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Spatial and temporal characteristics of CO2, CO, and CH4 in-situ mole fractions in an urban environment as part of the INFLUX project

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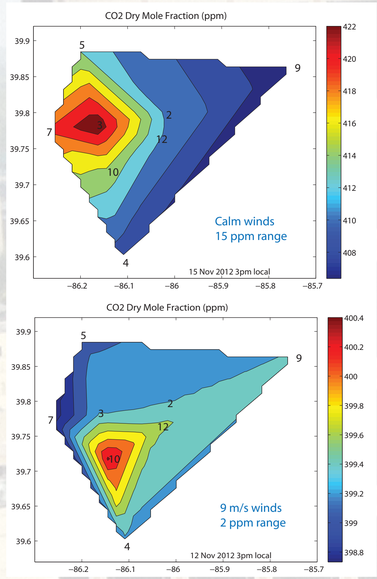
INFLUX (INdianapolis FLUX Experiment)

Independent verification of anthropogenic greenhouse gas emissions is an emerging need as legislation to regulate greenhouse gas emissions becomes more likely. As part of the INFLUX project, CO2, CH4 and CO mixing ratios are measured using wavelength-scanned cavity ringdown spectroscopy (Picarro, Inc.) at towers surrounding Indianapolis, IN, with expansion underway to a network of 12 GHG sensors. Sampling was initiated in October of 2010, with 9 sites deployed as of August 2012. The INFLUX project also includes bottom-up flux estimates, aircraft measurements, flasks at 5 towers, and NASA TCCON total-column CO2 and CH4 sensor. In this poster, we focus on results from tower-based in-situ tower data.

Overall Objective of INFLUX: To develop and assess methods of quantifying greenhouse gas emissions at the urban scale, using Indianapolis as the test site.

Spatial Distribution of CO2 within Indianapolis: Examples



Contour plot of CO2 dry mole fraction at 3pm local on 15 November 2012, at the highest measurement level for each site (ranging from 40 m AGL to 136 m AGL). The winds were calm. The CO2 ranged from 407 ppm at Site 09 (background site to the east of the city) to 422 ppm at Site 03 (downtown).

The contour plot for 12 November 2012, when the winds were 9 m/s and from the west, indicates a much weaker spatial gradient in CO2. The maximum difference between the sites is less than 2 ppm over the entire area. Modeling results (not shown) also show an inverse relationship between wind speed and CO2 spatial gradient.

Spatial Gradients, Differences, Distances, and Correlations

Time-averaged (1 Sept - 31 Dec 2012, 1300-1700 LST) spatial gradients, differences, distances, and correlation coefficients for each pair of sites for CO2. The distances between the sites averages 25 km and the smallest inter-site distance is 4 km between Site 02 and Site 12. The largest magnitude gradient (as large as 0.14 - 16 ppm / km) occur between Site 3 (downtown) and the surrounding sites. However, the mean gradient between nine pairs of sites is 0.01 ppm / km or less. In comparison, the average spatial gradient between site pairs with differing vegetation types in the Mid Continent Intensive was 0.03 ppm / km (Miles et al., 2012). The highest correlations (0.98) are between Sites 02/12 and Sites 10/12 and the lowest include Site 03, the downtown site (0.87 - 0.93).

CO2 (ppm/km, ppm, km, r)

	Site 02	Site 03	Site 04	Site 05	Site 07	Site 09	Site 10	Site 12
Site 01*	0.02/0.9/42/0.93							
Site 02		0.13/1.7/13/0.90	0.00/-0.1/24/0.93	-0.01/-0.1/19/0.93	0.01/0.2/22/0.91	0.03/-0.8/24/0.95	0.06/0.8/14/0.96	0.13/0.5/4/0.98
Site 03		-	-0.08/-1.8/22/0.87	-0.14/-1.8/13/0.93	-0.16/-1.4/9/0.91	-0.08/-2.8/37/0.88	-0.14/-1.0/7/0.90	-0.12/-1.3/11/0.90
Site 04			-	0.01/0.2/35/0.91	0.01/0.2/25/0.91	-0.01/-0.6/43/0.90	0.06/0.9/14/0.95	0.04/0.7/20/0.95
Site 05				-	0.00/0.0/15/0.95	-0.01/-0.5/39/0.91	0.04/0.8/20/0.91	0.03/0.6/20/0.93
Site 07					-	-0.01/-0.62/46/0.89	0.05/0.7/13/0.91	0.04/0.8/20/0.91
Site 09						-	0.04/1.7/38/0.93	0.05/1.3/28/0.95
Site 10							-	-0.03/-0.3/10/0.98

