Plume detection using a gas tracer and cavity ringdown spectrometer

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Introduction

The flux of methane (CH_4) from ruminants in New Zealand contributes significantly to the total CH_4 budget for the country. Agricultural emissions account for 50% of CO_2 – equivalent emissions, with CH_4 from livestock responsible for one-third of all New Zealand's greenhouse gas emissions.

"Top-down" techniques for determining paddock-scale methane emissions use meteorological and dispersion models to interpret concentration gradients inferred from measurements. Changes in concentration between profiles upwind and downwind of a pastoral area are ascribed to the ruminant emissions from the intervening area.

The upwind and downwind concentration values are obtained using gas chromatography on air samples collected over a period of a few hours. The samples are ideally taken at several heights from the surface up to 50 m above ground level downwind of a dairy herd. However, the emissions from the cows vary not only from animal to animal, but also from hour to hour, therefore the total emission from the herd is unknown.

Controlled releases of a gas can be employed to aid validation of dispersion models, uncertainties are reduced as the source locations and magnitudes are known, constant and stationary. However there can still be problems with this technique. These include extreme stability or instability and calm conditions resulting in the collected samples missing or near-missing the plume. Measurements need to be sampled across the whole gas plume, both vertically and horizontally.

Experiment design

The experiment took place on 3 April 2009 at Battersea in the South Wairarapa.

During the experiment the winds were generally light (maximum of 2 m/s) northeasterlies. Compressed natural gas (CNG) which is approximately 80% methane was released through equally-space holes in 1 km of 12 mm od polythene tubing distributed within a paddock area of 100 m x 50 m to simulate a herd of 150 grazing cows. Stainless-steel capilliaries were inserted in the tubing to provide equal flow rates from all point sources. Each release point was supported on electric fence standards at 1m above ground level to simulate the height of a cow head. The CNG release was controlled by a mass flow controller at a constant 0.77 standard litre/minute.

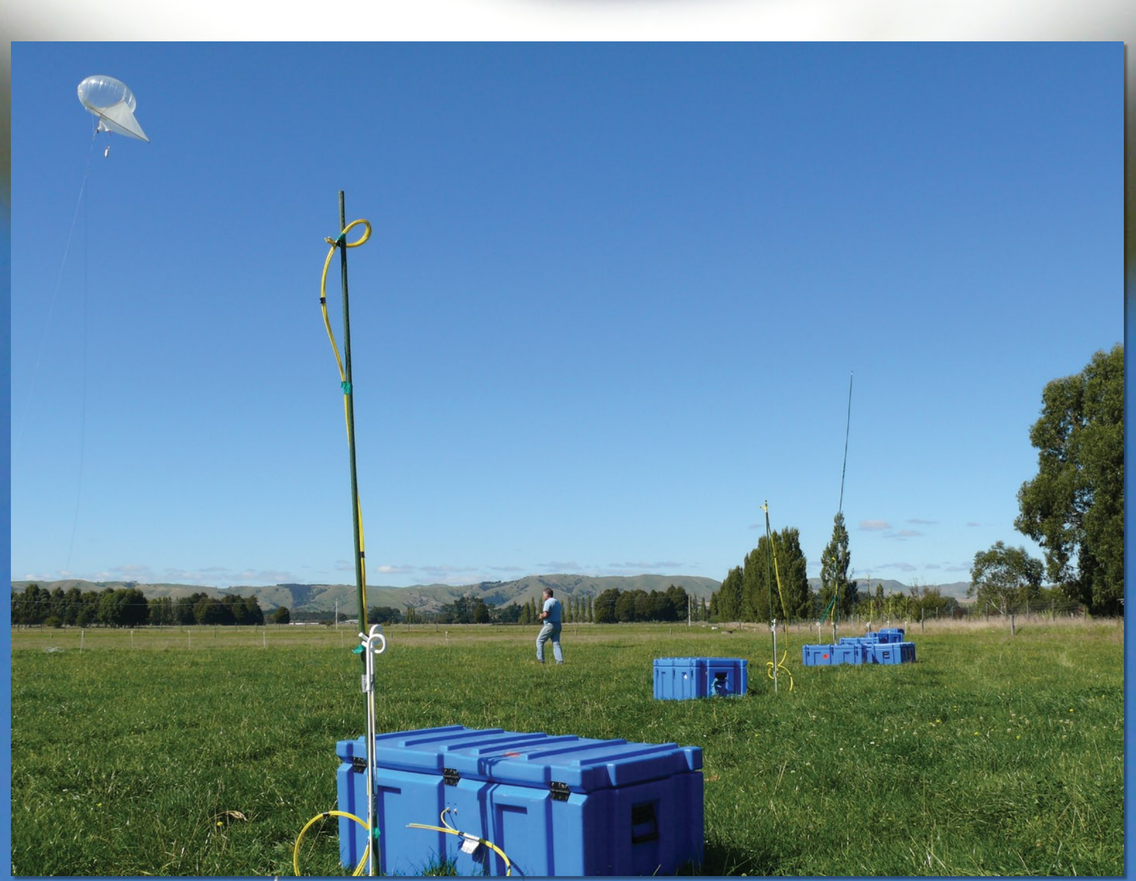
Meteorological parameters were logged from instruments located at various heights to 10 m above ground level on two masts located either side of the release array.

