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LIST OF ABBREVIATIONS

Abbreviation	Complete Name
AGL	Above Ground Level
AV	Aircraft Variant
CH_4	Methane
CNG	Compressed Natural Gas
$CO_{2\text{-eq}}$	Carbon Dioxide Equivalent
GHG	Greenhouse Gas
FEMP	Fugitive Emission Management Programs
LDAR	Leak Detection and Repair
UTC	Universal Time Coordinated

1.0 EXECUTIVE SUMMARY

GHGSat has met this project's objectives by having successfully developed satellite, aircraft, and analytics technologies, as well as the resulting satellite-aircraft hybrid services, envisioned in this project.

GHGSat-C1 satellite, successfully launched in September 2020, has demonstrated significant performance improvement over the demonstration satellite GHGSat-D. This improvement has been realized in spatial resolution, methane precision and geolocation accuracy, and leads to detection thresholds for the C-class of GHGSat satellites of 100 kgCH_4/hr. This was demonstrated through both controlled releases and deployment of the satellite-aircraft system on parallel projects in the Permian basin in 2020.

The aircraft variant instrument, GHGSat-AV, was successfully built and had its initial test flight in December of 2019. Subsequently, it was flown in southern Alberta during some controlled release test flights and was ready and commissioned for project and customer work for summer 2020. Through the controlled releases, as well as through the demonstration of the satellite-aircraft hybrid system in the Permian basin in 2020, the aircraft variant has achieved a detection threshold of 10 kgCH_4/hr.

GHGSat has successfully developed the operations, software toolchain and analytics to execute hybrid system data acquisition, processing, retrievals and emission rates. Furthermore, the analytics developed as part of the project have grown into SPECTRA, our global greenhouse gas emissions monitoring solution that provides access to weekly updates from third party datasets paired with GHGSat's methane data. Multiple data layers are available including methane concentration, flaring, hotspot detection and emission risk prediction utilizing machine learning algorithms. This service has been instrumental in tasking our satellite to the areas with the highest likelihood of emissions detectable by our satellites and aircraft.

The hybrid system was demonstrated at all four types of sites in Alberta identified for this project: (i) oil sands tailings ponds; (ii) conventional oil and gas producing areas; (iii) a landfill site, and (iv) an animal feedlot.

Nevertheless, significant challenges must still be overcome for GHGSat to achieve its full potential, particularly in Alberta and Western Canada.

- Detection threshold: GHGSat's satellite and aircraft sensor detection thresholds were designed to detect up to 90% of methane emissions by volume, based on scientific literature available at the time of their design. Ongoing research now suggests that while these thresholds are appropriate for the United States and many other parts of the world, they may be too high to meet all commercial and regulatory objectives in Alberta and the rest of Canada.

- Area sources: GHGSat's satellite and aircraft sensors are designed for detection of point source emissions. Area sources (e.g. landfills, oil sands tailings ponds) aggregate smaller emissions per unit surface area into more significant total emissions across their large area. These are therefore more difficult for GHGSat to detect, and more work is needed to improve performance for area source applications.

These challenges have led to limited results with demonstration partners on our ERA project in the Alberta context. One (1) methane emission was detected from project sites during the course of the project. However, in parallel to this project, GHGSat's satellite-aircraft hybrid system was demonstrated in the Permian basin in the USA leading to sufficient emissions being observed to validate the system.

Furthermore, we continue to have a compelling value proposition for global benchmarking of Canadian emissions intensity, and we continue to have compelling results for international markets with both satellite and aircraft sensors. GHGSat also plans to expand the satellite constellation and the fleet of airborne variant instruments to continue to improve the technical performance of the systems as well as add capacity and frequency of observations.

2.0 PROJECT DESCRIPTION

2.1 Introduction and background

Methane is a greenhouse gas that has a global warming potential 84 times greater than carbon dioxide over a 20-year period. Reducing methane emissions from industrial facilities is one of the most effective ways to reduce greenhouse gas emissions. Furthermore, much of the methane emitted can be attributed to a small fraction of sites behaving as so-called super-emitters. Studies[1] have shown super-emitter activity across multiple sectors (waste management, agricultural, and oil and gas) where 10% of point sources contributed to about 60% of the total emissions.

Cost-effective solutions that provide reliable detection and quantification of methane, especially those applicable for monitoring large areas frequently for those large point source emitters, are helping to enable industry's innovative efforts to reduce emissions.

GHGSat has pioneered the use of satellites for detection and quantification of methane emissions from industrial facilities and has leveraged its technology into a satellite-aircraft hybrid system. GHGSat has made Alberta its base for this hybrid technology, for export around the world.

In June 2016, GHGSat launched the world's first satellite-based sensor system ("GHGSat-D", or Claire) capable of measuring methane and carbon dioxide emissions from any specific, identifiable industrial site in the world. GHGSat has added two commercial satellites to reach a commercially-relevant scale for service in Alberta and beyond.

In Fall 2016, Boeing and GHGSat announced a partnership to further advance GHGSat's technology, including the development of an aircraft variant of GHGSat's technology. This pilot utilized the aircraft variant, and the resulting satellite-aircraft hybrid capability, in Alberta with multi-site demonstrations.

GHGSat envisions our satellite and airborne instruments for detecting and quantifying emissions as layers in a tiered alternative FEMP observation program. The satellite-aircraft tiers could address 90% of the methane released by volume and could be layered into a comprehensive emission management program that

[1] *Duren, R. M., Thorpe, A. K., Foster, K. T., Rafiq, T., Hopkins, F. M., Yadav, V., Bue, B. D., et al. 2019). California's methane super-emitters. Nature 575, 180–184. doi:10.1038/s41586-019-1720-3*

provides more frequent observations to catch leaks sooner and at a lower cost than incumbent technologies.

As an enabling technology, GHGSat can only estimate the indirect impact its services will have on methane emissions in Alberta. In Q2 of 2021, GHGSat's fleet of satellites measured methane emissions form 210+ sites worldwide, and the aircraft variant surveyed 35,000+ sites in North America. In the first half of 2021, GHGSat has mitigated over 600 kt$CO_{2\text{-eq}}$ in emissions globally.

2.2 Detailed technology description

GHGSat has invented a new method to measure greenhouse gas emissions from industrial facilities, based on a miniaturized Fabry-Perot interferometer launched on its own Low Earth Orbit ("LEO") satellite.

GHGSat's satellite orbits the Earth in a polar, sun-synchronous orbit, meaning that the satellite travels in a north-south direction while the Earth turns east-west underneath it, as depicted in the left panel of Figure 1. Each orbit takes approximately 98 minutes, so the satellite completes approximately 15 orbits while the Earth turns 360 degrees. Given these orbital mechanics and the satellite's relatively narrow field of view, the result is that a single satellite can measure any point on the surface of the Earth once every two weeks, on average.

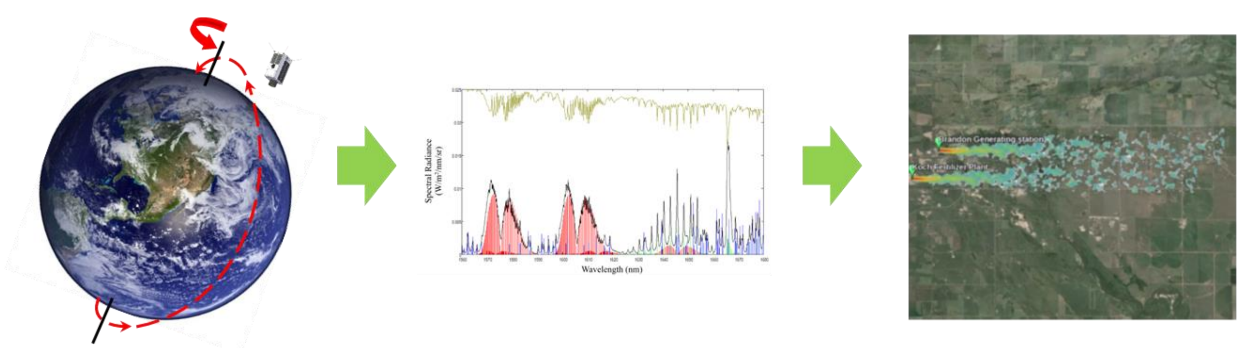


Figure 1: GHGSat satellite orbit, measurement principle, and imagery

Every gas absorbs light at specific wavelengths, resulting in a unique "spectral fingerprint". The middle panel in Figure 1 shows absorption lines for methane (green), carbon dioxide (red) and water vapor (blue). GHGSat's satellite measures the combined absorption profile of all three gases (light green, top). The higher the concentration of gas in the field of view of the satellite, the more light is absorbed. In this way, GHGSat can both detect and quantify the amount of methane present in its field of view.

GHGSat's satellite camera has approximately 200,000 pixels in its 12 km x 12 km field of view, and GHGSat obtains concentration measurements in each of these pixels. The resulting data is then made available to customers both as a dataset and as an image as illustrated in the right-hand panel of the above figure. In this image, higher concentrations are shown in red, and then progressively decreasing concentrations in orange, yellow, green and blue. GHGSat can determine emission rates at the source by analyzing such dispersion patterns with inverse dispersion models.

GHGSat's aircraft variant instrument is just that: a variation on the same technology that is built into our satellites but deployed on a fixed-wing platform and operated much closer to the ground, as Figure 2 illustrates.

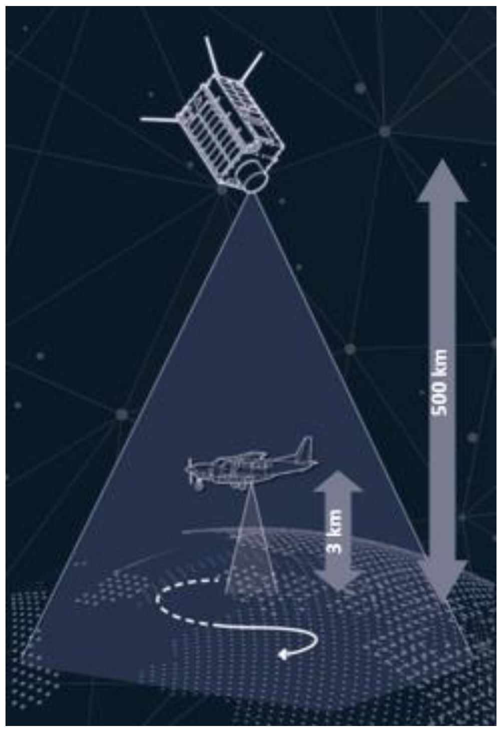


Figure 2: Illustration of the Aircraft platform compared to GHGSat satellites

The imaging spectrometer in the GHGSat-AV instrument is the same Fabry-Perot interferometer concept, with appropriate optics appropriate for the nominal altitude above the surface. Deploying GHGSat's technology in an aircraft platform closer to the ground than the satellite case enables detection and quantification of smaller sources and gives finer spatial resolution. It also enables calibration and verification of coincident satellite measurements. Coordinated use of instruments on both satellite and aircraft platforms therefore improve the quality of products and extend the range of services offered by GHGSat.

GHGSat's satellite-aircraft based solution combines: (i) sufficient detection sensitivity to detect the largest leaks; (ii) the spatial resolution to localize those emissions to specific facilities; (iii) higher frequency of observations to limit the duration of leaks; (iv) no costs or risks associated with ground-based deployment to remote areas; and (v) at a lower cost than incumbent solutions. The use of GHGSat's satellite fleet will enable high-frequency and low-cost monitoring for the largest leaks which are responsible for most methane emissions by volume. Complementing the satellite observations would be multiple airborne campaigns to detect and quantify emissions that may be too small for satellite. GHGSat can leverage the processing of the data from these two tiers using the same analytics and algorithms since both platforms utilize the same imaging spectrometer concept.

