Quantification of fossil fuel CO_2 emissions at the urban scale:

Results from the Indianapolis Flux Project (INFLUX)

Jocelyn Turnbull, *National Isotope Centre, GNS Science, New Zealand and CIRES, University of Colorado, Boulder, USA*

Maria Cambaliza, Colm Sweeney, Anna Karion, Tim Newberger, Doug Guenther, Pieter Tans, Natasha Miles, Scott Richardson, Thomas Lauvaux, Kenneth Davis, Paul Shepson, Kevin Gurney, Yang Song, Igor Razlivanov, Scott Lehman

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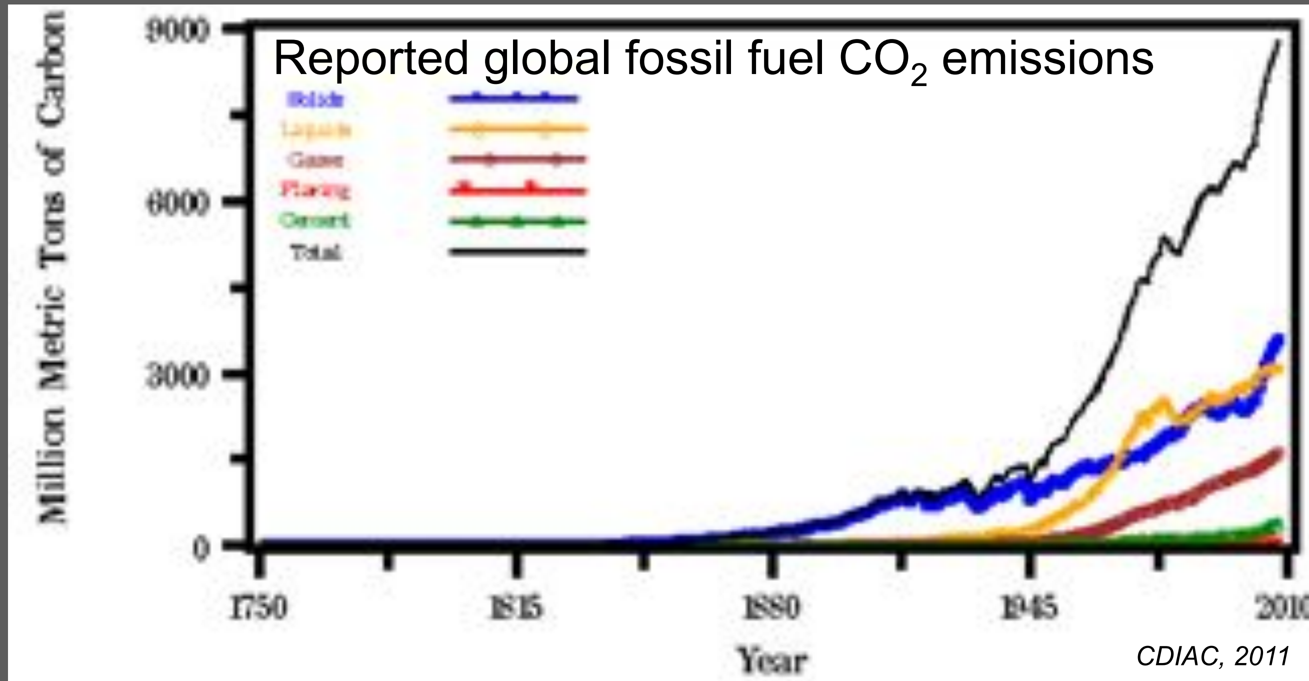
Why measure urban fossil fuel CO_2 emissions?



Emissions are increasing in spite of the global economic slowdown

Need to verify reported bottom-up inventories and monitor emission reduction efforts

Urban areas account for ~75% of total emissions

Need objective, independent estimates of emissions

Top-down method

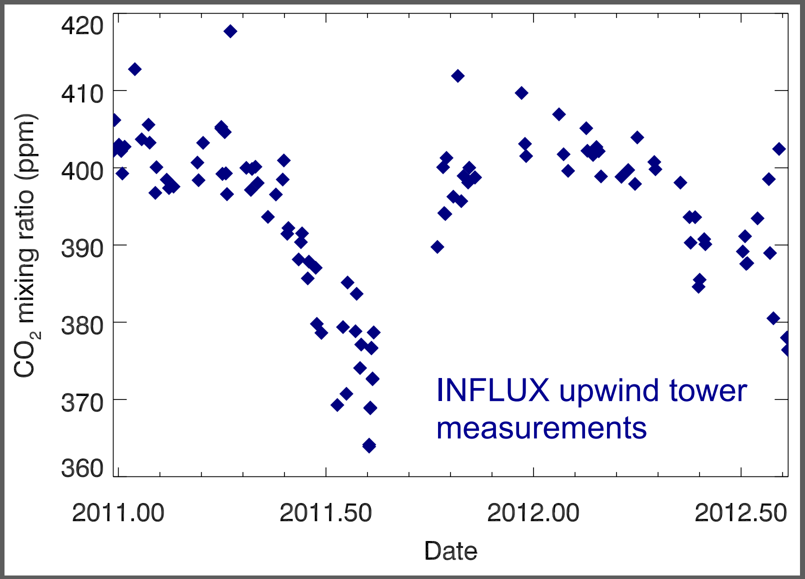
Measured CO_2ff mixing ratios

Atmospheric transport model

Calculated CO_2ff emission flux

Top-down method

$$CO_2obs = CO_2bg + CO_2ff + CO_2bio + CO_2oce$$



Large and varying CO_2 background

Signal is typically only a few ppm

Large seasonal, synoptic, diurnal variability
May be co-located with CO_2ff

Top-down method

Make local background measurements

^{14}C to quantify CO_2ff in flask samples

Identify correlate tracer co-emitted with CO_2ff

Empirically determine tracer:CO_2ff emission ratio

Use high resolution tracer measurements to obtain high resolution CO_2ff mixing ratios