Sample collection and measurement

The CNG plume was sampled directly downwind of the release array using a helikite to carry a sampling tube connected to a Picarro cavity ringdown spectrometer. The helikite was moved both horizontally and vertically enabling the boundaries of the plume to be defined. A GPS receiver and tethersonde attached to the helikite allowed the position of the sampling tube to be accurately determined and meteorological data recorded at every position.

The Picarro spectrometer is a field-deployable, real-time ambient gas monitor that measures atmospheric levels of methane and carbon dioxide with ppbv sensitivity, maintaining a high linearity, precision and accuracy over changing environmental conditions. It produces real-time methane data to a precision of better than 0.1 ppbv.

Measurements with the Picarro commenced 20 minutes before the CNG release began, and continued for another 20 minutes after the release was terminated, to determine the "background" methane value.



Results

The illustration shows the CNG release array, with the tracked position of the Picarro sampling tube as it was carried aloft by the helikite downwind of the release. The broad arrow indicates the mean wind direction during the experiment. The colours indicate the extent of the plume: blue to red in the centre of the track shows the central portion of the plume with elevated CH_4 between 2.5 ppm and 2.8 ppm, the green to blue indicates CH4 between 2.1 ppm and 2.4 ppm, and orange to yellow from background 1.7 ppm to 2.0 ppm. The main body of the gas plume has been delineated quite clearly, both in the horizontal and vertical.

More traditional integrated samples were also collected using automated samplers and Tedlar bags set at fixed points on the ground downwind of the release array. The bags are usually analysed some days later in the laboratory. This method has several drawbacks: often the wind direction will change slightly and the plume will miss a sampler totally or partially, the intake heights are restricted to being fairly close to ground level, so little vertical plume structure is captured, and results are usually not confirmed for some time after the experiment has ended.

This was our first-time use of the new Picarro spectrometer for this type of work; it illustrates the potential for directly tracking gas plumes from a source and being able to follow the plume body as it varies with changes in wind direction and speed, with the added advantage of monitoring the extent of the plume in real-time.

Further experiments are planned to refine our techniques and help enable verification of trajectory model results.

The experiment was modeled using WindTrax, which is a freely available software tool (www.thunderbeachscientific.com) for simulating the transport of trace gases in the atmospheric surface layer by applying the backwards Lagrangian stochastic dispersion modeling scheme of Flesch *et al.* (2004).

WindTrax was run using the measured CH_4 concentrations from the Picarro to estimate the CH_4 emission rate from the release array. This was done for two half-hour periods, for which Monin-Obukhov similarity theory was applicable (see Flesch *et al*. 2004 for details), within the release experiment. The modeled CH_4 emissions from the array for the two periods are 1.805 kg/hr and 2.322 kg/hr. The known emission rate was 2.645 kg/hr.

Reference
Flesch, T., *et al* (2004). Deducing ground-to-air emissions from observed trace gas concentrations: a field trial, *Journal of Applied Meteorology*, 43, 487-502.