This project advanced the state of the art in remote sensing of gas emissions by developing the world's first satellite-aircraft hybrid system and demonstrating it initially in Alberta. This project allowed GHGSat to: (i) design and build our first airborne instrument GHGSat-AV1 based on the satellite imaging concept (ii) develop multi-satellite operations by supporting the construction, launch, and operation of GHGSat's first commercial-relevant satellite GHGSat-C1 and advancing our capabilities towards operating a fleet of satellites; and (iii) Develop the systems/algorithms/analytics supporting the use of satellite and airborne data in the detection and quantification of emissions. Finally, this project culminated in a series of demonstrations to validate the satellite-aircraft hybrid system at different industrial sites around the province of Alberta.

2.3 Project objectives

The objective of the project was to combine this commercially-relevant satellite and prototype aircraft system into a satellite-aircraft hybrid capability, and perform a multi-site demonstration with it.

The work breakdown structure for the project is illustrated in Figure 3. This structure built on experience with GHGSat's demonstration satellite as it followed the same approach, with the same industrial team, with one added work package for the aircraft variant.

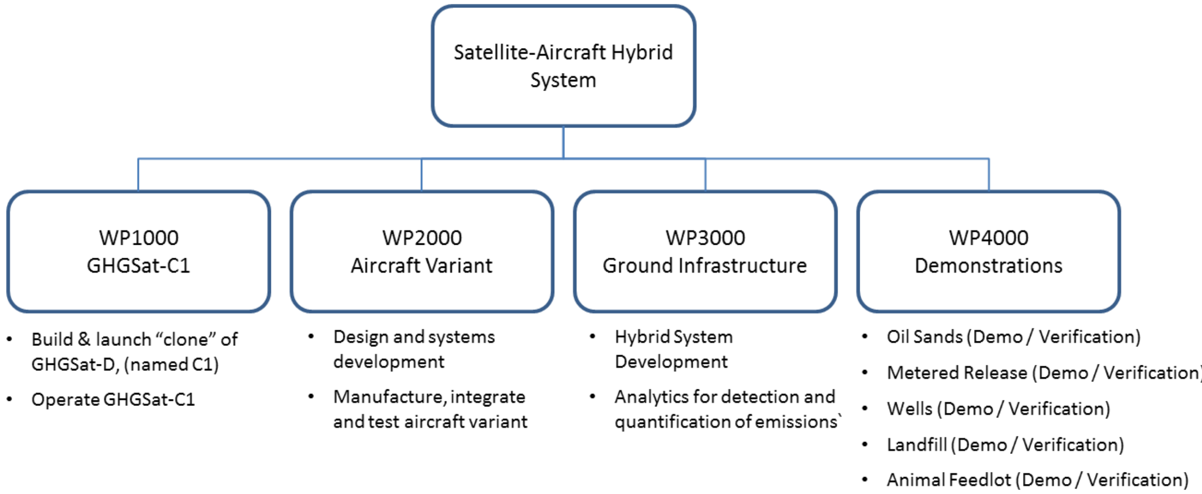


Figure 3: Work Breakdown Structure

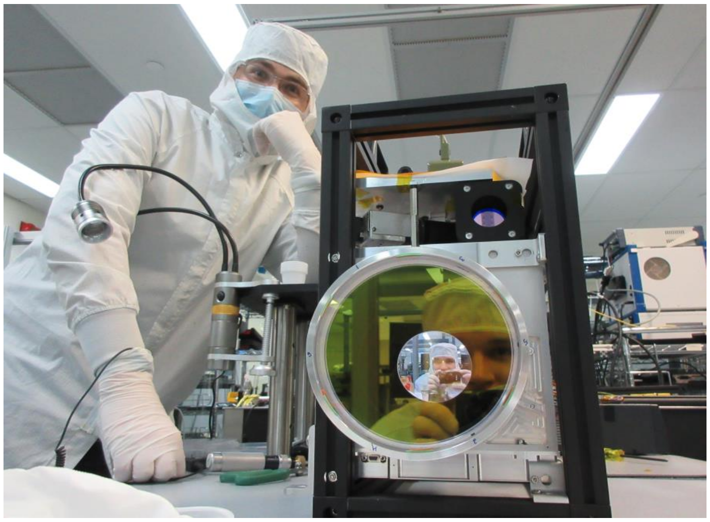
The first three packages (WP1000, WP2000 and WP3000) were performed in parallel with major subcontractors. WP4000 was performed using the outputs of the other three packages, with the support of project partners.

2.4 Work scope overview

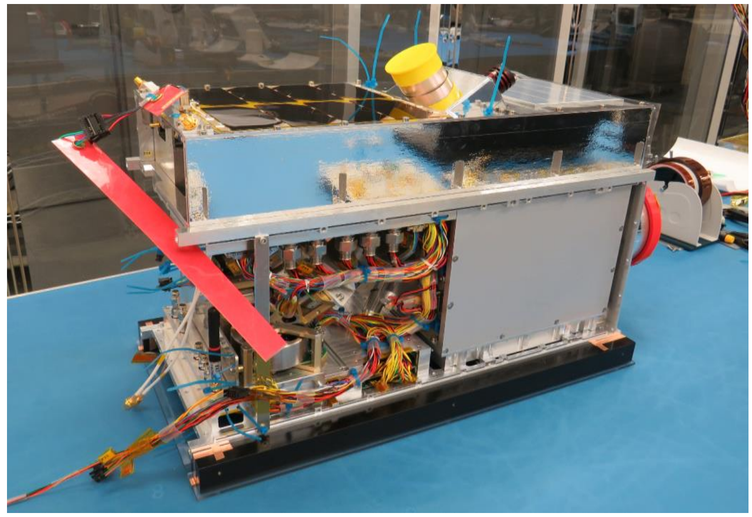
2.4.1 WP1000 – GHGSat-C1

GHGSat built, launched, and operated a "near-clone" of GHGSat-D, designated as GHGSat-C1 (Iris). The design of GHGSat-C1 was as close as possible to GHGSat-D, embedding lessons learned to improve performance while minimizing technical development and schedule risk. Examples of lessons learned from GHGSat-D that were critical for demonstrating a commercially-relevant service in Alberta included: a dedicated design for methane, improved imaging artifact controls, enhanced radiation protection, and improved camera characterization.

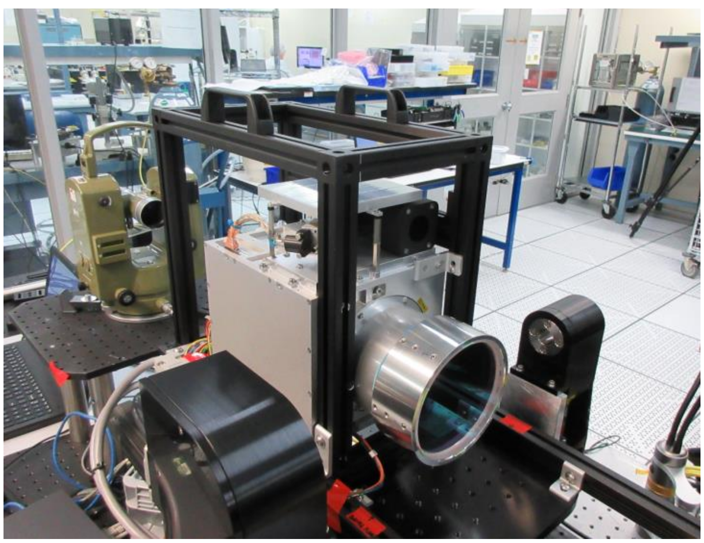
GHGSat has implemented these and a collection of other improvements in GHGSat-C1. GHGSat-C1 was launched successfully in September 2020 onboard an Arianespace Vega Rocket. Following a month of commissioning, GHGSat was able to confirm that all systems were nominal. As a result, the performance of GHGSat-C1 was improved by an order of magnitude compared to GHGSat-D.



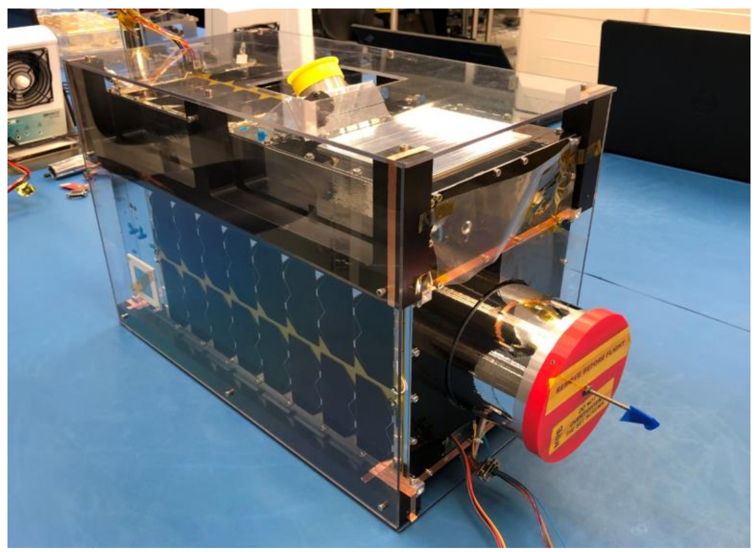
a) GHGSat-C1's payload completed and ready for integration in the spacecraft



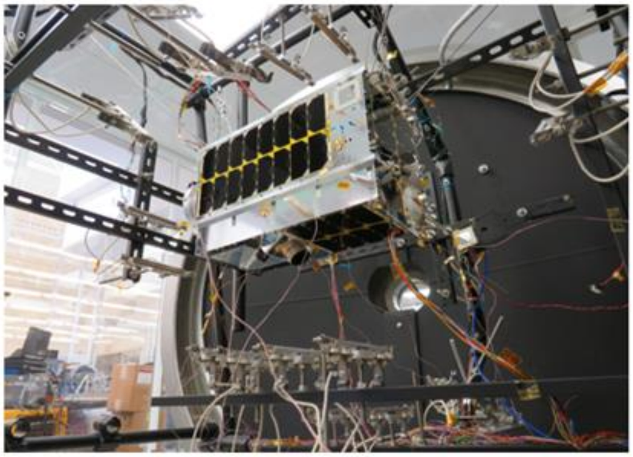
b) GHGSat-C1's spacecraft with all the subsystems integrated



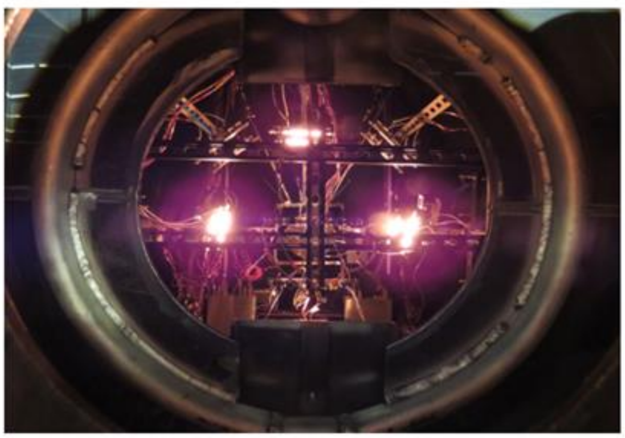
c) GHGSat-C1's payload in final testing



d) GHGSat-C1 completed, in burn-in phase before shipping to launch



e) GHGSat-C1 in preparation to a critical test (Thermal Vacuum Test (TVAC))



f) GHGSat-C1 during TVAC

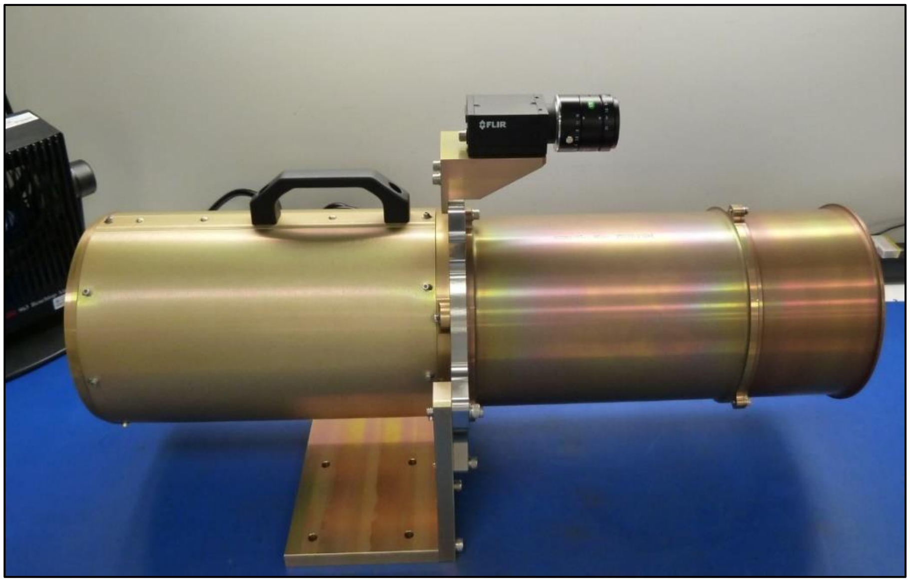
g) GHGSat-C1's launch in September 2020 on a Vega rocket (Arianespace)

