Inverse Modeling Challenges at Urban Scales

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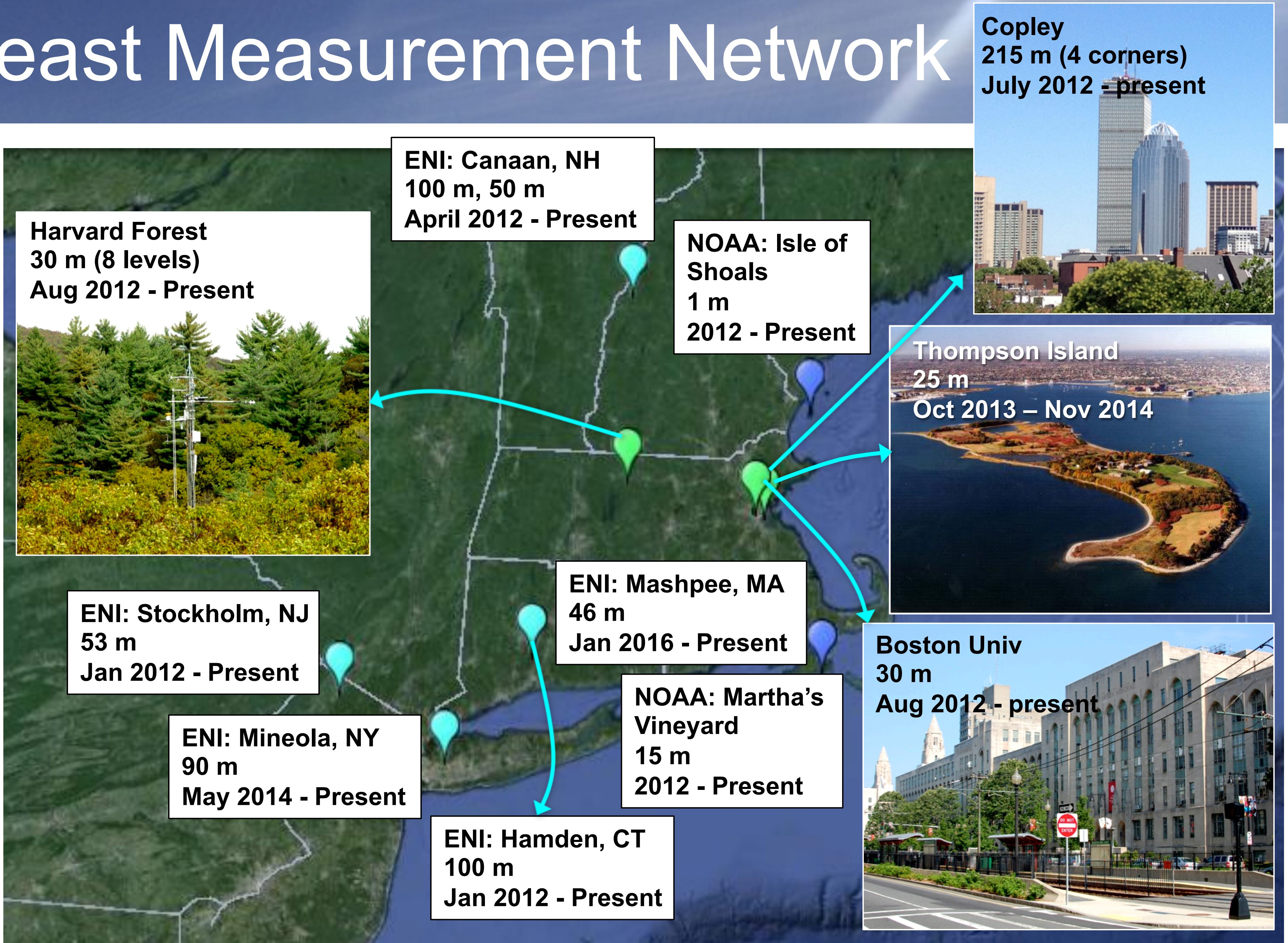
CO_2-Urban Synthesis and Analysis Workshop