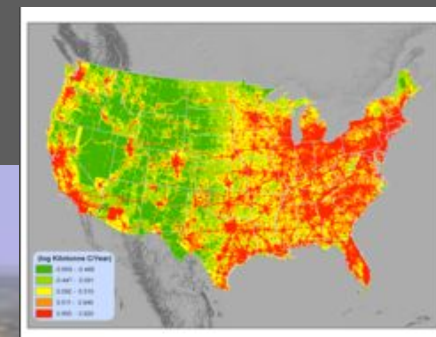
Atmospheric transport model

Calculated CO_2ff emission flux

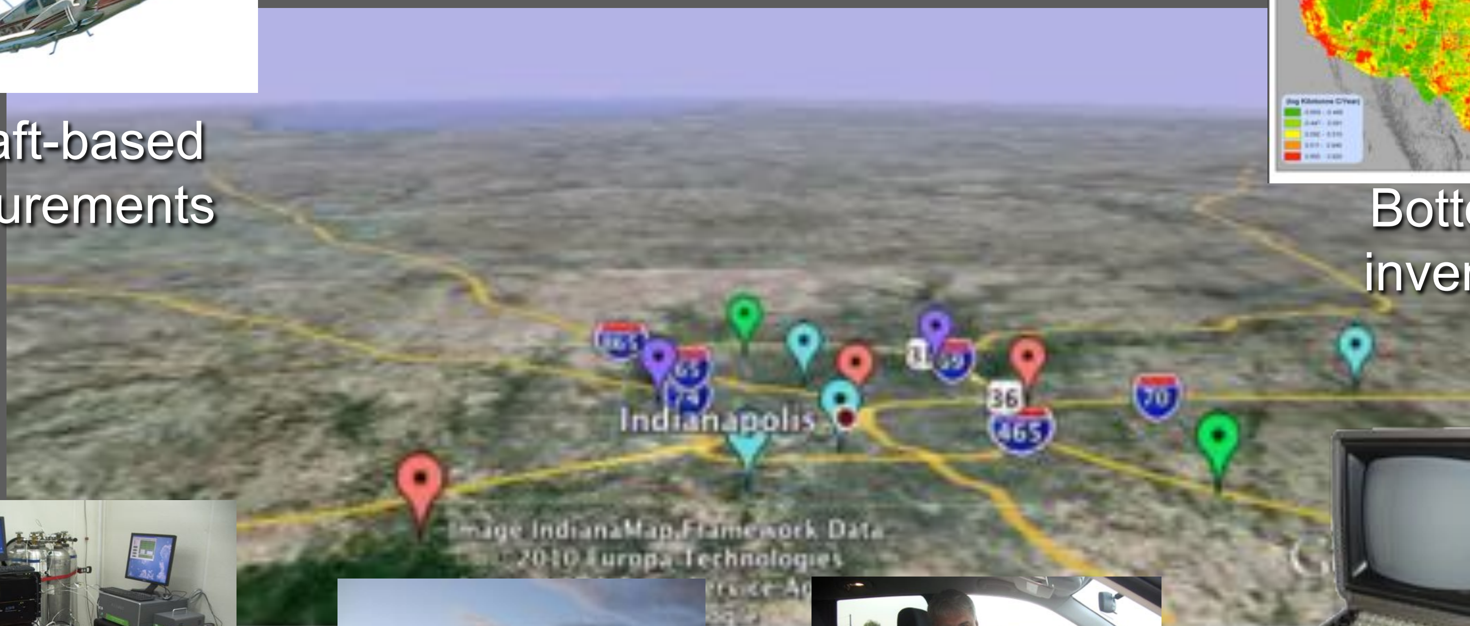
INFLUX: Indianapolis Flux Project

Develop and test techniques/approaches for measurement of urban-scale greenhouse gas emission fluxes and to quantify uncertainties

Aircraft-based measurements



Bottom-up inventories



Tower-based measurements

FTS

Driving tours

Data analysis and modeling

Sampling Strategy

12 cell phone towers, 75-150m high

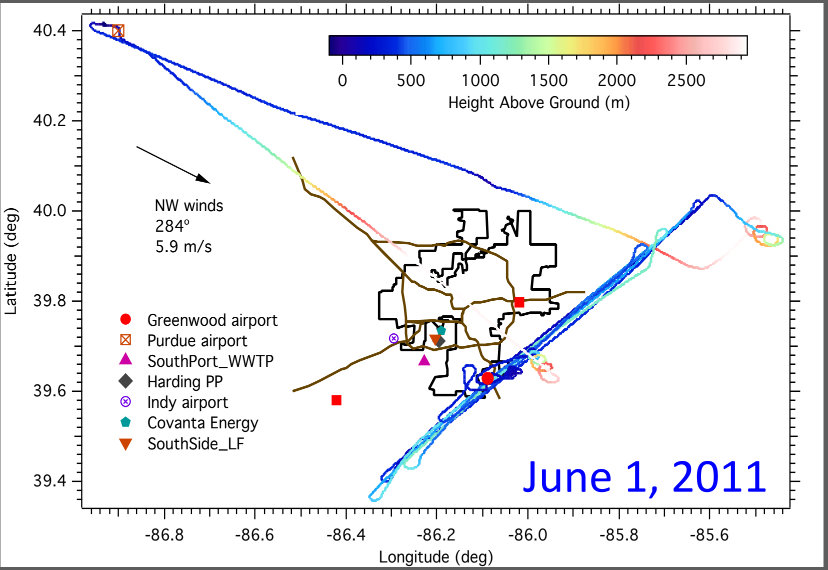
Continuous in situ CO_2/CH_4/CO

Mid-afternoon conditional flask sampling

~50 species measured:

