High-accuracy, high-precision, high-resolution, source-specific monitoring of urban greenhouse gas emissions?
Results to date from INFLUX

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INFLUX motivation and goals
Indianapolis Flux Experiment (INFLUX)

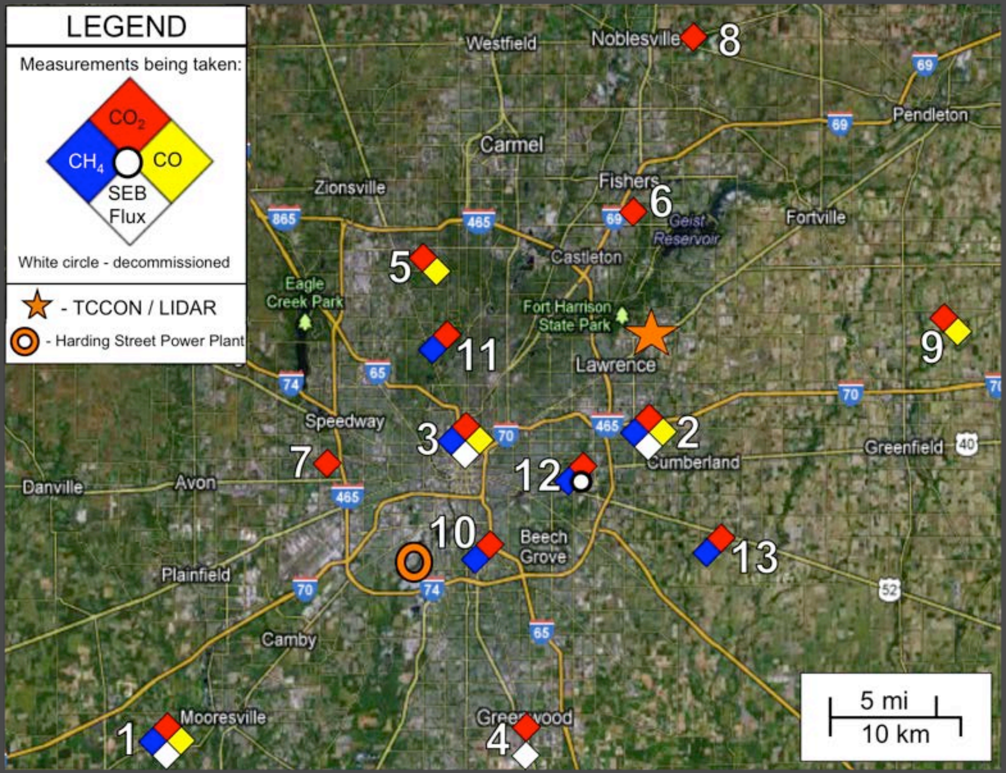
- **Motivation**
  - Anthropogenic greenhouse gas (GHG) emissions are uncertain at local / regional scales, where emissions mitigation will happen.
  - Validation of emissions mitigation will require independent measurements.
  - Atmospheric GHG measurements can potentially provide such independent emissions estimates.
- **Goals**
  - Develop and assess methods of quantifying GHG emissions at the *urban scale*, using Indianapolis as a test bed.
  - Determine whole-city emissions of CO_2 and CH_4
  - Distinguish biogenic vs. anthropogenic sources of CO_2
  - CO_2ff source sector attribution
  - Quantify and reduce uncertainty in urban emissions estimates
  - Evaluate and improve bottom-up data products

INFLUX toolbox

- Stationary atmospheric observations:
  - 12 GHG Towers with in situ CO_2, CH_4, CO
  - 6 flask samplers $^{14}CO_2$, other trace gases
  - Doppler lidar
  - 4 eddy covariance flux towers
- Mobile atmospheric observations:
  - periodic aircraft flights (GHG, met, flasks)
  - periodic automobile GHG sampling
- Emissions products:
  - Hestia (250m resolution, Indianapolis)
  - ODIAC (1km resolution, global)
- Modeling system:
  - WRF-Chem, 1km, nested, with meteorological data assim.
  - Lagrangian Particle Dispersion Model.
  - Bayesian matrix inversion.
  - Modeled and directly observed GHG lateral boundary conditions.