Figure 4: GHGSat-C1 In various stages of testing

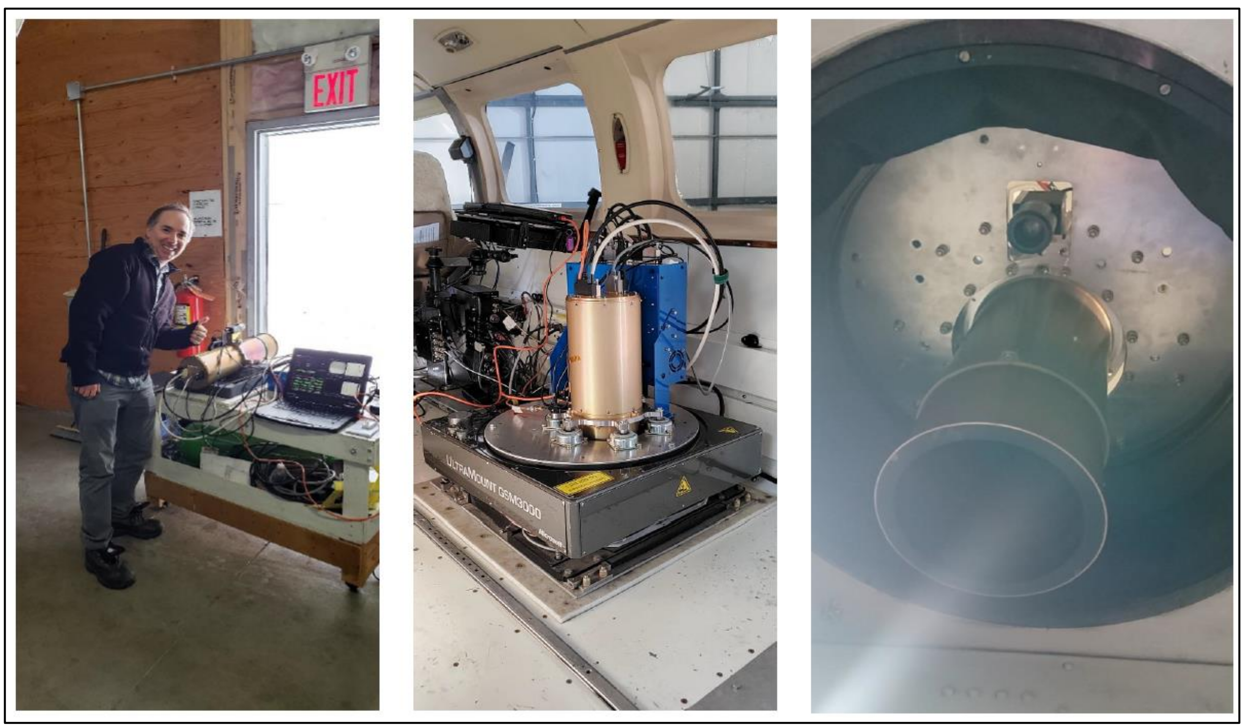
2.4.2 WP2000 – GHGSat-AV

GHGSat built and fielded an aircraft prototype of its instrument to detect and quantify emissions from smaller sources than is possible from a satellite. This instrument is based on GHGSat's satellite technology but is tailored for fixed-wing aircraft imaging environment.

GHGSat-AV1 first flight was performed in December 2019. After a few flight campaigns, GHGSat began regular operations in Spring 2020.



a) GHGSat-AV1 instrument



b) Left – Warren Shaw (Manager Airborne Systems) doing the last tests before the first test flight.
Center – GHGSat-AV1 first field installation aboard an airplane.
Right – View of GHGSat-AV1 from the outside of the aircraft

Figure 5: GHGSat-AV1 in varying stages of preparation

2.4.3 WP3000 – Ground Infrastructure

GHGSat expanded its post-processing capacity to support the satellite-aircraft hybrid system to support two additional sensors (GHGSat-C1 and GHGSat-AV1). As such, the full suite of software processing tools was reviewed and updated.

2.4.4 WP4000 – Satellite and Aircraft observations and processing

This work package included the verification and validation of GHGSat's satellite-aircraft hybrid system at four different sites in Alberta: (i) oil sands tailings ponds; (ii) conventional oil and gas producing areas; (iii) a landfill site, and (iv) an animal feedlot.

2.5 Performance/Success metrics

As planned, during the project the technology readiness level (TRL) moved from TRL7 to TRL8 for the satellite technology, from TRL4 to TRL7 for the Aircraft sensor and from TRL5 to TRL7 for the Hybrid system. GHGSat was able to demonstrate the technology in a near commercial plot or in a commercial-scale demonstration by measuring sites with the satellites and the aircraft. Furthermore, the performance metrics of both instruments (satellite and aircraft) were also met as per the table below.

Table 1: Technology Readiness Level (TRL)

TRL 3 Experimental Proof of Concept Demonstration	**TRL 4** Technology Development & Validation	**TRL 5-6** Prototype Development & Testing	**TRL 7** Near Commercial Pilot Demonstration	**TRL 8** Commercial-Scale Field Demonstration	**TRL 9+** Commercial Implementation and Market Rollout
			Project Start (Satellite)	Project Completion (Satellite)	
	Project Start (Aircraft)		Project Completion (Aircraft)		
		Project Start (Hybrid)	Project Completion (Hybrid)		

Table 2: Performance Metrics Summary

Success Metric	**Commercialization Target**	**Project Target**	**Note**
Spatial Resolution	< 50 m (satellite) < 10 m (aircraft)	< 50 m (satellite) < 10 m (aircraft)	Achieved
Methane Precision	<5% of background	<5% of background	Achieved
Geolocation Accuracy	< 25 m (satellite) < 5 m (aircraft)	< 25 m (satellite) < 5 m (aircraft)	Achieved
Emission Rate Precision	<20%	<20%	Achieved

3.0 PROJECT OUTCOMES AND LEARNINGS

3.1 Detected emissions from Alberta sites

Four monitoring missions specific to unique methane emitting industries were launched with this project related to the oil sands, oil and gas wells, agriculture, and waste management. Each of these monitoring missions were comprised of routine satellite monitoring with GHGSat-C1, as well as a one-time aerial methane survey with GHGSat-AV1 in either the fall of 2020, or summer of 2021, depending on location. One (1) emission was detected in the Athabasca oil sands with an estimated source rate of *17 kg hr*$^{-1}$. Figure 6 shows the emission, which was detected on June 14, 2021.

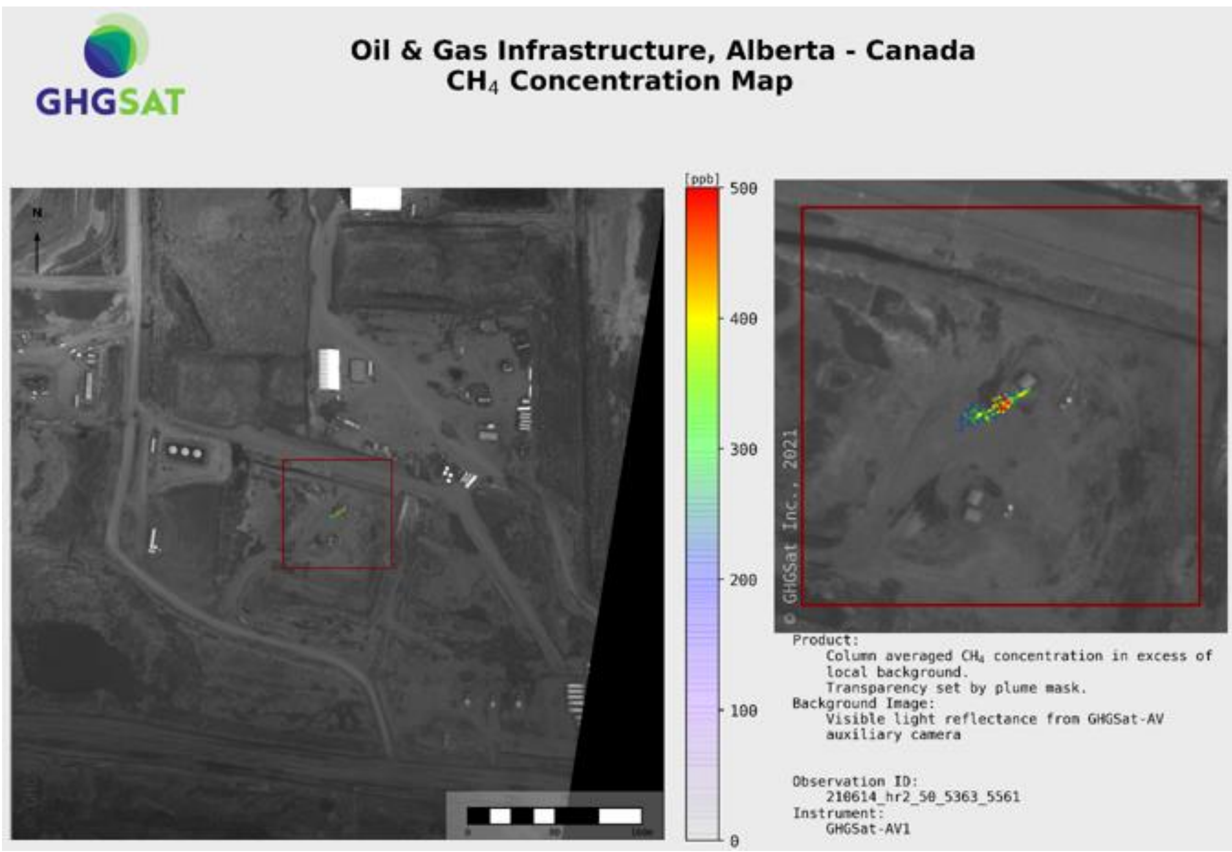


Figure 6: GHGSat-AV1 Concentration Map of the emission detected at an Alberta Oil Sands Mine

3.2 Project Partners in Alberta

This project was designed to demonstrate the satellite-aircraft hybrid system at four different industries within the province of Alberta. Industrial partners in each of the four represented industries was important component in the design of the project:

1	Oil Sands
2	Oil and Gas
3	Landfills
4	Agriculture / Feedlots

Conversations with key project partners early in this project helped GHGSat to understand the unique emission profiles of these different industries, as well as the challenges associated with monitoring greenhouse gas emissions at industrial sites. Furthermore, campaign planning and site selection were supported by meetings and discussions with project partners.

In addition to interacting with the industrial partners on this project, GHGSat engaged with other potential customers within the province. Having an active Alberta-based demonstration project supported by ERA helped to facilitate positive discussions with existing and potential customers in the province and beyond.

3.3 Satellite and Aircraft observations

3.3.1 Satellite Observations

Over the project period, GHGSat attempted 322 satellite observations at ERA project sites. Of these observations, 128 were successful, while 195 failed due to inadequate weather conditions at the time of observation. Details regarding the project sites and the success of the observations there can be found in the following subsections.