CO_2 $^{14}CO_2$ CO CH_4 SF_6

hydrocarbons, halocarbons

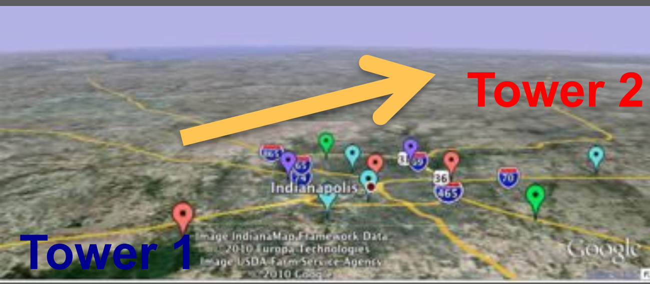


Aircraft flights ~ every 2 weeks downwind of city

Continuous in situ CO_2/CH_4

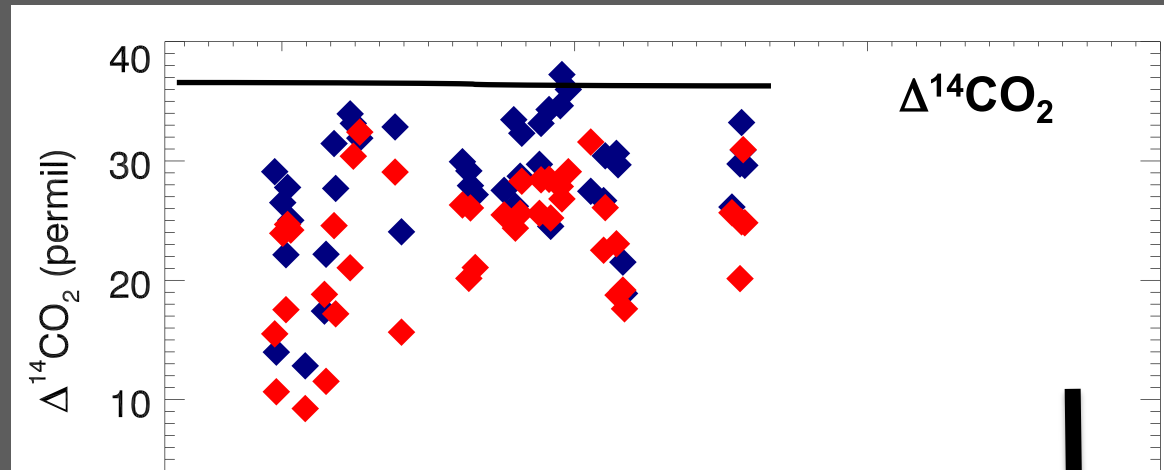
6-12 flask samples per flight

Determine fossil fuel CO_2 from $\Delta^{14}CO_2$

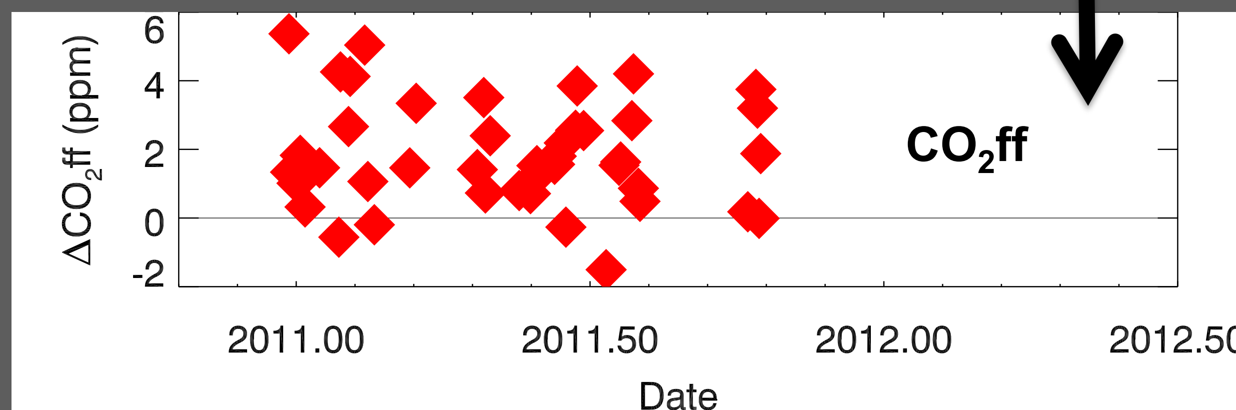


$\Delta^{14}CO_2$ is lower at Tower 2

^{14}C-free CO_2ff decreases $\Delta^{14}CO_2$

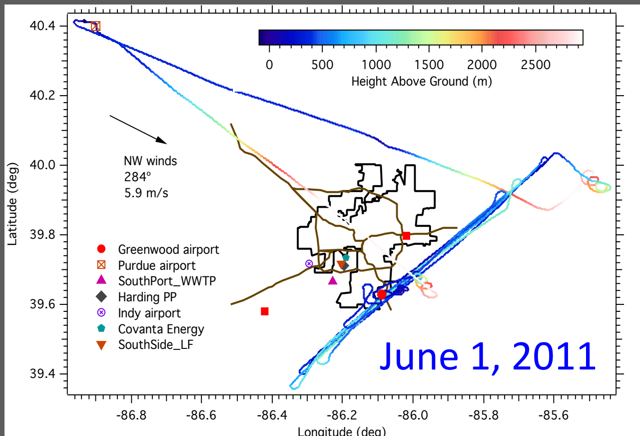


$$CO_2ff = \frac{CO_{2obs}\,(\Delta_{obs} - \Delta_{bg})}{\Delta_{ff} - \Delta_{bg}} - \frac{CO_{2r}\,(\Delta_{r} - \Delta_{bg})}{\Delta_{ff} - \Delta_{bg}}$$

