OPLS was mounted on the M600, the winds had shifted to an easterly direction. This wind situation is preferable for identifying emission locations at this location, since the facility is oriented north / south. Initially, two fifteen minute surveys were conducted to identify the approximate locations of the major leaks. During these surveys, the M600 was flown around the main part of the facility, including the storage tanks, outhouses, and pipes. As can be seen from Figures 7 and 8 below, emissions from a number of sources other than the storage tanks were identified.

A total of four science flights were carried out. These are described below and are summarized in Table 1 and shown in Figures 7 - 10. Flights 1 and 2 were used for reconnaissance of the site in order to determine the approximate areas from which the greatest leakage was occurring. It was confirmed that the primary source of emissions detected were the storage tanks. Flight 3 produced no usable data and so was not included in any further analysis. Flight 4 was used to quantify the emission flux from the storage tanks by flying back and forth in a downwind curtain pattern, with the altitude of each pass increasing by 5 m. Flight 5 also adopted a curtain pattern and tested the range of detection out to 200 m downwind.

4.1.1 Diagrams

Flight diagrams are provided below for all flights for which data was collected. Each diagram comprises the overhead view showing the flight track, with the start and end of each flight included, as well as the location of prominent methane spikes. An inset diagram is also included for each flight which shows areas where elevated methane concentrations were observed during the flight, with the colour scheme showing a gradation from moderate levels of methane (red) to high levels (blue). Graphs are also provided showing methane along with sensor altitude, and methane along with relative northing. Relative northing is simply the number of meters north from the nearest 1 km UTM grid intersection Because of the north / south orientation of the site, and the orientation of most flights, this provides a much better appreciation of the different flight lines than the relative easting, especially for flights conducted in a curtain pattern.

***Table 1**: Summary of flights carried out on August 30th, 2017*

#	Purpose	Duration (min)	Wind vel. (m/s) & dir.
1	Survey	15.1	1.6, 75°
2	Survey	15.1	1.4, 69°
4	Flux quantification	17.4	1.5, 52°
5	Downwind range test	20.4	3.6, 60°

4.1.2 Flight 1

Flight 1 on August the 30th was carried out as a preliminary reconnaissance. The flight lasted 15 minutes, and the sensor was flown around the site to determine where the major concentrations of methane were located. Methane spikes shown on the graphs below suggested that the main source of leakage was from thief hatches on the storage tanks at the southern end of the site.

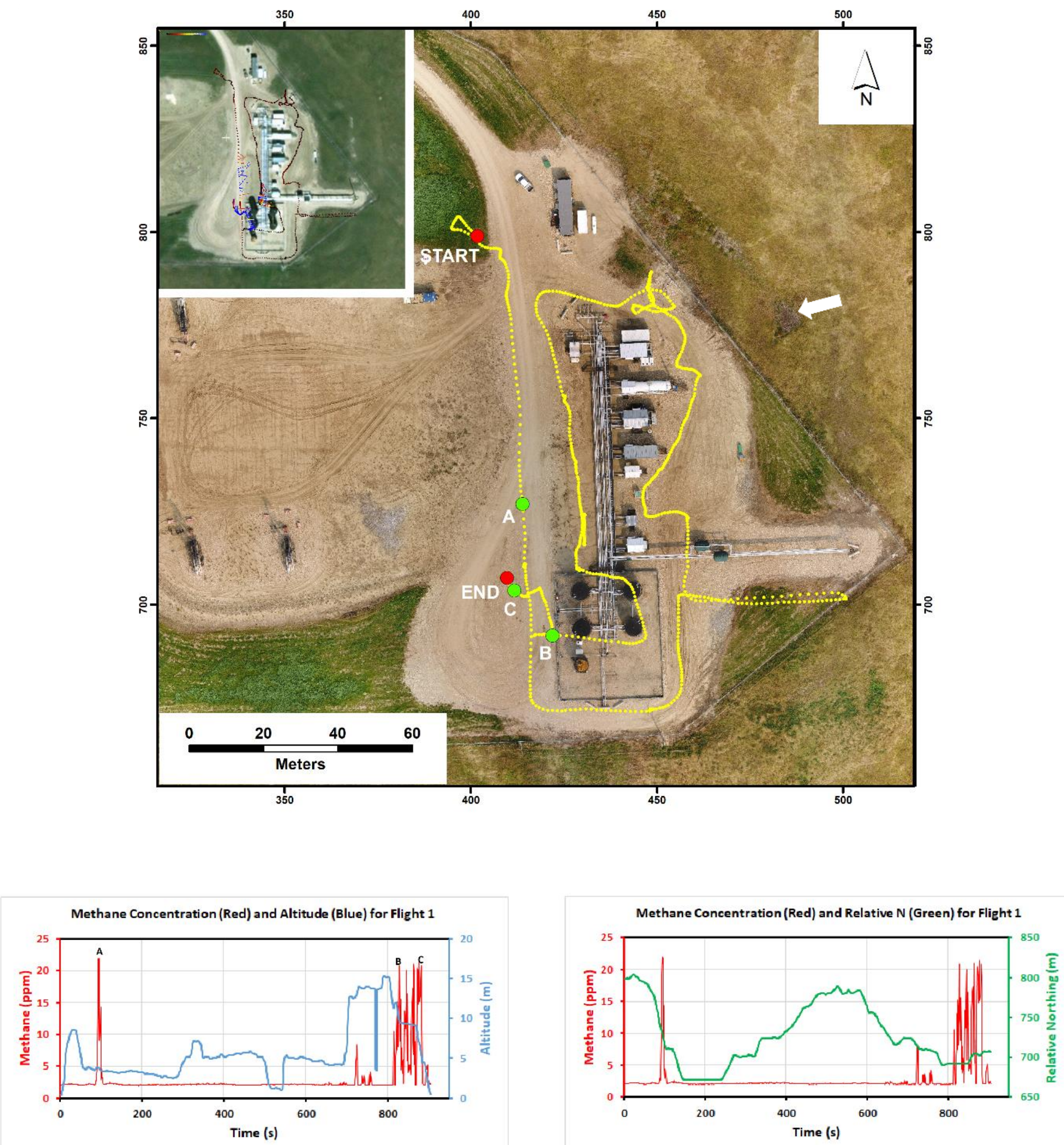
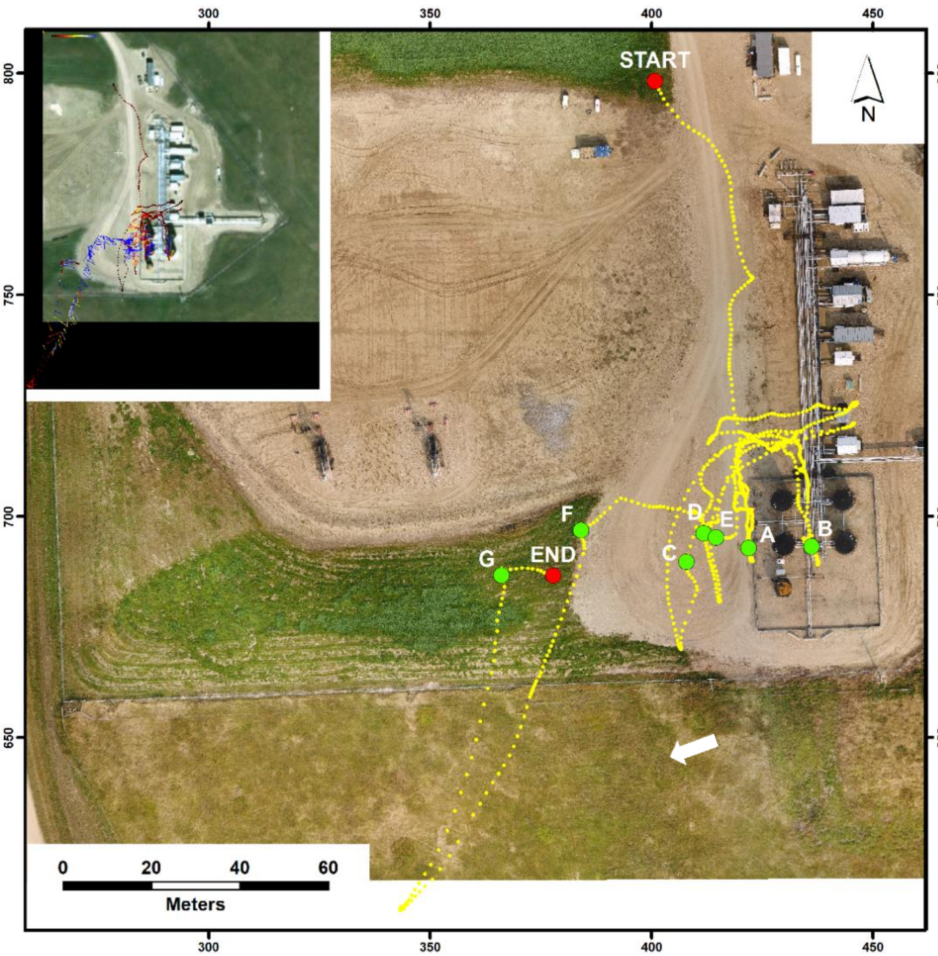
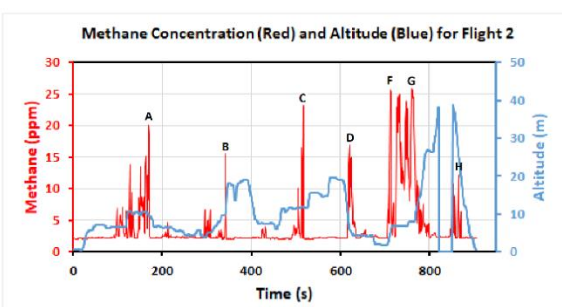


Figure 7: *August Flight 1 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

4.1.3 Flight 2

Flight 2 was designed to investigate the area where the largest methane concentrations were detected in more detail. The OPLS was flown downwind of the storage tanks at a variety of altitudes up to 15 m, in order to narrow down the potential leak sources. This flight also lasted 15 minutes. Spikes A - H occur in a linear pattern downwind from the storage tanks, indicating this is the likely source of the leaks.





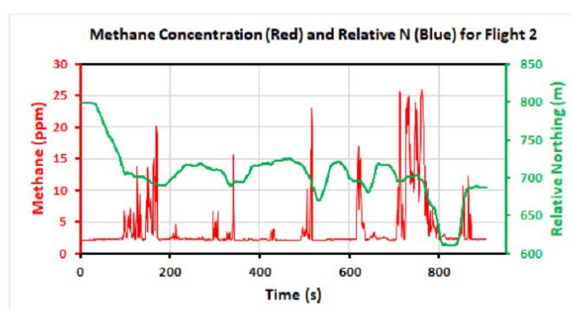


Figure 8: *August Flight 2 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

4.1.4 Flight 4

Flight 4 was designed to pinpoint the leak locations and produce flux estimations. To do this, the sensor was flown back and forth in a curtain pattern, 50 m downwind of the storage tanks. Each flight line was 5 m higher than the preceding leg, up to a maximum altitude of 25 m, as can be seen in the graph below. This flight lasted just over 17 minutes.