3.3.1.1 Athabasca Oil Sands

Several sites in Alberta's Athabasca Oil Sands region were observed with GHGSat satellites as part of this project, with the majority of observations being made of two separate sites. Since the beginning of the project, 77 satellite observations have been attempted at the first site's tailings pond by GHGSat with 28 of those observations having been successful. Furthermore, 61 observations have been attempted at this site's mine since 2018, with 22 of those observations being successful.

In addition, 16 observations of a second oil sands tailings pond were made by GHGSat since 2018, with six being successful. The Athabasca Oil Sands region of interest that encompasses sites 1 and 2 can be seen in Figure 7.

Figure 7: Athabasca Oil Sands Region of Interest for GHGSat observations

Unsuccessful satellite observations were caused by inadequate weather conditions at the time of observation. During the project period, no emissions were detected by GHGSat satellites at any of the Athabasca Oil Sands sites.

3.3.1.2 Alberta Landfill

GHGSat attempted satellite observations for an Alberta landfill. The extent of the satellite observation at the Alberta landfill can be seen in Figure 8.

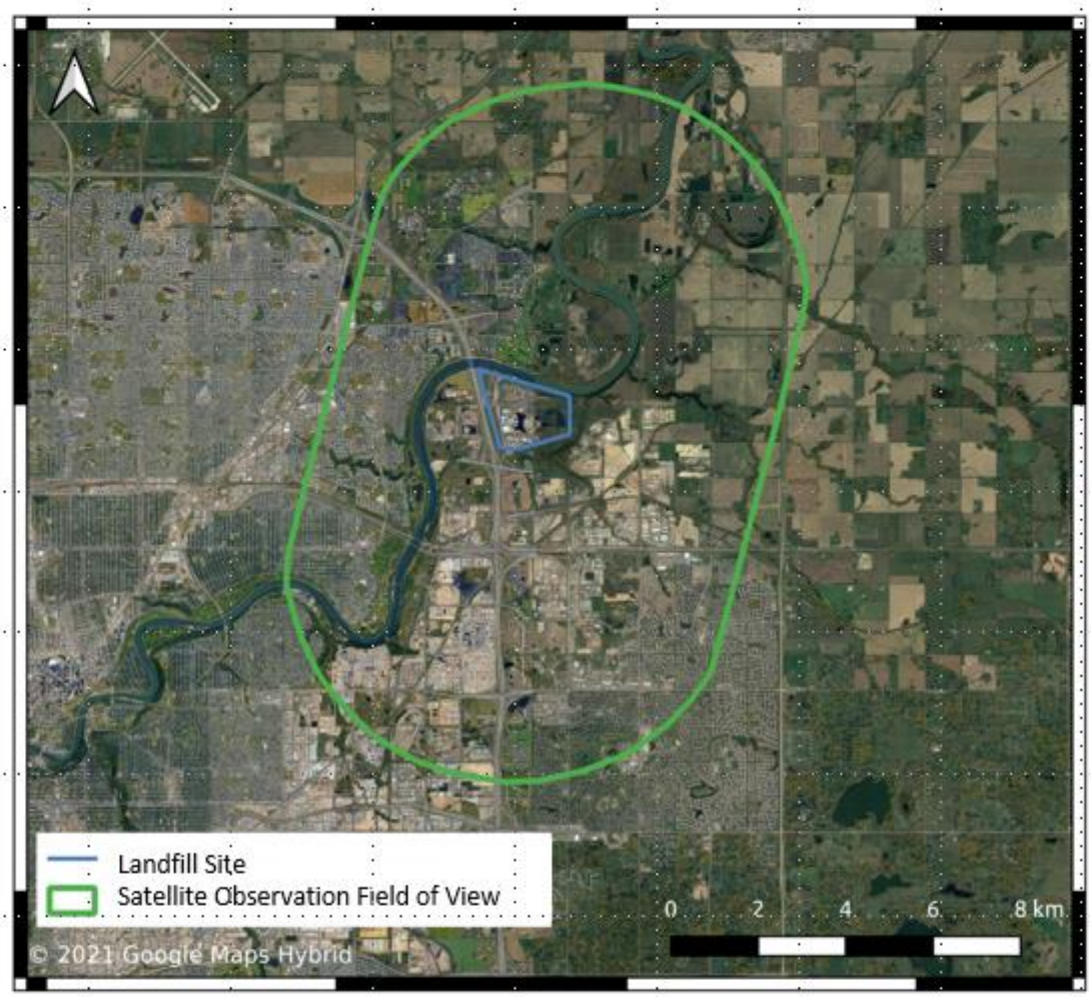


Figure 8 : Observation Extent of the Alberta Landfill Site

Since the beginning of the satellite monitoring program, 26 satellite observations have been attempted at this landfill site by GHGSat. 15 of those observations have been successful, while 11 have failed due to inadequate weather conditions. No emissions were detected from the landfill or waste management facility during the project.

3.3.1.3 SE Alberta Feedlot

The attempted satellite observations for a South-Eastern Alberta feedlot site. The extent of a typical satellite observation at the feedlot can be seen in Figure 9.

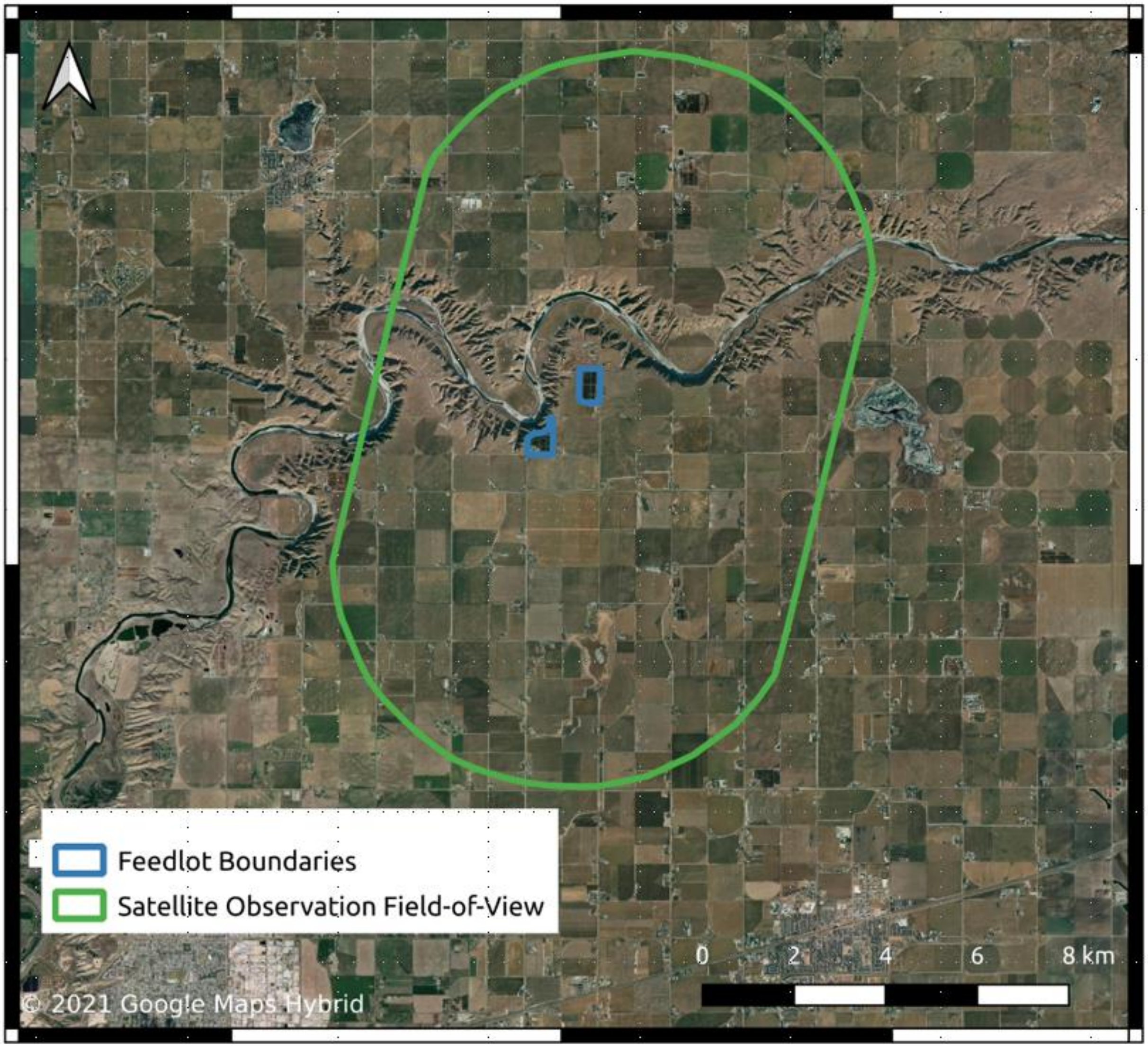


Figure 9: Observation Extent of the SE Alberta Feedlot Sites

Since the beginning of the satellite monitoring program, 62 satellite observations have been attempted at these feedlots by GHGSat. 31 of the of those observations have been successful, while 31 have failed due to inadequate weather conditions. No emissions were detected from these feedlots during the program.

3.3.1.4 Alberta Duverney Oil and Gas Area

GHGSat attempted satellite observations in Alberta's Duvernay Gas Field. The typical extent of a satellite observation at this site can be seen in Figure 10.

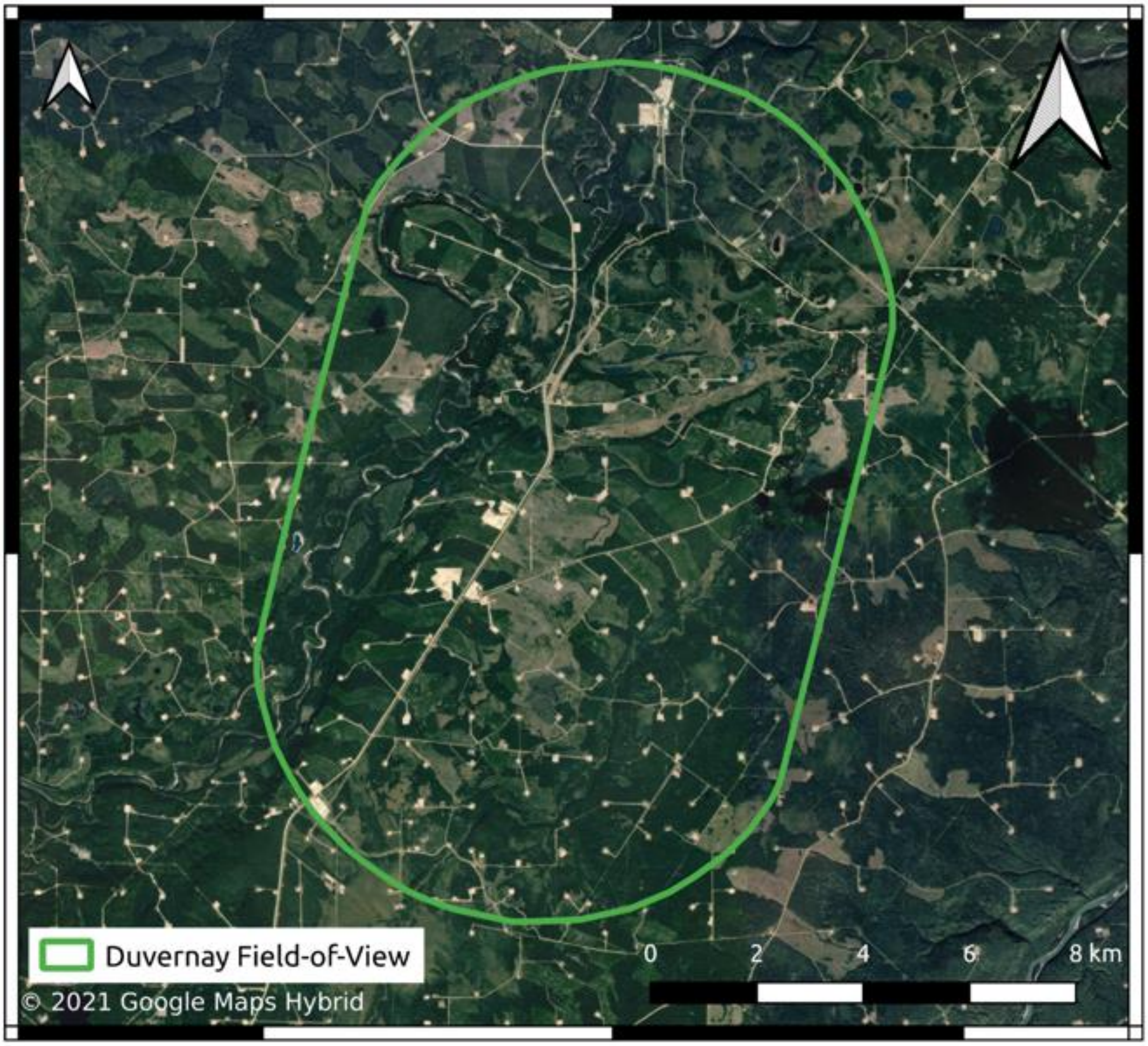


Figure 10: Observation Extent of the Duvernay Gas Field site

Since the beginning of the satellite monitoring program, 80 satellite observations have been attempted at the Duvernay Gas Field by GHGSat. 26 of the of those observations have been successful, while 54 have failed due to inadequate weather conditions. No satellite emissions were detected from the Duvernay Gas Field.