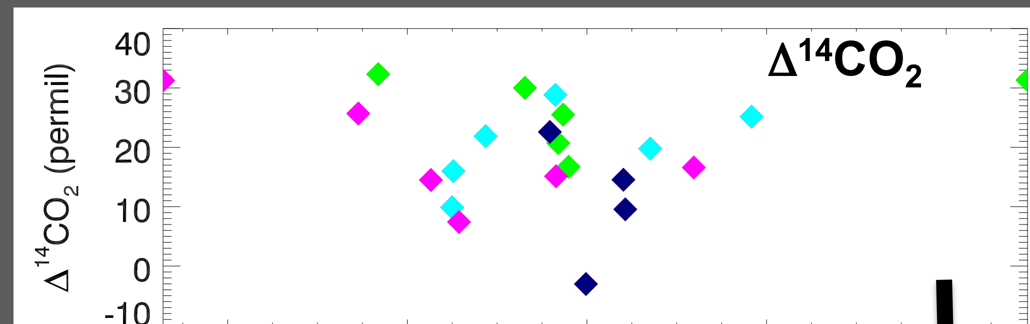


Fossil fuel CO_2 enhanced at Tower 2

Determine fossil fuel CO_2 from $\Delta^{14}CO_2$

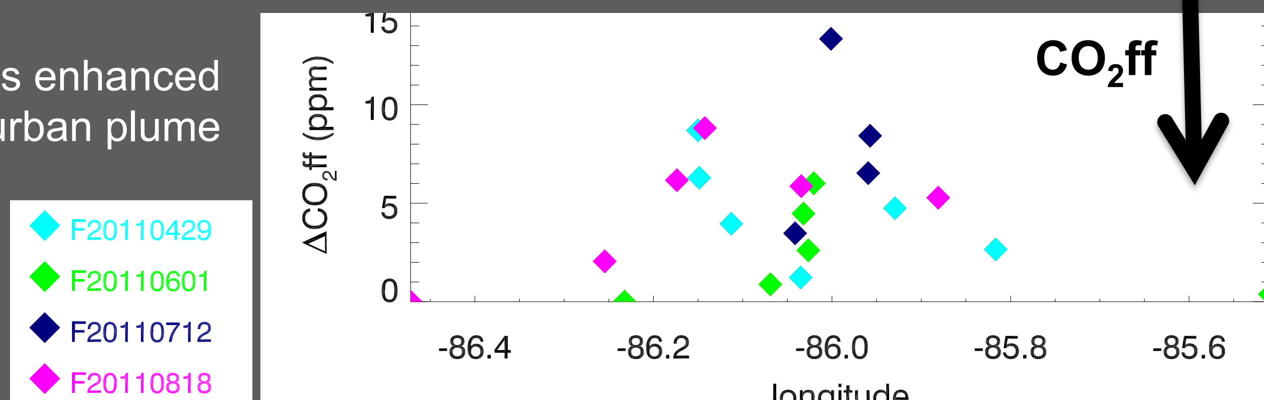


For each flight, a sample taken outside the urban plume is used as background

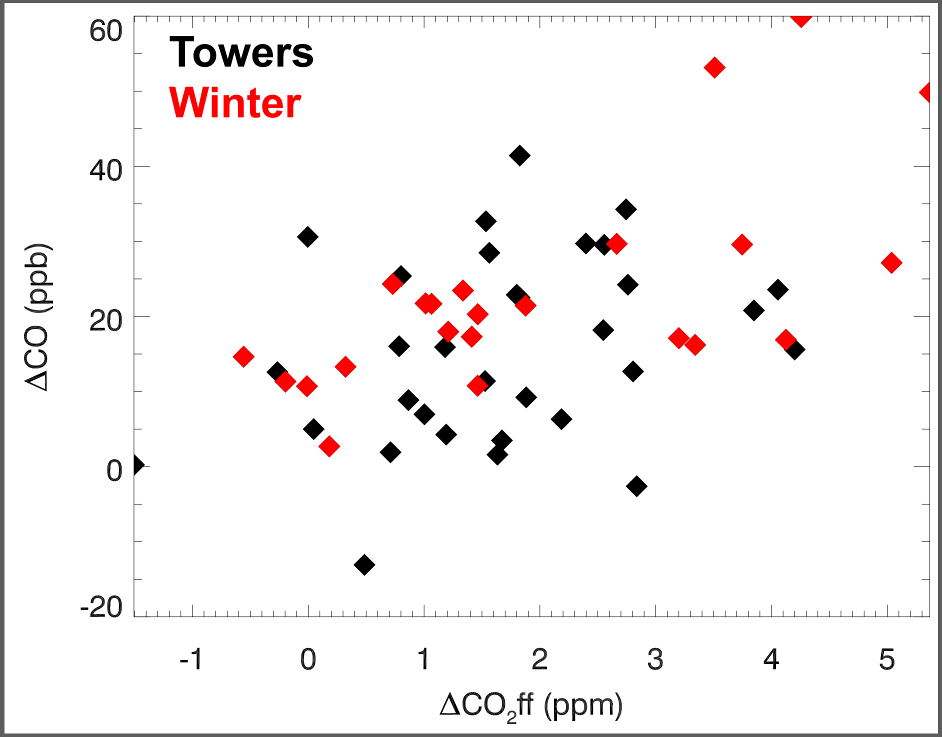


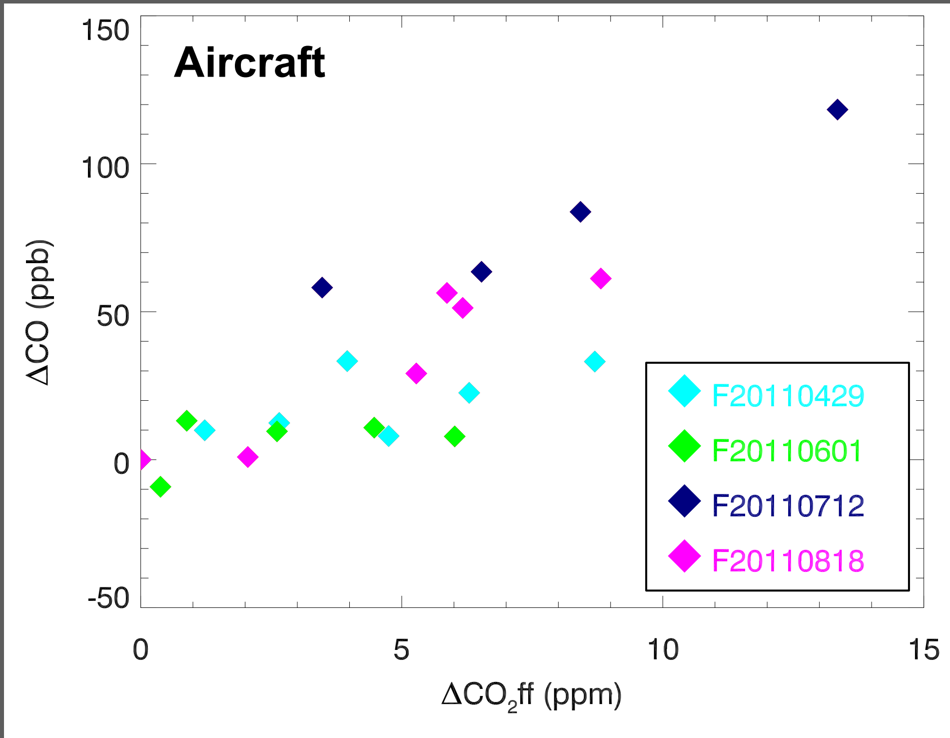
$$CO_2ff = \frac{CO_{2obs}(\Delta_{obs} - \Delta_{bg})}{\Delta_{ff} - \Delta_{bg}} - \frac{CO_{2r}(\Delta_r - \Delta_{bg})}{\Delta_{ff} - \Delta_{bg}}$$