08/25/2018

Northeast Measurement Network



Anthropogenic and biogenic CO_2 fluxes in the Boston urban region

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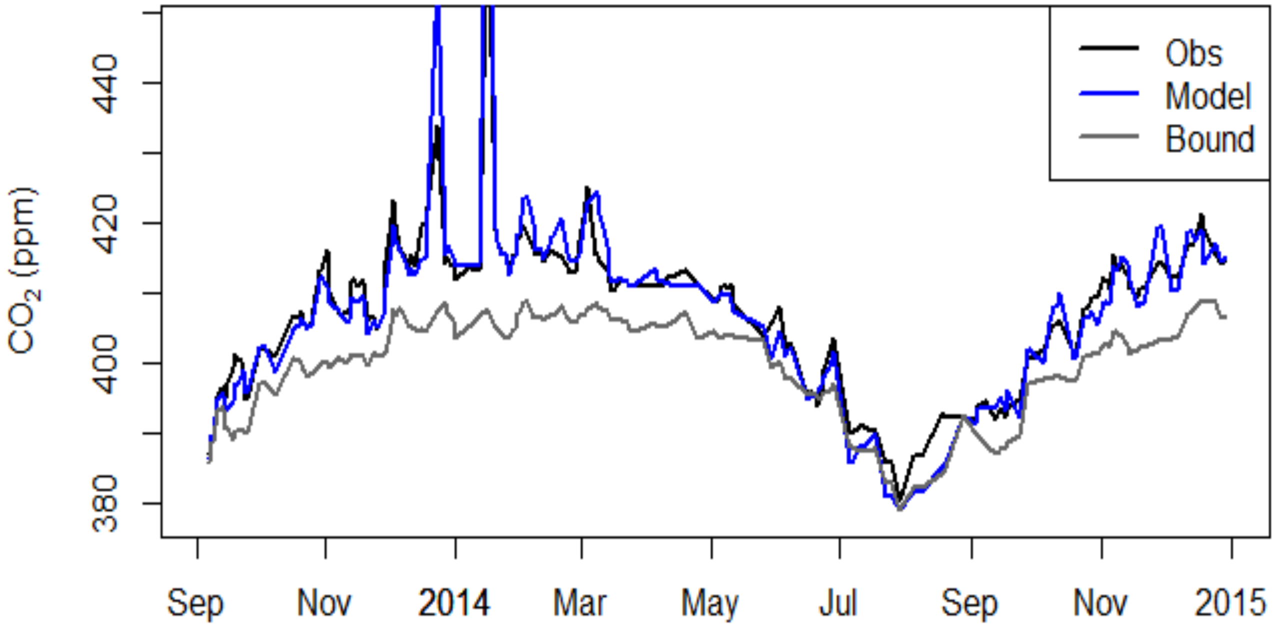
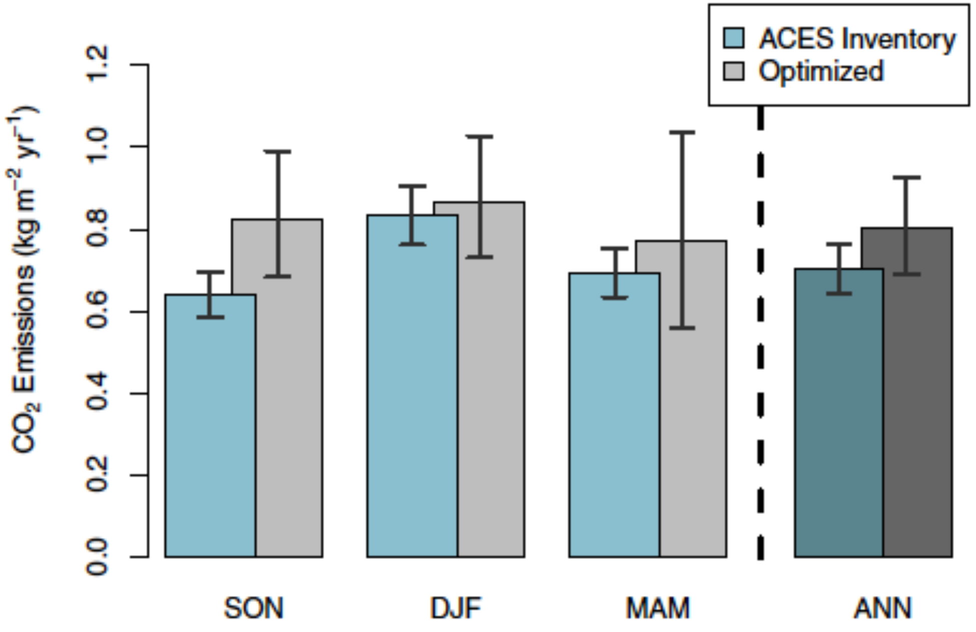
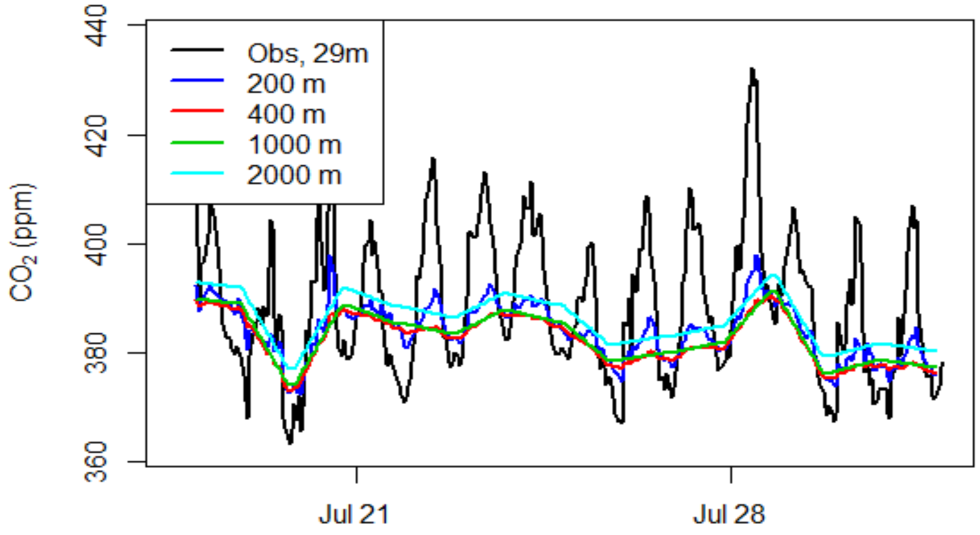