INFLUX TOWER NETWORK
Inversion-based flux estimates

Communications towers ~100 m AGL

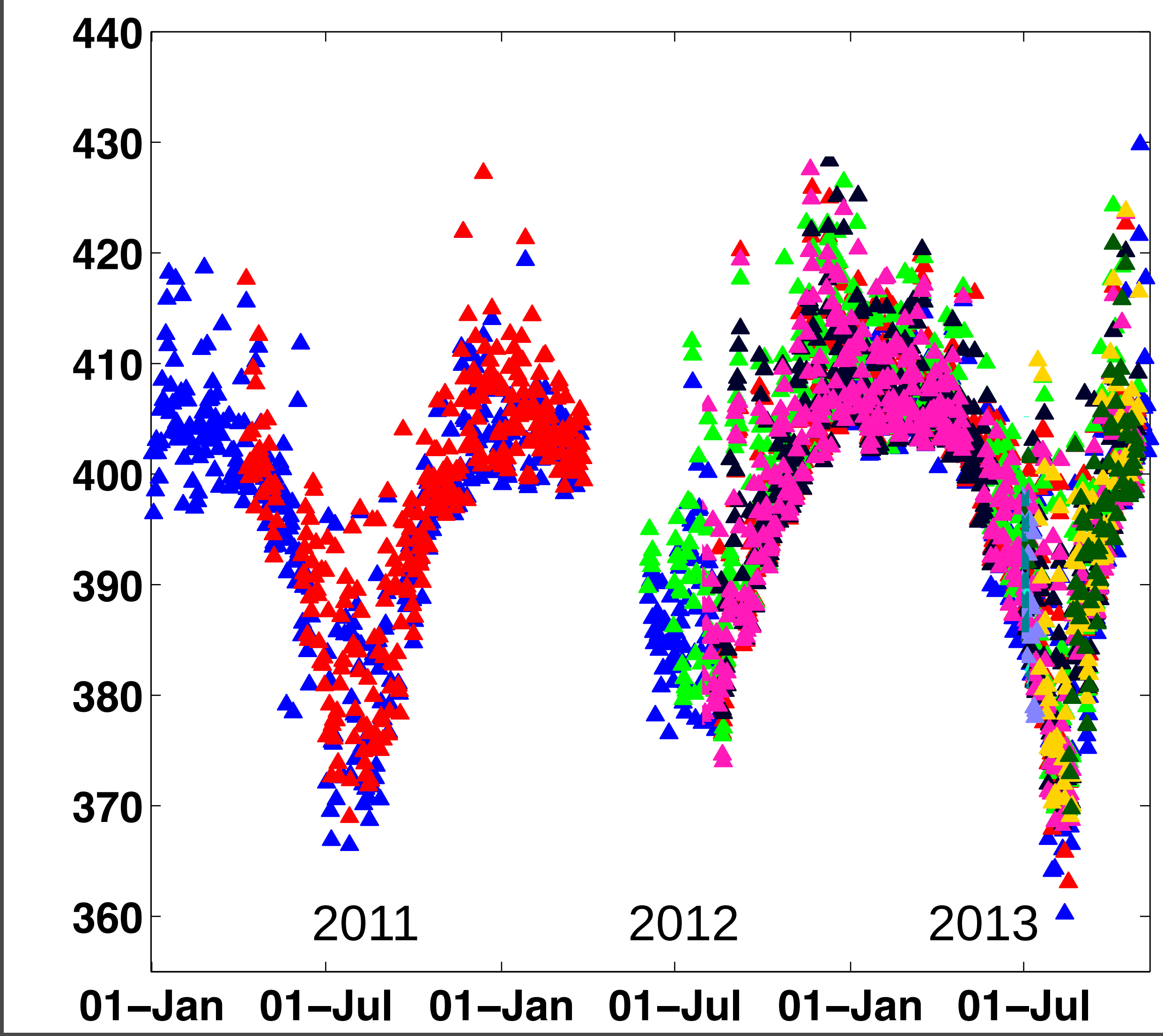


Picarro, CRDS sensors
12 measuring CO_2
11 with CH_4
5 with CO

6 NOAA automated flask samplers
50 species

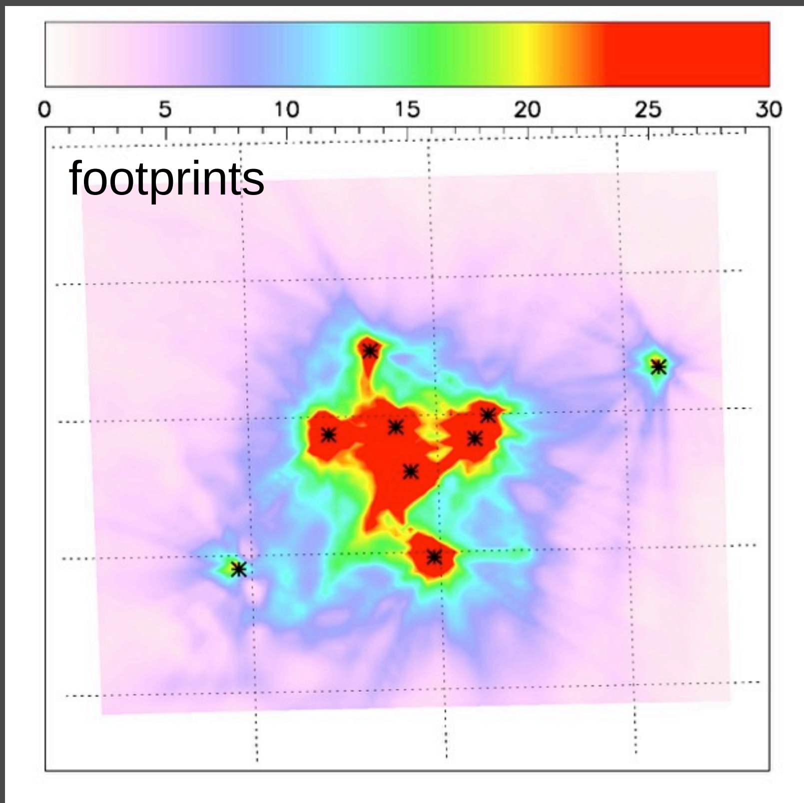
[CO_2] at INFLUX towers

- Afternoon daily [CO_2]
- Seasonal signal is apparent
- Significant overlap between sites (weather-driven variability)

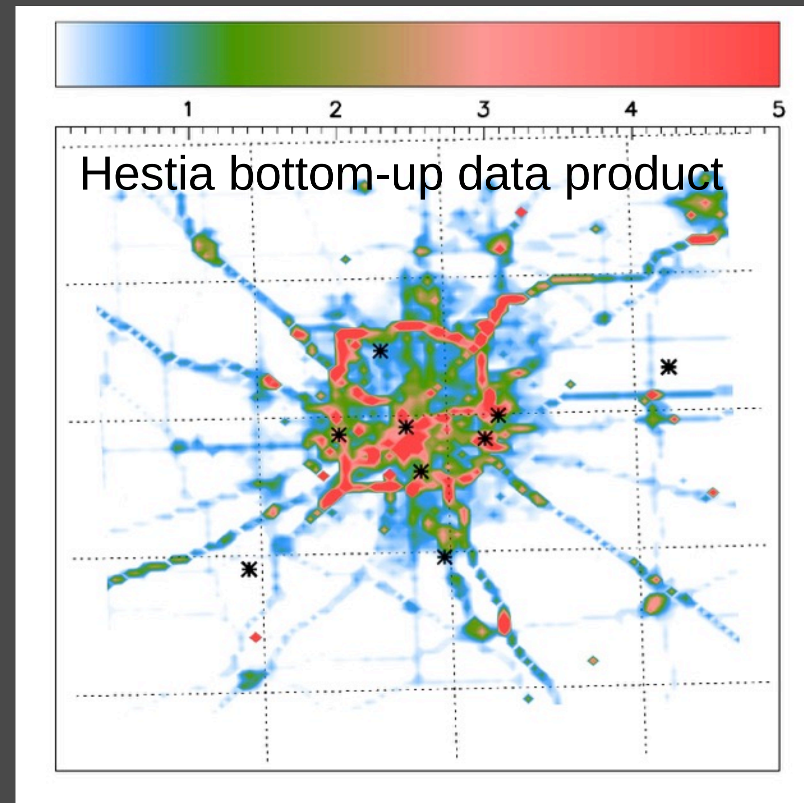


Miles et al, in prep

Model framework



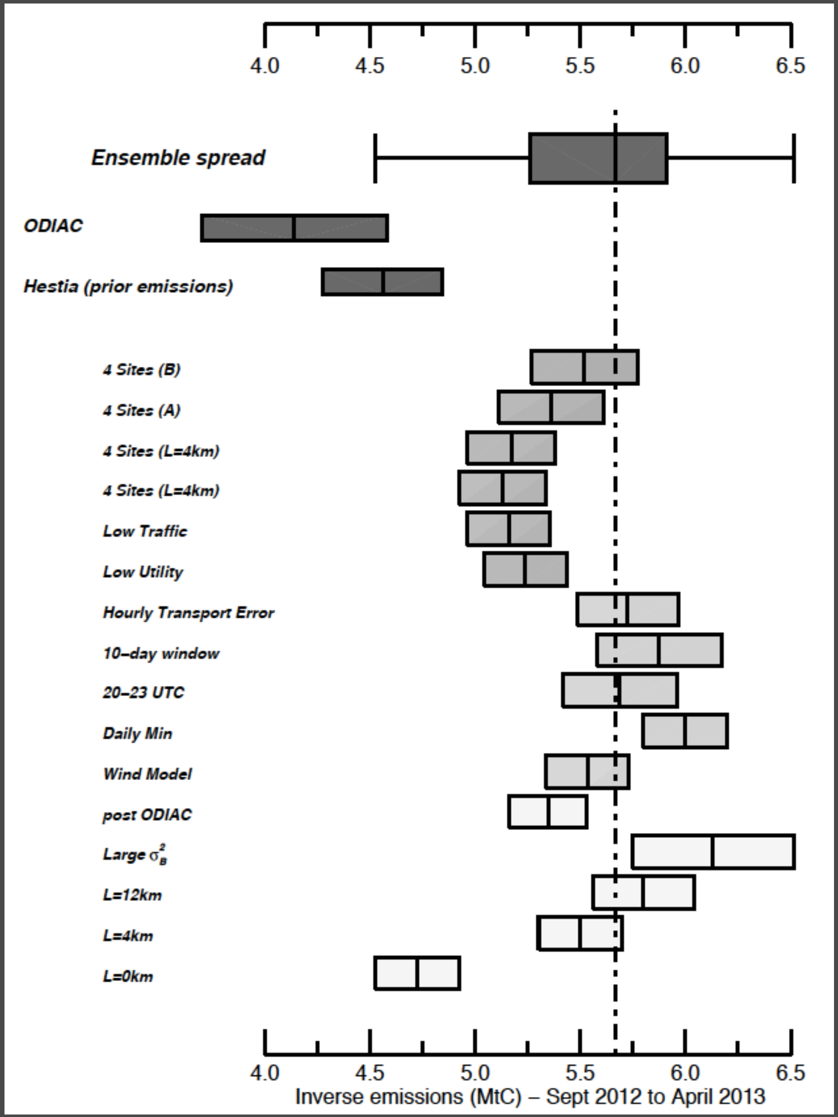
X



Combination of tower surface footprints with prior CO_2 emissions to generate modeled mixing ratios