Fossil fuel CO_2 is enhanced in urban plume



CO as a correlate CO_2ff tracer in Indianapolis

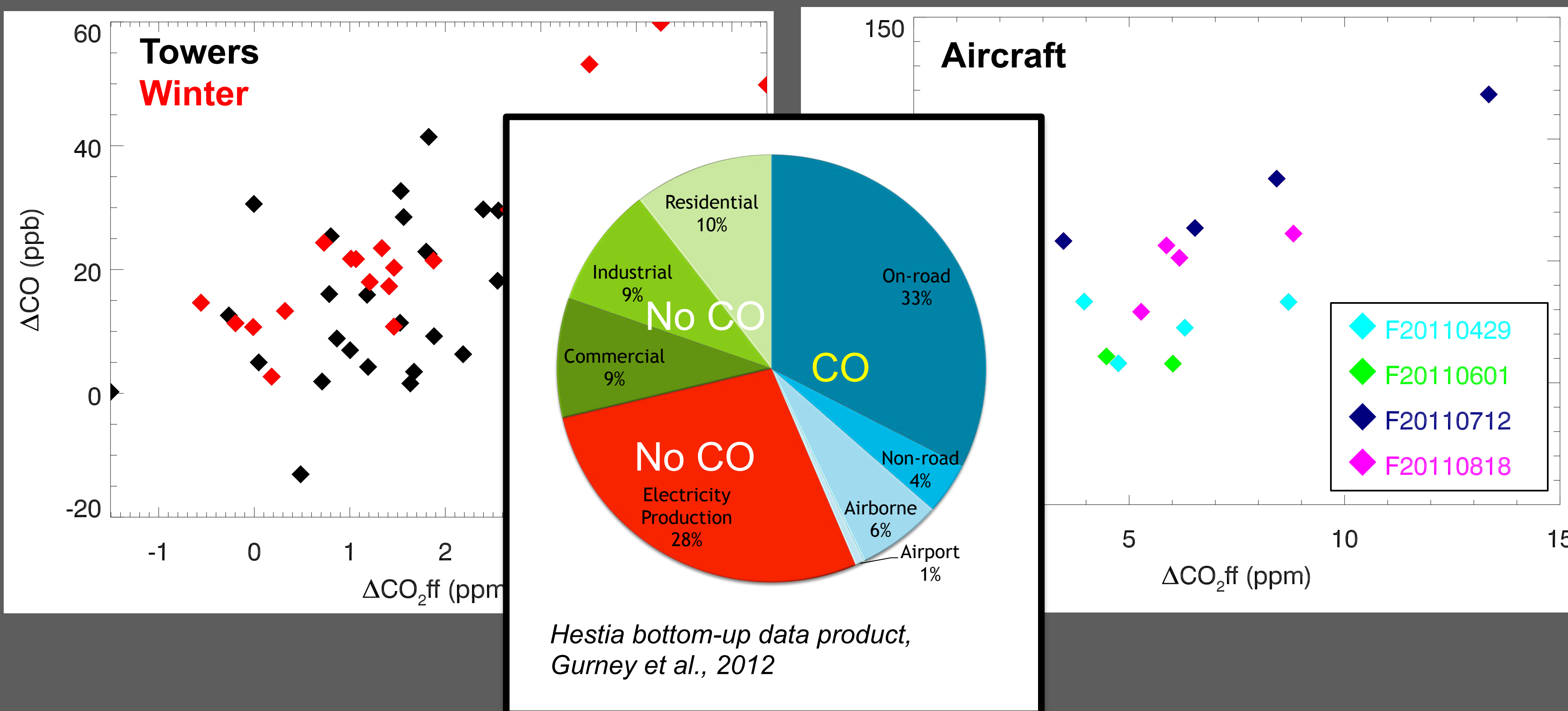




Variable CO:CO_2ff ratio, especially at towers

CO associated only with mobile CO_2ff source sectors

CO as a correlate CO_2ff tracer in Indianapolis



Variable CO:CO_2ff ratio, especially at towers

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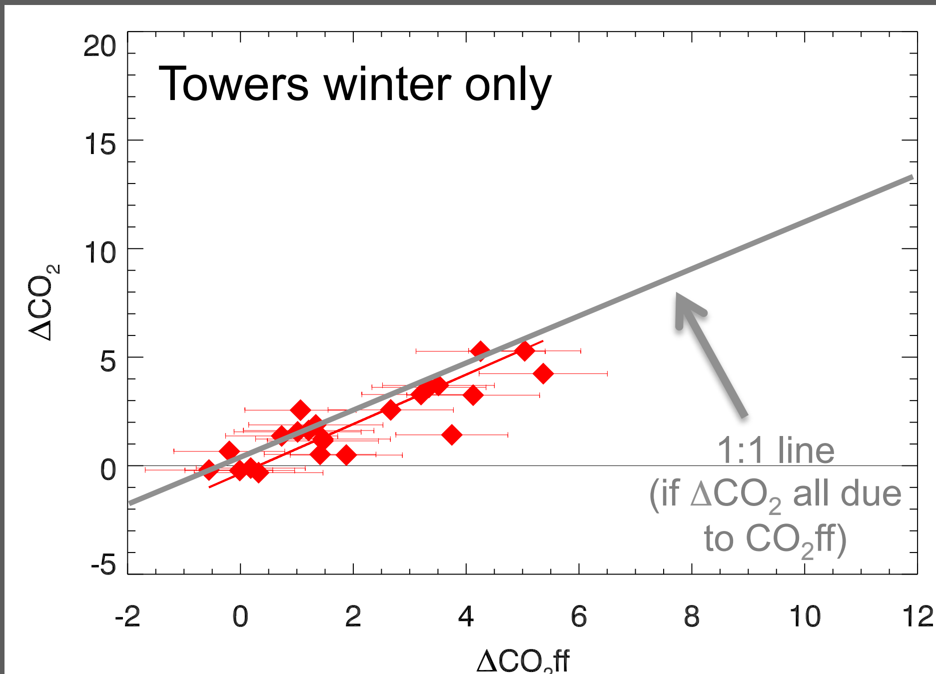
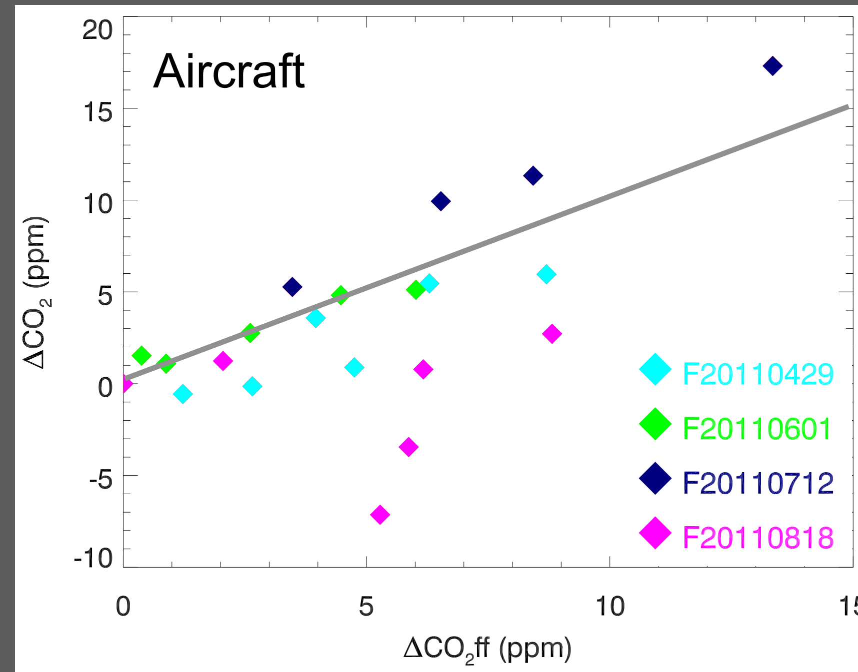
Contributions to CO_2 enhancement





