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Mapping CO2 And CH4 Emissions: Field-Trial Evaluation Of LightSource For Remotely Estimating The Locations And Mass Emission Rates Of Sources

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Summary

We describe and report the field performance of LightSource, a Shell proprietary technique for remotely detecting and locating multiple gas emission sources and simultaneously estimating their individual mass emission rates. The system was originally developed to provide atmospheric monitoring over the Quest CO2 storage site in Canada. It operates automatically using a ground-based optical sensor and is suited to continuous area monitoring. This new work supports enhanced CO2 source detectability by exploiting any naturally present CH4 released through CO2 migration in the subsurface. In these tests, we use a radically new open-path optical beam gas sensor based on Laser Dispersion Spectroscopy, LDS, which offers substantial operational advantages over the commercially available sensors we have used previously. We report on the method and performance achieved during 17 calibrated methane gas releases at the Chilbolton Observatory test site in the UK. The resulting concentration and wind data were processed using our LightSource code.

Introduction

We describe and report experimental results for a new gas emission survey method, called LightSource, for detecting and locating multiple gas emission sources and simultaneously estimating their individual mass emission rates. The method has successfully been deployed at the Quest CO_2 storage site, Alberta, since 2015 (Hirst, 2017a). We now extend the application to other gases such as methane. Two novel aspects of our approach are: our solution of the associated inverse gas dispersion problem using Markov chain Monte-Carlo techniques within a Bayesian framework (this provides us with confidence bounds on all results, such as locations and mass emission rates). The second is our use of a prototype open-path gas sensor developed by MIRICO Ltd and based on Laser Dispersion Spectroscopy (LDS) rather than absorption spectroscopy; as used by all commercially available open path gas sensors. LDS offers dramatic improvements in sensor precision, linearity, available beam lengths, speed of measurement and immunity to common sources of measurement noise: such as the confusion of optical transmissivity variations (resulting from beam misalignments, rain, fog, snow and atmospheric scintillation) with concentration changes.

The advantages of the LightSource approach over other approaches such as the GreenLite Ground Remote Sensing system (https://www.harris.com/solution/greenlite-ground-remote-sensing) are that the required instrumentation is simpler (fewer beams and retro-reflectors), the volumes of data lower, and our approach can cope with sources located outside of the beam array. Other methods have been tested at the Ginninderra CH_4 and CO_2 release experiment, showing the challenges and opportunities of various technologies, including the promising attributes of laser beam sensors (Feitz, 2018).

LightSource method

The LightSource method uses open path gas detectors which provide a concentration measurement averaged along the optical beam, reported as a path-averaged gas concentration (PAC) typically in parts per million (PPM). This provides a much more stable (low variance) concentration measurement than point data can, and better characterizes how much gas is present within an area. By sequentially steering the optical beam along multiple paths we can collect sufficiently detailed data that, when combined with wind data and a suitable gas dispersion model, enables inference of the location and mass emission rate of the sources responsible for the data observed. We use a Gaussian plume atmospheric eddy dispersion model as our forward model. This provides predictions of ensemble averaged concentrations across the area of interest, given mass emission rates, source locations, and wind conditions. The inverse gas dispersion problem is then solved using Markov chain Monte-Carlo techniques within a fully Bayesian framework.

Critical to the successful operation of LightSource is making rapid, high-precision path averaged gas concentration measurements along multiple beams on a shorter time scale compared to the time taken for gas to transit the area of interest. For the Chilbolton Observatory field trials reported here, we used the novel LDS gas sensor technology from MIRICO.

Laser Dispersion Spectroscopy (LDS)

MIRICO has developed an open path gas sensor using Laser Dispersion Spectroscopy (LDS), a new spectroscopic technique that provides unique advantages well suited to long open path gas sensing (Nart S. Daghestani, 2014). LDS is a novel approach for quantitative trace gas detection based on molecular *optical dispersion* measurements, not to be mistaken with *gas dispersion*. In contrast to most gas sensing methods, LDS does not measure the absorption of light by the molecules but instead detects the refractive index changes that occur when the frequency of the light is close to a molecular transition. Because LDS is essentially an optical phase detection technique, the measurement becomes highly immune to variations of optical power at the photodetector. This makes LDS ideal for long open-path remote sensing, where the received power level may strongly fluctuate due to rain, fog, humidity and atmospheric scintillation (Belal, 2018).

Controlled methane release tests

We designed a short series of controlled methane gas release tests to establish the combined performance of LightSource using data from an early prototype LDS methane sensor. The tests were executed at the Chilbolton Observatory, Hampshire, which specializes in meteorological science and is an out-station of the Rutherford Appleton Laboratory, UK (Hirst, 2017b). The intention was to perform the tests under as near ideal conditions as possible: flat terrain without major flow-perturbing obstructions.