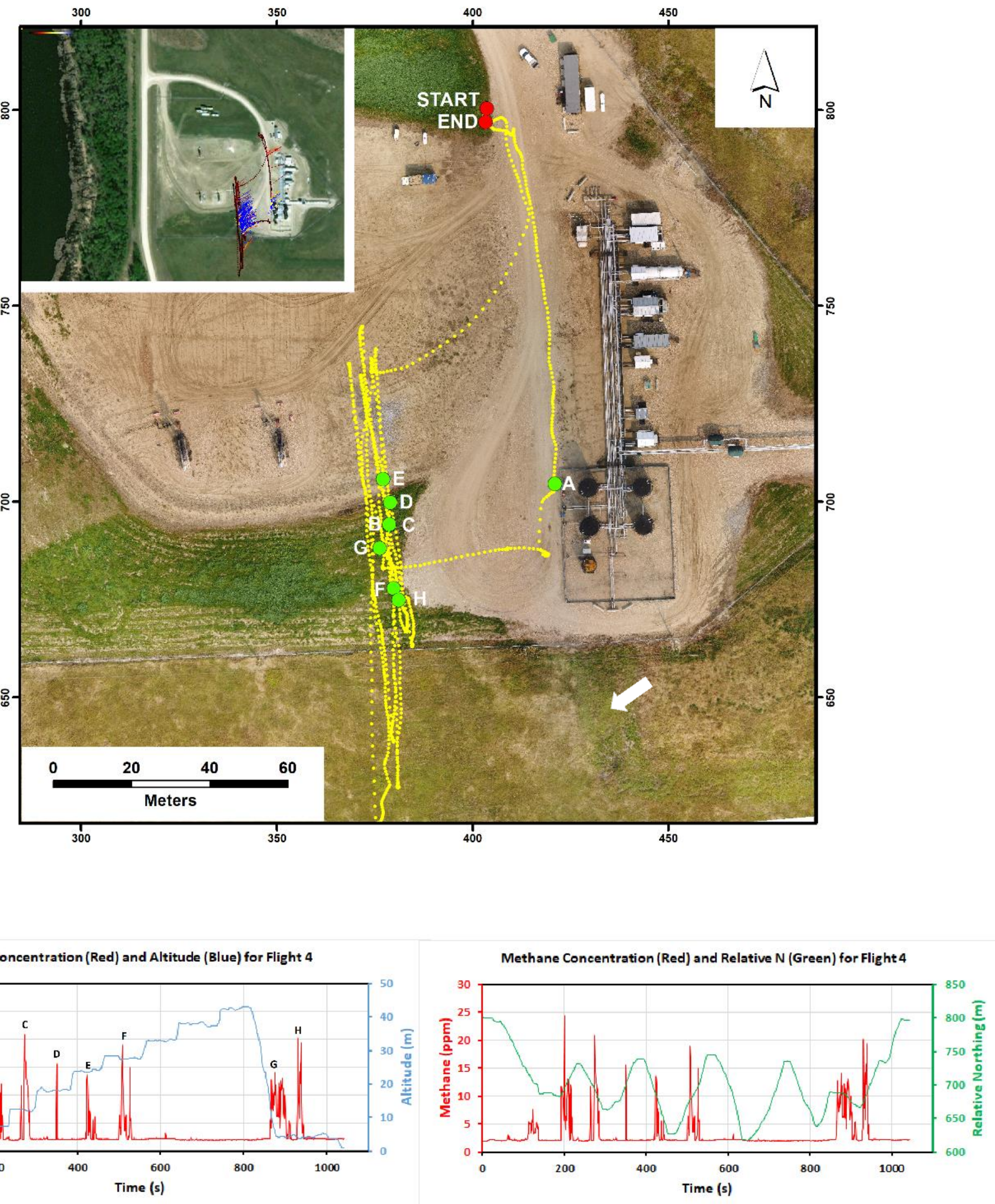


Figure 9*: August Flight 4 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

4.1.5 Flight 5

Flight 5 was designed to test methane detection at an extended range. It was conducted in a similar way to Flight 4, with the sensor being flown back and forth in a curtain pattern, 200 m downwind of the storage tanks. The total length of this flight was over 20 minutes.

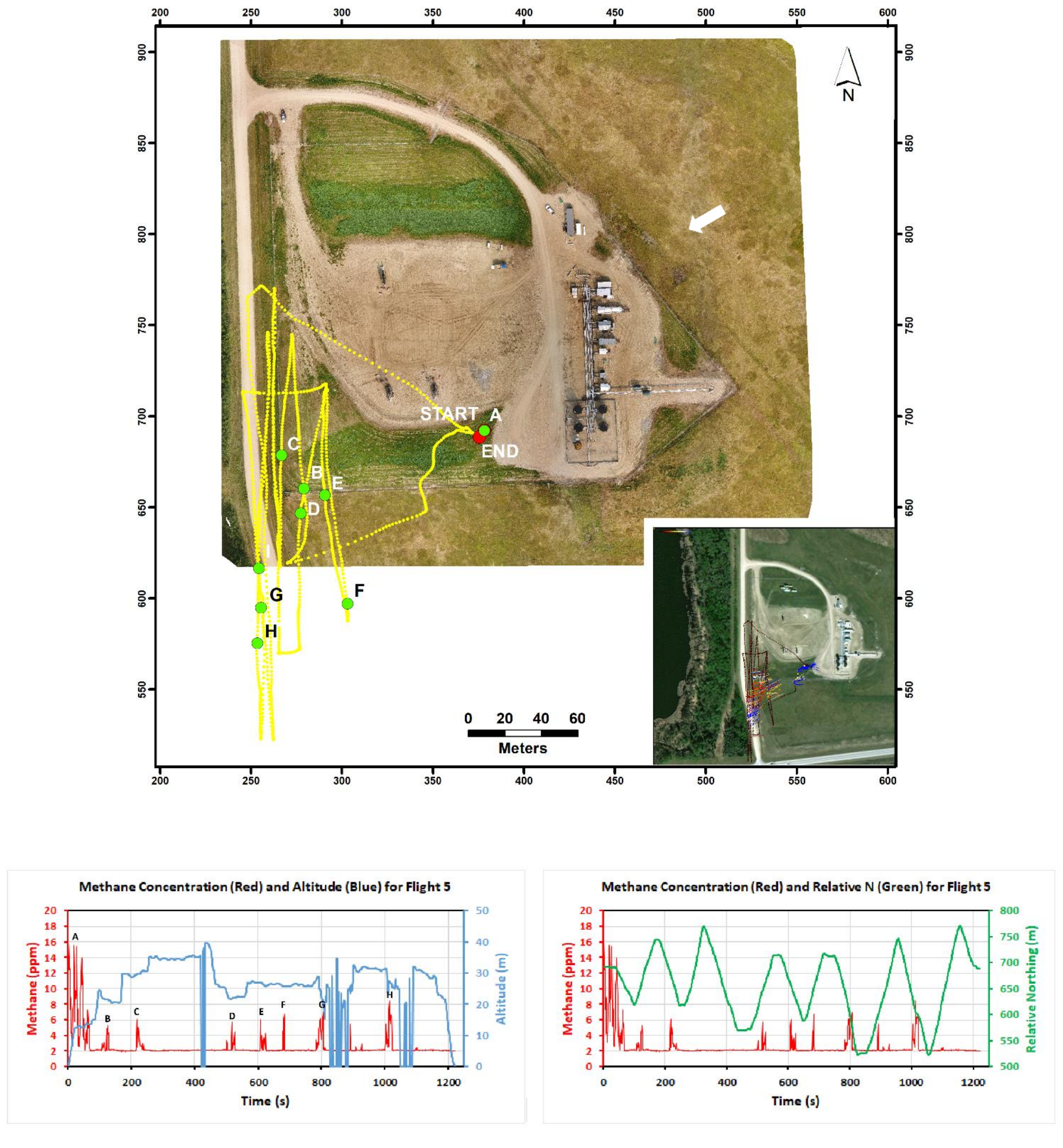


***Figure 10**: August Flight 5 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

4.2 Results from field campaign 1

4.2.1 Flux quantification

After data analysis was complete, two large leaks were identified, originating from thief hatches on top of the westernmost two storage tanks on site. These were determined from analysis of the sensor data from Flight 4, which was flown back and forth in a curtain pattern. Using wind direction, vectors were established which pinpointed the origin of the methane leaks to an estimated accuracy of better than 1 m. The determination of leak location from Flight 4 is shown in Figure 11 below. In this figure the green vector shows the direction to the major leak source from the averaged centre point of the flight. In this case two leaks were identified, one from each of the westernmost storage tanks. The green line shown in Figure 11 shows the aggregate of methane from the two leaks. The location of each leak was determined from analysis of the signal, by isolating spikes corresponding to the same methane source on each successive pass.

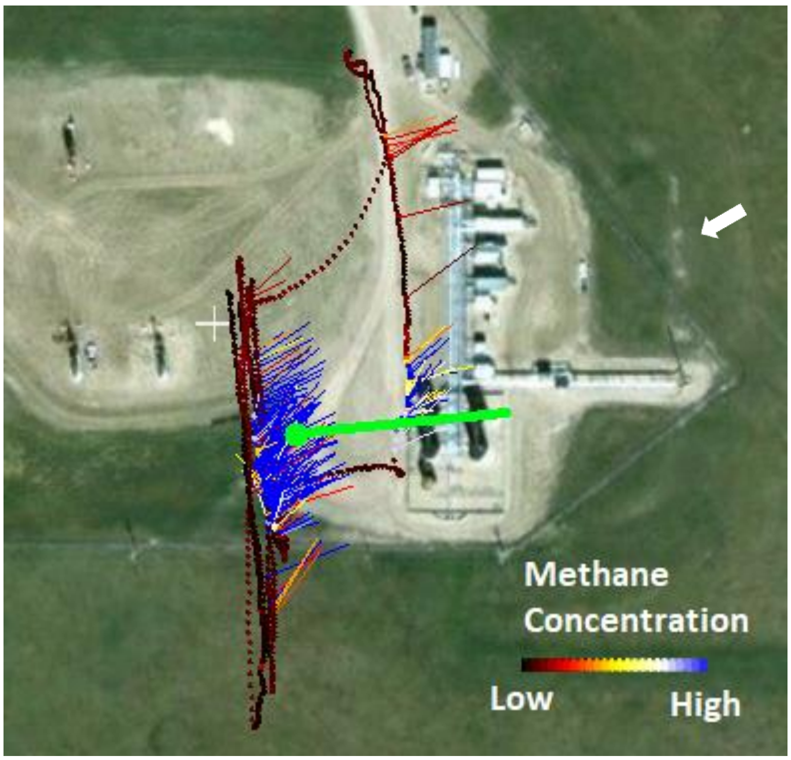


Figure 11: *Determination of direction to main leak locations from Flight 4. The coloured vectors show elevated methane concentrations, with blue representing the highest concentrations. The length of the vectors indicates the wind strength and their direction indicates wind direction. The thick green line shows the calculated direction from the averaged centre point of the flight to the primary source of emissions. This vector has been derived from all measurements obtained during the flight.*

The combined flux rate for the two main leaks was calculated as being 440 $\pm$ 230 standard cubic feet per hour (SCFH), or 12.5 $\pm$ 6.5 cubic metres per hour (CMH). The relative intensity of the methane plumes were plotted on a vertical plane perpendicular to the average wind direction. This is shown in Figure 12, below. Note that the level of uncertainty is approximately 50%, since the survey was carried out only once. This uncertainty can be reduced by repeating the survey multiple times to account for turbulence within the plume. This is clearly illustrated in Figure 13, which shows a large Eddy Simulation of a methane plume. It can be seen that increasing the number of measurements will allow for more accurate determination of the average flux rates through any given sampling plane. Note that this is a simulation provided for illustration purposes, and is not derived from actual data gathered during the survey.