Inversion to optimize the Hestia prior emissions

Inversion: Indianapolis whole-city CO_2 emissions



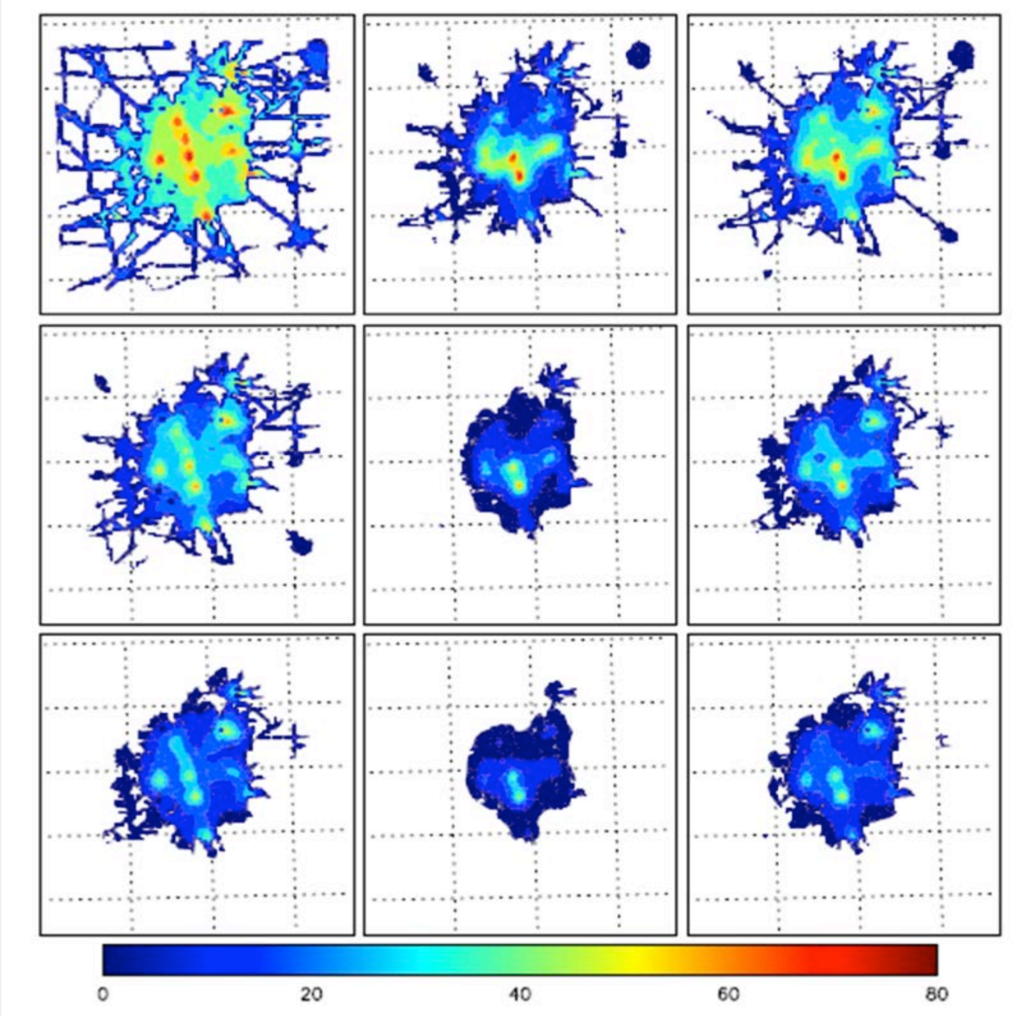
Sept12 – Apr13 Indianapolis CO_2 emissions:

Hestia bottom-up: 4.6 MtC

Inversion: 5.7 MtC +/- 0.2 MtC

Lauvaux et al, in press

Impact of CO_2ff observations on an inversion OSSE: CO_2ff observations recover signal lost due to biological fluxes



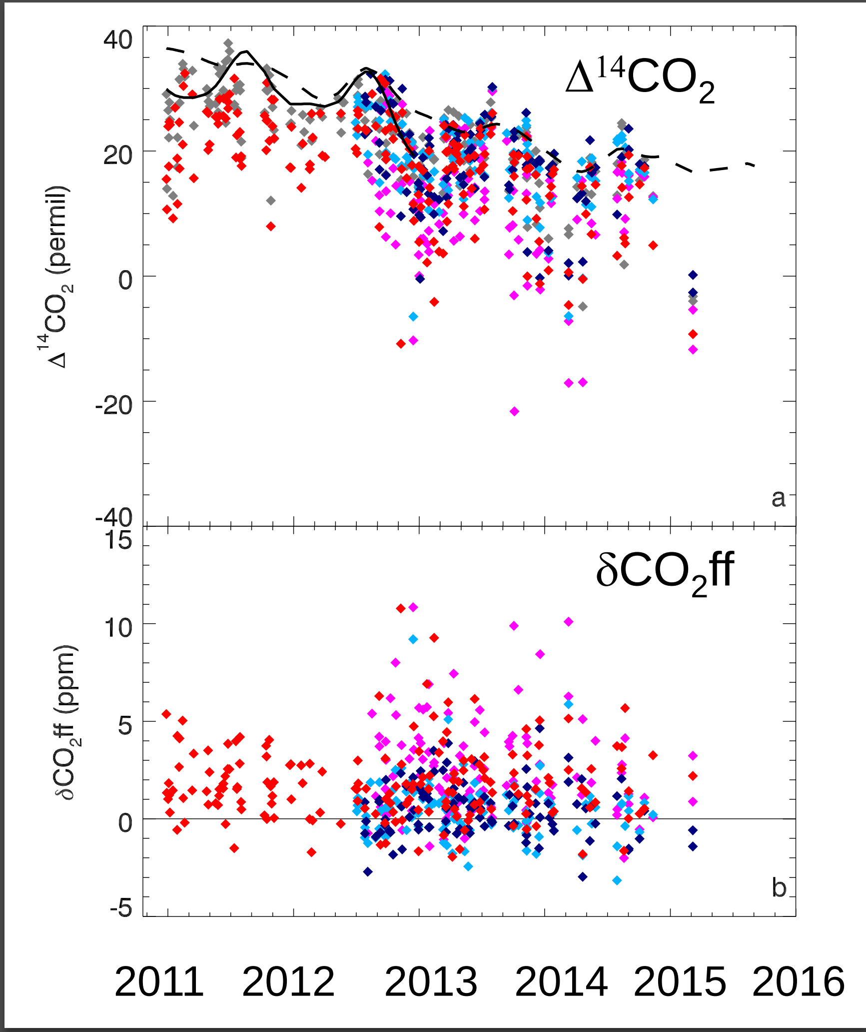
reduction in the prior error

How can we constrain CO_2ff?

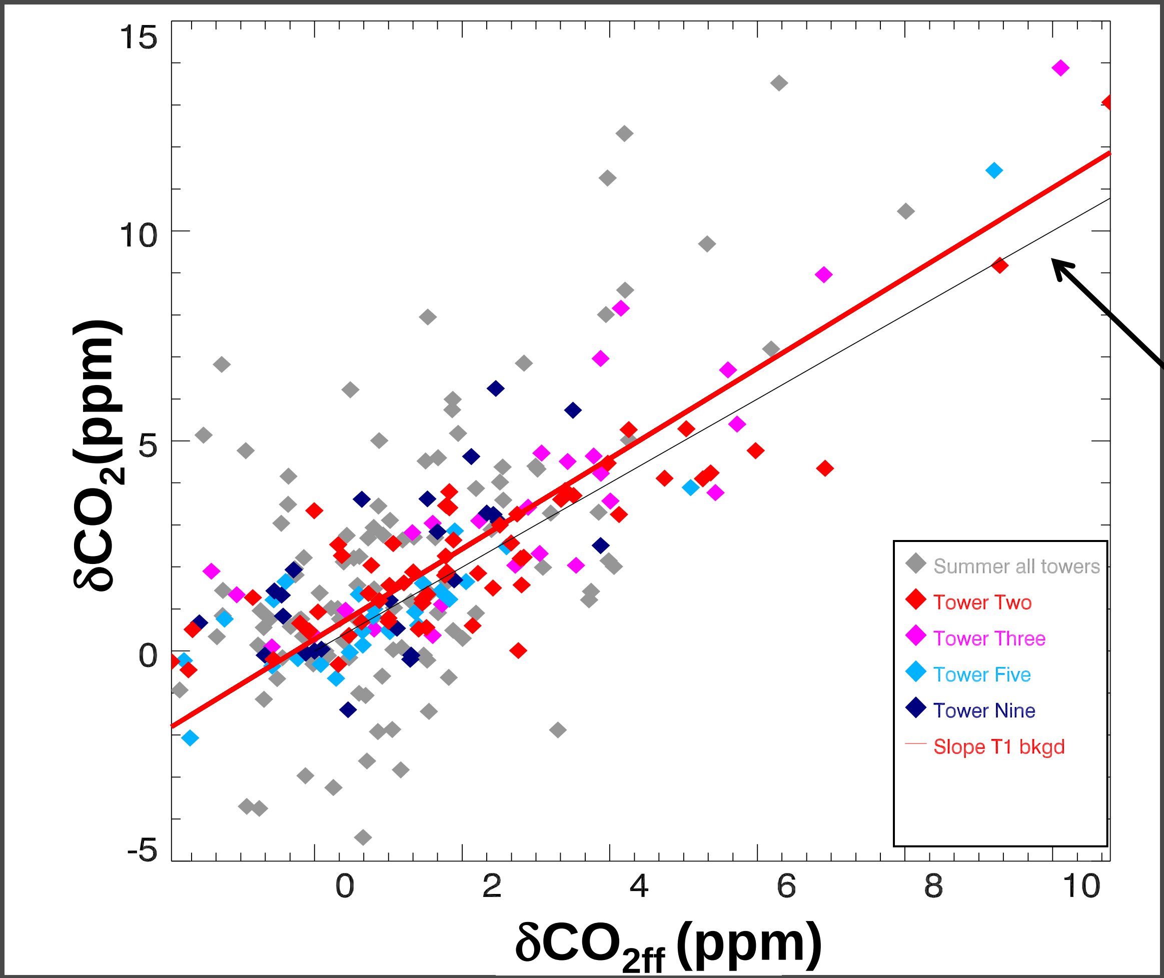
Flask $^{14}CO_2$ determines CO_2ff

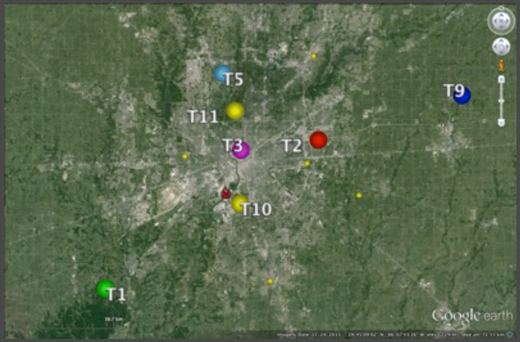
BUT limited flask data
(~ 6 samples/month)