Figure 1 shows the experimental set up: Seven beam paths between the sensor and respective retro-reflectors. The beam is steered sequentially to the seven retro-reflectors and each path is measured for about 200ms, completing a scan cycle in just over a second. For this prototype the beam scanner allowed an angular range of just 40 degrees, hence the rather narrow beam "fan" angle seen in the figure. Distributed in and around the beams are four different gas release locations, each source comprises a 2x2m frame covered in a screen that is periodically perforated with a 1cm spaced matrix of small holes. This ensures the gas is evenly emitted across the 2x2m area and enters the atmosphere without momentum that could enhance gas dispersion. The most remote source was about 100m from the sensor; gas release rates were in the range of 1-1.6kg/hr per source depending on the test. These mass emission rates were directly obtained by logging the weight of the gas cylinders during the releases; hoses of equal flow resistance connected the gas cylinders to the source(s) for each test. The test area used for these experiments was approximately 120x120m, limited by the site boundaries which were low level sparse hedges unlikely to have a significant impact on disturbing the wind over the experimental area (Figure 2).

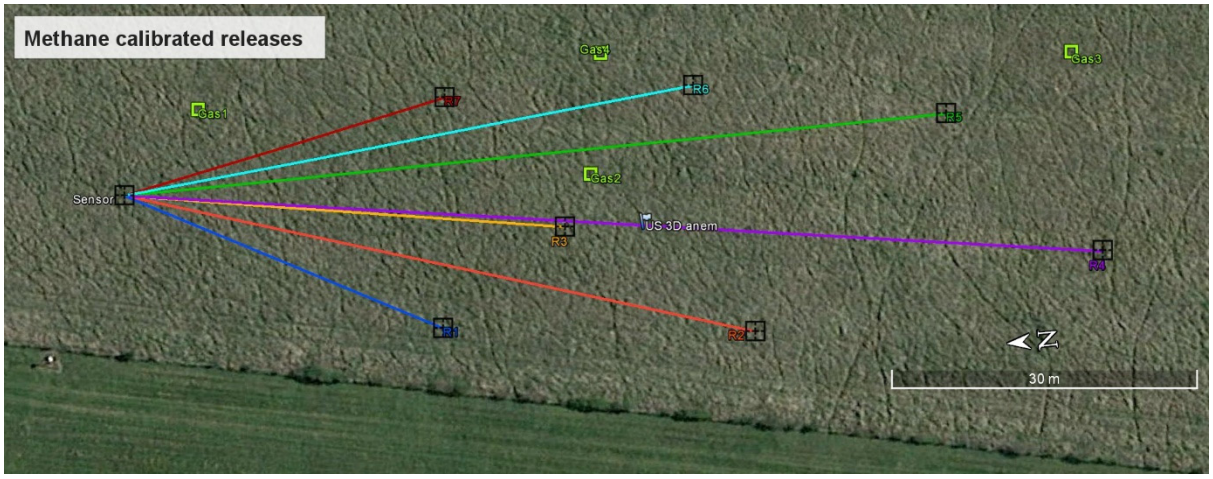

Figure 1 *Top view of the spatial arrangement of the sensor, retroreflectors, gas release locations and ultrasonic 3-D anemometer at the Chilboton Observatory Hampshire, UK. The green squares indicate gas release locations, the black boxes the retroreflector locations and the grey flag the weather station location.*