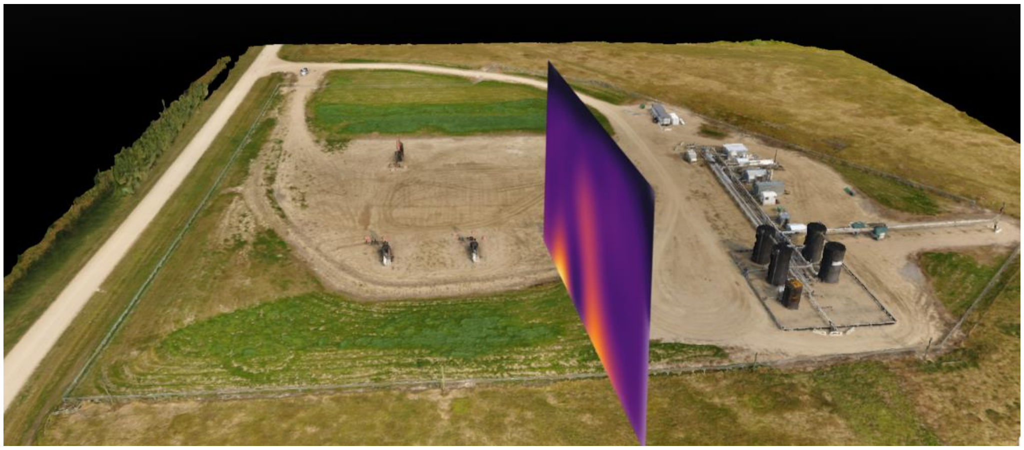


Figure 12: *Methane plumes projected onto the plane defined by Flight 4.*

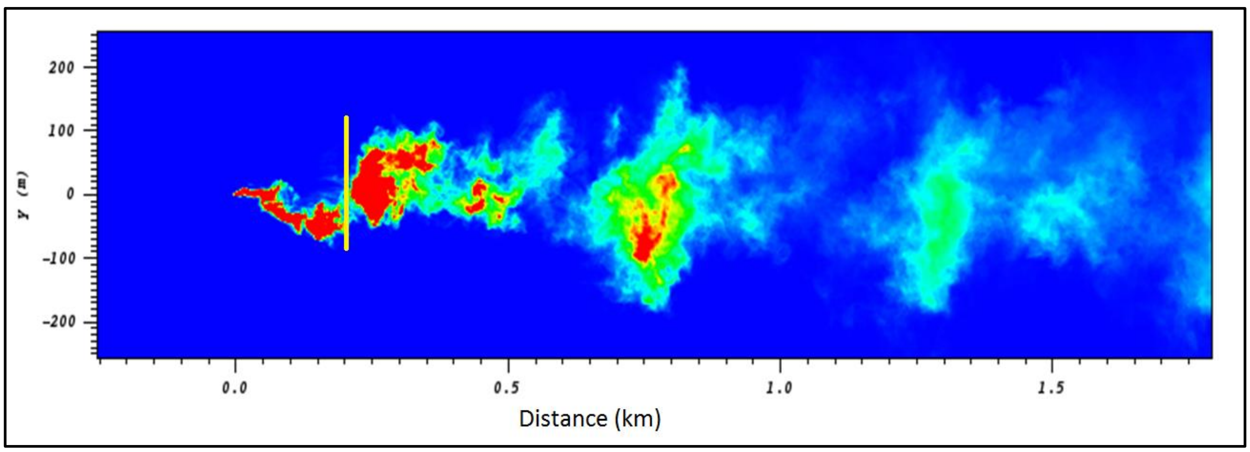


Figure 13: *Large Eddy Simulation model of methane plume at 2.0 m/s winds.*

4.2.2 Range tests

Flight 5 tested how far downwind and at what height elevated methane concentrations could be observed. At 250 m downwind distance from the storage tanks, the median maximum spike in elevated methane was about 2.2 ppm. For comparison, the signal-to-noise floor of OPLS is about 25 ppb at 1 Hz. This flight also provided valuable insight into how effective a single-pass downwind of a site is for detecting a leak. At elevations below 34 m, every single traverse downwind resulted in a clear, measured spike in elevated methane. However, at 34 m and higher, no spikes were observed.

5 Field Campaign 2: October 19th 2017

5.1 Site Conditions and Flight Overview

The second field campaign was carried out on the 19th of October, 2017, under typical seasonal conditions. Automated Aeronautics was again contracted to carry out the flights. The weather was generally calm and sunny, with temperatures ranging between 6° C and 13° C. Winds were light through the day, and at one point the wind speed remained < 0.8 m/s for an extended period of time (> 15 minutes). This necessitated a gap between flights 3 and 4 in the middle of the day, since the OPLS requires wind speeds in excess of 0.8 m/s in order to accurately estimate back trajectories and flux rates. In the afternoon winds picked up, providing a more suitable environment for carrying out measurements.

When the wind conditions were stagnant (< 0.8 m/s for 5 minute average), leak indications flooded the site making it easy to know that leaks were present, but making it difficult to know exactly where the methane originated from. This was the case for Flights 2 and 3, which were conducted under low wind conditions, and which are shown in Figures 14 and 15, respectively. Flights 4, 5, and 6 (Figures 16, 17, and 18) were conducted with wind speeds of > 1 m/s, which made it much easier to identify emission sources.

All flights carried out are listed in Table 2, with Flights 2-5 being described below and shown in Figures 14 - 18. Flight 1 is not described below, as its purpose was simply to confirm that all components were working correctly.

Table 2: *Summary of flights carried out on October 19th, 2017*

#	Purpose	Duration (min)	Wind vel. (m/s) & dir.
1	Engineering checkout	4.1	0.6, 125°
2	Survey	11.1	0.5, 105°
3	Survey	7.2	0.8, 97°
4	Survey	11.6	1.3, 80°
5	Survey	8.0	1.3, 85°
6	Flux quantification	16.4	1.1, 126°

5.1.1 Flight 2

Flight 2 lasted around 11 minutes, and was conducted under light easterly winds. The purpose of this flight was to conduct a preliminary reconnaissance of the site, and the OPLS sensor was flown around the entire site. The flight was conducted under light winds, and as a result, although strong leak indications were seen, no clear pattern could be discerned as to where the methane originated from.

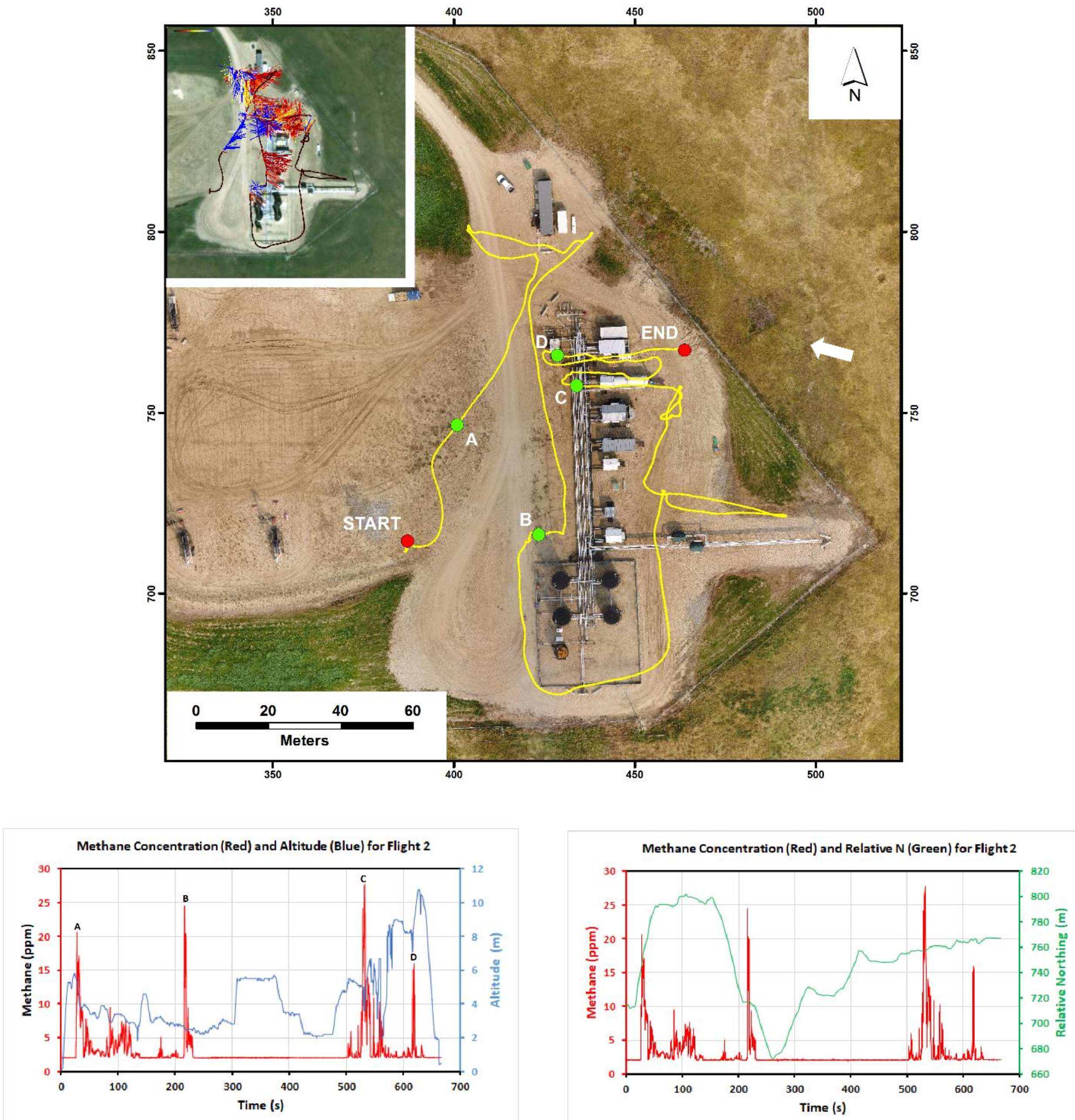


Figure 14: *October Flight 2 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

5.1.2 Flight 3

Flight 3 was carried out to investigate potential methane leaks north of the main storage tanks. The flight lasted approximately seven minutes, and was conducted under light wind conditions. It can be seen from the inset that strong indications of fugitive methane were present, but the low wind speeds prevented the emissions sources from being identified.