Need higher temporal resolution CO_2ff



In winter, δCO_2 approximates δCO_2ff





1:1 line if all δCO_2 is due to δCO_2ff

Winter correlations	Slope $\delta CO_2/\delta CO_2ff$ (ppm/ppm)	r^2
All towers	1.1±0.1	0.8
Tower Two	0.9±0.2	0.8

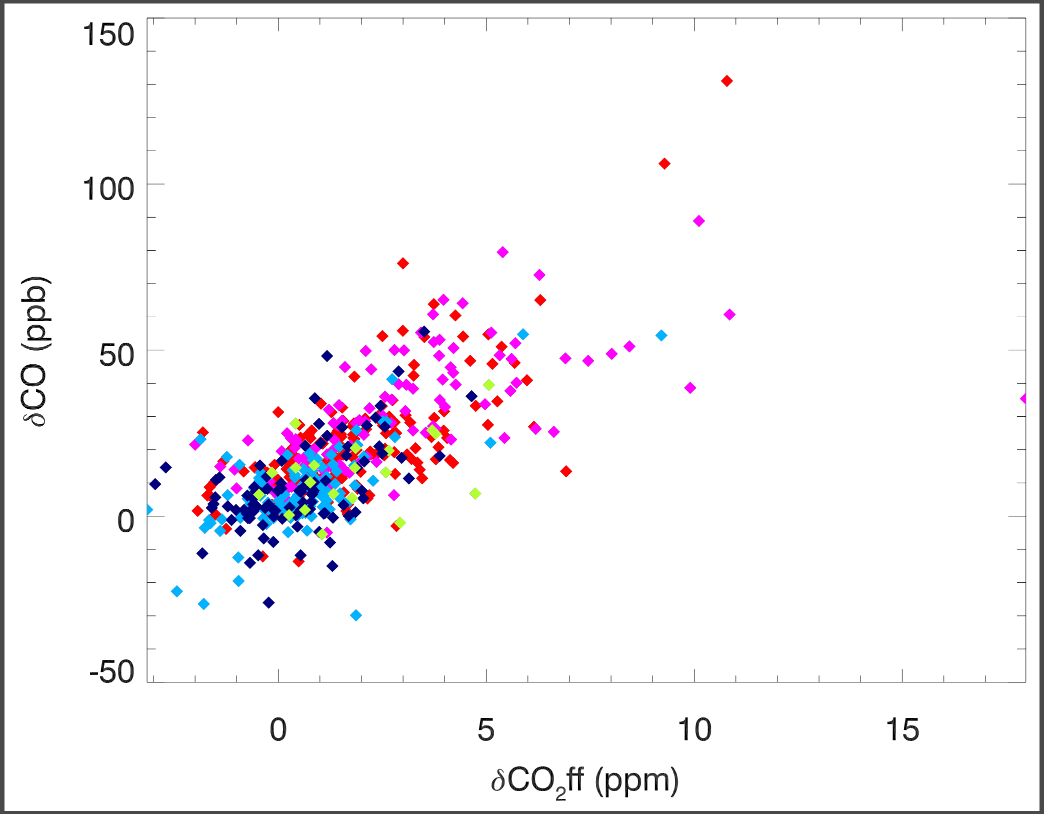
Flask measurements of $^{14}CO_2$ to determine CO_2ff

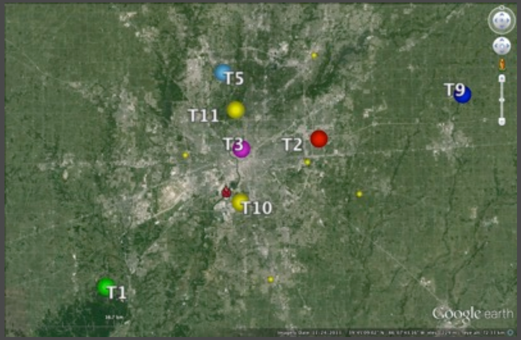
In winter, δCO_2 can be entirely explained by δCO_2ff

But not in summer!

Turnbull et al., 2015

CO as a proxy for CO_2ff throughout the year



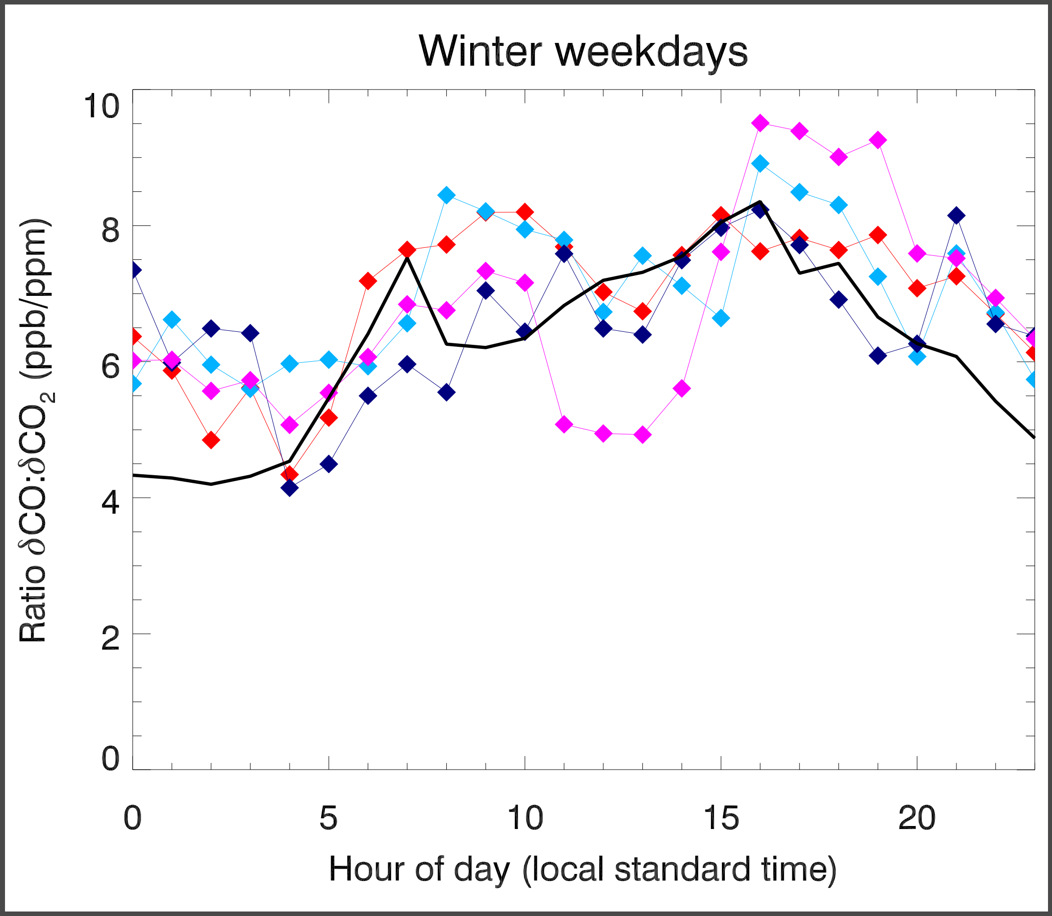


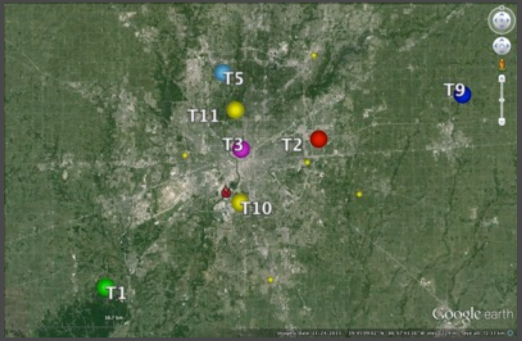
	R_{CO} (ppb/ppm)
All towers	8±1
T2	9±1
T3	6±2
T5	7±1
T9	8±2