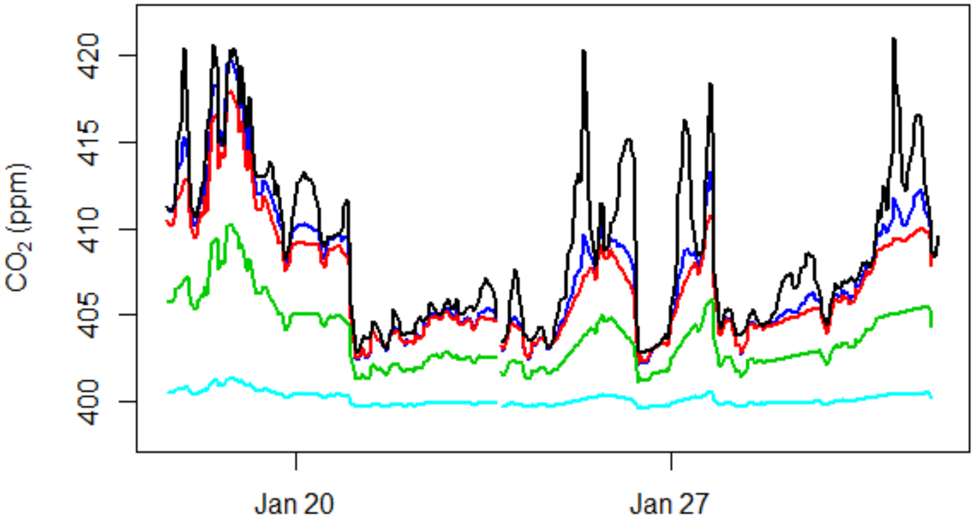
- Afternoon CO_2 concentrations (7-day running average) in Boston at 215 m (blue, model; black, observed), and inflow/background values (grey).