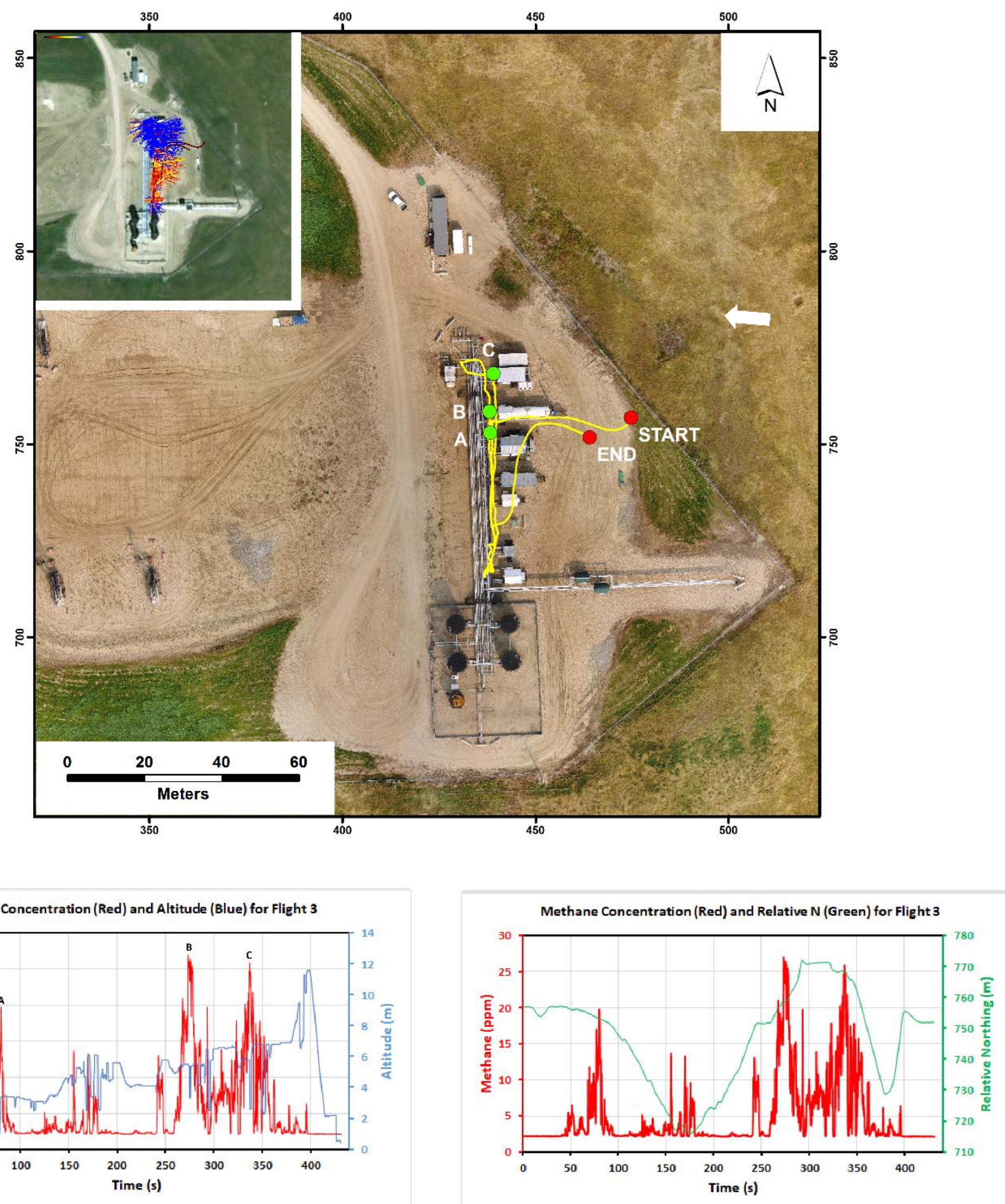


Figure 15: *October Flight 3 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

5.1.3 Flight 4

Flight 4 lasted 11 minutes and was conducted under steady wind conditions, with speeds averaging 1.3 m/s. This provided much improved conditions for identifying emissions sources. For this flight, the OPLS was flown back and forth in a curtain pattern, up to 23 m in altitude. Using this flight pattern, the main source of emissions on site was identified as being the storage tanks to the south of the site, and emissions from this source were localized to the upper portions of the tanks within two minutes.

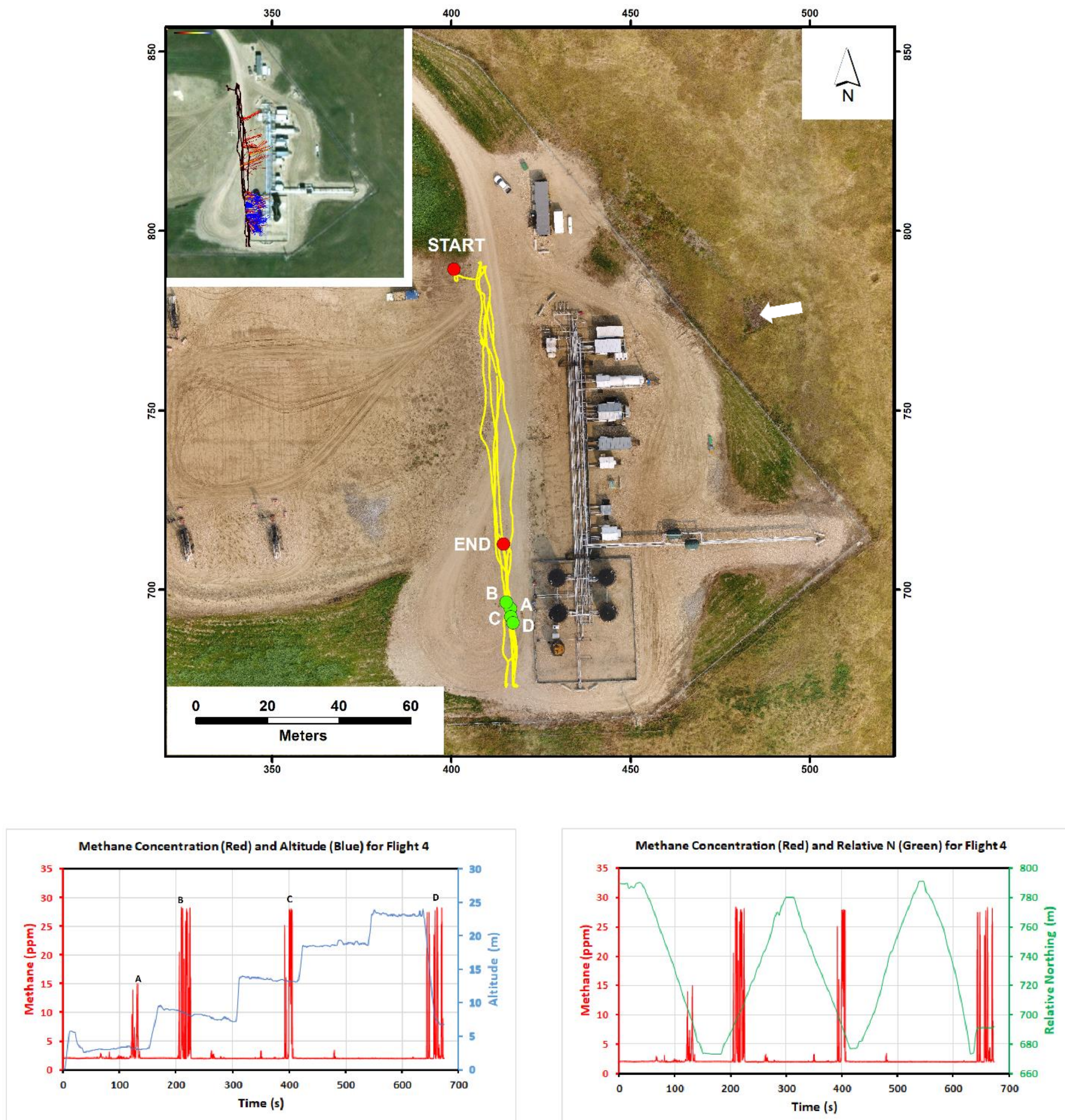


Figure 16: *October Flight 4 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

5.1.4 Flight 5

Flight 5 was a shorter flight of eight minutes, which was designed to look for leaks in the area to the north of the storage tanks. While the storage tanks were clearly the main source of onsite methane emissions, the sensor had given clear indications in previous flights that there were other emissions sources. From this survey, three additional leaks were identified to the north of the tanks, using back trajectories. The results of this analysis will be discussed below in the Results section.

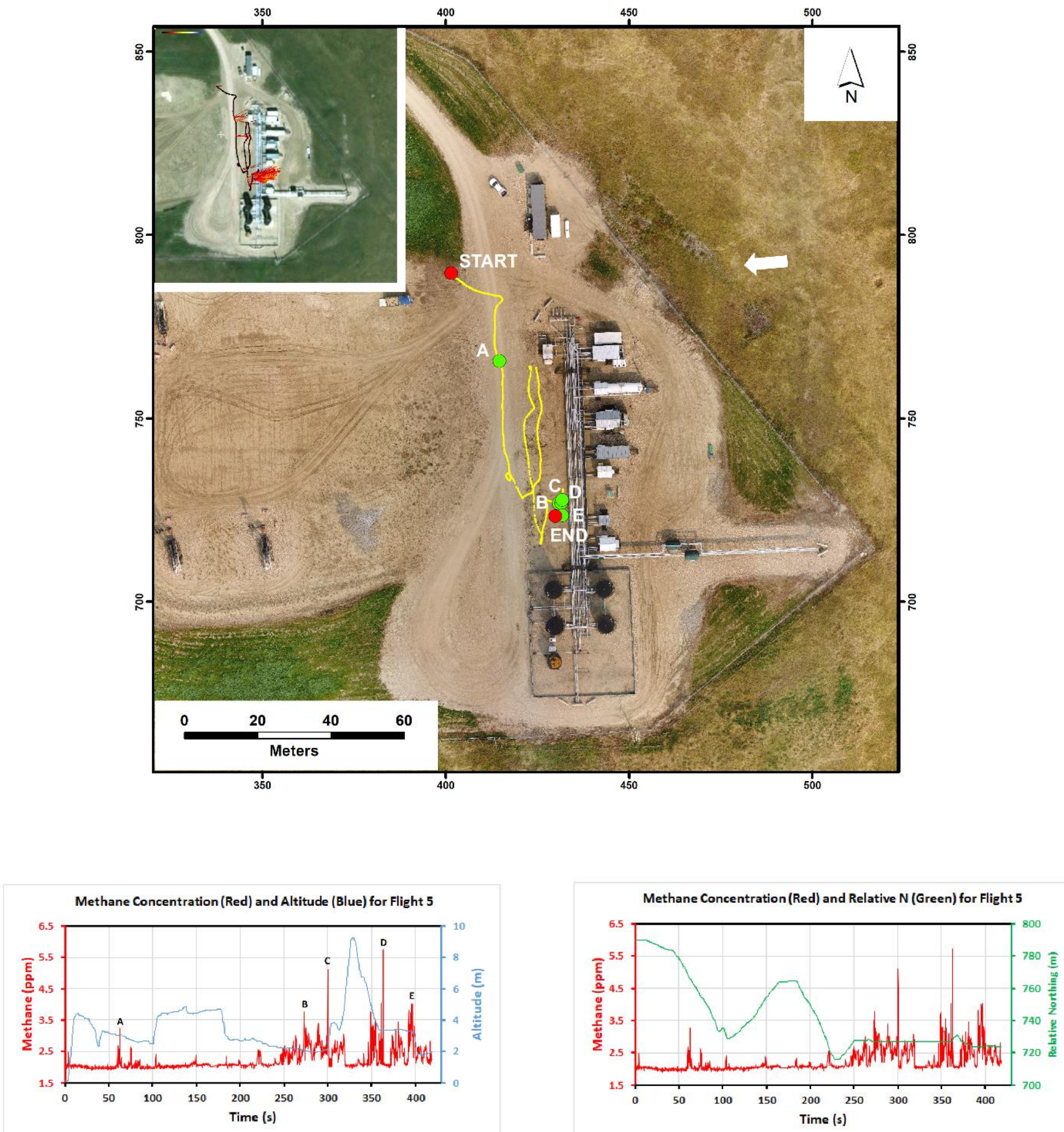


Figure 17: *October Flight 5 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

5.1.5 Flight 6

Flight 6 was designed to measure the overall flux from the site. The OPLS was flown back-and-forth downwind of the infrastructure in a curtain pattern at several different heights up to 27 m. This flight lasted for over 16 minutes, with the average wind speed being 1.1 m/s, and the winds blowing from the southeast.