$CO_2obs = CO_2bg + CO_2ff + CO_2bio + CO_2ocean$

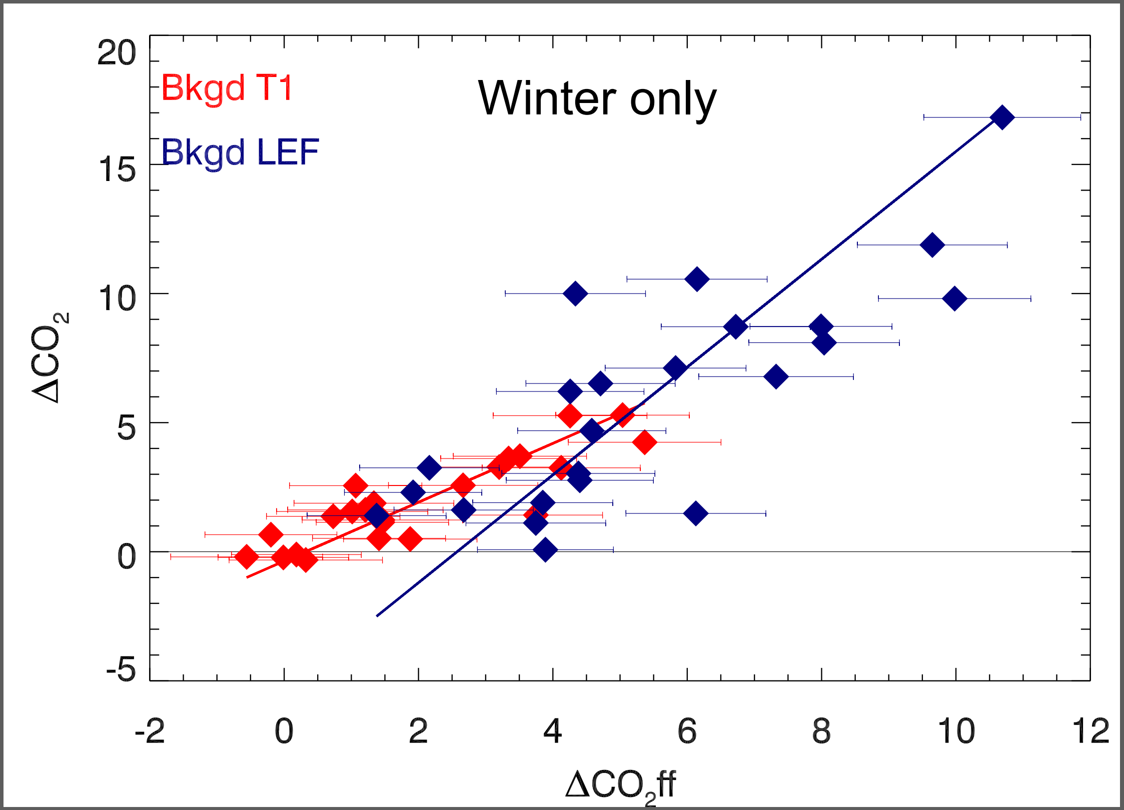
$\Delta CO_2 = \Delta CO_2ff + \Delta CO_2bio$

ΔCO_2 in winter can be entirely explained by CO_2ff addition

No apparent biosphere (respiration/ photosynthesis) contribution

	Slope (ppm/ppm)	**r^2**
Towers Winter	1.1±0.2	0.8
29 Apr 2011	1.1±0.1	0.8
1 Jun 2011	0.9±0.1	0.9
12 Jul 2011	1.2±0.1	1.0
18 Aug 2011	N/A	0.0

Why is Indianapolis total CO_2 enhancement dominated by CO_2ff?