- Seasonal prior and optimized anthropogenic CO_2 emissions for September 2013 to December 2014 based on the NAM−HYSPLIT model for the average of the BU and COP sites.
- **Model-measurement framework capable of detecting changes in emissions of greater than 18%**

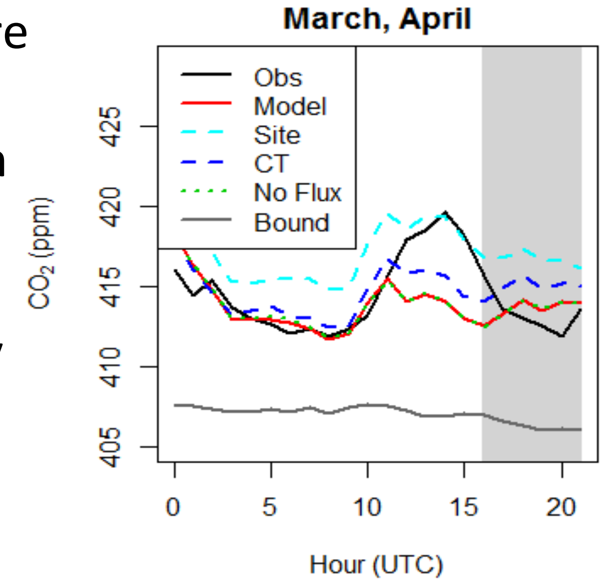


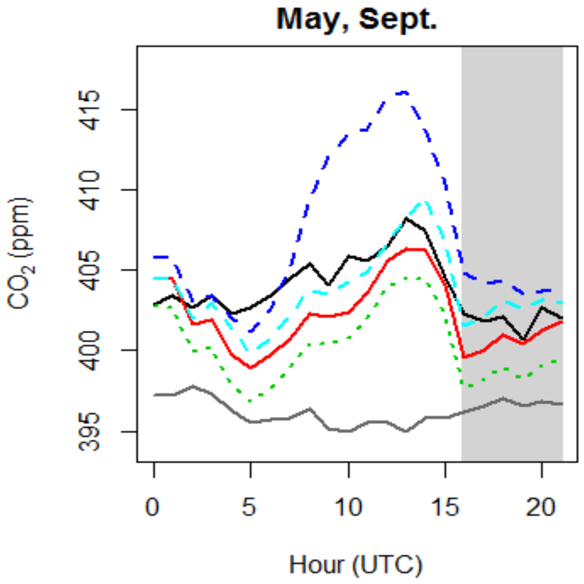
Boston CO_2 Background Concentrations



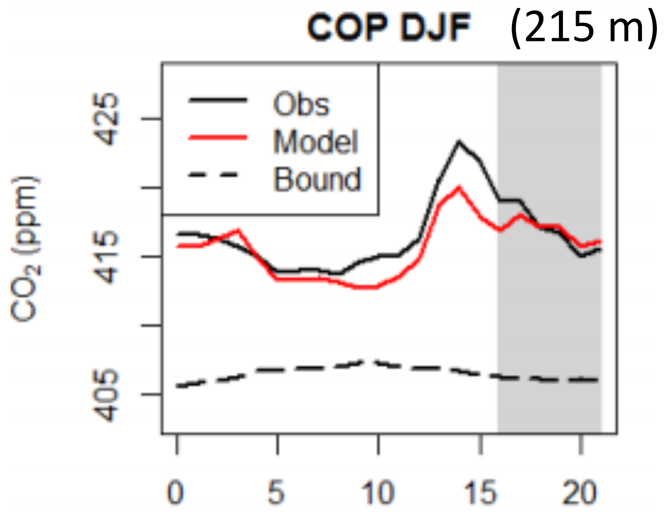


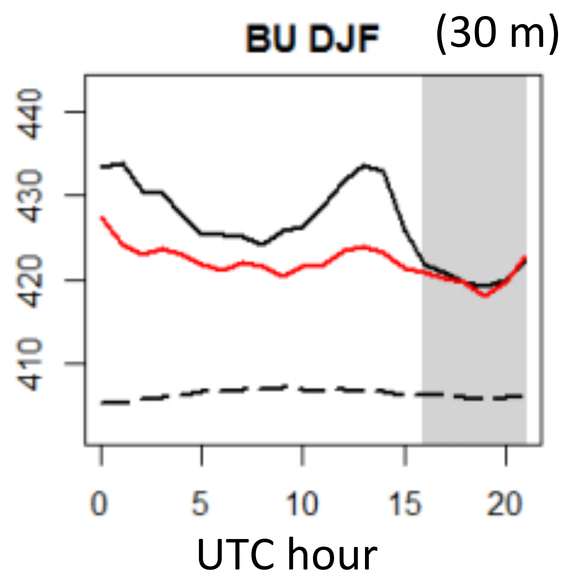
- Boundary site and altitude chosen based on where particles exit 90 km radius circle