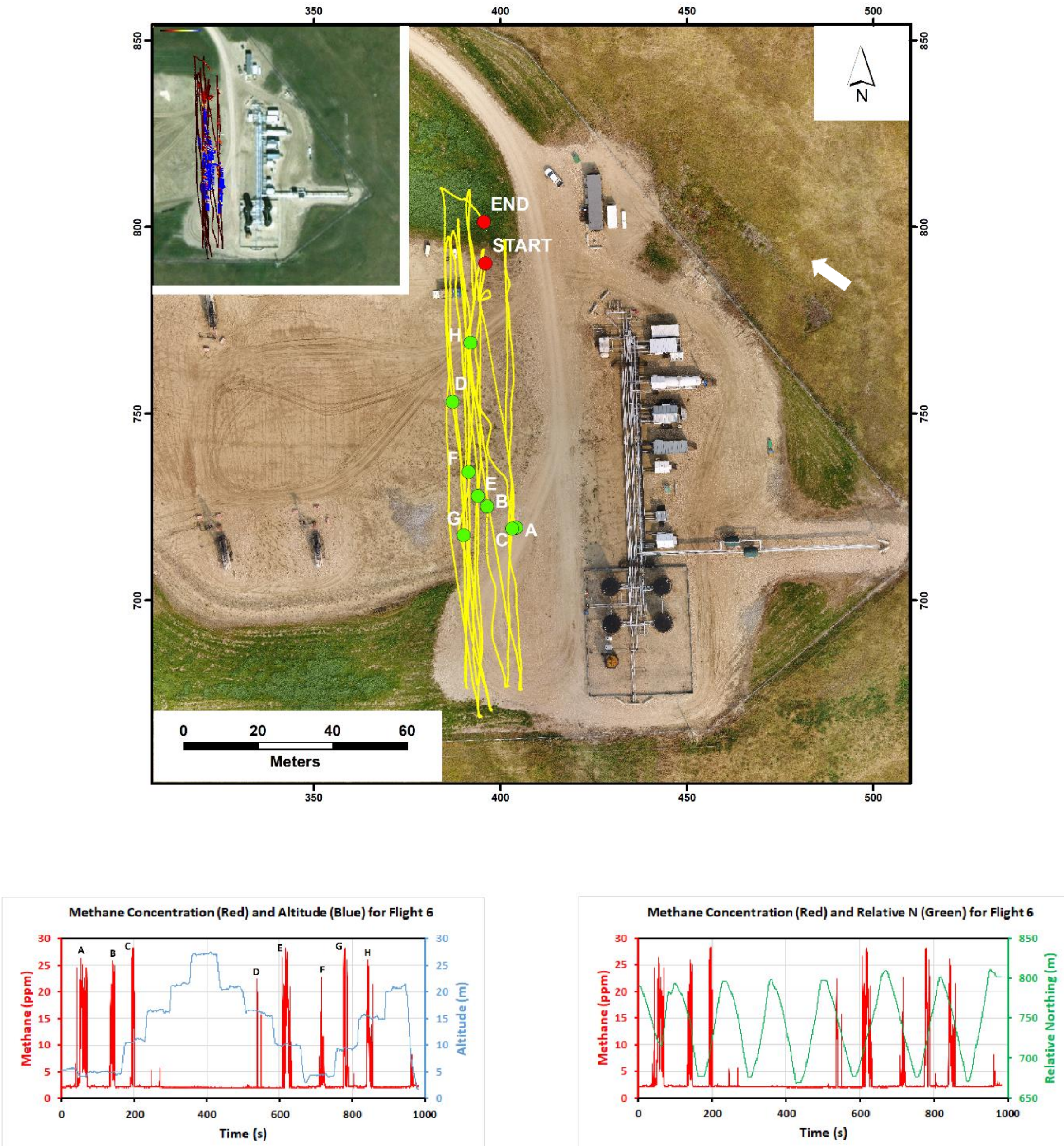


Figure 18: *October Flight 6 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

5.2 Results from second field campaign

Due to light winds, Flights 2 and 3 indicated the presence of methane on site, but were of little use in identifying where it originated from. In the afternoon, winds in excess of 1 m/s meant that Flights 4, 5, and 6 were considerably more successful. For Flight 5, three additional leaks were identified as originating from buildings to the north of the storage tanks. These locations are shown in Figure 19, below. To obtain these locations, wind back-trajectories were calculated whenever elevated methane concentrations were observed. Infrastructure where back-trajectories overlap is colored red. Based on the magnitude of the elevated methane signal and its estimated horizontal extent, and following procedures outlined in EPA's OTM 33A recommendation (Thoma & Squier, 2014), individual emission rates were calculated. These are also presented in Figure 19. More time was spent investigating the southern-most leak; therefore, its emission rate estimation is considered to be more accurate.

Figure 19: *Leak localization from Flight 5 data.*

It took about 8 minutes to localize these emissions north of the storage tanks. From Flight 4, the storage tank emissions were localized to the upper portions of the tanks within two minutes. With more practice and experience, it is not inconceivable that specific leak locations for a similar sized facility can be identified to ±2 m with a 15 min flight for such a facility.

Flight 6 focused on measuring overall flux from the site. The OPLS was flown back-and-forth downwind of the infrastructure at several different heights up to 27 m. This technique is referred to as 'mass balance' or the 'box method'. No atmospheric modeling is required to infer flux. Flux is calculated by Kriging the methane measurements on a plane downwind of the emissions sources and multiplying these methane area values by the wind velocity through the plane. The relative concentrations of methane through the flux plane measured during flight 6 are shown in Figure 20. For this technique to be successfully applied it is important to understand the local background contribution to methane, to ensure that only emissions originating from the site are quantified.

The background methane level can be obtained in several different ways. For the present experiment, we flew the UAV high enough that it did not see any enhancement in methane during a horizontal run (i.e. methane time series was a flat line). This was then subtracted from the calculated estimates of flux. The majority of emissions project back to the storage tanks but there is a sizeable contribution which originates to the north of the storage tanks. Overall, the estimated methane flux was 465 ± 172 SCFH, or

13.2 ± 4.9 cubic metres per hour (CMH), which is similar to the overall value obtained from the August survey.

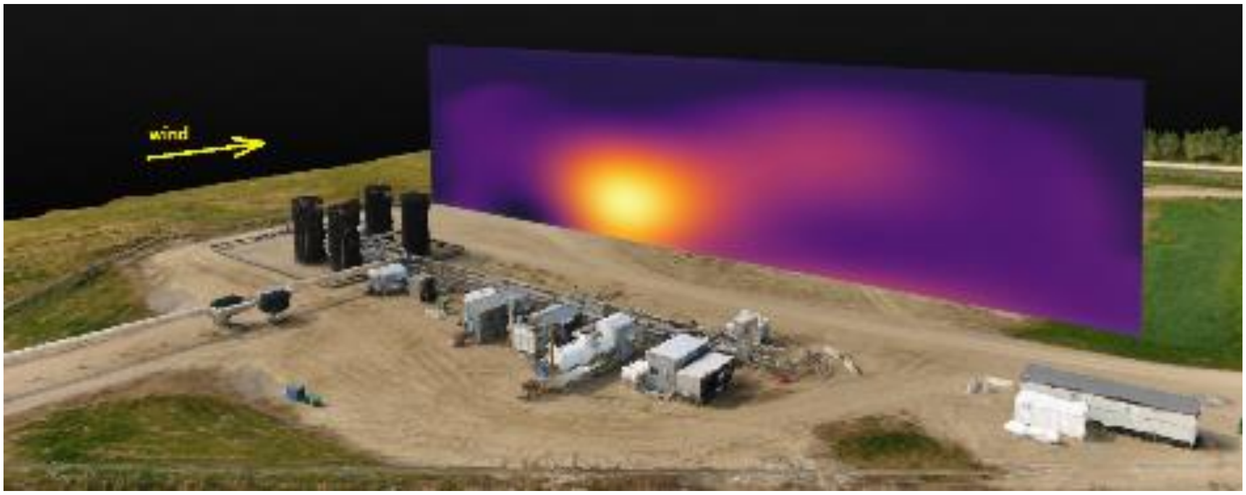


Figure 20: *Methane plume projected onto the plane defined by Flight 6.*

5.2.1 Improving the Accuracy of Flux Measurements

The largest source of error is due to natural atmospheric turbulence. Figure 13 above shows a Large Eddy Simulation of a methane plume for mid-latitude summer with 2.0 m/s wind speed. The yellow vertical line represents the mass balance technique used to infer flux. Due to atmospheric turbulence, at any instantaneous time, the amount of methane moving through the line will vary significantly, depending on overall wind conditions, topology, and solar irradiance. To increase our accuracy in flux estimation, the mass balance plane has to be repeated a certain number of times. For Flight 6, this measurement plane was repeated twice to give a 35% uncertainty.

One advantage of using a UAV as opposed to a manned aircraft is that the measurement planes can be repeated rapidly owing to the maneuverability of the UAV. It took 16.4 minutes in total to fly two planes. In one hour, seven measurement planes could potentially be completed, which would reduce uncertainty to ± 10%. The benefit in a higher accuracy flux measurement must be weighed against the cost to conduct the flights. Over time, we expect to improve our methodology for flux measurement. This could be done by cutting down on the time it takes to fly each measurement plane, either by flying faster or by making use of multiple UAVs at the same time.

6 Field Campaign 3: March 20th 2018

6.1 Site Conditions and Flight Overview

The third field campaign took place on March 20, 2018. Conditions through the day were clear with diffuse sunlight. Temperatures were milder than average for the time of year, ranging between +2°C and +8°C, with an average of +3.5°C. Winds were light and highly variable through the day, making for less than ideal conditions for pinpointing leak locations and determining flux. In spite of the conditions, a total of five flights were carried out, although the conditions encountered during Flight 1 meant that no useful measurements could be obtained. Surveys 2 to 5 were more successful, but conditions through the day were unsuitable for flux estimation. For Survey 4, the OPLS was actually detached from the UAV, and was carried around the facility, with the idea of providing a more detailed inspection that was possible using the sensor mounted on the M600.

Flights were again conducted by Automated Aeronautics, using a DJI-M600 platform with the configuration described in the Equipment section above. Ideally the M200 used for the October survey would have been preferred for the survey, as it is more compact and more maneuverable and is designed to work at lower temperatures. However, as reported above, there have been a number of reports of unpredictable flight performance affecting the M200, which are believed to be due to compass issues. The M600 was therefore used for the March survey, as this platform has a reputation for reliability. The air temperatures during the day fell within the low end of the allowable operating range for the M600, so the substitution was justified. SAIT also deployed the same stationary weather station used in the October campaign to collect background data on ambient conditions.

One purpose of this experiment was to test the performance of the OPLS sensor at colder temperatures. The minimum temperature encountered during the fieldwork was +2° C, which is mild in comparison with typical winter lows in the area. However, this is still significantly colder than the average temperatures reported for the previous two field experiments. To ensure consistency, all flights were carried out using the same OPLS instrument (serial number 01 “white”) that was used for the August and October flight experiments.

Below we describe results from the four individual flights and one ground-based hand-held survey. Flights have been renumbered from their original designations in order to be consistent with numbering of the prior two field campaigns.

Table 3: *Summary of surveys carried out on March 20th, 2018.*

#	Purpose	Duration (min)	Wind vel. (m/s) & dir.
1	Preliminary reconnaissance	16	negligible, 295° (highly variable)
2	Mass flux measurement	20	1.03, 206°
3	Mass flux measurement	23	0.92, 297°
4	Leak detection (hand held)	16	0.85, 247°
5	Stack emissions test	20.7	0.56, 201°

6.1.1 Flight 1

Flight 1 was a preliminary reconnaissance flight around the site. Overall, the wind was negligible (< 1 m/s) so localization was difficult. Emissions from the storage tanks expressed themselves on the northeastern leg of the survey. For a period of time during the first part of the survey, the wind was blowing out of the southwest and back-trajectories indicated that an emissions source might be the northwest building.

