The INFLUX Project: Indianapolis as a Case Study for the Accurate and High Resolution Determination of CO_2 and CH_4 Emission fluxes from an Urban Center

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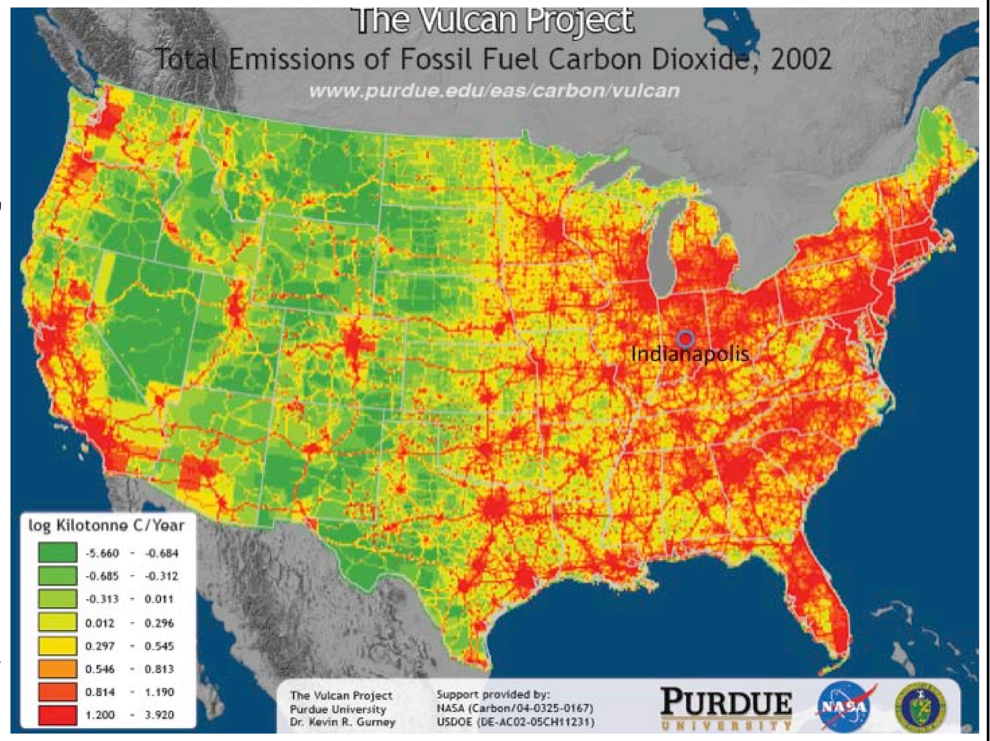
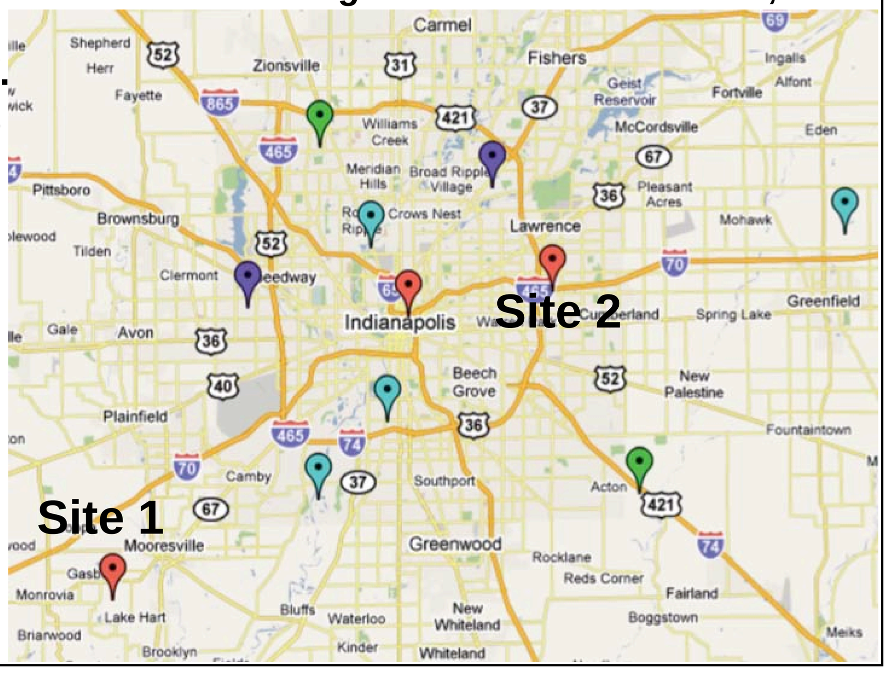
INTRODUCTION AND BACKGROUND

