Investigation of methane emission sources from Indianapolis using an aircraft-based platform

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A13F-0288

INTRODUCTION

Quantification of the magnitude and uncertainties of greenhouse gas emissions is important for establishing scientifically sound policies for mitigating fossil fuel emissions in urban environments. Recent studies have shown that urban city centers are significant sources of anthropogenic methane (e.g. Wunch et al., 2009). However, urban CH_4 fluxes do not correlate with emissions from combustion sources (Mays et al., 2009). While the emission inventory for carbon dioxide is relatively well understood, the methane source function is less defined because of the diverse range of sources and relatively limited observational studies of this potent greenhouse gas.

In the spring and fall of 2008, carbon dioxide and methane were measured in the air shed of Indianapolis using an aircraft-based platform (Purdue University's Airborne Laboratory for Atmospheric Research, see Figure 1), equipped with a cavity ring-down CO_2/CH_4 spectrometer, a flask sampling system, and a Best Air Turbulence probe for high-resolution wind measurements. Because Indianapolis is significantly removed from other metropolitan areas, greenhouse gas signals from this urban center can be detected with relative ease, making it an ideal location for developing methods for fossil fuel emission measurements. The aircraft-based measurements in 2008 enabled the estimation of the area-wide CO_2 and CH_4 emissions from the Indianapolis urban environment (Mays et al, 2009).

In this work, we revisit the 2008 aircraft-based measurements with the specific goal of examining the observed high CH_4 concentration (methane hotspots) emitted from the Indianapolis air shed. We investigate the area of influence of these methane hotspots by (1) calculating the associated emission footprint using a Lagrangian model, and (2) applying simple air parcel trajectory simulations using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) particle dispersion model (Draxler and Rolph, 2003).

Fig. 2. Installation of the Picarro CRDS and NOAA flask package system in Purdue University's ALAR.

ACKNOWLEDGEMENT This study is part of the **Indianapolis Flux Experiment** (INFLUX), which is funded by the National Institute of Standards and Technology.

Fig. 1. The Purdue University Airborne Laboratory for Atmospheric Research (ALAR) flying over an instrumented tower.

CO_2 and CH_4 Measurements

Continuous measurements of CO_2 and CH_4 were performed using the CRDS technique. Data were collected at a frequency of 0.2 Hz using the Picarro ESP – 1000. In the CRDS method, narrow-band laser light is rapidly pulsed into an optical cavity to measure the ring-down time, which is then utilized to precisely quantify the analyte's concentration (Crosson 2008). Precisions for CO_2 and CH_4 were determined to be better than 0.3 ppmv and 1 ppbv, respectively (i.e. better than 0.1% for both). Additionally, flask samples were taken at various times during flight experiments to compare the measured concentrations from the Picarro system. Figure 2 shows the installation of the Picarro CRDS and NOAA flask sampling system in ALAR.

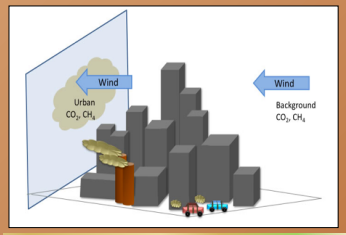


Fig. 3. Wind carrying background concentrations of CO_2 and CH_4 blows over the city, where it intercepts and picks up strong greenhouse gas emissions from anthropogenic sources such as cars, power plants, land fills, etc.

Lagrangian Particle Dispersion Model

The aircraft observation footprint was calculated using the meteorological variables from the mesoscale atmospheric model WRF at 2-km resolution (20m resolution for the first vertical level), coupled to the Lagrangian Particle Dispersion Model (Uliasz, 1994). Particles are released at the exact locations of the observations during the flight, every few seconds. The integration of the particles at the surface show the area of influence corresponding to elevated CH_4 measurements (>1890ppb).

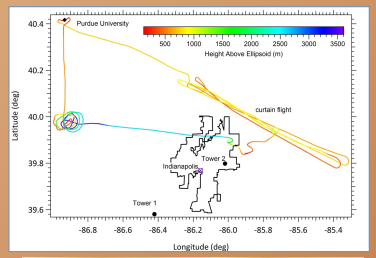


Fig. 4. Typical flight path showing the curtain flight transects from a recent flight experiment on Nov. 22, 2010.

FLIGHT DESIGN

The flight plan was designed based on the experimental theory depicted in Figure 3. Wind (from the right) carrying background concentrations of CO_2 and CH_4 blows over the city, where it picks up greenhouse gas emissions from anthropogenic sources such as cars, power plant, etc. By flying perpendicular to the wind direction using horizontal "curtain" transects, the on-board aircraft sampling system is able to intercept, detect and quantify concentration "hot spots" that correspond to CO_2 and CH_4 plumes emitted from the city.