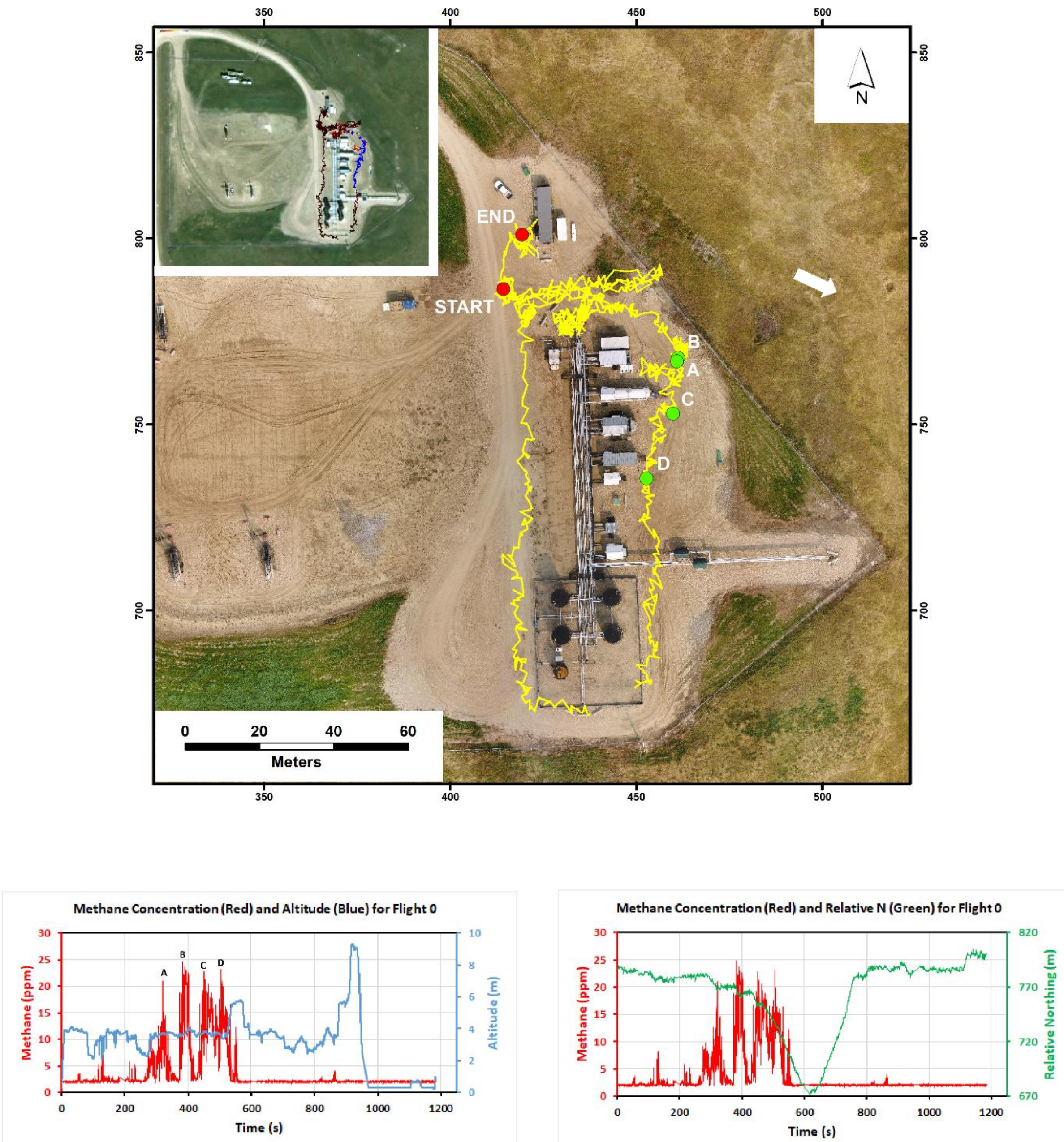


Figure 21: *March Flight 1 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

6.1.2 Flight 2

By the time Flight 2 was conducted, the wind speed was approaching 1 m/s, blowing out of west-southwest. A mass flux measurement of the emissions from the storage tanks was attempted. Emissions as high as 25 ppm were observed up to 20 m altitude. On subsequent analysis of the data, it was found that insufficient data had been collected at lower altitudes, making it difficult to invert these measurements into a flux plane. To allow successful determination of flux, several more passes would have been necessary. This flight lasted just over 20 minutes.

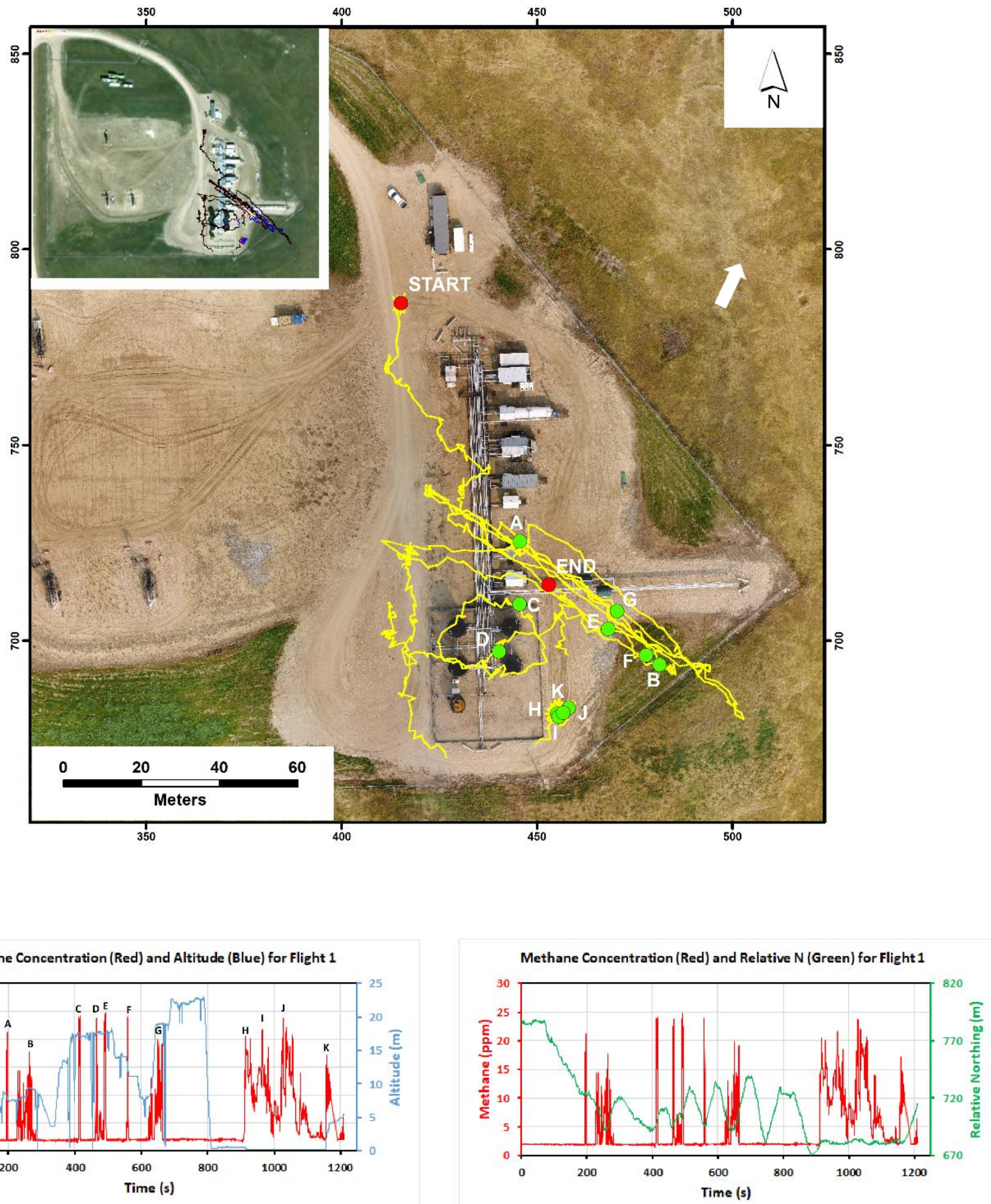


Figure 22: *March Flight 2 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

6.1.3 Flight 3

Early on in Flight 3, an attempt was made at doing a mass balance flux plane on the west side of the facility but the winds were unfavorable (blowing out of the west). The wind strength was also less than 1 m/s for much of the flight, making it difficult to identify leak locations with a high level of accuracy. In spite of less than optimal conditions, very high measurements (off-scale) were observed to the east of the storage tanks.

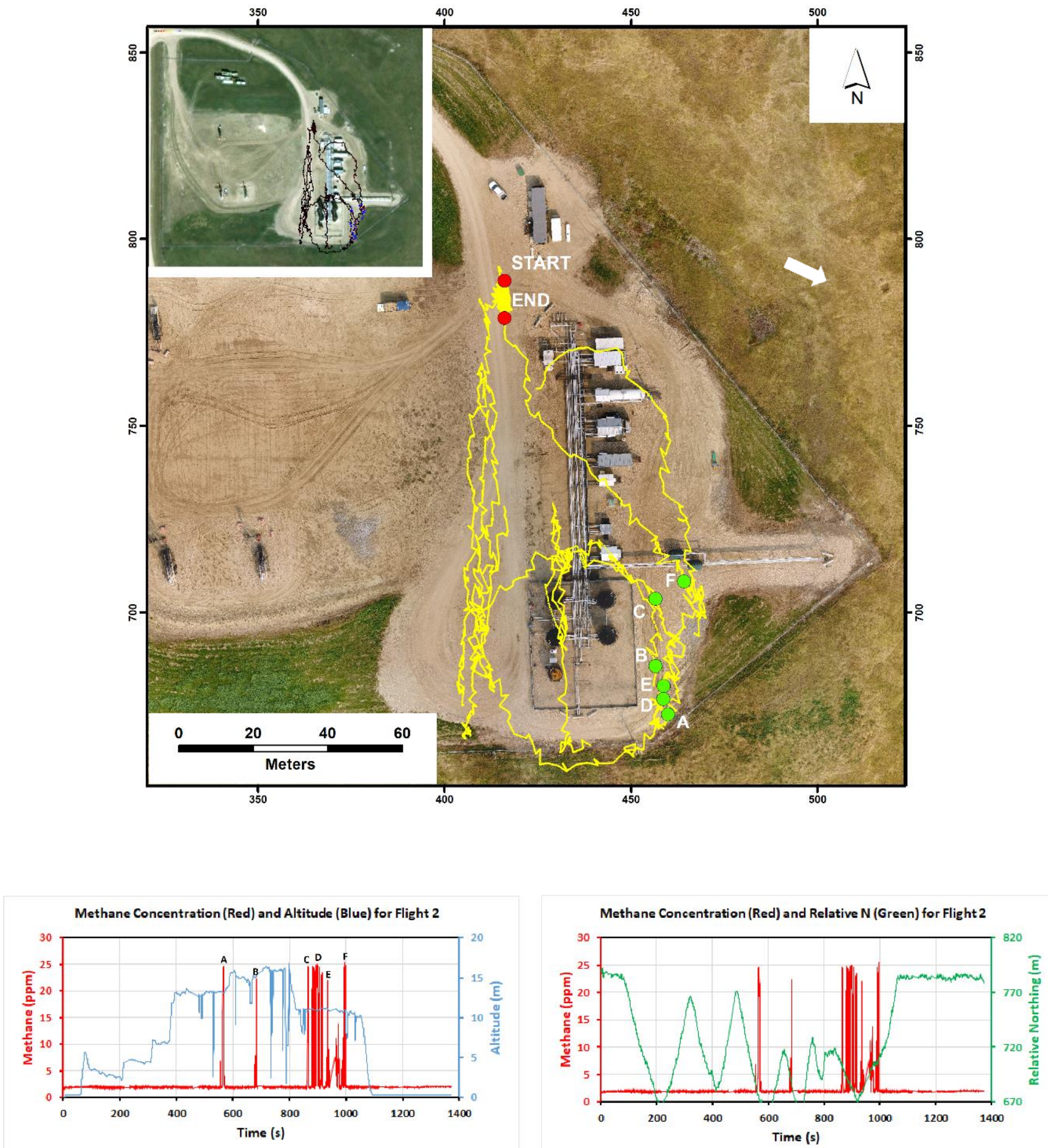


Figure 23: *March Flight 3 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

6.1.4 Survey 4

Survey 4 was actually a hand-held survey to follow up on Flight 1, and took just over 16 minutes to complete. This survey was carried out to confirm the locations of two leak sources north of the storage tanks. These data should be compared with Flight 5 from October 2017, where three leak locations were identified based on back trajectories from flight data as shown in Figure 19 above. The 2nd building to the north of the storage tanks (close to location E) was found to be a source of leaks on both dates.