- Vertical concentration profile constructed at each boundary site combining observations and CT vertical gradient (above)
- Flux measurements at HF correct for local canopy exchanges
- Vertically-resolved boundary curtain significantly improves model-measurement agreement (right)





Vertical Mixing Uncertainties





There are large uncertainties associated with vertical mixing and boundary layer height When using in situ sensors mounted on towers and buildings.

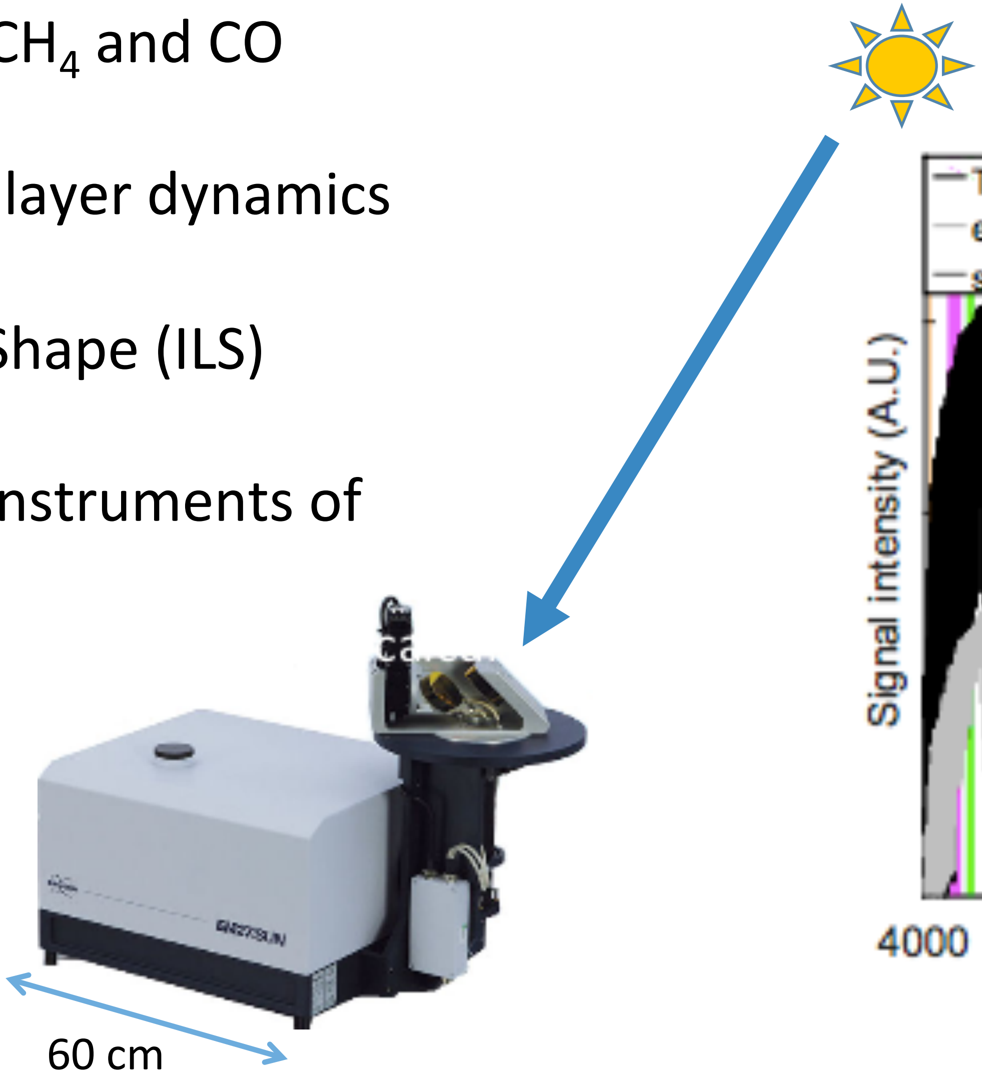
For this reason, only data from afternoon hours, when the boundary layer is likely well-mixed, is used in many inversion frameworks.