CO is co-emitted with CO_2ff
When emission ratio R_{CO} is known, determine CO_2ff from in situ CO at high resolution
Determine emission ratio R_{CO} from afternoon flask data
Varies by tower – differing source mixture in footprints of each tower

Turnbull et al., 2015

Derive diurnally varying R_{CO} from Hestia bottom-up data product

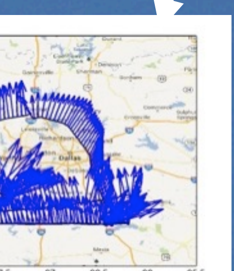




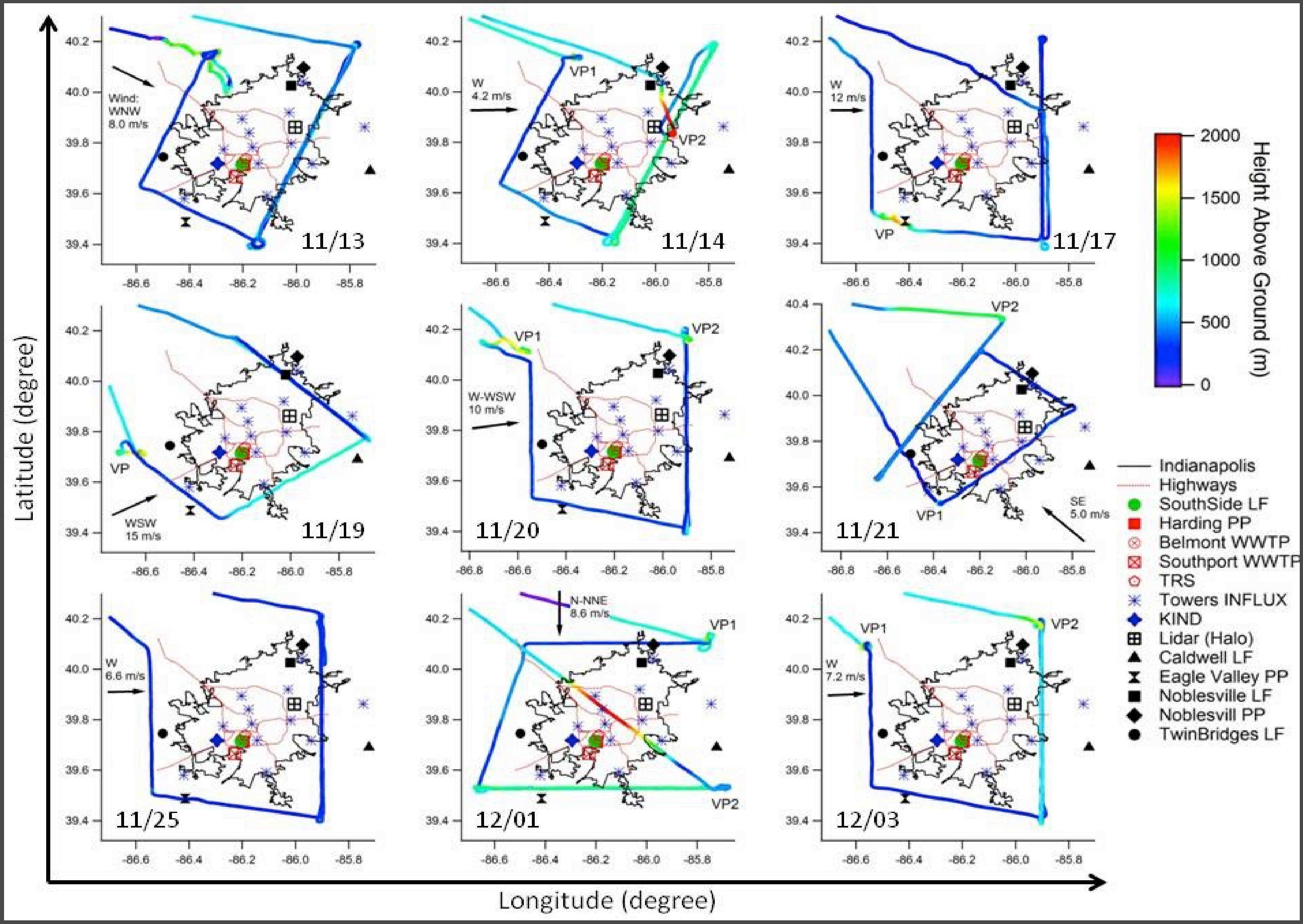
Assign time-varying R_{CO} based on Hestia bottom-up data product
Upcoming refinement: convolve modelled footprints and Hestia for tower- and time-specific R_{CO}

Turnbull et al., 2015

Aircraft
Mass balance CO_2 flux estimates

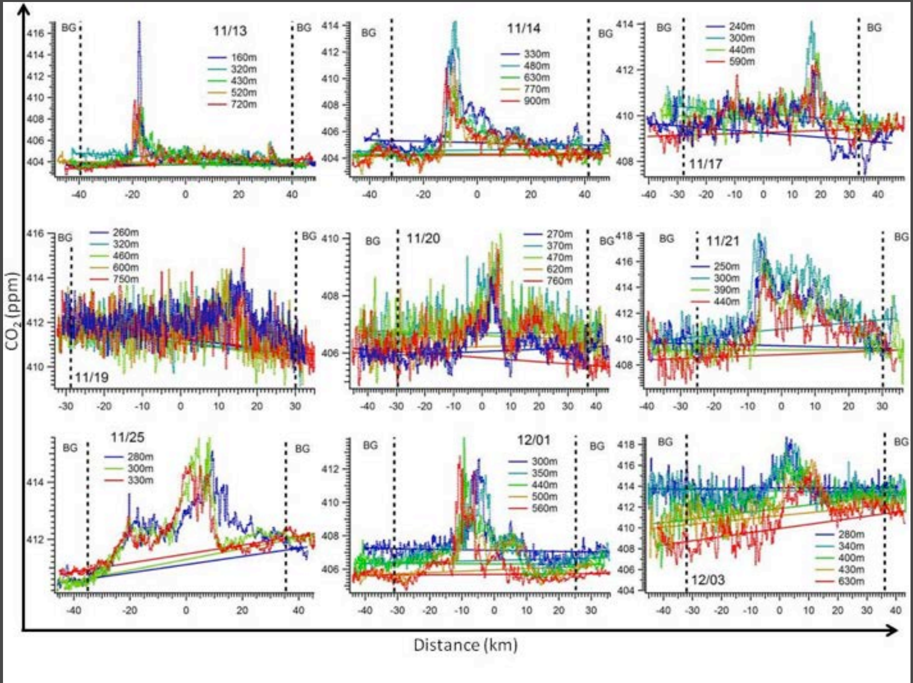


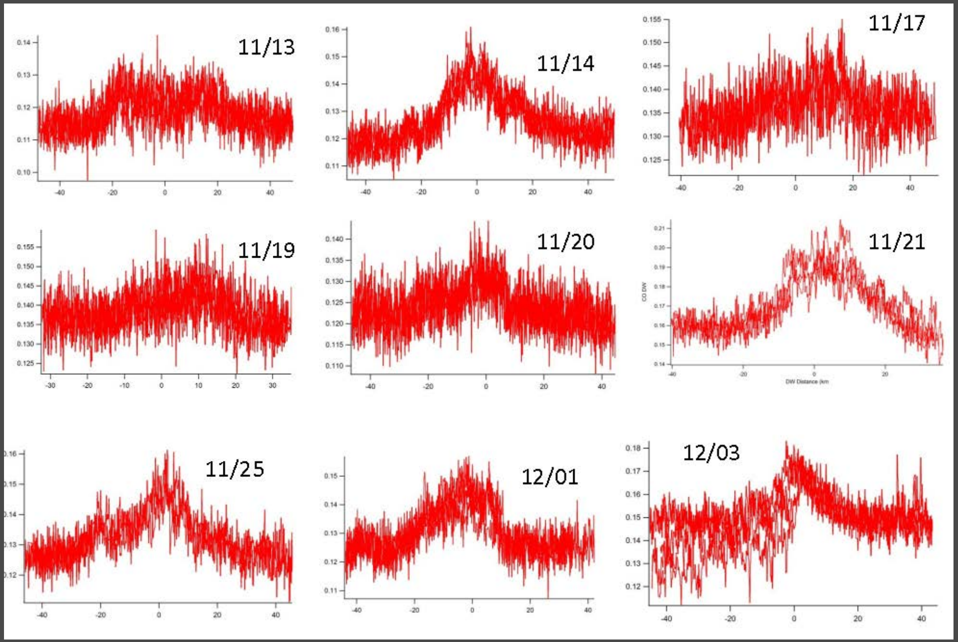
Mass Balance method : whole city CO_2 flux determination from aircraft