3.3.2 Aircraft Observations

During the months of July 2020 and June 2021, GHGSat completed a series of airborne methane campaigns over potential methane emitting sources throughout Alberta. Observations were acquired using GHGSat's own aircraft variant instrument referred to as GHGSat-AV1. Over 400 km^2 were surveyed with GHGSat-AV1 as part of the ERA project. Flights were conducted during predicted low wind speeds on the ground and the observations were made at flight altitudes ranging from 6,600 to 10,000 feet (ft) above-ground level (AGL).

3.3.2.1 Athabasca Oil Sands

The Athabasca Oil Sands campaign comprised of multiple survey blocks planned across project participant assets. The airborne flight-blocks targeted the same sites of interest as for the satellite monitoring, as shown in Figure 7. Observations were acquired over approximately 30 flight lines on June 13th and 14th, 2021, which covered an area of approximately 70 km^2. Flights were conducted at an altitude of 6600 feet (ft) above-ground level (AGL). An example Methane Concentration map from the campaign can be seen in Figure 6 (above).

3.3.2.2 Alberta Oil & Gas Field

The Alberta Oil & Gas area demonstration was comprised of several survey blocks that covered resources attributed to one of the project partners throughout the region (Figure 11). Observations were acquired over 11 flight lines on July 22nd, 2020, and July 26th, 2020 that covered an area of 325 km^2. The flights were conducted at a flight altitude of 10,000 feet (ft) above-ground level (AGL). A photos taken with the AV1 auxiliary camera of an oil & gas site during the Alberta campaign can be seen in the following figure.

Figure 11: AV1 auxiliary visible image of a site in the Alberta Oil & Gas Field acquired during the AV Flight Campaign – July 2020

3.3.2.3 Alberta Landfill

The Landfill program was comprised of a single survey block that covered the entire extent of an urban Alberta landfill site (Figure 12). Observations were acquired over four flight lines on July 26th, 2020, that covered an area of 10 km^2. Flights were conducted at a flight altitude of 10,000 feet (ft) above-ground level (AGL). A photo taken with the AV1 auxiliary camera of the landfill during flight can be seen in the following image.

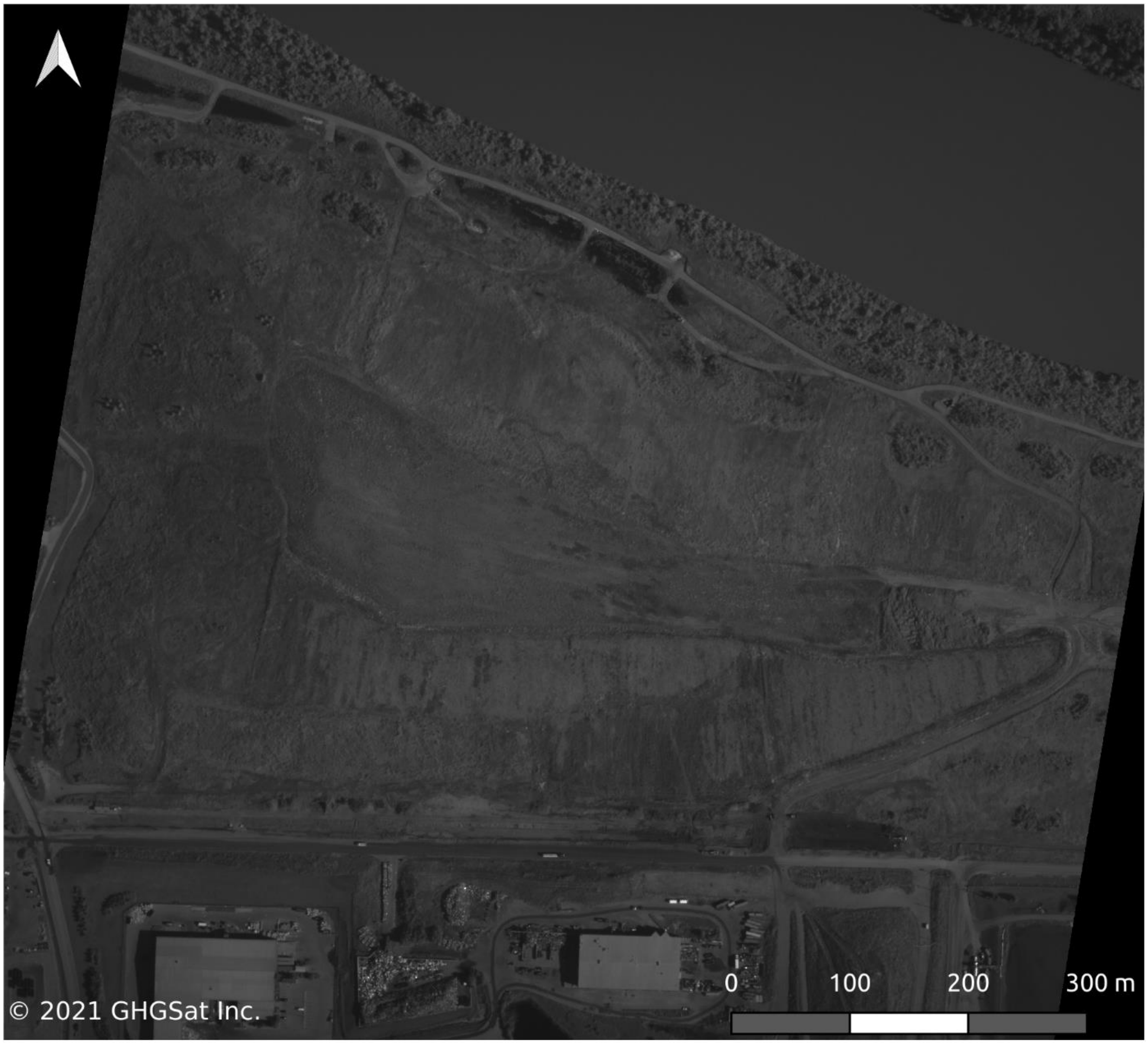


Figure 12 : AV1 auxiliary visible image of the project landfill acquired during the AV Flight Campaign – July 2020

3.3.2.4 SE Alberta Feedlots

The agricultural feedlot program was comprised of a single survey block that covered two feedlots in SE Alberta (Figure 13). Observations were acquired over four flight lines on July 22nd, 2020, covering an area of 5 km^2. Flights were conducted at a flight altitude of 10,000 feet (ft) above-ground level (AGL). A photo taken with the AV1 auxiliary camera of one of the feedlots can be seen in Figure 14.