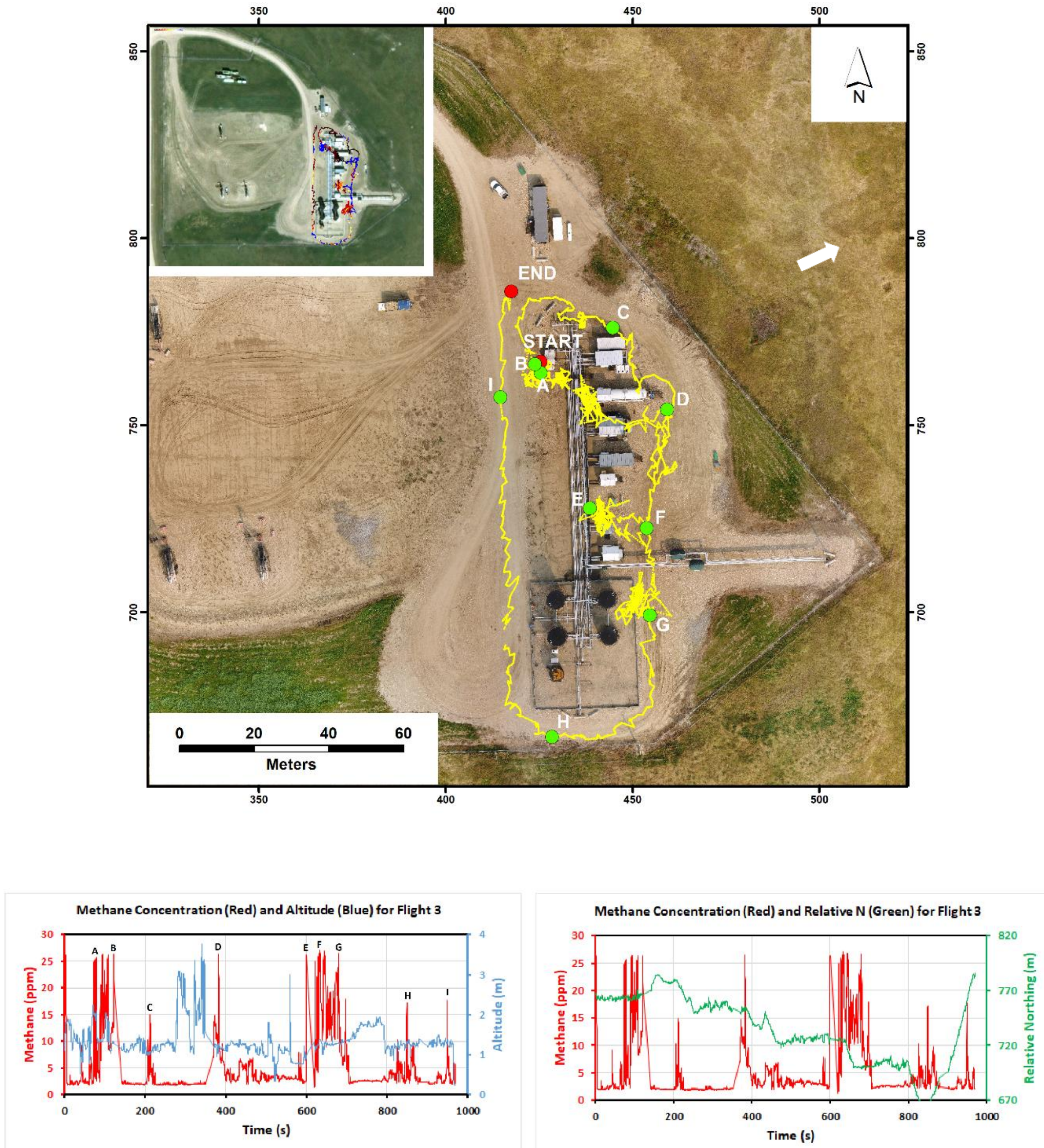


Figure 24: *March Flight 4 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

6.1.5 Flight 5

Flight 5 sought to measure the emissions from the flare stack. During the survey, flaring was initiated on purpose by the site operator. The signal at 470 seconds is very likely due to the flare stack due to its height and location. The signal at 500 seconds (point C) is also likely from the flare, due to its location. The other signals are likely due to methane leaks originating from the storage tanks. However winds were extremely light during this survey, so it is difficult to accurately determine sources of methane.

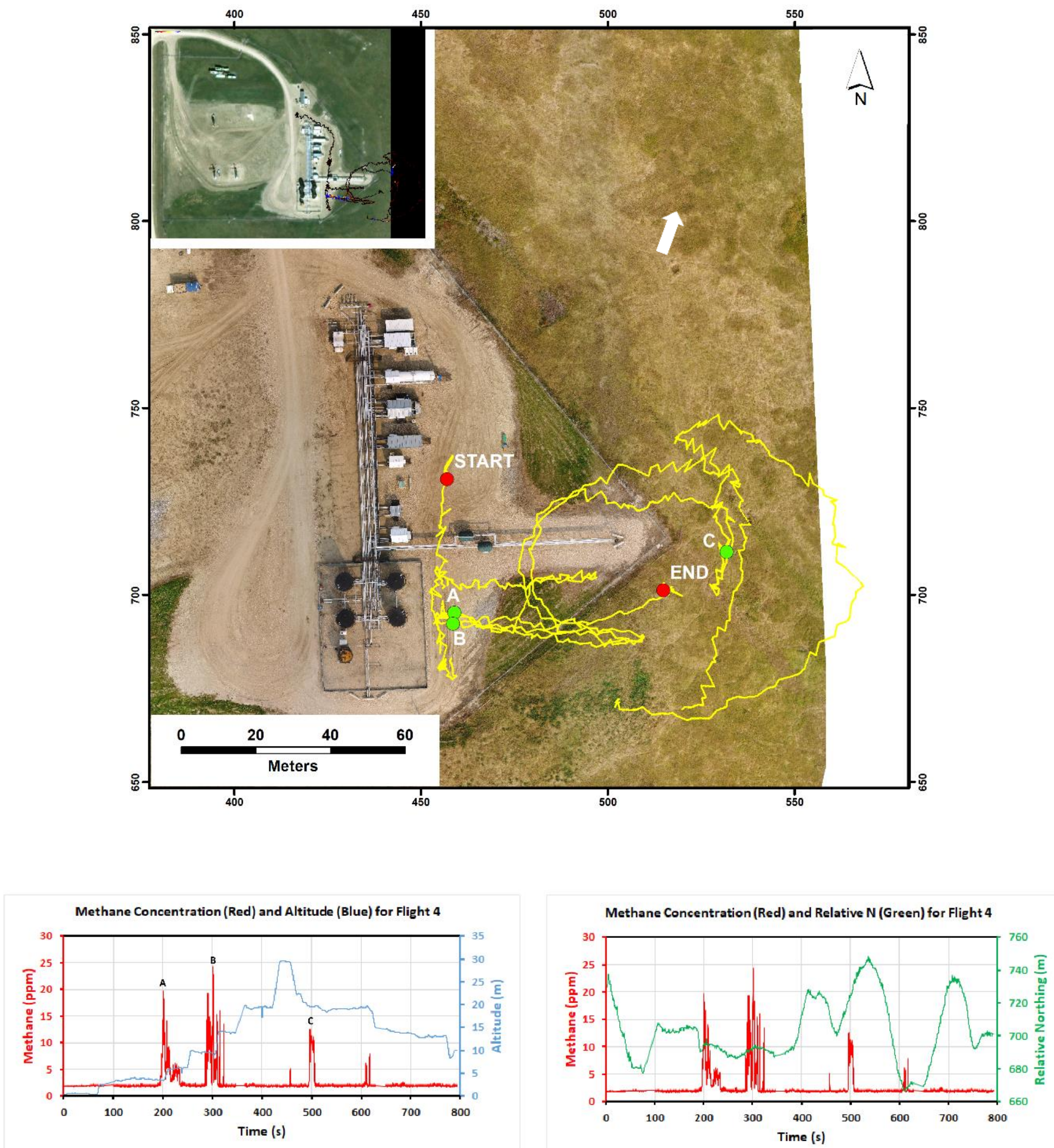


Figure 25: *March Flight 5 track (main image), inset shows detected methane concentrations ranging from red (lowest), to blue (highest), with vector length and direction corresponding to wind speed and direction. The average wind direction is indicated by the white arrow. Graphs show methane and altitude over duration of flight (left) and methane and relative northing (right).*

6.2 Results from March 2018 Field Campaign

While the results from the third field campaign do not initially appear as encouraging as those from the two previous field campaigns, they provide valuable insight on the importance of having steady winds during the survey. None of the March 2018 flights were carried out under ideal conditions. Winds were light through the whole day and their direction was constantly changing, often several times during the same flight. This meant that it was challenging to identify methane sources with any degree of reliability, since methane under such conditions tends to pool, making it easy to detect but providing little or no information which can allow back trajectories to be calculated. This is a characteristic common to all so called “sniffer” detectors, since such the presence of steady winds of at least 1 m/s are typically required in order to allow accurate determination of the source of leaks. Also, in the absence of steady winds, it is not possible to estimate flux by flying the UAV downwind in a curtain pattern. Thus much of the advantage of mounting the sensor on a UAV is negated.

In the absence of suitable wind conditions, removing the sensor from the UAV platform and walking around the site by hand, as was done in Survey 4 is likely to be the most effective way to look for leaks, as the operator can slowly narrow in on the leak based on the relative strength of the signal, without relying on the directional component which is derived from the wind direction. While this approach can be effective, it is much more time consuming than having the sensor mounted on a UAV platform. In this case, point source leaks were detected in three of the outbuildings located to the north of the storage tanks, including one leak that was originally detected in the October 2017 survey.

Also noteworthy about the March 2018 data was an apparent degradation in system performance compared to the previous two campaigns. Inspection of the five flights above (Figures 21 - 25) shows that the GPS track is noticeably less smooth in each case than in the previous surveys, with random jumps of up two 2 m between successively measured positions along the UAV flight path. The data from the OPLS is also considerably noisier than that obtained from the August and October field surveys (see Figure 26 below). During Flight 3, there was a period of time in which the signal-to-noise (SN) of the system during flight could be assessed. This is compared with data from Flight 3 of the October survey in Figure 26. In can be seen that the SN for the March 2018 flights was nearly four times poorer than for the October 2017 flights.