Heimberger et al., in prep

Mass Balance whole city
CO_2 flux determination from aircraft

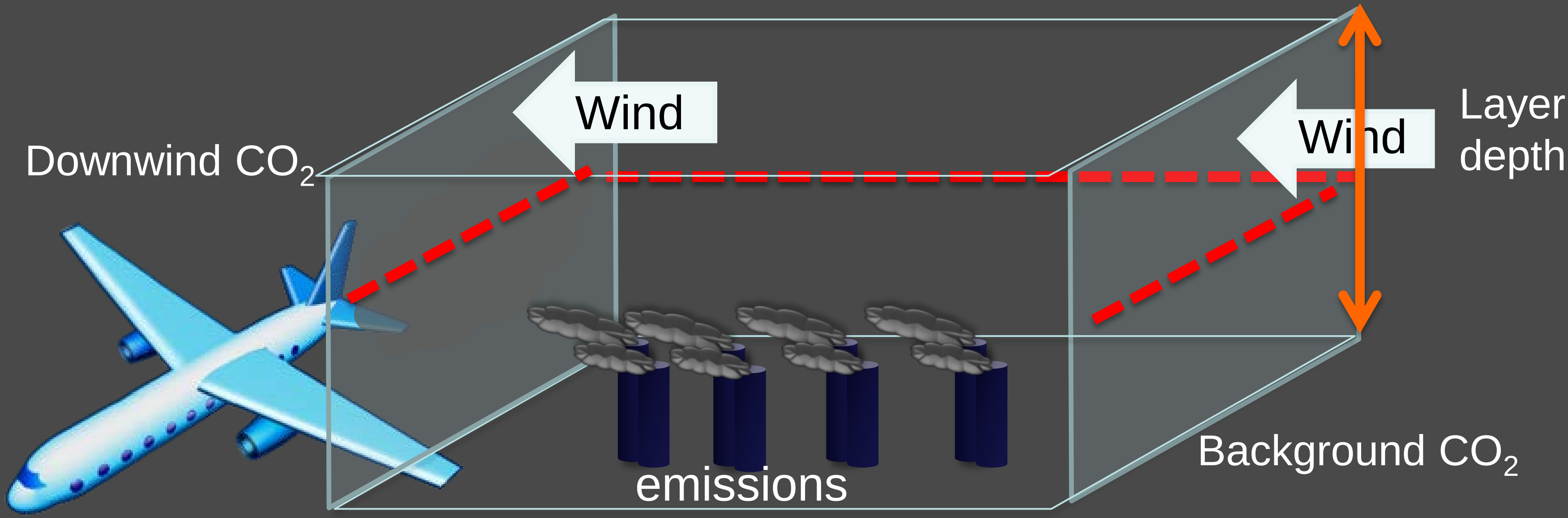




Use mass balance technique to determine whole-city emission flux for each flight date

Heimberger et al., in prep

Aircraft Mass Balance Method



Molar CO_2 enhancement in air layer

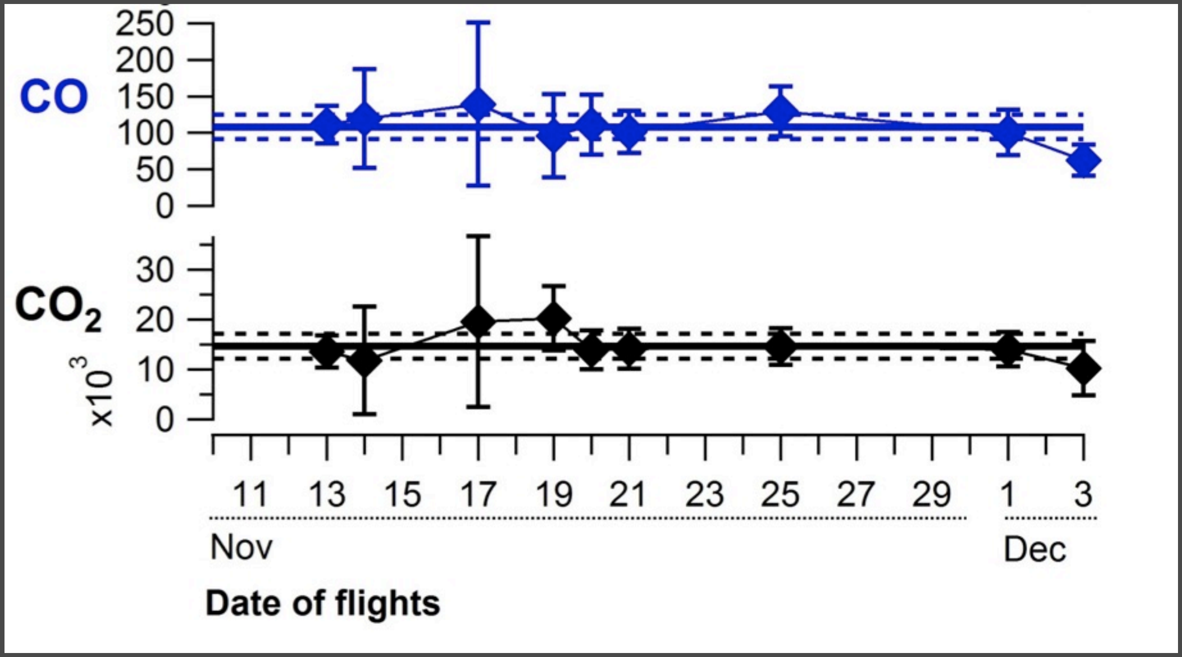
CO_2 flux

$$\dot{n}_{CO_2} = V\cos\theta \int_{-b}^{+b} \Delta X_{CO_2} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air}\, dz \right) dx$$

Perpendicular wind speed

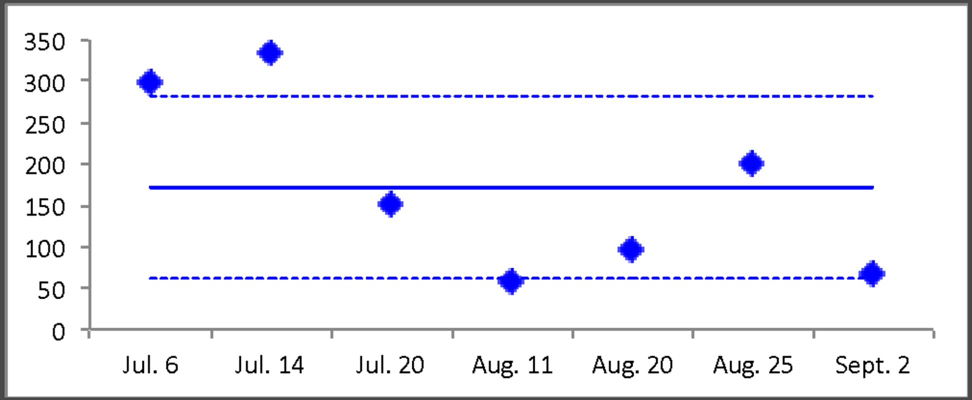
References: White et al., 1976; Ryerson et al., 2001; Cambaliza et al., 2014