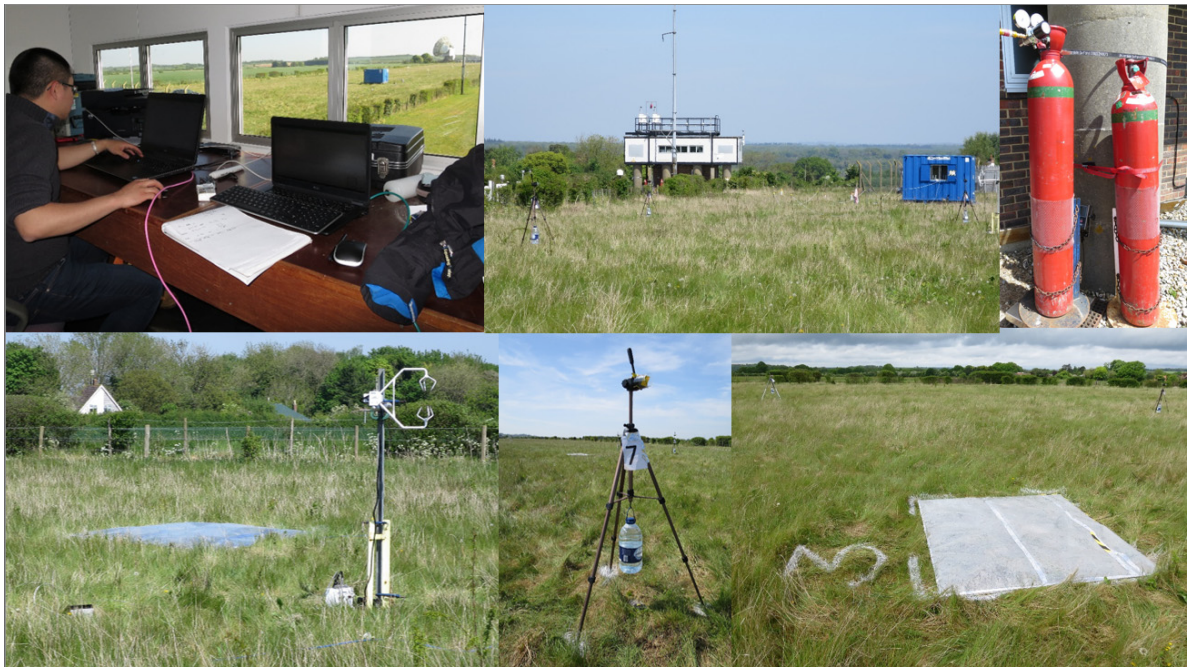

Figure 2 *Top left shows control room. Top middle is the view of control room across the test area with sensor housed in blue hut. Top right depicts the commercial grade methane cylinders standing on electronic weigh scales. Bottom left shows the Ultrasonic 3D anemometer. Bottom middle is the tripod holding a corner-cube retro-reflector, the bottle is just to prevent tripod blowing over! Bottom right is an image of the 2x2m diffuse area release frame.*

Figure 3 shows a representative example analysis plot (neither the best nor worst result of the four different release cases measured) with results from a single 2x2m source (actual location indicated by pink x) in the middle of the beam array. The location prediction was excellent; the strongest predicted peak emission rate was just ~0.85kg/hr as compared to the actual emission rate of 1.38kg/hr; however, adding the predicted supplementary adjoining sources brings the total emission very close to the actual emitted rate.

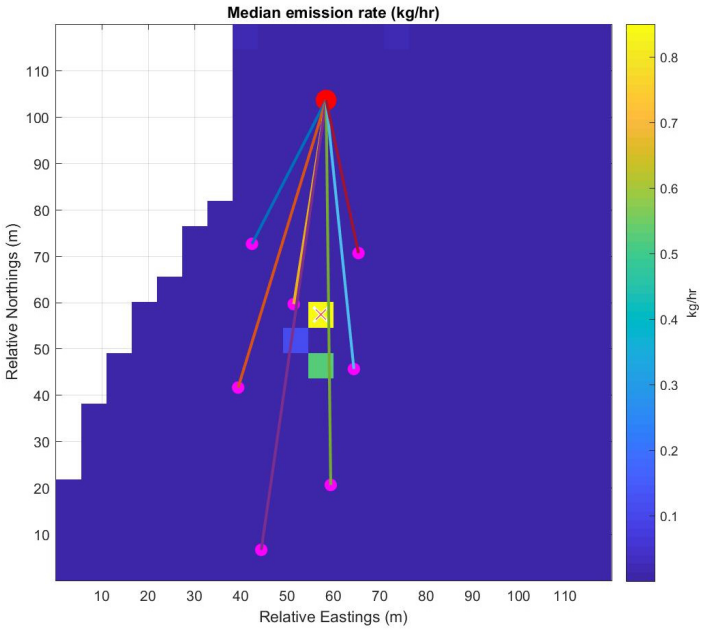

Figure 3 *Example analysis plot with results from a single 2x2m source (actual location indicated by pink x) in the middle of the beam array. The yellow square indicates the strongest estimated emission location and peak emission rate, but neighbouring cells bring total emissions very close to actual total emission rate of 1.38kg/hr.*

Conclusions

Our full experimental results demonstrate that we can distinguish and usefully estimate the individual mass emission rates of single and multiple methane sources both within and outside the beam array based on surprisingly limited changes in windspeed and direction for this simple test arrangement. The inferred locations and emission rates are consistent with the confidence estimates (presented in the full results) and most source locations were correctly identified within a few meters. Standard deviation plots of residuals revealed some optical detection saturation effects, that reduced data precision for short beams on some releases, marginally degrading those results. The LDS system has now been modified to prevent this. In future, we will simultaneously measure CO_2 and CH_4 to test the potential for using naturally present methane as a tracer for CO_2 emission enhancing source detectability.

References

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