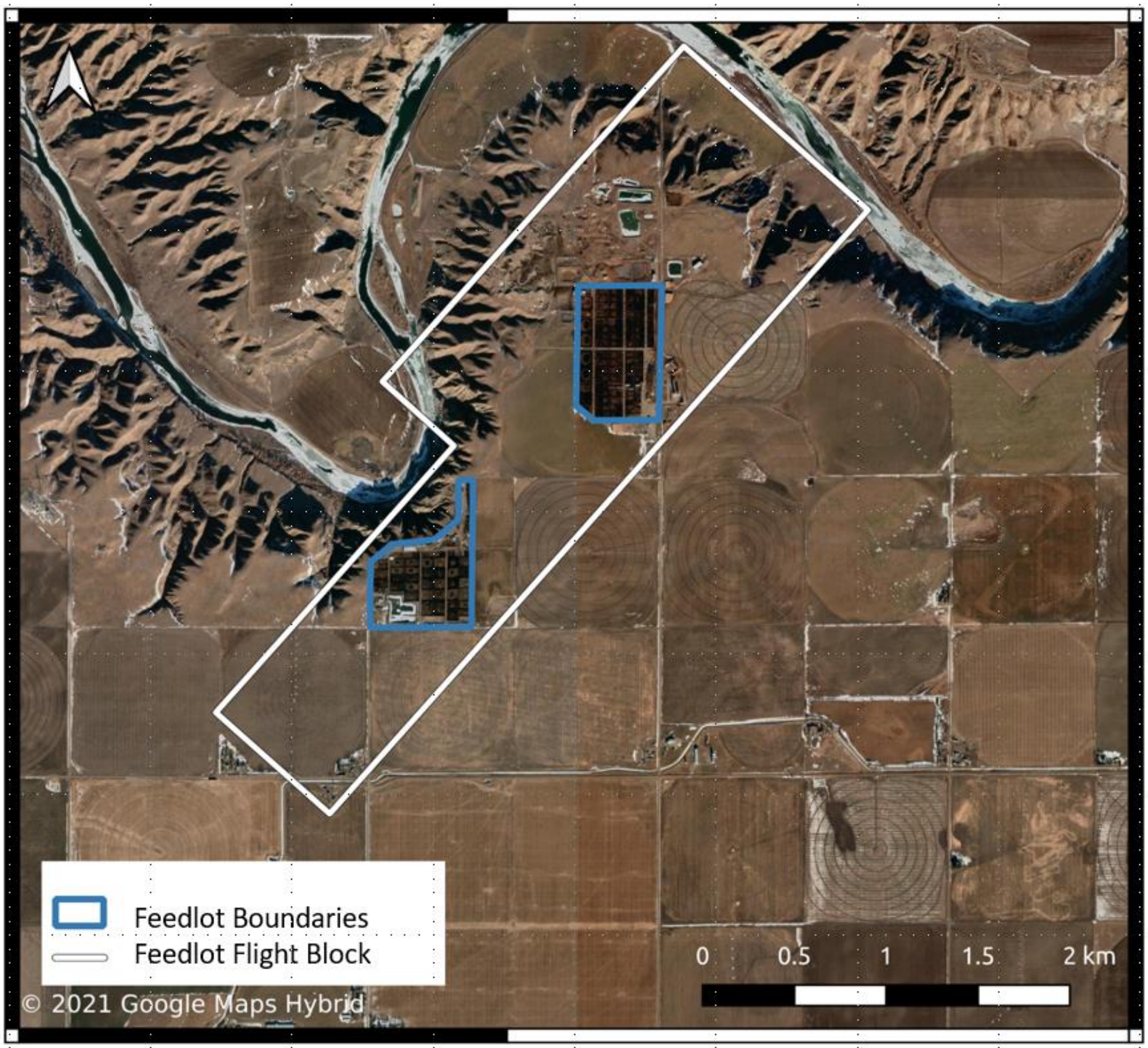


Figure 13: SE Alberta Feedlots Campaign Overview – July 2020

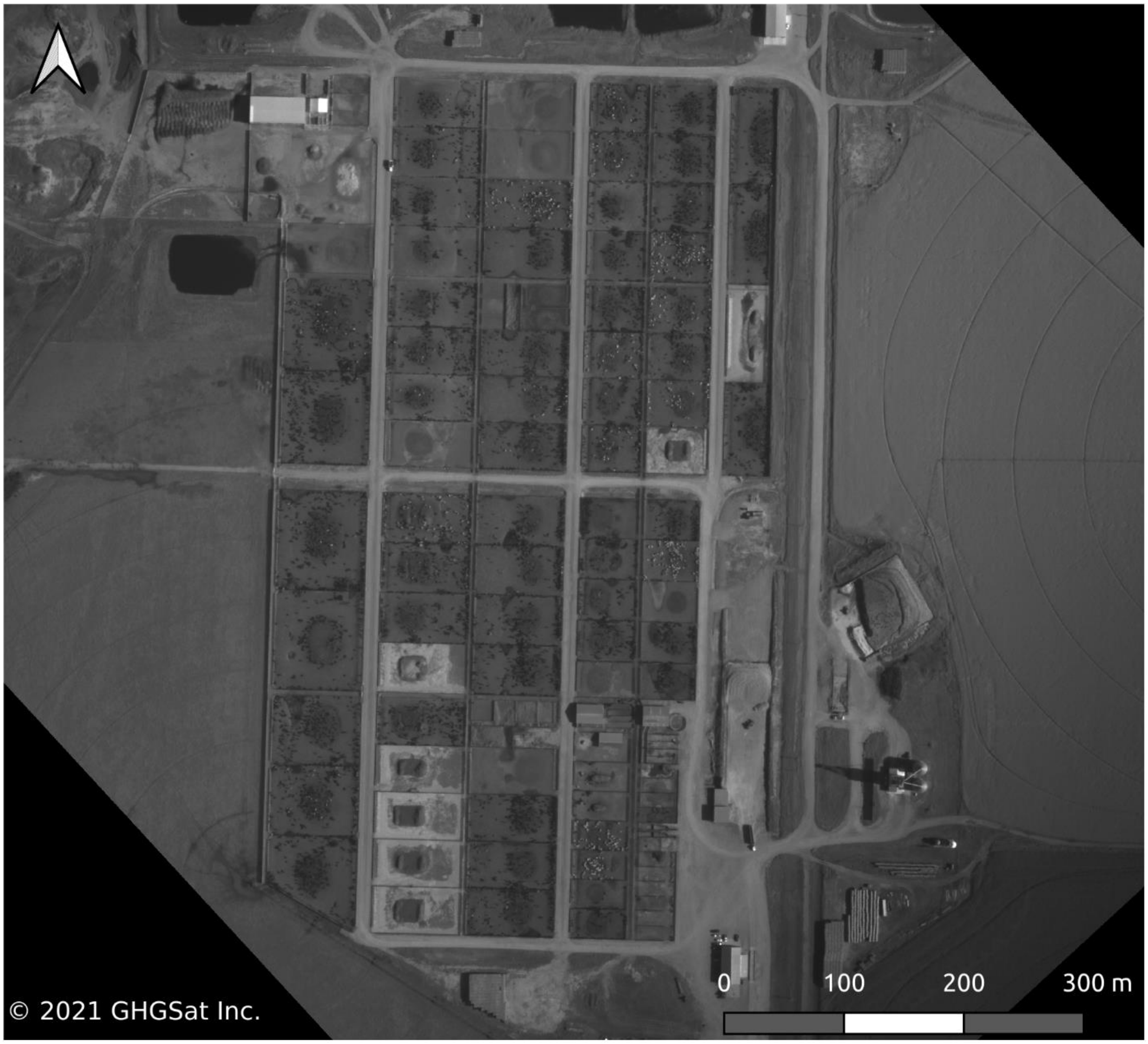


Figure 14: AV1 auxiliary visible image of one of the SE Alberta Feedlots acquired during the AV Flight Campaign – July 2020

3.3.3 Controlled Releases

3.3.3.1 GHGSat-C1 Controlled Releases

Since the inception of GHGSat's commercial constellation in September 2020, GHGSat has executed a series of controlled releases for calibration and validation purposes. The main purpose of this activity is to verify the detection threshold of our satellites and check the calibration of our full retrievals process, from raw images to source rate estimates. It also gives us benchmark data against which to carefully study the properties of our retrievals and optimize their performance. Another benefit is to help our customers and other stakeholders understand the performance of our system better and thereby build confidence

The concept of the controlled release test is to release a steady, metered flow of methane from a point-like source for a sufficient period of time leading up to an acquisition sequence by one of GHGSat's satellites. Most of the controlled releases in this report were organized and conducted by GHGSat personnel from a site in southern Alberta, Canada. However, in some cases the release on the ground was run by a third party – such that GHGSat was blind to the specific location of the release as well as the release rate.

The compressed natural gas (CNG) is acquired off-site and brought to the release site using a trailer that is equipped with 16 large-volume, high-pressure tanks. The composition of the natural gas is analysed in a laboratory to determine the methane fraction of the CNG. During the controlled release, the pressure of the gas is regulated before it passes through a calibrated, differential-pressure flow meter which measures the flow rate (or emission rate). The flow rate is increased or decreased by adjusting the pressure regulator. The gas then passes through a gas conditioner which conditions the gas to the current ambient conditions. Finally, the methane travels to a 5-meter vertical stack and is expressed to the atmosphere. There is a high-resolution ultrasonic anemometer on site that measures the 3D wind vector.

Based on analysis of controlled release tests using GHGSat-C1 and GHGSat-C2 from September 2020 through May 2021, we infer that (a) our retrieval system is well-calibrated and (b) we have achieved our target detection threshold.

3.3.3.2 GHGSat-AV Controlled Releases

Since the first flight of the aircraft instrument in December 2019, GHGSat has successfully completed numerous commercial campaigns throughout North America. Additionally, we have performed 125 independent airborne measurements of controlled releases where the gas composition and emission rates were known. Most of the releases have been performed by GHGSat at a location within SE Alberta.

GHGSat has performed controlled release campaigns for the GHGSat-AV instrument in: February, March, and September 2020, as well as March 2021. These campaigns were performed at a variety of altitudes with a range of sensor acquisition parameters, and with varying surface winds, illuminations conditions, and ground cover (i.e. different times of year with variation in vegetation and snow).

Controlled releases of methane were performed at varying surface winds and illumination conditions, and at different times of the year. Additionally, during the controlled release campaigns, the sensor was flown at different above-ground altitudes between 3,000 ft and 10,000 ft AGL using a range of sensor acquisition parameters.

The methane release rates are measured using advanced differential pressure flow meters and mass flow controllers. The compressed natural gas is stored in tanks and is conditioned to ambient conditions prior to being metered. The gas composition is analyzed in the laboratory to determine the methane fraction.

The data is resultant of all 125 independent controlled release airborne measurements where the released gas composition is known, the release rate metered, and anemometer data recorded within 100 m of the controlled release point. A minimum detection limit has been determined for the GHGSat-AV system which meets the expected system performance requirement.

The methodologies, instruments, data collection procedures, and data have been reviewed and corroborated by multiple organizations and a team of scientists. Variables that may influence the results are surface albedo, ground cover, ground terrain, solar zenith angle, surface winds, meteorological conditions, and airplane turbulence.

3.3.3.3 Satellite – Aircraft Combined Controlled Releases

GHGSat has also performed controlled releases that have been concurrently imaged by GHGSat-C1 and our AV instrument. For example, Figure 15 shows methane concentration maps from the satellite and airborne instruments for a controlled release of CNG that was performed in Alberta on September 15, 2020. In order to develop the plume, the CNG release started several minutes prior to the satellite being overhead. The aircraft instrument measured the methane plume immediately preceding and following the satellite measurement. The winds were shifting during the controlled release, which is corroborated visually by the comparison of the satellite and aircraft methane plume shapes.

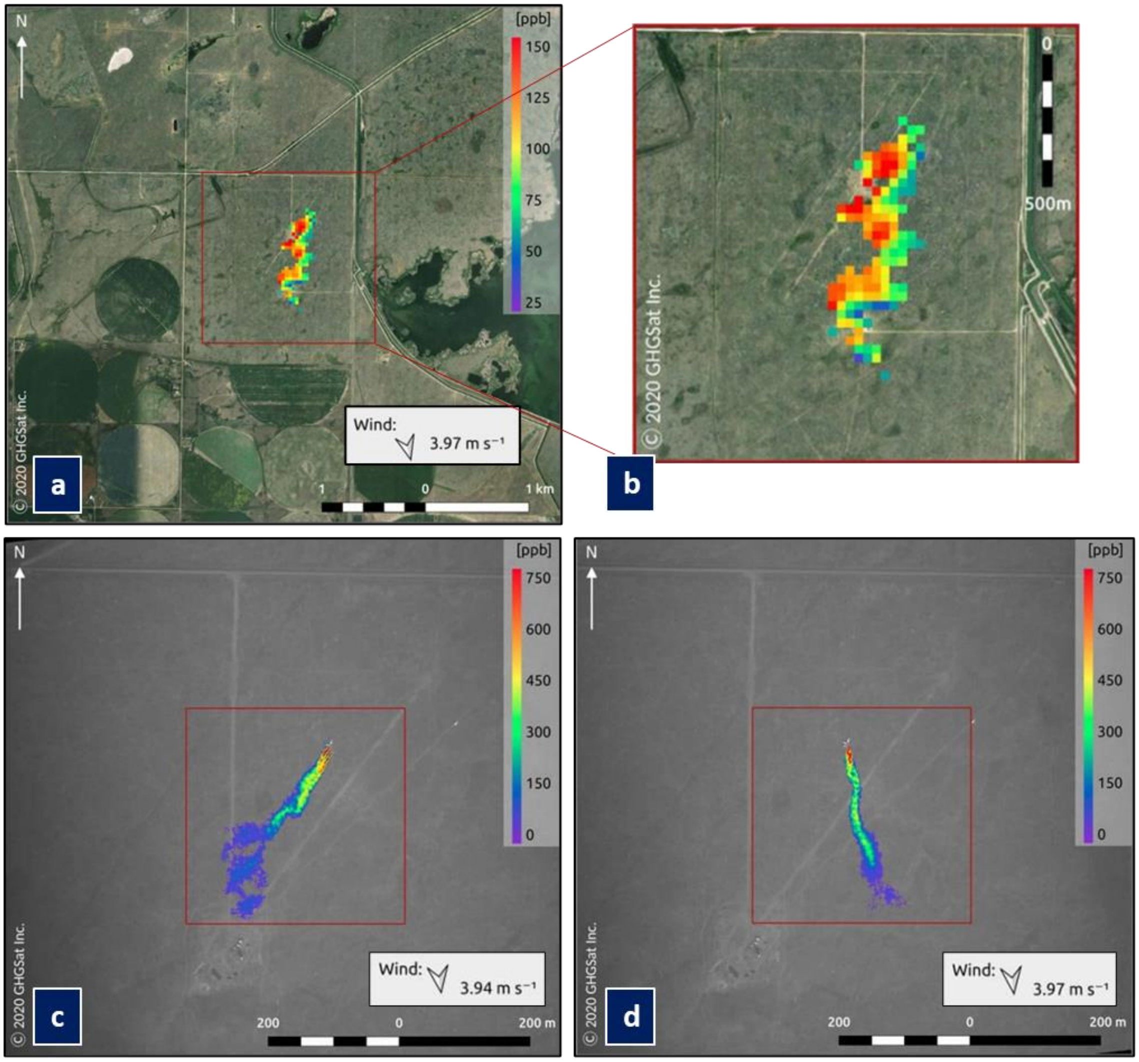


Figure 15 : Satellite (GHGSat-C1) and airborne (GHGSat-AV) instrument measurements of a controlled release of compressed natural gas is conducted in Alberta on September 15, 2020. (a) GHGSat-C1 CH4 column-average concentration measurement in excess of local background (Timestamp: 18:31:58.00 UTC). The background is Google map data. (b) Zoomed area highlighted by a red box in (a). (c) GHGSat-AV column-average concentration measurement in excess of local background for the same controlled release in Alberta, Canada (Timestamp: 18:27:49 UTC). The background image is visible light reflectance from GHGSat-AV monochromatic auxiliary camera. (d) GHGSat-AV concentration map but later in time. (Timestamp: 18:32:26 UTC).