In light of efforts to control greenhouse gas emissions world wide, to better define sources and sinks, and in light of the need to evaluate and understand satellite column retrievals for these species, there is a strong need to be able to quantitatively understand the temporal and spatial variability of anthropogenic emissions, and the drivers of those emissions, for urban environments, on a global scale. With the aim of developing improved methods for determination of urban area-wide emissions fluxes, and to minimize and understand the uncertainties in those measurements, we created the "Indianapolis Flux Experiment ("INFLUX"), with funding support from NIST. Indianapolis was chosen as a test case because of its relatively well-defined and isolated urban core, and the relatively tractable meteorological context. Indianapolis has also been previously studied in a limited way through measurements[1], and is a test case for the high resolution CO_2 emissions modeling effort, Vulcan[2], which produces high spatial and temporal sector-based emissions for Indianapolis (and the U.S.). The location of Indianapolis on a Vulcan total emissions map is shown at right. We describe here the approaches to be used for a two-year multi-component measurement and modeling effort that will produce highly constrained emissions flux measurements for CO_2 and CH_4.



INFLUX Tower Measurements

Tower sites are being established at 11 locations in and around the city, from which measurements of CO, CO_2 and CH_4, along with met. measurements will be made in 2011 and 2012. A map of the tower locations is shown below right. Site 1 in Mooresville, and Site 2, at E. 21st. St. are currently operating. See: http://influx.psu.edu/. Tower data can be used to calculate a flux using a simple lagrangian transport model from measurement of Z·d(CO_2)/dt, where t is the boundary layer height, and t is the advective transit time. These data will also be utilized as a central component of an inverse modeling approach, in which the temporal and spatial patterns in atmospheric CO_2 and CH_4 mixing ratios are combined with a transport model to infer the surface fluxes.



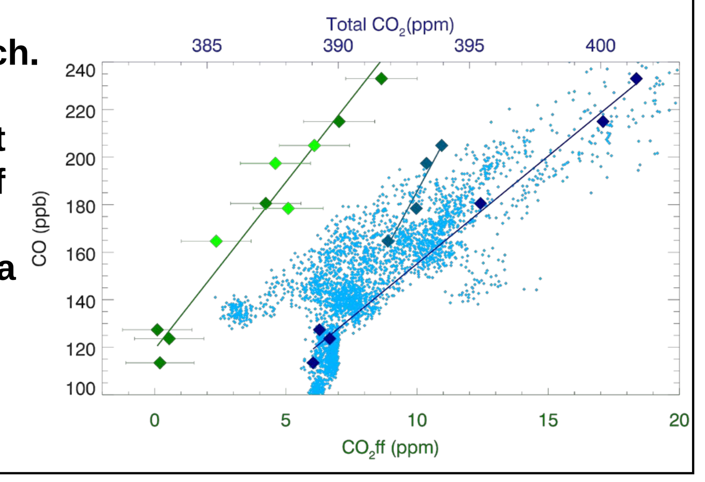
$^{14}CO_2$ Measurements

$^{14}CO_2$ in integrated samples will be measured from tower sites and from the aircraft. That data, along with CO, will allow us to separate the fossil-fuel $(CO_2)_{ff}$ and respiration components of the measured CO_2 fluxes. $\Delta^{14}CO_2$ enables $(CO_2)_{ff}$ measurements via the equation shown at right. The emission flux can be determined from the measured CO_2 enhancement (E) over background, from