Mass balance emission rates



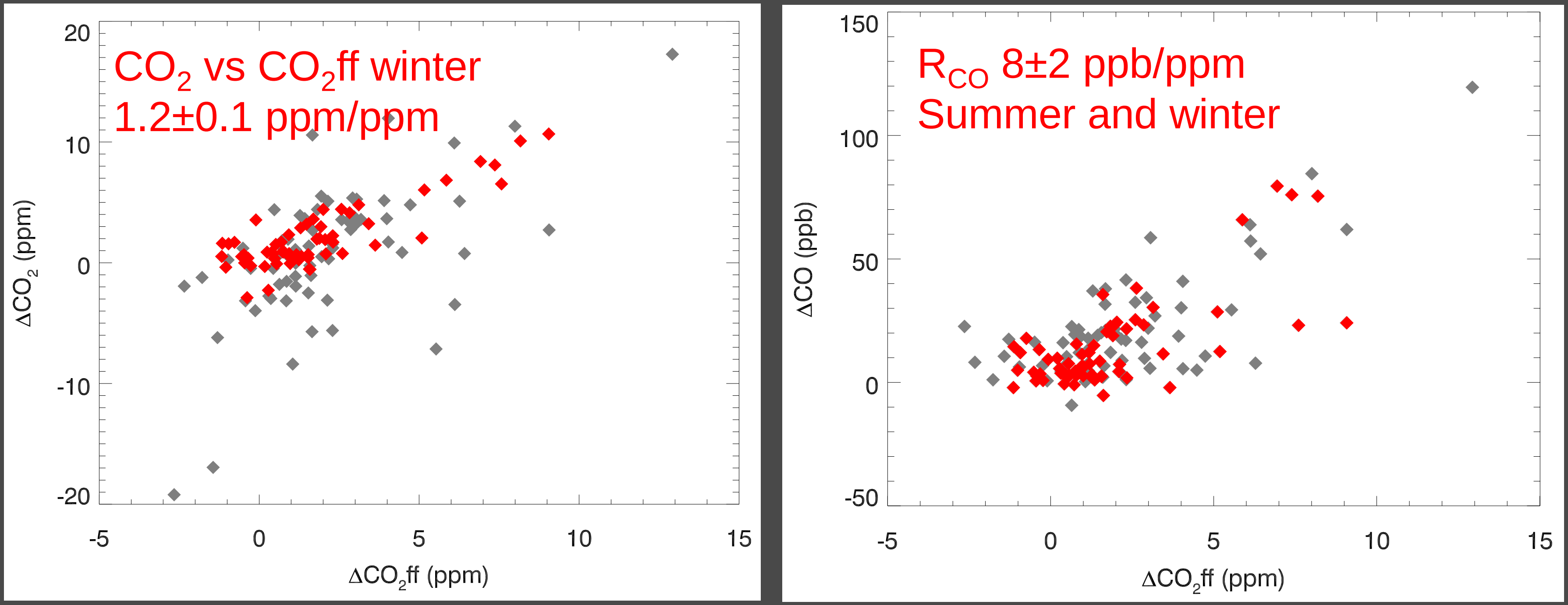
	Emission rate (mol/s)
CO winter 2014	108 (16%)
CO_2 winter 2014	14,600 (17%)
CO summer 2015	172 (64%)

CO



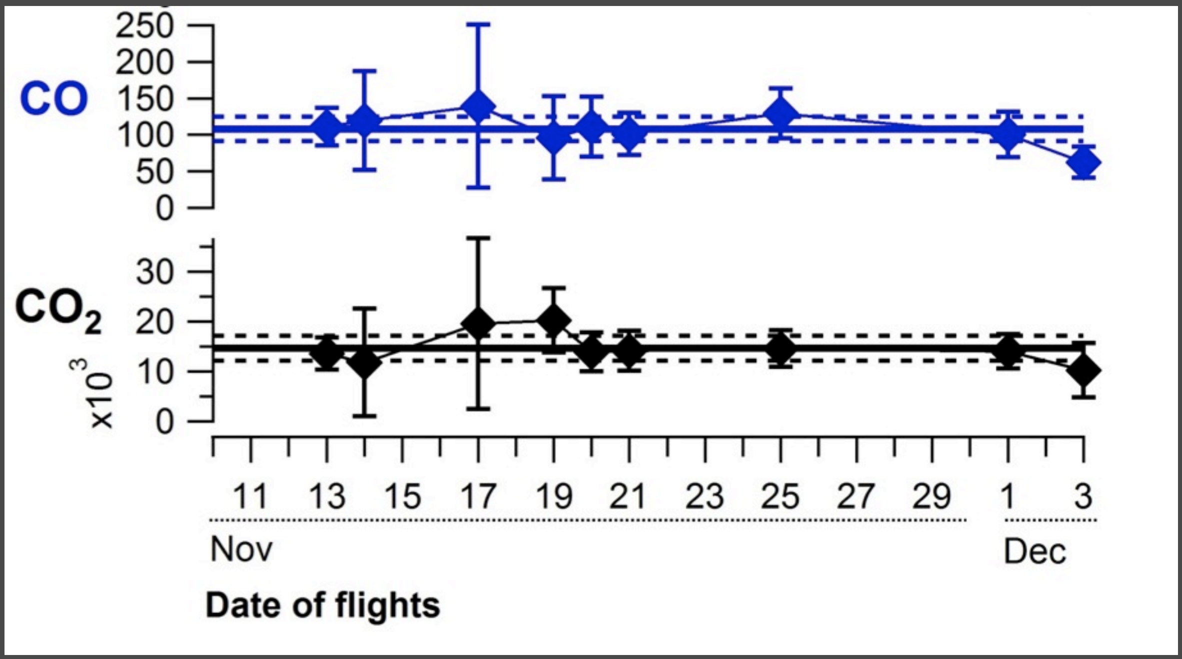
Heimberger et al., in prep

Aircraft flask-based emission ratios



4-6 flasks per flight
Consistent with tower ratios

Mass balance emission rates



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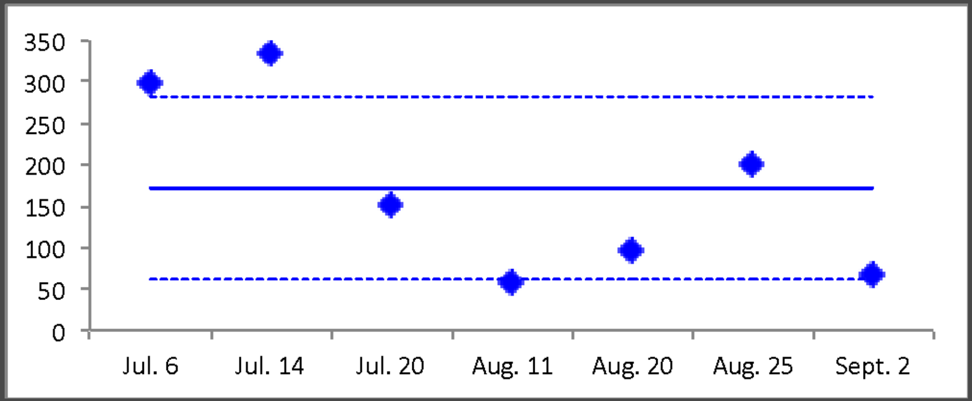
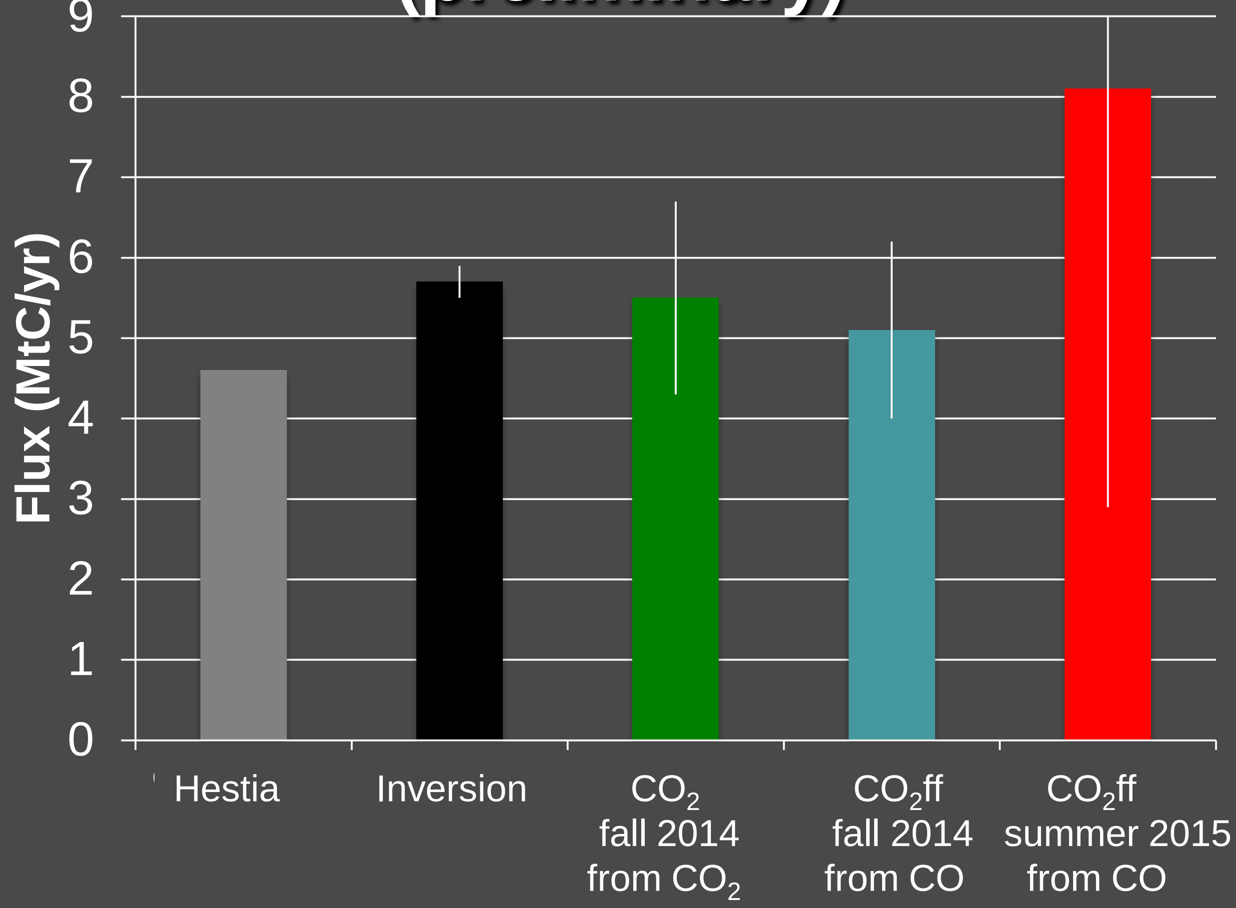