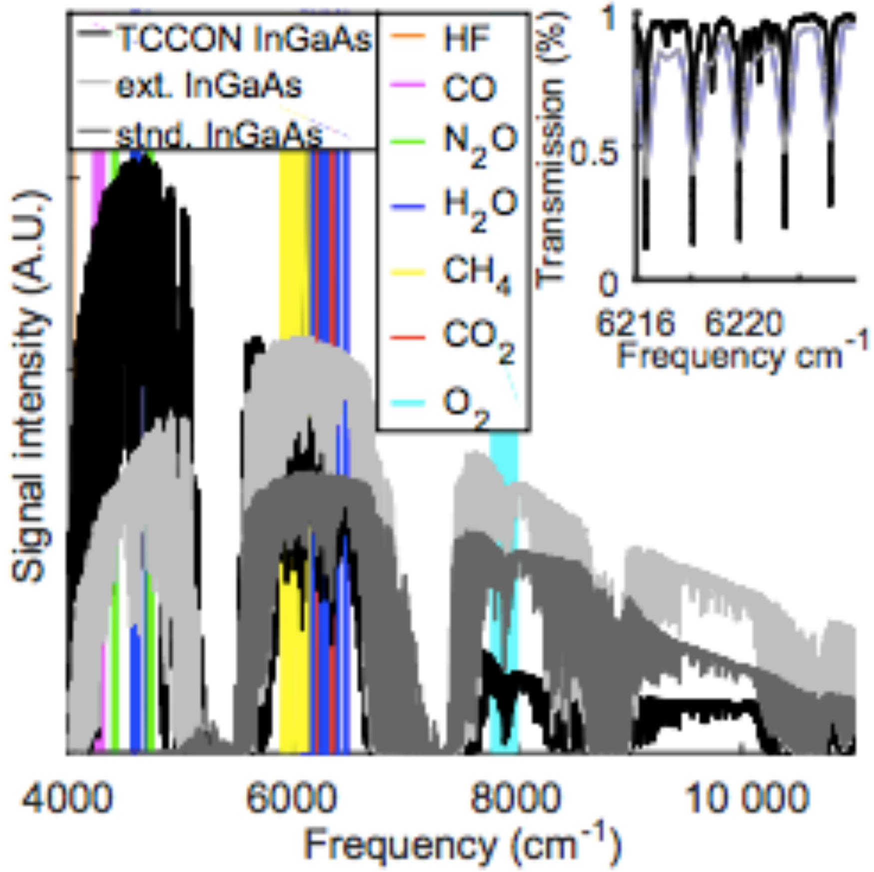
"Boston requires the placement of sensors within the city to capture the urban enhancement, as emissions are lofted above the surface layer over the ocean as they exit the city. During times of westerly winds, CO_2 concentrations measured at Thompson Island in Boston Harbor typically show enhancements relative to HF of less than half of those observed at PRU."