CO (ppb/km, ppb)

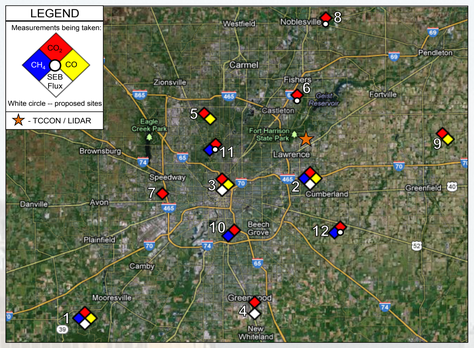
	Site 01	Site 02	Site 03	Site 05	Site 09
Site 02	0.2/10	-	1.7/22	0.2/3	-0.3/-6
Site 03			-	-1.3/-17	-0.8/-30
Site 05				-	-0.2/-9

Gradients and differences for CO and CH4. CO gradients between Site 03 (downtown) and the surrounding sites are the largest, as would be expected. The inter-site differences in CO are 3 - 30 ppb. Inter-site differences for CH4 are 4 - 5 ppb for the available site-pairs.

CH4 (ppb/km, ppb)

	Site 01	Site 02	Site 10
Site 02	0.1/5	-	0.3/4

INFLUX Ground-based Measurement Sites

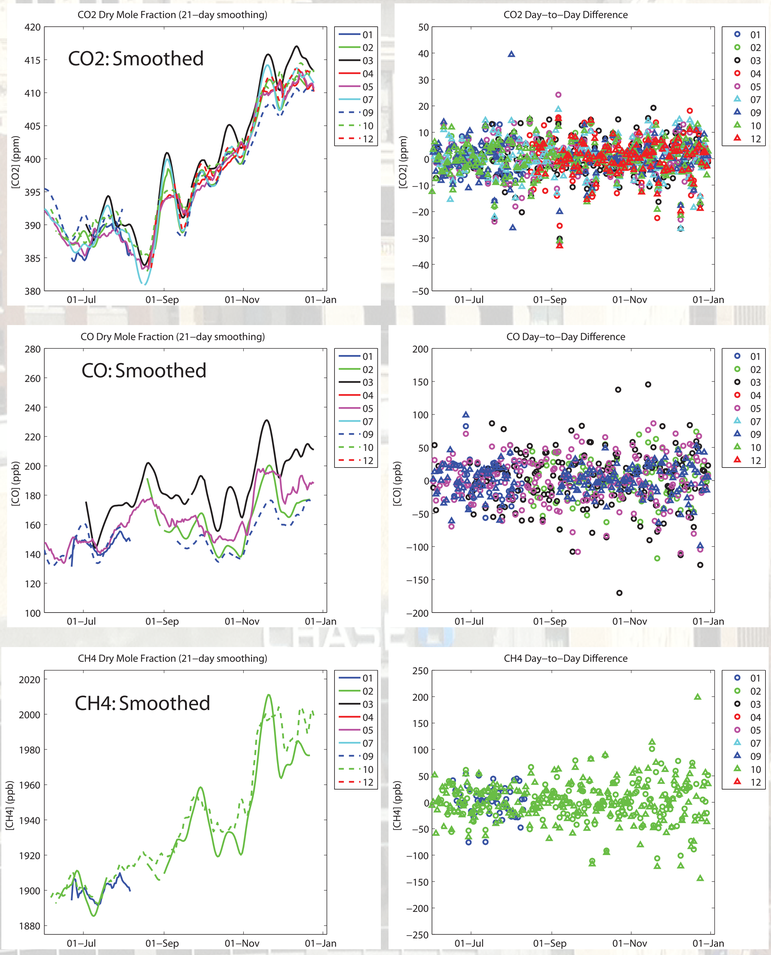


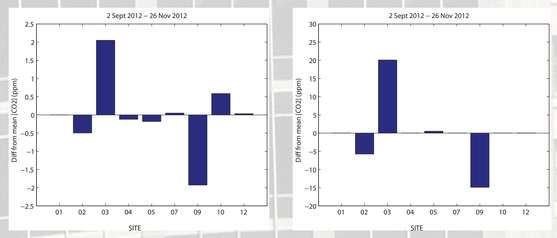
Map of INFLUX ground-based measurement sites and the city of Indianapolis, IN. The color of the marker represents the measurements at each site: red for CO2, yellow for CO + NOAA flasks , blue for CH4, and white for surface energy balance fluxes. Eight of the in-situ sites are deployed currently, with Sites 06, 08, and 11 to be deployed in the coming months. Site 12 is currently at a temporary location close to Site 02, but will be relocated. Currently the surface energy balance is measured at Site 02, and the remaining sites planned. The NASA TCCON was deployed from August - Decemeber 2012 at the site denoted by a star; a NOAA lidar is planned to be deployed at the same site.