Heimberger et al., in prep

Comparison of whole city flux estimates (preliminary)

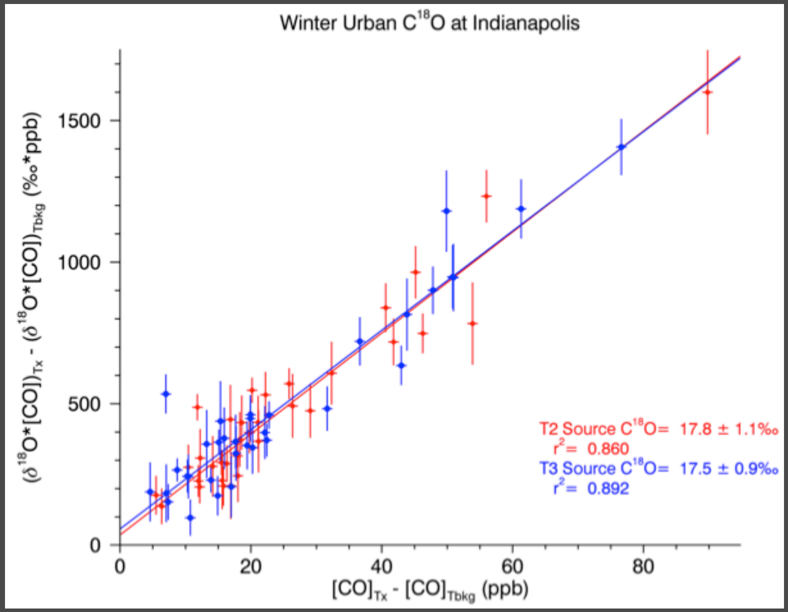


Generally good agreement across methods

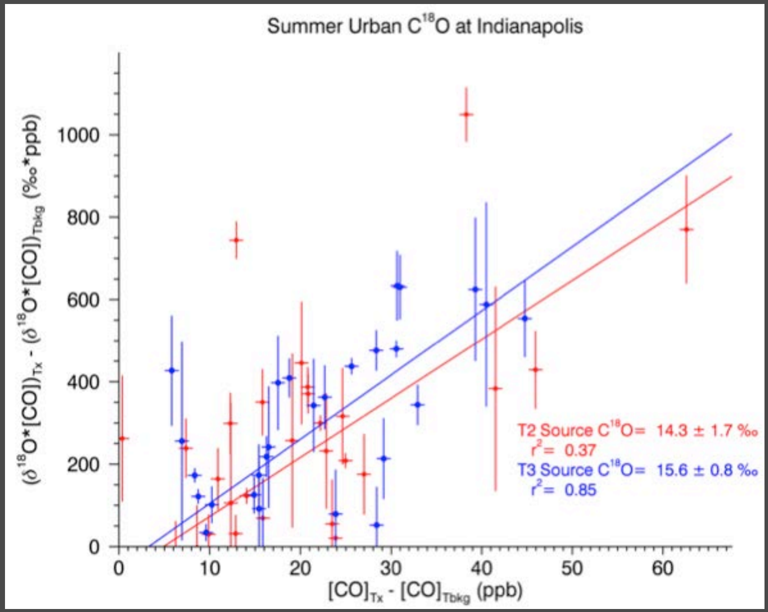
Summer estimate appears too high – R_{CO} biased by additional CO source?

Source of CO from oxidation of biogenic VOCs in summer?

CO stable isotopes partition emission sources



Winter: All CO derived from fossil fuel combustion

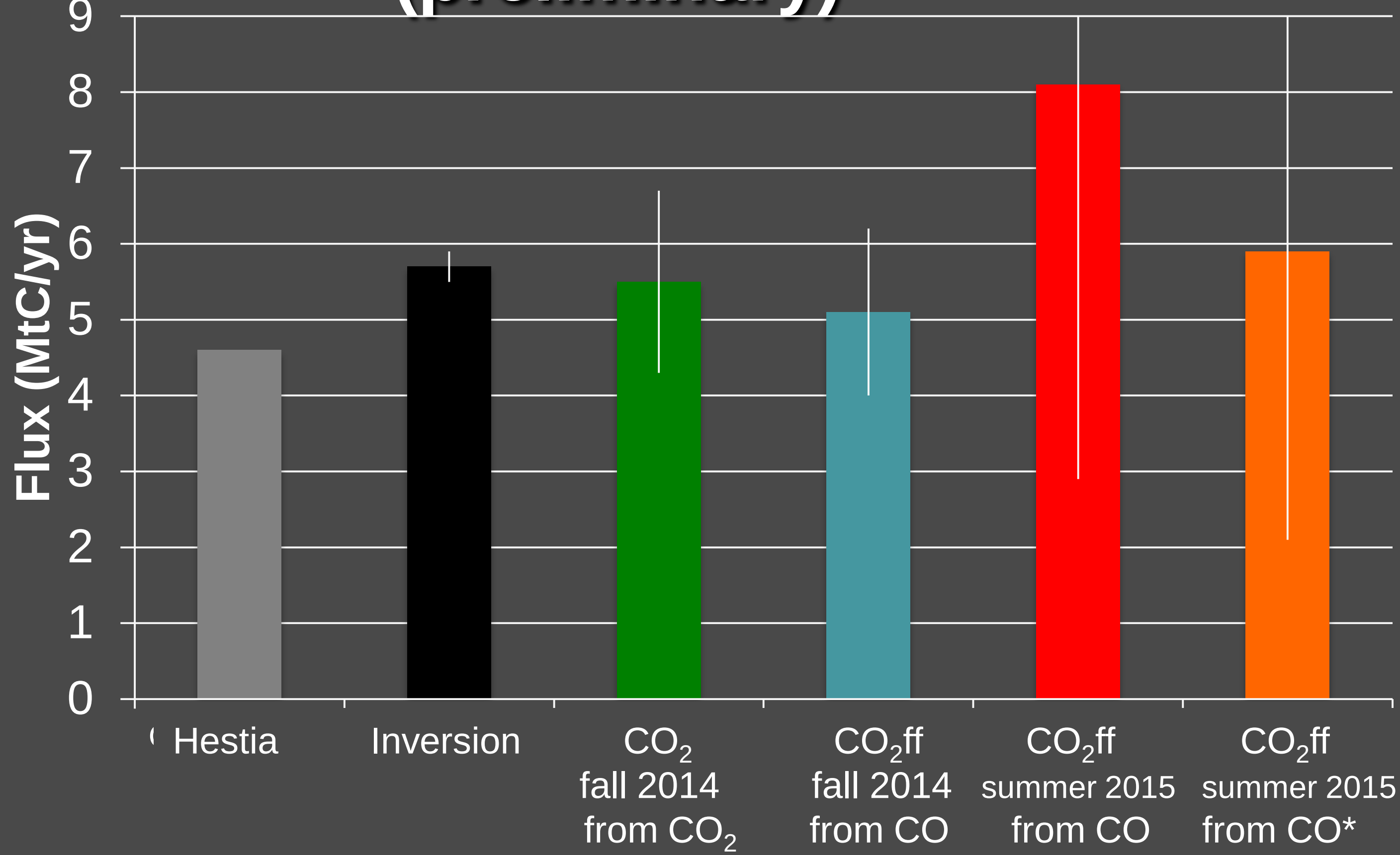


Summer: 20-25% of CO from VOC oxidation

Poster P-7 today

Vimont et al., in prep

Comparison of whole city flux estimates (preliminary)



Generally good agreement across methods

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Conclusions

Top-down constraints on urban CO_2ff emissions

- **Tower-based inversion increases CO_2 flux relative to Hestia bottom-up data**
  - Next steps use flask/in situ CO to separately constrain CO_2ff in inversion
- **Aircraft-based mass balance flux agrees with inversion**
  - In winter, CO_2-based mass balance and flask/CO-based mass balance agree
  - Summer flask/CO-based mass balance much higher, appears to be due to contribution of CO from VOC oxidation.
- **All top-down methods suggest higher flux than Hestia bottom-up estimate**