$$CO_{2ff} = \frac{CO_{2obs}(\Delta_{obs} - \Delta_{bg})}{\Delta_{ff} - \Delta_{bg}} - \frac{CO_{2r}(\Delta_r - \Delta_{bg})}{\Delta_{ff} - \Delta_{bg}}$$

$$E = \Delta CO_{2ff} * (w*h)/f * (\rho_{air}/M_{air})$$

where h is the BL height, w is the wind speed, and f is the fetch. As discussed by Turnbull et al., 2010[3], regression of CO against $(CO_2)_{ff}$ enables quantification of the anthropogenic CO_2 flux. The figure at right shows such a regression for the city of Sacramento, as discussed in Turnbull et al., 2010[3].

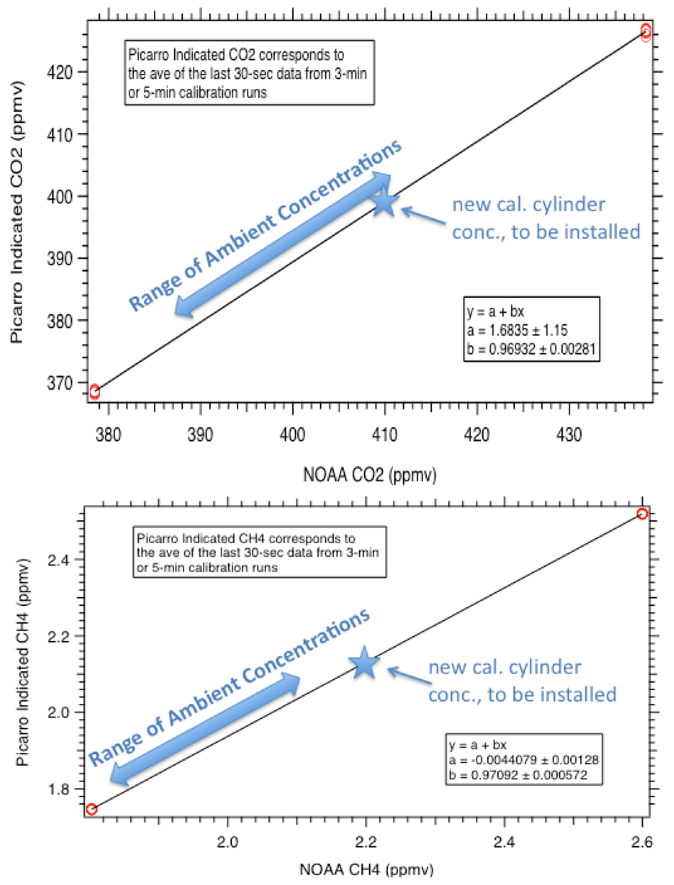


APPROACH AND METHODS

INFLUX will utilize a number of complimentary approaches to produce highly contrained and improved flux measurements. Here we descibe each of aircraft-based mass balance measurements, a network of tower-based measurements that will produce CO_2 and CH_4 and some CO measurements, to which a lagrangian flux model will be applied, and inversion modeling will be applied using the full tower and aircraft data sets. Temporal and spatial characteristics of the flux measurements will be compared to Vulcan model output.