Figure 4 shows an example of a typical flight path from a recent experiment on Nov. 22, 2010. Note that the curtain flight transects span distances much larger than the diameter of the city (~40 km) to clearly distinguish background concentrations of CO_2 and CH_4 from elevated fossil fuel signals from the Indianapolis air shed. Figure 5 shows the curtain transects for flight experiments conducted in the spring and fall of 2008.

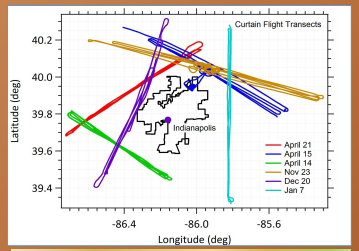
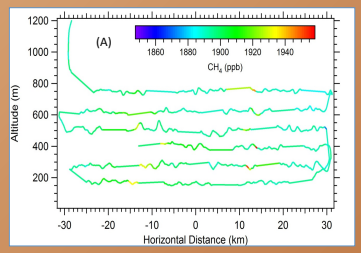


Fig. 5. Curtain Flight Transects in the spring and fall of 2008.



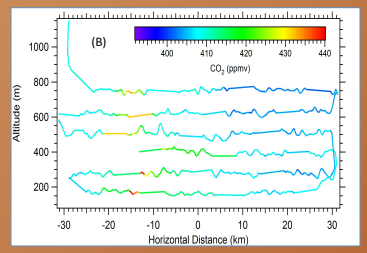


Fig. 6 (A) CO_2 and (B) CH_4 concentrations as a function of altitude and horizontal distance across the curtain flight transect. Data from April 14, 2008. CH_4 hotspots were observed at distinct points where no CO_2 hot spots were observed, and vice versa.

RESULTS AND DISCUSSION

Figures 6 (A) and (B) show the CO_2 and CH_4 concentrations as a function of altitude and horizontal distance (data from April 14 flight experiment). CH_4 hotspots were observed at distinct points on the horizontal trajectory where no CO_2 hotspots were detected, and vice versa. This result suggests that there are sources that are unique to these two gases.

Figure 7 shows the footprint corresponding to a wide (~25 km) plume of CH_4 with concentrations above ~1890 ppbv observed on April 14. The locations of large number of particles indicate the areas that have the most probable influence on the measured CH_4 concentrations. A large number of particles was observed north of the Indianapolis urban area and coincided with the location of Kokomo, a small city with a population of ~50,000 in Howard County. This preliminary result suggests that both wide and narrow plumes of CH_4 must be analyzed to distinguish anthropogenic sources from the Indianapolis urban area as well as from neighboring city centers.

Back trajectories (figure 8) associated with the observed methane hot spots were calculated using the HYSPLIT particle dispersion model. Also shown in figure 8 are the locations of potential CH_4 sources such as waste water treatment plants, natural gas pumping and delivery stations, and landfill sites. Most but not all of the back trajectories intersected the Indianapolis urban area, which clearly indicates that not all observed methane hot spots are brought about by emissions from this urban environment. The back trajectories that traverse the Indianapolis urban area will serve as guides for future modeling efforts in investigating emissions sources.

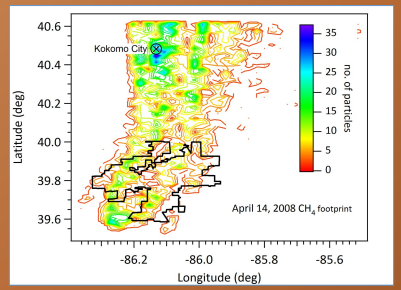


Fig. 7. Footprint corresponding to a wide plume of CH_4 observed on April 14, 2008.

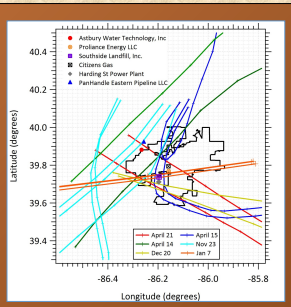


Fig. 8. HYSPLIT – derived back trajectories corresponding to elevated methane concentrations.

CONCLUSIONS

CH_4 is a very important greenhouse gas that is 25 times more potent than CO_2. Because of its high global warming potential and relatively short life, reductions in its abundance may have a significant near-term effect. Urban emissions of CH_4 were observed to be much higher than currently reported in emission inventories, clearly indicating that there are uncharacterized sources of CH_4 in urban environments. We present here initial results of our efforts to investigate the areas of influence associated with observed elevated CH_4 concentrations in the Indianapolis air shed. The combination of aircraft measurements and inverse modeling provides a unique opportunity to further investigate unknown CH_4 sources from this urban environment.

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