-Sargent et al, 2018

The EM27/Sun Spectrometer

- Total slant column CO_2 CH_4 and CO concentrations
- Insensitive to boundary layer dynamics
- 0.5 cm^{-1} resolution
- Stable Instrument Line Shape (ILS)
- GFIT software (TCCON)
- relative error between instruments of 0.01%*





-Hedelius et al, 2015

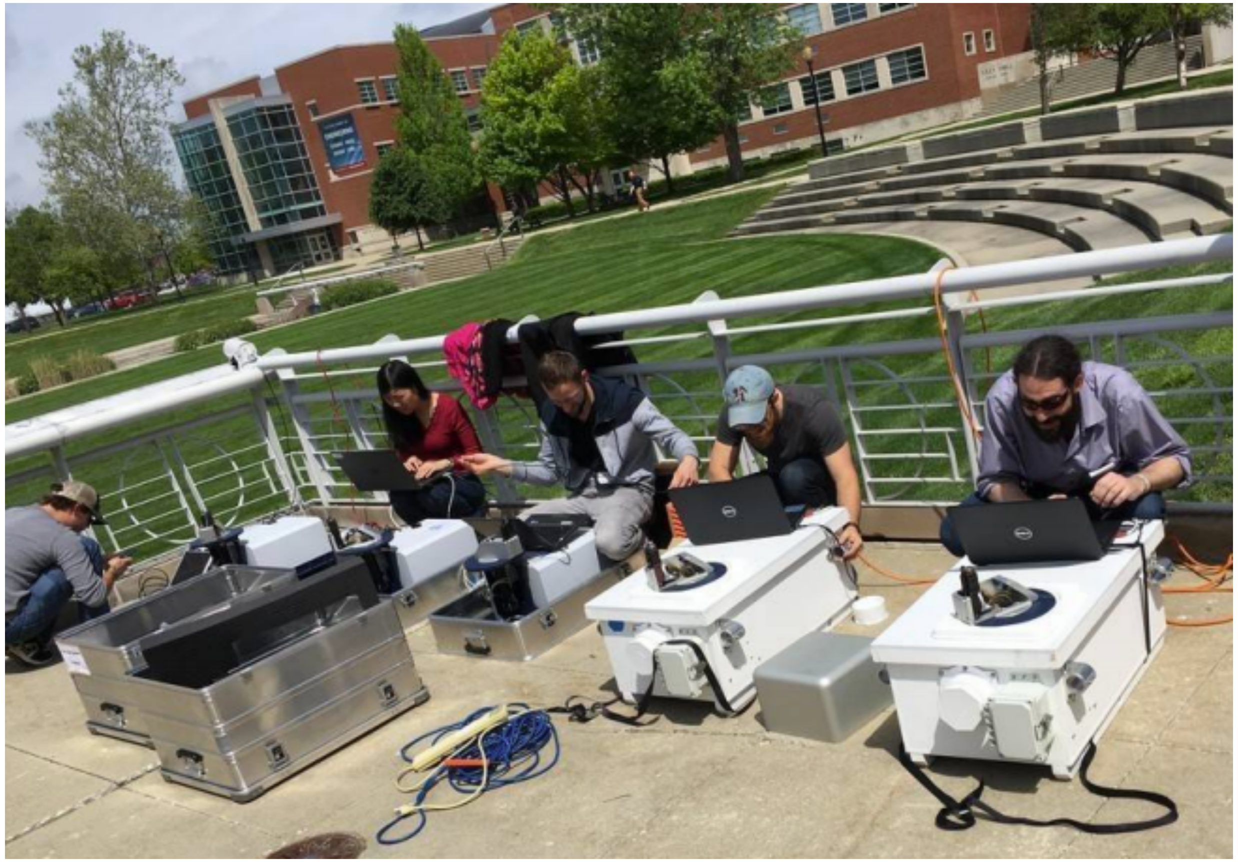
**Chen et al, 2015*

The EM27/Sun Spectrometer

Portable Total Column Instruments can be easily deployed at ground level while still measuring emissions aloft.

They can provide validation for current and future satellites, such as OCO-2 and OCO-3.