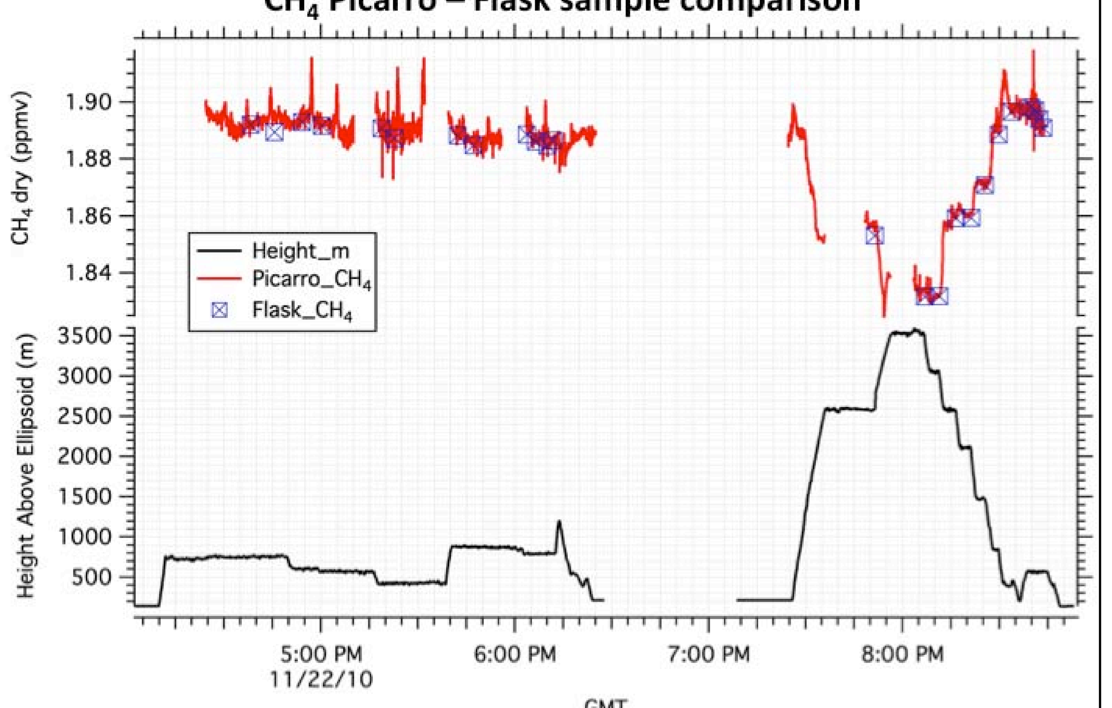
1.Aircraft Mass Balance Measurements

All tower-based and aircraft measurements will be conducted using Picarro cavity ringdown instruments, for CO, H_2O, CO_2, and CH_4. Roughly bi-weekly flights of Purdue's Airborne Laboratory for Atmospheric Research (ALAR; http://www.chem.purdue.edu/shepson/alar.html will take place. The ALAR aircraft is shown at right. ALAR is equipped with a Picarro H_2O, CO_2, and CH_4 instrument that can measure these species at 1s time resolution, or ~60m spatial scale. The Picarro instrument installation is shown below right. There is also a calibration system for routine in-flight calibrations using NOAA certified cylinder standards, and a pressurized flask package system that enables acquisition of flask samples for comparison to NOAA lab determinations, measurement of a suite of other gases, and acquisition of samples for $^{14}CO_2$ measurements. There is also a 3D wind system that provides pressure, T, position, and 3D winds at 50Hz. The ALAR aircraft has limited payload, but provides low-cost and highly flexible operation. The current system involves periodic (e.g. every 15 minutes) calibration using the NOAA compressed gas standards. The figure below, left, shows the measurement points (red) from 6 pairs of calibrations with the two cylinders, for altitudes ranging from 500 – 3500m. As shown there is very little variability in Picarro response to the standards, as a function of altitude, or time. In early 2011 we will add a third standard for 3-point calibrations, as indicated by the star. In the Figure below, right, we show results for methane measurements during a recent INFLUX flight in which we compare CH_4 determined by the Picarro with the results of analysis of simultaneous flask samples by the NOAA GMD lab. As shown, the comparison is quite good, and independent of altitude.