When local upwind background is used,

$\Delta CO_2 \cong \Delta CO_2$ff

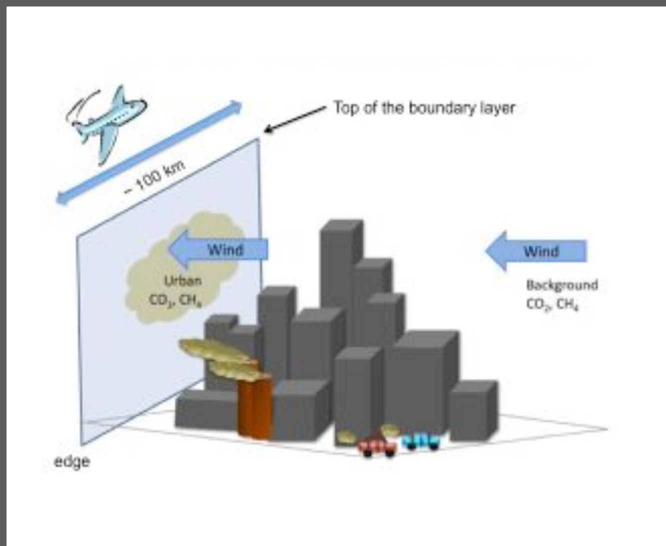
When continental background is used,

$\Delta CO_2 \cong 2x\, \Delta CO_2$ff

Choice of background directly upwind of city isolates ONLY the urban influence

Continental background has a strong respiration influence in winter, consistent with previous studies

Urban flux estimate using aircraft in situ CO_2 and mass balance approach



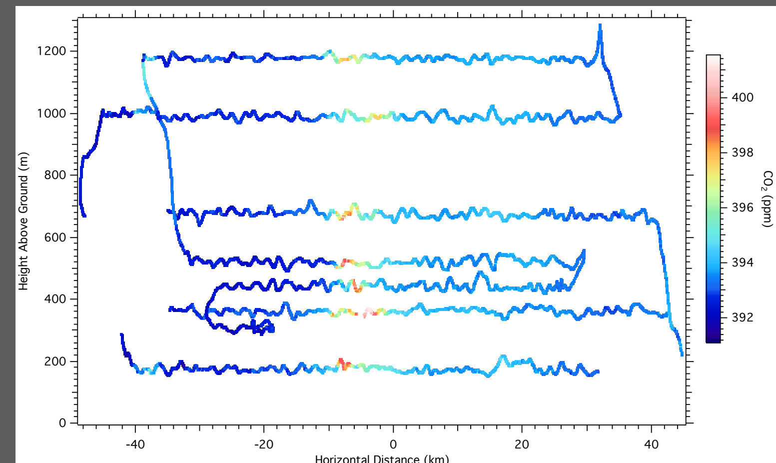
$$F_c = \int_0^{z_i} \int_{-x}^{+x} \left([C]_{ij} - \overline{[C]}_b \right) * U_{\perp ij} \, dx \, dz$$