Ground measurements of the controlled release confirmed an emission rate of 260 kg CH_4/hr. The mean emission rates for all measurements were calculated using the Integrated Mass Enhancement (IME) technique of reverse dispersion modeling and were in good agreement with the ground measurement, where most of the uncertainty is associated with the wind data.

3.3.4 Hybrid System Performance and the Alberta Context

The main project objective was to develop satellite-aircraft hybrid system utilizing a commercially-relevant satellite and prototype aircraft system, and to perform a multi-site demonstration of the system. GHGSat has been able to meet that objective both technically and operationally. The technology itself has progressed to higher TRL levels in this project and key performance metrics were achieved, as shown in Table 1 and Table 2. Section 3.3.3 above provided a summary of the controlled release campaigns for both satellite and airborne instruments, and the data verified that the expected detection thresholds of the instruments were achieved during this project period.

Only one emission was found as part of the demonstration of the satellite-aircraft hybrid system. The emission that was detected was observed using the GHGSat-AV airborne instrument and was presented in section 3.1. No emissions were detected at the project sites with GHGSat-C1 satellite instrument. Having only one emission detected is lower than the project expectations. Based on the results from the controlled release studies presented above we have confidence that the system was functioning up to the expected performance levels throughout this project. Furthermore, outside the scope of this project, a similar demonstration of the satellite-aircraft hybrid system in the Permian basin in Texas and New Mexico, USA, demonstrated that GHGSat's hybrid system can measure substantial emissions from oil and gas industrial sites.

Larger leaks, the type that a satellite-aircraft hybrid system is designed to address, are infrequent by nature, yet these larger leaks contribute the majority of the methane emitted by volume. Therefore, timely monitoring for larger leaks remains an important goal for operators. GHGSat plans to grow the satellite constellation to include three additional satellites in 2022. Furthermore, the higher latitude location of Alberta results in more potential observation opportunities for sun-synchronous polar-orbiting satellites. Therefore, as more satellite observations are acquired and airborne campaigns are flown in the province, the increased sampling of the province's methane profile will yield more emissions detected.

Furthermore, it is important to note that measurements of target scenes with no detected emissions are still communicating important information to customers: namely, that there are no emissions at the imaged targets larger than the detection threshold of the system at the time of observation. This provides confidence to

Alberta industries and operators that there are no sizeable leaks from their infrastructure being monitored.

In summary, GHGSat's satellite-aircraft hybrid system has met its technical objectives in terms of performance, and it is an effective and important tool that Alberta-based operators can utilize as part of their methane emissions management programs.

3.4 Key findings and challenges

At the sites measured as part of this report, GHGSat did not find any methane emissions using GHGSat-C1 satellite, and only one emission using the aircraft instrument. No emissions were measured in the agricultural (i.e. feedlots) sector nor the waste management (i.e. landfills) sector in Alberta during this program.

The verification campaigns involving controlled releases have confirmed that GHGSat's satellite and aircraft instruments have met their respective detection thresholds. Furthermore, the satellite-aircraft system has been successfully demonstrated other airborne and satellite projects in the province of Alberta and around the world.

In the US Permian basin, for example, GHGSat performed a Satellite-Aircraft hybrid survey in West Texas and New Mexico in Q4 2020. Figure 16 shows separate examples of GHGSat-C1 and AV measurements from that campaign along with aggregated results in Figure 17.

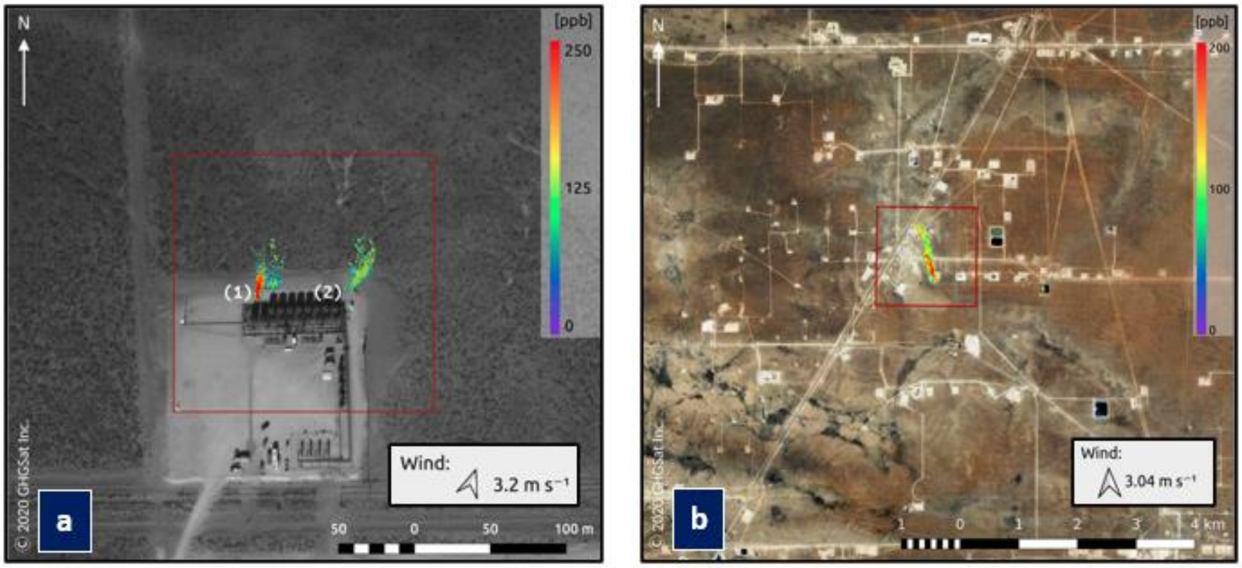


Figure 16 Concentration maps for emissions detected at sites in the Permian basin: (a) Methane concentration plumes observed with GHGSat-AV airborne instrument overlaid on visible light reflectance image acquired at the same time with the onboard auxiliary camera; (b) Methane concentration plume observed with GHGSat-C1 satellite displayed on Google Maps background data.

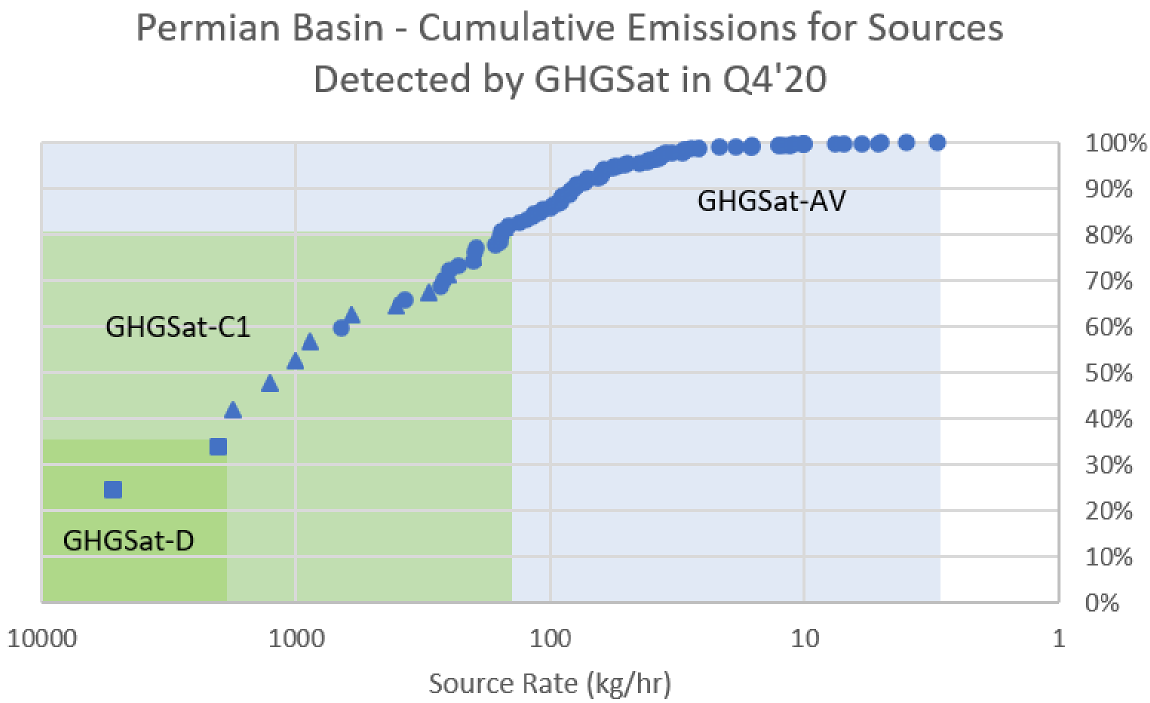


Figure 17. Cumulative emissions distribution for sources measured by the satellite-aircraft hybrid system in the Permian basin. The coloured boxes indicate the detection threshold ranges of the instruments.

The cumulative emissions for sources detected from both satellite and airborne data show a representative distribution to Brandt et al. (2016)[2] and would indicate nearly 90% of emissions by volume are detected using the hybrid system based upon our detection thresholds and measurement results in the field. Frequent high resolution GHGSat-C1 monitoring detected 13 unique leaks accounting for 80% of the cumulative volume of methane detected with a hybrid model. GHGSat-AV1 flight campaigns detected 68 unique leaks detected accounting for the remaining 20% of leaks by volume. This is an expected result based on the long-tailed nature of the distribution of oil and gas leaks. Exact emission rates do have inherent uncertainty as a result of wind speed and direction measurements.

Several verification campaigns using controlled releases were performed during this period, confirming GHGSat's satellite and aircraft detection thresholds. While analysis is incomplete with a limited sample size, these preliminary results suggest that the emissions profile in Figure 17 from US facilities is different than that

[2] Bandt, A. R., Heath, G. A., and Cooley, D. (2016). Methane leaks from natural gas systems follow extreme distributions. *Environmental Science & Technology* **50**, 12512–12520. doi:10.1021/acs.est.6b04303

measured in Canada and methane emissions from oil & gas facilities in Canada have lower leak rates than those from the US sites represented in Figure 17.

3.4.1 Commercialization

GHGSat has successfully developed the satellite, aircraft and analytics technologies, as well as the resulting satellite-aircraft hybrid services, envisioned in the project proposed to ERA in 2017.

Project performance metrics for spatial resolution, methane precision and geolocation accuracy have been met and even exceeded, leading to detection thresholds of 100 kgCH_4/hr and 10 kg CH_4/hr for the satellite and aircraft sensors, respectively.

GHGSat's satellite-aircraft hybrid system, developed with the support of ERA, has been offered for commercial service in North America since summer 2020, and is now being offered for the first time in Australia and Europe for service in 2022.

GHGSat successfully raised equity investment since the start of its project with ERA. By the end of 2023, GHGSat will have 12 satellites in orbit (1 demo, 10 methane, 1 carbon dioxide), 2 aircraft sensors, and offices in Calgary, Houston, Ottawa, London (UK) and Montreal.

Nevertheless, significant challenges must still be overcome for GHGSat to achieve its full potential, particularly in Alberta and Western Canada.

- Detection threshold: GHGSat's satellite and aircraft sensor detection thresholds were designed to detect up to 90% of methane emissions by volume, based on scientific literature available at the time of their design. Ongoing research now suggests that while these thresholds are appropriate for the United States and many other parts of the world, they may be higher than desired to meet some commercial and regulatory objectives in Alberta and the rest of Canada. Modelling efforts are taking place to define alternatives to utilize GHGSat's hybrid offering in these areas.
- Area sources: GHGSat's satellite and aircraft sensors are designed for detection of point source emissions. Area sources (e.g. landfills, feedlots, oil sands tailings ponds) aggregate smaller emissions per unit surface area into more significant total emissions across their large area. These are therefore more difficult for GHGSat to detect, and more work is required to improve area sources emissions retrievals.