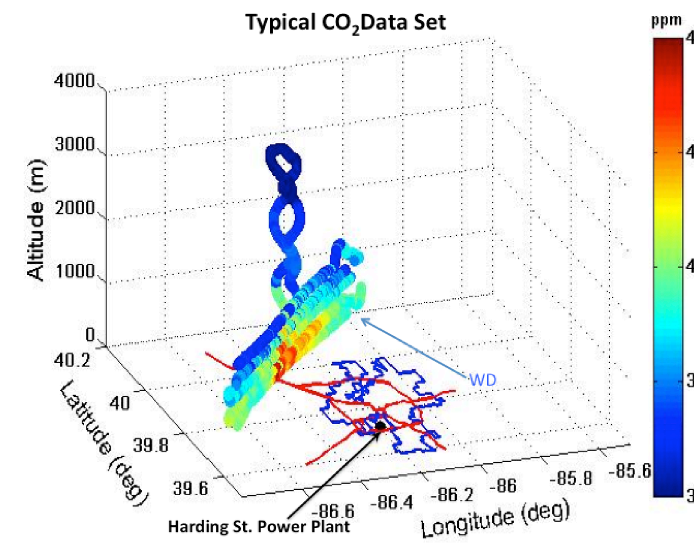
INFLUX Flight Number 2, November 22, 2010, Indianapolis

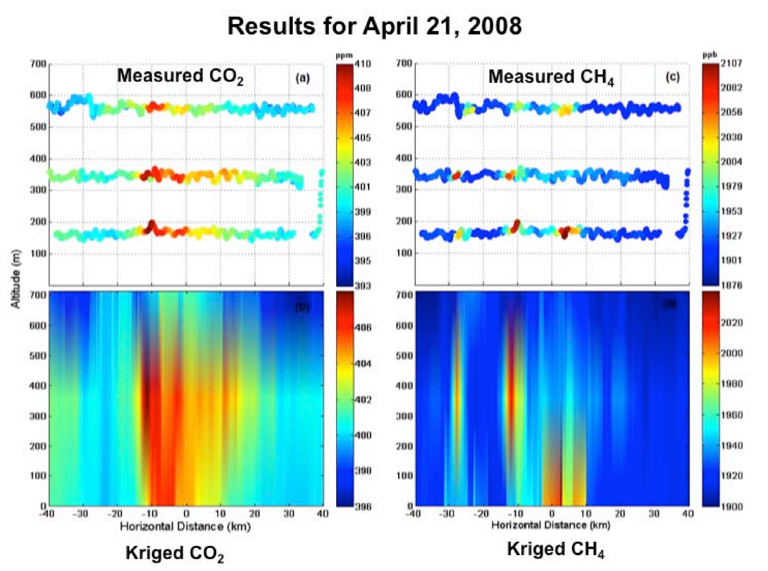
CH_4 Picarro – Flask sample comparison



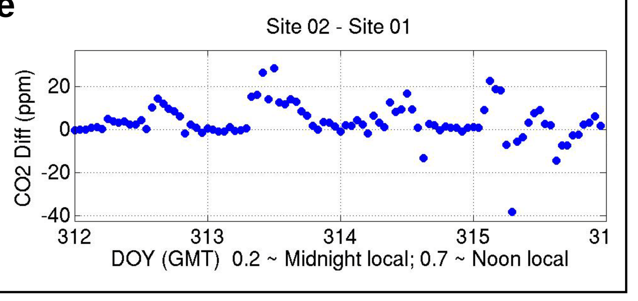
RESULTS

The aircraft-based fluxes are calculated by integrating over all elements of ΔCO_2·(wind speed) in a plane downwind of the city, that is perpendicular to the wind direction, from the surface to the top of the boundary layer, as discussed in Mays et al.[1] An example from that work is shown in the figures below. A surprising result from that study is the large magnitude of the CH_4 fluxes, relative to the EDGAR emissions inventory. During INFLUX, we will pursue this further, in part by flying upwind in the CH_4 plumes, to aid in source identification.