Spatial Distribution of CO2 within Indianapolis: Time Series

Shown in the left column of figures are time series of CO2, CO, and CH4, averaged between 1300 and 1700 LST each day, and smoothed with a 15-day filter. Note that the tower heights range from 40 to 136 m AGL. Synoptic-scale variability is apparent, as well as coherence between the sites. Site 03 (downtown) is generally higher in CO2 and CO than the other sites. Site 09 (background site to the east of the city) measures the lowest CO2 and CO.

The day-to-day change (1300-1700 LST) for CO2, CO, and CH4 is shown in the right column of figures. The mean magnitude of changes in CO2 is 4.8 ppm, with Site 03 having the largest mean change, 5.7 ppm. The mean magnitude of changes in CO ranges between 18 ppb for Site 09 and 33 ppb for Site 03. The mean magnitude of changes in CH4 is 22 - 30 ppb.



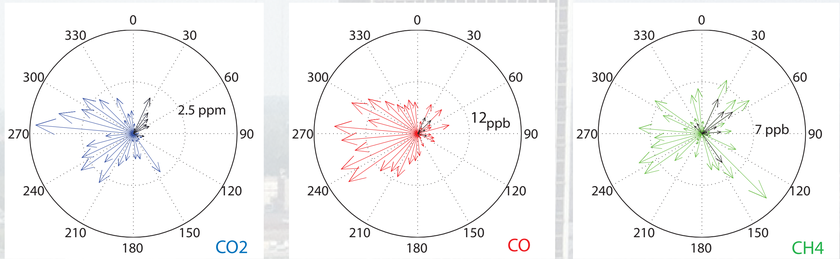


Time-averaged (Sept - Nov 2012) daytime CO2 (left figure) and CO (right figure) for the INFLUX sites. On average, Site 03 measures the largest CO2 and CO, 2 ppm and 20 ppb above the average. Site 09 measures 2 ppm and 15 ppb below the average.

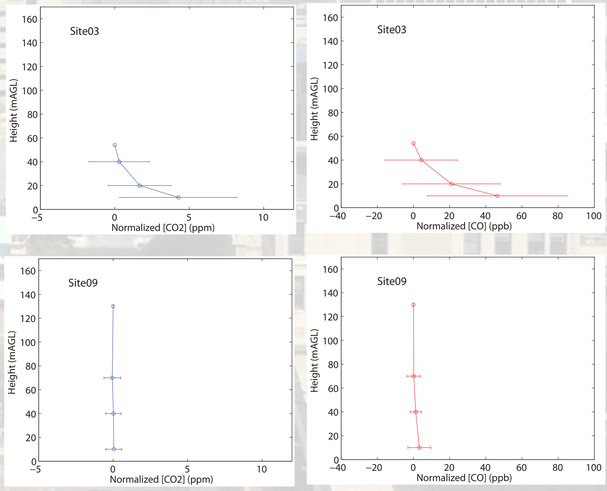
*Background photo shows the view from the Soldiers and Sailors Monument in downtown Indianapolis.