- Competition: GHGSat is still the only satellite operator in the world with the capacity to detect emissions from individual facilities at an actionable resolution and threshold. However, there are other satellites that can detect large emissions. Also, new entrants in satellite, and particularly in aircraft methane detection, are increasing competition.

3.4.2 Lessons Learned

As the first demonstration of GHGSat's satellite aircraft hybrid system, several lessons have been learned from this project.

- The Alberta methane emission profile from oil and gas assets is lower when compared to the US permian basin profile. This result is encouraging as it showcases that the regulatory environment in Alberta and the industrial best practices being utilized by Alberta operators are working towards the goal of reduced emissions of greenhouse gases from industry.
- Top-down technologies screening for large methane emissions provide value even when emissions are not detected. They provide a backstop for operators to have strong confidence that no large emissions exist within their sites where one large leak can undermine the gains being achieved as part of LDAR and FEMP programs for more frequent smaller leaks. However, detection threshold that allows for more plumes to be found brings value to customers as it can be perceived to have more actionable value than just a backstop alone.
- From discussions with the industrial operators apart of this project, as well as other stakeholders in the oil and gas sector, it has become clear that compliance to the regulatory environment is one of the key factors for operators when considering alternative screening and quantification technologies. Therefore, demonstrating equivalence to the regulatory benchmarks becomes an important criterion to consider as GHGSat continues to develop and improve the satellite-aircraft hybrid system.
- Three types of sites within this project are better characterized as "area-sources" (landfills, feedlots, and tailings ponds within the oil sands sites) as opposed to point sources. Further developments to GHGSat's satellite-aircraft hybrid systems in the context of area would help move the value proposition forward for operators in these industries.
- Controlled release campaigns play an important role for verifying and validating system performance and providing confidence to customers.

In summary, analysis and review of this project has helped GHGSat learn from this experience and incorporate the learnings into improved procedures, designs and technical developments that have helped move GHGSat and the quality of our services forward.

4.0 Greenhouse Gas Benefits

GHGSat is detecting methane emissions worldwide on a regular basis, as summarized for Q2 2021 in Figure 18, which was released publicly in July 2021. In the first half of 2021, GHGSat has mitigated over 600 ktCO2e in emissions worldwide. Although the direct impact of emission reductions in Alberta are limited with only one detection, the impact globally has been significant and will continue to increase as we add aircraft variant instruments, and our constellation of satellites grows.

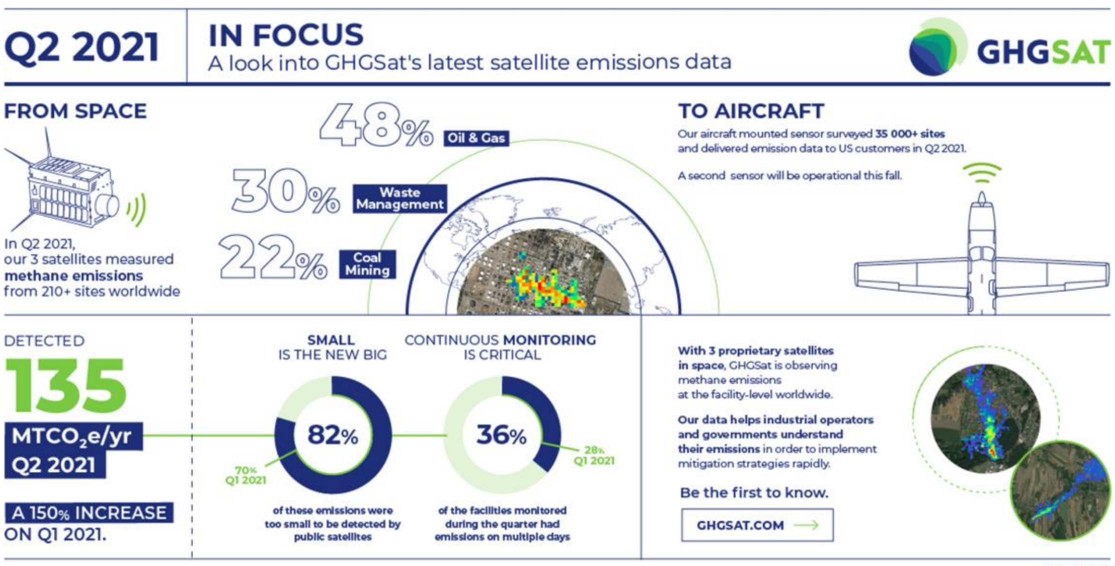


Figure 18 : GHGSat's Q2 2021 Emission Detection Summary

Through GHGSat's various technologies and working with Alberta clients we will provide cost effective solutions for a tiered methane monitoring solution through analytics, satellites, and aircraft to ensure Alberta continues its performance as a world leading jurisdiction with respect to methane emissions.

GHGSat's satellite-based system enables environmental benefits across several market segments.

- CH4 from Oil & Gas (Upstream): More frequent monitoring with a combination of satellite and aircraft ("Satellite-Aircraft Hybrid") enables faster repair.
- CH4 from Oil & Gas (Midstream): More frequent monitoring of compressor stations using satellites enables faster repair.

- CH_4 from Landfills in OECD countries: Monitoring of changes in methane emissions due to unplanned incidents (fire, equipment failure, etc.) enables faster repair.
- CH_4 from Landfills in non-OECD countries: Monitoring of methane emissions motivates installation of gas recovery systems.
- CH_4 from Coal mines in non-OECD countries: Monitoring of methane emissions motivates installation of gas recovery systems.
- CO_2 from Industrial Facilities: Monitoring of GHG emissions (primarily CO_2) provides better knowledge to financial services of the environmental risk associated to their investments.

GHGSat projects emissions reductions of 345 MtCO2e/yr within 10 years. The methodology used by GHGSat was reviewed by an independent environmental firm, the Delphi Group.

5.0 Economic Impacts

GHGSat promised to generate economic benefits in Alberta by (i) creating high-quality employment opportunities in a new office in Alberta, (ii) driving satellite-aircraft hybrid business growth from its new office, (iii) developing strong operational and reseller relationships with its Alberta partners, and (iv) advancing its technology through academic collaboration in Alberta.

GHGSat has delivered on its promises.

Employment Opportunities in Alberta

GHGSat's Calgary office is responsible for commercializing GHGSat's satellite-aircraft hybrid capability. This has already resulted in six (6) high-quality, full-time jobs in technology development, data processing, and business development (targeted at oil & gas in US and Canada). In addition, GHGSat has hired its first intern in Calgary, and GHGSat's Chief Technology Officer works part-time from Calgary to provide regular senior management support.

GHGSat will continue to hire technical, business development and management resources to scale the Calgary office with successful commercialization. The technical resources will include scientific / engineering staff (typically with advanced technical degrees and several years of experience in remote sensing), as well as data processing staff (typically entry-level technical positions for recent graduates from post-secondary institutions).

The headcount in Alberta is based on projected revenues and metrics derived from GHGSat's full business plan. Headcount in 2021 is consistent with GHGSat's original proposal of seven resources, and GHGSat remains on track for the projected 21 resources by end of 2027.

Economic Benefits

Business Growth

GHGSat intends to operate its Calgary office as a profit center, which will give GHGSat's Alberta management full responsibility for office growth. The proposed project has also helped build up technical and science capacity in Alberta for four key areas. Specifically:

- Engineering integration of the aircraft variant with various aircraft platforms is led from Alberta.

- Satellite-aircraft hybrid analytics is supported from Alberta, enabling those responsible for the product to develop and provide value-added services to GHGSat customers.
- Post-processing support, both for satellite and aircraft platforms, is being performed from Alberta, as well as supporting post-processing work from other GHGSat offices.
- Aircraft variant design improvements are being informed by the team in Alberta, which may eventually provide opportunities for suppliers in Alberta with specialized optical, electrical and mechanical systems expertise to participate in GHGSat's supplier base.

The business development team in Calgary is initially focusing on oil & gas opportunities in Alberta, with some exposure to the US and international oil & gas markets.

Operational Partners

GHGSat's satellite-aircraft hybrid system will also benefit its operational partners in Alberta. Remote sensing measurements will need to be verified, both for the proposed demonstrations and for ongoing validation of system performance over time. GHGSat values associations with such groups as the Petroleum Technology Alliance of Canada (PTAC), Sundre Petroleum Operators Groups (SPOG), as well as local partners such as the Containment and Monitoring Institute (CaMI) who are providing support to GHGSat's remote sensing verification and validation efforts.

In the medium-term, GHGSat expects to expand its relationships with its operational partners to include the resale of GHGSat products and services. Schlumberger, for example, can multiply GHGSat's direct sales force both in Alberta, and internationally.

Academic Collaboration

As part of the project, GHGSat worked with the Southern Alberta Institute of Technology (SAIT) to develop new georeferencing technology.

Industry & Community Relations

GHGSat supports the development of strong Canadian space and clean technology industries. The Canadian Space Agency introduced GHGSat as a mentor to an Alberta satellite start-up, and GHGSat intends to continue supporting the development of space and greenhouse gas remote sensing capabilities in Alberta.

6.0 CONCLUSION

GHGSat is pioneering the use of satellites for detection and quantification of methane emissions from industrial facilities and has leveraged its technology into a satellite-aircraft hybrid system.

The ERA project successfully implemented this system and deployed it to four unique methane emitting industries (oil sands, oil and gas wells, agriculture, and waste management) in Alberta.

Through the course of the project, one (1) methane emission was detected from project sites by AV1 in the Athabasca Oil Sands. GHGSat has successfully completed numerous controlled releases verifying the performance of AV1 and C1 with respect to detection thresholds. In addition to the controlled releases, we have numerous detections in North America with AV1 and throughout the world with C1.

GHGSat continues to grow our fleet of methane detecting instruments with plans to have over ten satellites in orbit and two AV instruments deployed in 2023, all supported by GHGSat analytics. The system developed in part with support from ERA will enable GHGSat to achieve our goal of being the world leader in methane emission detection at the facility level.

7.0 NEXT STEPS

The satellite-aircraft hybrid system developed during this project will expand with an increasing fleet of satellite and airborne instruments, along with enhanced analytics services.

A second commercial satellite, GHGSat-C2, with a very similar design and performance to C1, was launched from Cape Canaveral aboard a SpaceX Falcon 9 rocket on January 24th, 2021. Following the launch and satellite commissioning phase, C2's performance is meeting expectations, and doubles our observational capacity. Three additional satellites are being planned for a 2022 launch, with another six satellites in following years.

The next airborne instrument, GHGSat-AV2, has been completed. Delivery of this instrument has occurred in late-September of 2021, and initial test flights were performed in early October 2021. This instrument has a similar design to AV1, thereby doubling observational capacity for flight campaigns. An additional airborne instrument is also being planned for 2023.

Alberta Context

GHGSat is currently involved in a project with a federal government agency for satellite methane monitoring of various locations throughout Alberta. Additionally, we have imminent contracts with Alberta-based groups to utilize our analytics service, SPECTRA – Emission Analytics, to compare Alberta's methane performance to similar jurisdictions globally and to trend performance over time. Finally, GHGSat continues to pursue several opportunities with our suite of offerings with operator clients.

EMISSIONS REDUCTION ALBERTA	**Project Emissions Reductions**	**ID: F0160114**
Recipient Organization	GHGSat Inc.	
Title	Satellite-Aircraft Hybrid Detection and Quantification of Methane Emissions	

GHG Emission Reductions (ERs): 2011–2050

2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	0
2022	0
2023	0
2024	0
2025	0
2026	0
2027	0
2028	0
2029	0
2030	0
2031	0
2032	0
2033	0
2034	0
2035	0
2036	0
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2038	0
2039	0
2040	0
2041	0
2042	0
2043	0
2044	0
2045	0
2046	0
2047	0
2048	0
2049	0
2050	0

Please Refer to ERA’s Website For the Quantification Methodologies
https://www.eralberta.ca/calculating-ghg-emissions-reduction/