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Laser-based sensors on UAVs for quantifying local emissions of greenhouse gases

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Small unmanned aerial systems (UAS) provide an ideal platform to sample both locally near an emission source as well as within the atmospheric boundary layer. However, small UAS (those with wingspans or rotors on the order of a meter) place severe constraints on sensor size ($\sim$ liter volume), mass ($\sim$ kg), and power (10s W). Laser-based sensors employing absorption techniques are ideally suited for such platforms due to their high sensitivity, high selectivity, and compact footprint.

We have developed and flown compact sensors for water vapor, carbon dioxide and methane using new advances in open-path, laser-based spectroscopy on a variety of platforms ranging from remote control helicopters to long-duration UAS. Open-path spectroscopy allows for high frequency sampling (10-25 Hz) while avoiding the size/mass/power of sample delays, inlet lines, and pumps. To address the challenges of in-flight stability in changing environmental conditions and any associated flight artifacts on the measurement itself (e.g. vibrations), we use an in-line reference cell at a reduced pressure (10 hPa) to account for systematic drift continuously while in flight. Wavelength modulation spectroscopy is used at different harmonics to isolate the narrow linewidth of the in-line reference signal from the ambient, pressure-broadened absorption lineshape of the trace gas of interest. As a result, a metric of in-flight performance is achieved in real-time on the same optical pathlength as the ambient signal.

To demonstrate the great potential of laser-based sensors on UAS, we deployed a 1.65 micron-based methane sensor (4 kg, 50 W, 100 ppbv precision at 10 Hz) on a UT-Dallas remote control aircraft for two weeks around gas/oil extraction activities as part of the EDF Barnett Coordinated Campaign in October 2013. We conducted thirty-four flights around a compressor station to examine the spatial and temporal characteristics of its emissions. Leaks of methane were typically lofted to altitudes well above the surface (up to 100 m). In addition, plumes were very narrow horizontally (10-30 m width) within 200 m of the emission origin. By using a mass balance approach of upwind versus downwind CH4 concentrations, coupled to meteorological wind data, the CH4 emission rate from the compressor station averaged 13 $\pm$ 5 g CH4 s-1, consistent with individual, leak surveys measured within the compressor station itself. More recently, we developed a mid-infrared version of the same sensor using an antimonide laser at 3.3 microns. This sensor has a precision of 2 ppbv CH4 at 10 Hz, a mass of 1.3 kg, and consumes 10 W of power. Flight tests show the improved precision is capable of detecting methane leaks from landfills and cattle feedlots at higher altitudes (500 m) and greater distances downwind (several km) than the near infrared CH4 sensor.

Sampling strategy is particularly important for not only UAS-based flight patterns but also sensor design. Many tradeoffs exist between the sampling density of the flight pattern, sensor precision, accuracy of wind data, and geographic isolation of the source of interest, and these will be discussed in the context of airborne-based CH4 measurements in the field. The development of compact yet robust trace gas sensors to be deployed on small UAS opens new capabilities for atmospheric sensing such as quantifying local source emissions (e.g. farms, well pads), vertical profiling of trace gases in a forest canopy, and trace gas distributions in complex areas (mountains, urban canyons).