GHG Concentrations as a Function of Wind Direction

Urban enhancement (difference between urban Site 02 and rural Site 01) for daytime hours April - November 2011, as a function of wind direction. The median enhancements are 1.2 ppm CO2, 8 ppb CO, and 3 ppb CH4. However, the magnitudes are strongly dependant on wind direction. Colored arrows indicate positive urban enhancements, whereas black indicates negative enhancement. Essentially, the arrows point to the sources. At Site 02, CO and CO2 come from the city as would be expected from distributed sources. The magnitudes of enhancement as a function of wind direction are as large as 20 ppb for CO and 5 ppm for CO2. In addition to the source of CH4 from city, there is an additional source from the southeast. Collaborators from Purdue plan to investigate this source further via drive-arounds. The magnitude of the enhancement from the city is as large as 10 ppb CH4. For CH4, negative enhancement when the winds are aligned from Site 01 to Site 02 is more prominent than for CO and CO2.

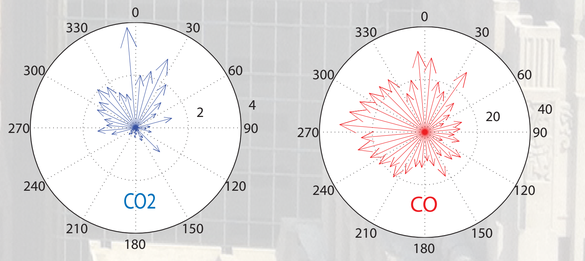


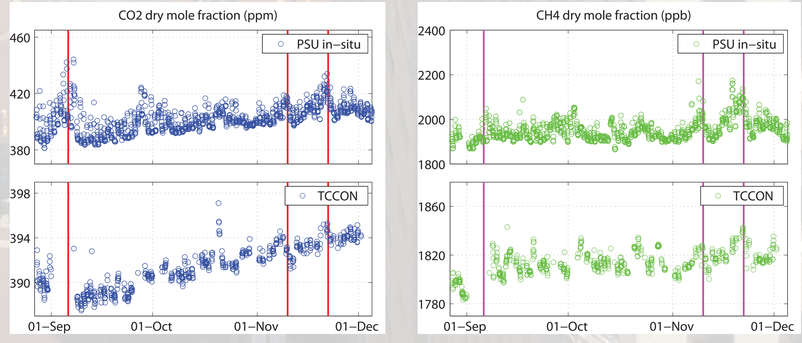
Variation with height: CO2, CO, and CO2/CO



Profiles of CO2 and CO measured at 3 pm LST in October 2012 and normalized to the highest measured level are shown to the left. Error bars indicate the standard deviation of the daily values. Averaged over June - Dec 2012, Site 03 (downtown) measures 1.7 ppm higher CO2 at 20 m AGL and a 4.3 ppm higher at 10 m AGL, compared to the top level, 54 m AGL. CO is elevated by 20 ppb at 20 m AGL and by 45 m ppb at 10 m AGL. Site 09 (background) is comparitively constant with height.

Shown to the right is the vertical enhancement for CO2 and CO for daytime hours April - November 2011, as a function of wind direction. Site 02 is just south of an interstate (I-70) which seems to be contributing strongly to the CO2, whereas CO seems to be originating from the west (urban center) in addition to the north.



NASA TCCON CO2/CH4: Comparison with In-Situ

A NASA TCCON (Total Carbon Column Observation Network) instrument measuring total column dry air mole fraction of CO2 and CH4 was deployed in Indianapolis 4 km from Site 02 from Aug - Dec 2012. Thus, the TCCON measurement is influenced by both the surface conditions, as reflected in the tower-based observations, and concentrations in the free-troposphere. Comparing the in-situ PSU data to the TCCON data, we see events in which the two are highly correlated and some in which they are not, suggesting that at times the total column value is significantly influenced by the surface conditions, but at other times is not so clearly driven by local sources and sinks. The correlation coefficient (r) between the in-situ and total column data for CO2 is 0.79 and for CH4 is 0.54. While CO2 is significantly affected by synoptic events, sources for CH4 are predominantly local; this is consistent with the lower correlation for CH4.