CO_2ff flux

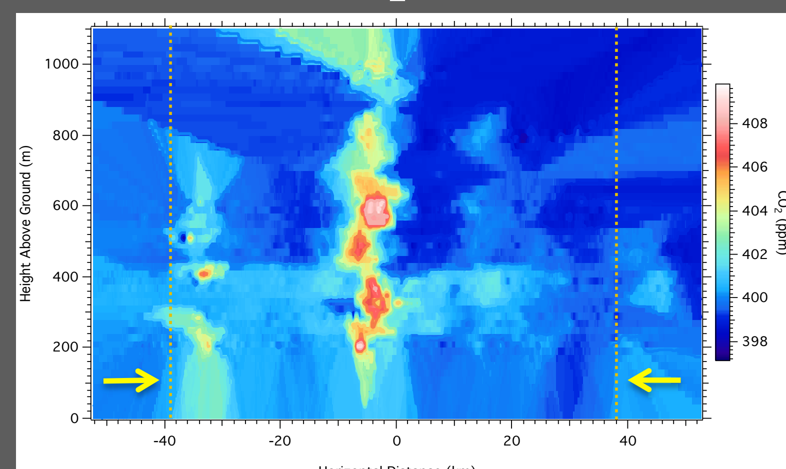
CO_2 enhancement over background

wind speed

In situ CO_2 measurement

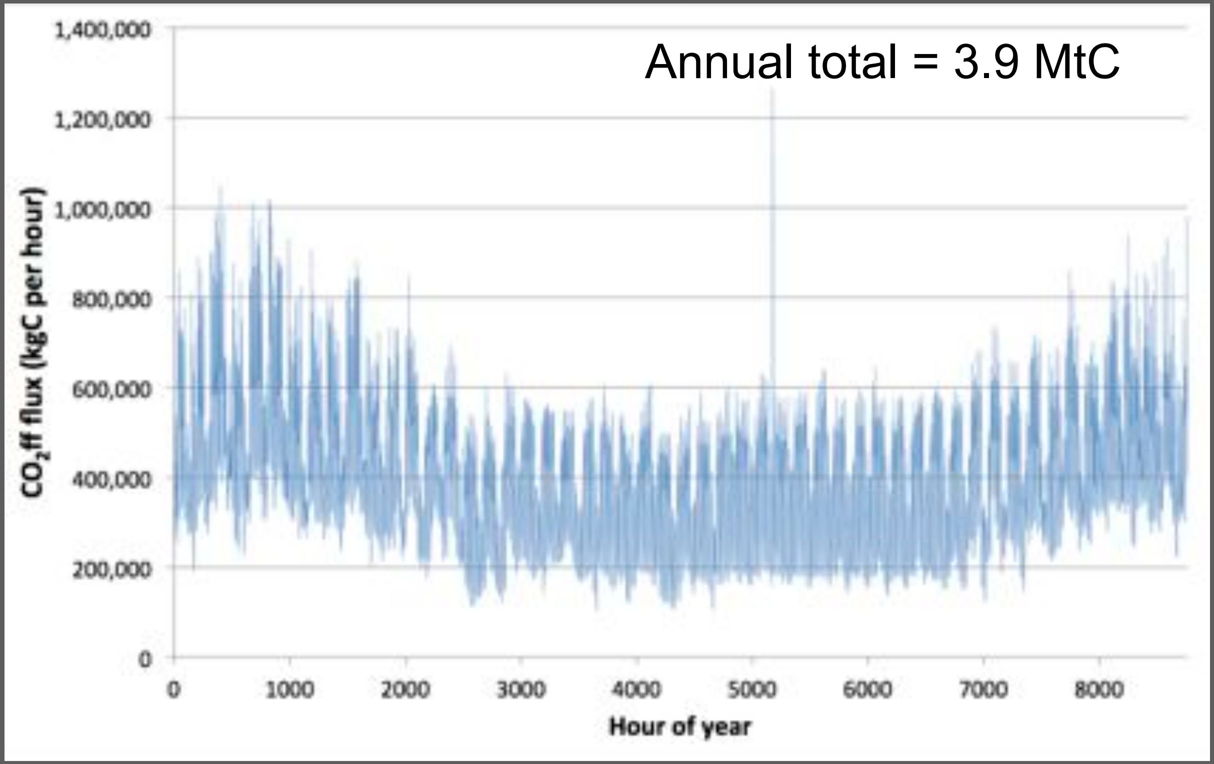


Kriged CO_2 surface



Cambaliza et al., in prep

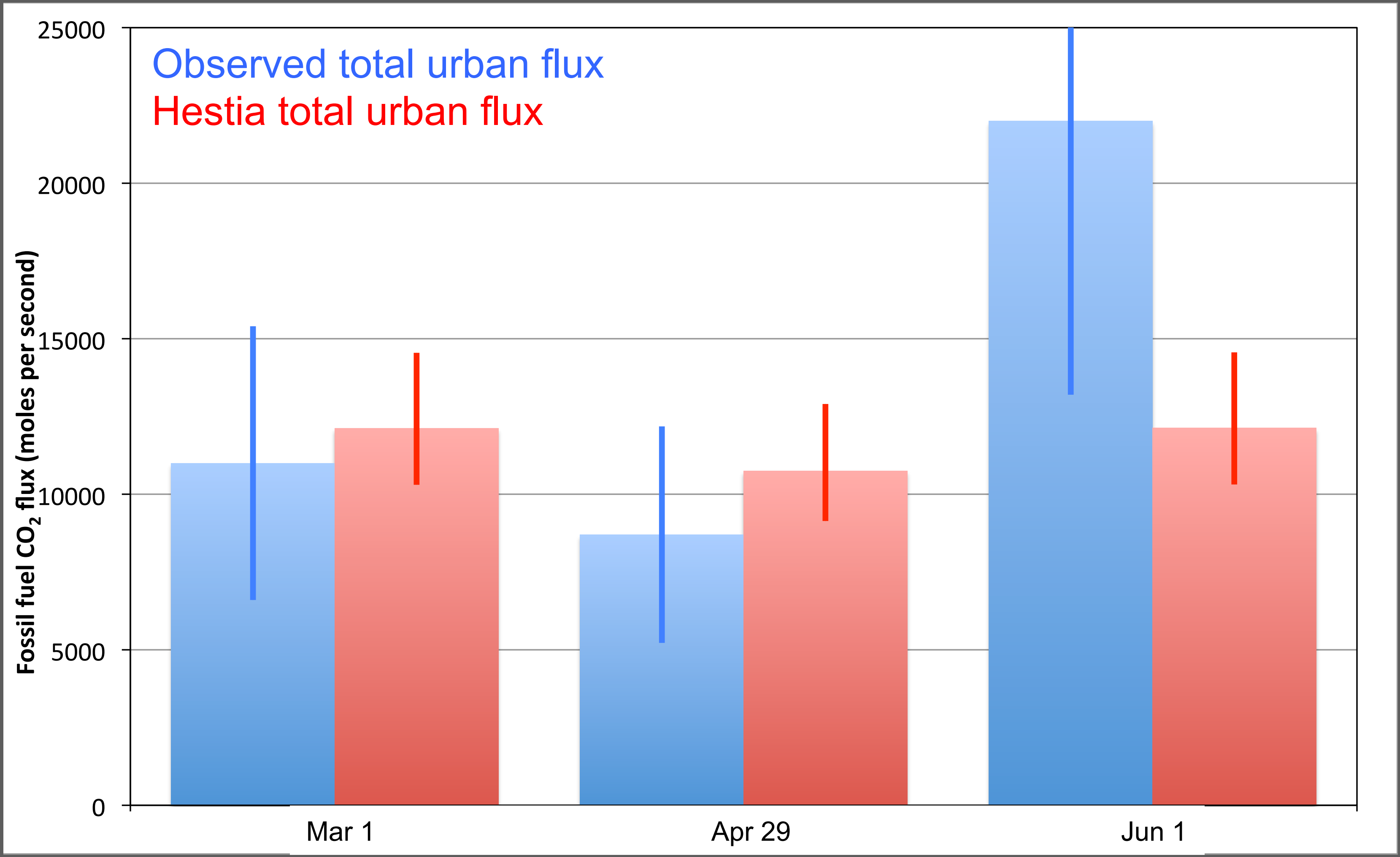
Hestia bottom-up emission estimates for Indianapolis



Gurney et al., 2012

- Annual totals have been distributed to hourly resolution
  - Power plant emissions at native hourly resolution from stack monitor
  - Estimated diurnal, weekly and seasonal cycles for transport, residential, commercial sectors

Comparison of flux estimates from atmospheric observations and bottom-up estimates



Cambaliza et al., in prep

Top-down and bottom-up estimates agree quite well

Conclusions

^{14}C provides a strong constraint on fossil fuel CO_2
Ancillary tracers can potentially be used to partition the CO_2ff source sectors

With appropriate choice of background site, we found that CO_2 enhancements over Indianapolis are entirely due to fossil fuel CO_2 during most of the year

In situ CO_2 measurements from aircraft were used to estimate the fossil fuel CO_2 flux
Initial data shows bottom-up and top-down methods agree quite well

Ongoing research

Inverse mesoscale modeling to determine flux from tower observations

10 additional towers will test network design

Quantify uncertainties in top-down flux calculation

CO_2ff source sector apportionment with multi-species measurements