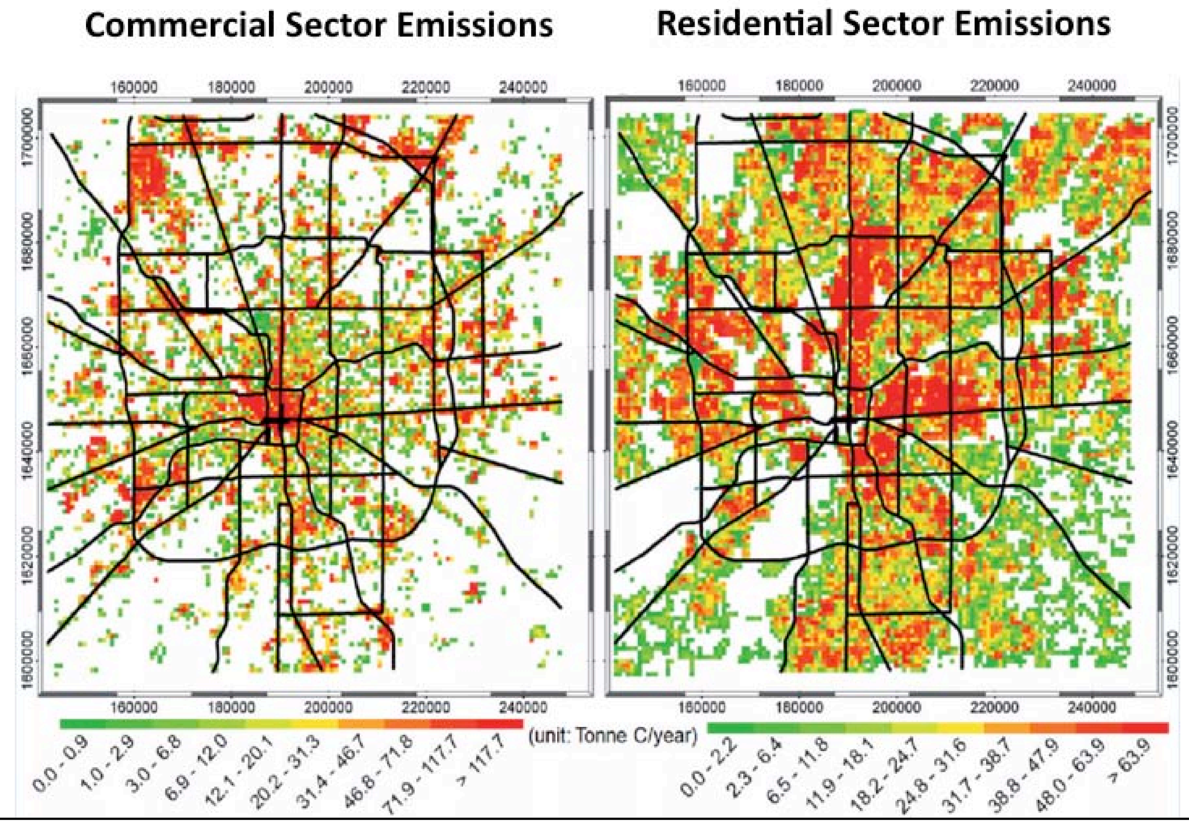


We have begun to acquire and analyze data from the first two tower sites to come on line. In the figure at right we show the difference in concentration between them, which indicates that the Indy plume can be as large as 20 ppm, detected with winds in both directions.



VULCAN Results

Vulcan is producing high resolution emission data for the residential, commercial and industrial sectors, in addition to the transportation and electricity production sectors. Shown below is 250m resolution data (annual) for Indianapolis, for the commercial sector (left) and residential sector (right)[4].



DISCUSSION/CONCLUSIONS

The INFLUX project is well underway, and is unique in terms of the array of approaches, including aircraft and intensive tower measurements, application of $^{14}CO_2$ measurements, the use of inverse modeling, and the application of the high resolution Vulcan emissions model. INFLUX hopes to pave the way for future studies in other cities, e.g. those that are less well characterized, or with less publicly available data. INFLUX can be significantly improved with enhanced meteorological measurements, especially wind profiling and continuous BL height measurements, as well as source-specific species measurements, e.g. SO_2. We welcome collaborators; interested parties should contact Paul Shepson, pshepson@purdue.edu, or other members of the INFLUX team.

ACKNOWLEDGMENTS

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REFERENCES

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