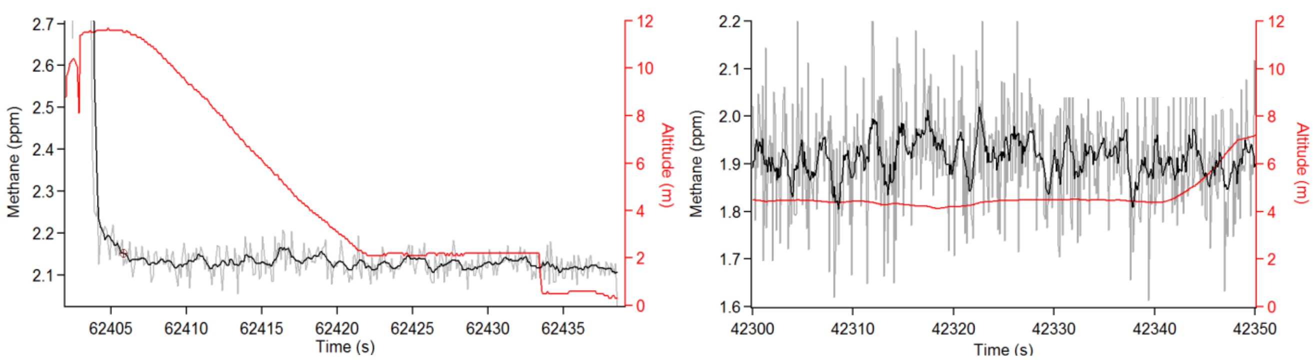


Figure 26: *Comparison of Signal to noise between Flight 3 from October 2017 (left), and Flight 3 from March 2018 (right). The vertical scale, representing methane detections is the same for both dates to allow comparison. Individual methane readings are represented in grey, with the aggregate signal being shown in black.*

It is unclear what caused this degradation in signal quality. Some possibilities are the cold temperature affecting optical alignment, repositioning of the sensor relative to the platform which made OPLS more susceptible to vibrational noise, and / or wear on the OPLS itself, such as dirty mirrors. The fact that the GPS data also appears to be degraded suggests that some kind of electronic interference may possibly also be affecting the overall signal. Efforts are ongoing to track down the source of this signal degradation.

While the degradation in the signal quality points to some technical issues with the sensor and telemetry during the March survey, the overall results from this survey are still believed to valid. Gas leaks were detected on site and were validated by the AER representative during the survey. In a number of cases, these matched leak locations identified from previous visits. It is likely that the degradation in signal would be most noticeable for quantitative analysis, potentially increasing the level of uncertainty associated with flux measurements. However during the March campaign, it was not possible to make flux measurements because of the weather conditions, so this hypothesis remains untested.

7 Discussion and Conclusion

This report details the result of three surveys carried out at a facility in the Drayton Valley area in August and October 2017, and March 2018. The results from the three surveys provide evidence that the OPLS sensor was able to detect methane at concentrations of only a few parts per billion. In each of the three surveys, the major leaks as determined independently by representatives from the AER, were successfully detected. In addition, the surveys carried out in August and October were able to identify back trajectories to suspected leak locations, with an estimated accuracy of better than 1 m. The main leaks detected during each of the three field visits were found to originate from the top of the two western storage tanks. Flights conducted downwind of the suspected leak locations were also able to provide quantitative estimates of flux for the major leaks, and these were found to be of similar magnitudes for the surveys carried out in August and October. No flux estimate was calculated for the March field visit, due to insufficient data being available. During the October and March surveys, a number of smaller leaks were detected from the outbuildings. The largest of these, from a building located just to the north of the storage tanks was observed during both of these surveys (see Figure 19).

This suggests that the OPLS sensor mounted on a small UAV has the potential to collect accurate data on methane concentrations in and around oil and gas production facilities. Such surveys will likely form a key component of any future integrated monitoring strategy, by providing detailed facility-level inspections to allow for leak detection and flux estimation. The other key piece which will need to be addressed moving forward, is the ability to carry out rapid preliminary assessments of facilities to determine whether a more detailed inspection is required. This will require the use of complementary forms of technology, which can detect methane remotely. Possible approaches to this challenge will be discussed under recommendations for future work in the following section.

From the flights carried out throughout this study, and from prior experimental testing of the OPLS, it has been established that small leaks of around 1 SCFH can be reliably detected from several tens of meters away under suitable wind conditions. Larger leaks of > 200 SCFH can be detected downwind at distances of several hundred meters. The smallest practical leak size for detection is estimated to be around 0.2 SCFH, with the optimal flying height for leak detection being estimated as being < 8 m, at a distance of around 30 m, although this is obviously dependent on the height of emissions source. For example, it is likely that flying higher would be more effective for detecting emissions originating from a flare stack.

One area of uncertainty is the effect of turbulence on the measurement process. Turbulent air in the rotor wash from the UAV can be expected to have the same methane concentration as the surrounding air, and would therefore theoretically elicit a similar response from the OPLS. However it is possible that turbulence could cause the sensor to behave in unexpected ways. To avoid this possibility, every effort was made to ensure the OPLS was physically located outside of zone of turbulence generated by the rotors. Prior wind tunnel experiments carried out during the development of the OPLS suggested that the problem of turbulence can be largely avoided if the sensor is mounted ahead of the platform and if the platform is moving forward at a speed of greater than 1m/s, or alternatively if the wind speed exceeds 1 m/s.

While the OPLS sensor shows considerable potential, the problem of methane detection and flux quantification is complex. There are two important factors which can affect the success of any mission. The first is weather. The three field campaigns underscored the fact that the collection of good data for leak detection and quantification was dependent on steady winds in excess of 1 m/s. Though not encountered during any of the three field surveys, strong, gusty winds could be expected to also degrade system performance. Optimal conditions therefore require light to moderate, but steady winds. Cold is another factor which can potentially impact the survey. Although temperatures encountered during the March 2018 survey were warmer than expected, there did appear to be some degradation in the sensor signal to noise ratio, as described in Section 6.2. There is insufficient evidence to attribute this to temperature, but the possibility exists that lower temperatures may impair system performance. Obviously, the persons carrying out the survey have no control over weather, but further research can help to identify conditions which are unsuitable for data collection, and which should therefore be avoided.

The second factor to consider is the flight pattern to be used in the UAV survey. The technique used in each of the three surveys was to fly around the site and identify the main concentrations of methane, which were assumed to be associated with fugitive emissions. Once the areas with the highest concentrations were identified, the strategy was then to fly downwind of these areas, back and forth at different altitudes in a curtain pattern. This allows estimation of methane flux through a vertical plane which is defined by the UAV flight lines. Each set of measurements has approximately a 50% accuracy for flux determination, but repetition of this flight pattern several times can considerably improve the estimation of accuracy. While this approach has given good results for this particular site, it may not be appropriate for other production facilities, where there may not be sufficient space for downwind measurements to be made. Other flight patterns, or possibly ground-based measurements may have the potential to provide better results under such circumstances.

Measurement of GHG concentrations under real world conditions will always be prone to variability. In addition to atmospheric variables and the influence of the chosen UAV flight pattern, temporal factors can play a significant role in determining total emissions from a facility. For example, methane emissions can be expected to increase during periods of flaring, due to incomplete combustion. Maintenance activities can lead to releases of methane, as can venting associated with day to day operations of a facility. These factors are however well known, and can be accounted for in a well-designed monitoring program. The site chosen for this initial phase of the study was a controlled site, with no intended venting. However, this cannot be assumed for all sites in the future.

Sensor calibration is another issue which needs to be addressed. The sensor was calibrated at NASA / JPL prior to the August field trial. A basic calibration was also carried out at SAIT prior to the March survey, in which the sensor was tested using a mix of calibration gas in an enclosed environment. The results for this showed the sensor to be performing as expected. To address industry and scientific concerns, it is important that that sensor readings are regularly calibrated against a known standard. One of the priorities for follow up work is to develop a field calibration system, in which the sensor can be calibrated immediately prior to each use. This will provide certainty that readings given by the sensor reflect the reality of the situation in the field.

All in all, Phase One of the project can be considered a success as a pilot study. The main goal of this phase of the project was to provide experimental validation that UAV based surveys using the OPLS sensor are effective, and can be used to identify methane leaks and determine flux rates for oil and gas production facilities under controlled conditions. Results from the three field experiments suggest that this is indeed a practical approach. A potential Phase Two will look at developing an operational approach, which can be used to determine methane emissions from a variety of oil and gas production facilities, quickly and effectively.

8 Recommendations for Further Work

The proposed Phase Two will be designed to build on the successes and on the lessons learned from the current study, and will seek to provide a roadmap towards the development of an operational system, which can be used for routine assessments of fugitive emissions from oil and gas production facilities. To this end, we propose working with several different facilities with different emissions characteristics, preferably clustered within a limited area. This will enable us to conduct UAV flights over several facilities at once, while keeping the UAV platform within line of sight, as per Transport Canada regulations. The assistance of the Alberta Energy Regulator will be invaluable in identifying a suitable cluster of facilities to carry out fieldwork.

The work proposed for Phase Two will comprise several components, which together will advance the project to the overall goal described above. The first of these is to develop a field calibration system for the OPLS, to allow it to be calibrated prior to each flight. This will provide certainty that the readings provided by the sensor are valid, and will help to assuage industry concerns that reported methane concentrations truly reflect the situation on the ground.

Another goal of any follow up work is to speed up the process for flux estimation. Currently results have to be sent for analysis at NASA / JPL, with a subsequent delay of several days. This is not an option for any system moving towards operational testing. Part of the proposed Phase Two will therefore involve the development of algorithms and software for automated flux analysis.

NASA / JPL has recently developed a modified version of the OPLS, which is capable of detecting ethane. Ethane is uniquely present in natural gas, making it possible to distinguish emissions originating from oil and gas facilities from methane originating from background sources, such as wetlands, landfills, and cattle feedlots. We are interested in incorporating this technology into our Phase Two work, as it will provide the industry and regulators with a degree of certainty that measured emissions are associated with the activities of a given production facility.

There is also a need to employ some form of complementary technology to carry out rapid assessment of oil and gas production facilities. There are two main possible approaches. The Pergam Laser Methane Mini is produced by Swiss company Pergam-Suisse. It is a lightweight active laser instrument which can be easily adapted to be carried by a UAV. This instrument is able to measure methane concentrations at the ppm level. While not as sensitive as the OPLS, it has the advantage of being able to detect methane without having to be located in the plume. This instrument is therefore ideal as a tool for rapid preliminary inspection of a facility. A preliminary assessment flight can be quickly carried out by flying in a grid pattern above the facility. Areas of potential concern can then be investigated in more detail using the OPLS.

A second potential approach involves the use of hyperspectral imagery. The AVIRIS sensor, developed and operated by NASA / JPL, has been shown to be an effective tool for detecting methane plumes. A number of different algorithms have been developed, using methane absorption peaks, including a significant peak located at a wavelength of approximately 2,300 nm. The use of the AVIRIS sensor is not a practical option, as it is extremely large and is typically flown at high altitudes from a manned aircraft. However there are a number of hyperspectral sensors that have been developed for UAV applications, including the Headwall Photonics Nano-Hyperspec and Micro-Hyperspec SWIR systems. SAIT has access to these instruments, and it is believed that they may have the potential to form an effective rapid assessment tool.

The main advantage of utilizing either the Pergam system or a hyperspectral imager is that neither form of sensor needs to be located within the methane plume. It is therefore possible to measure methane concentrations close to the ground from a considerable distance away. By using such a system mounted on a UAV, we believe it will be possible to overfly a facility and identify whether there are significant quantities of methane requiring further investigation. This process can be carried out quickly and cost-effectively and will make it possible to distinguish those production facilities which require further investigation.

In both cases, the OPLS will then be used for second stage investigation of facilities where methane concentrations detected from the preliminary assessment exceed a specified threshold. The techniques developed in Phase One will be used to detect leak locations and measure flux rates. During Phase Two, we will also develop procedures to use the OPLS in the most effective way possible, potentially incorporating surveys from a ground-based rover. Over the duration of Phase Two, the operating procedures for the OPLS will be continuously improved. This year will also see the introduction of the first commercial versions of this sensor, produced by San Francisco based company RKI Instruments. We intend to work closely with the company to develop an integrated system, which will serve as an effective tool for leak detection and flux estimation.

9 References

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