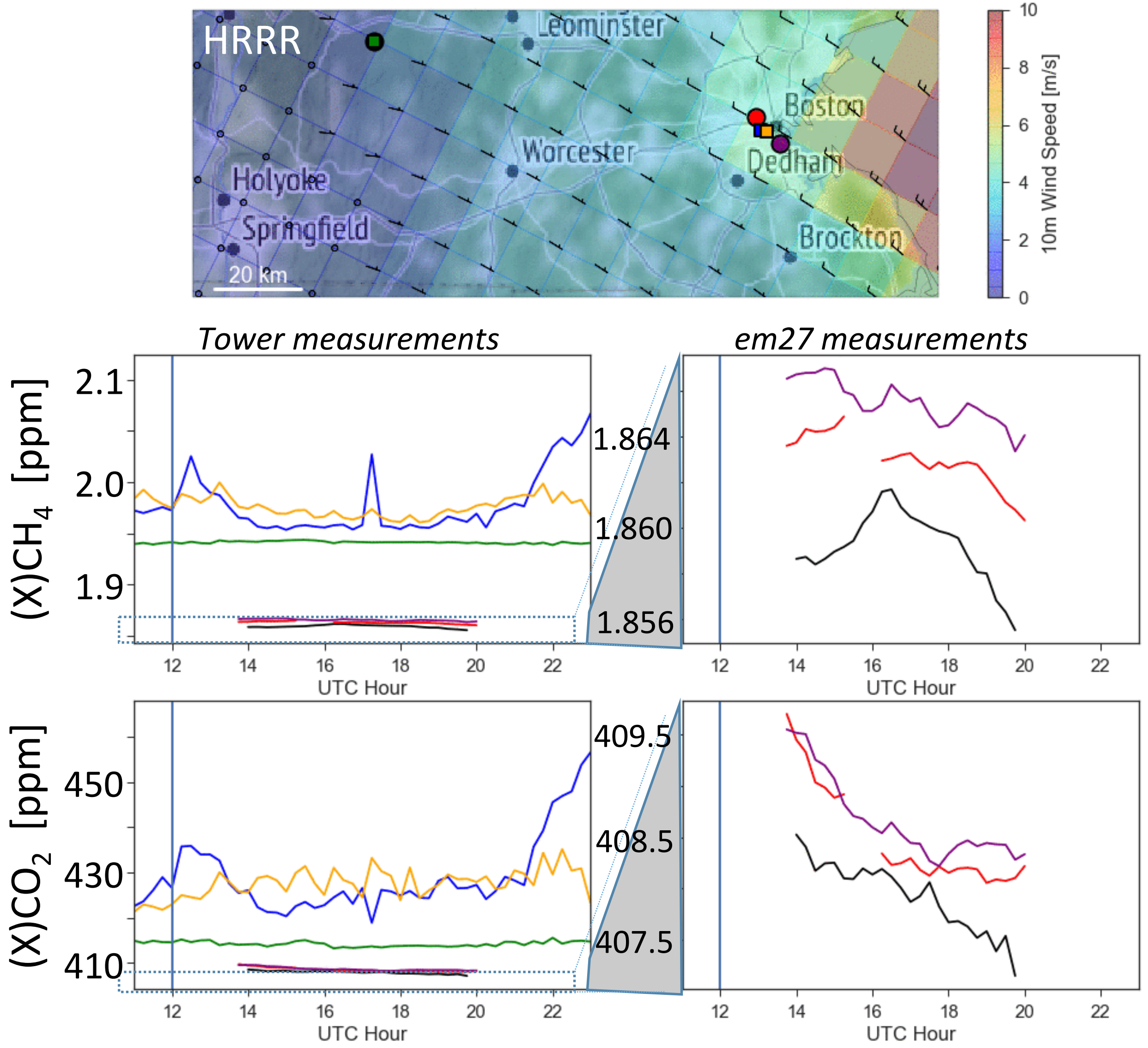
Both temporary field campaigns and long term automated measurements are possible.



Wintertime Boston Column Measurements

in situ tower measurements typically show stronger enhancements as they are more sensitive to local emissions and have greater footprint values.

This particular day (Jan 26, 2018) shows clear enhancements from **Harvard Forest** to **Cambridge** and from **Cambridge** to **southeast Boston**.



Flux Inversion using Total Column Data

An inversion was performed using one day of total column data from four FTIRs.

HYSPLIT in STILT mode was used as the transport model, driven by HRRR meteorology. Pressure-weighted slant column footprints were created at 1km^2 resolution.

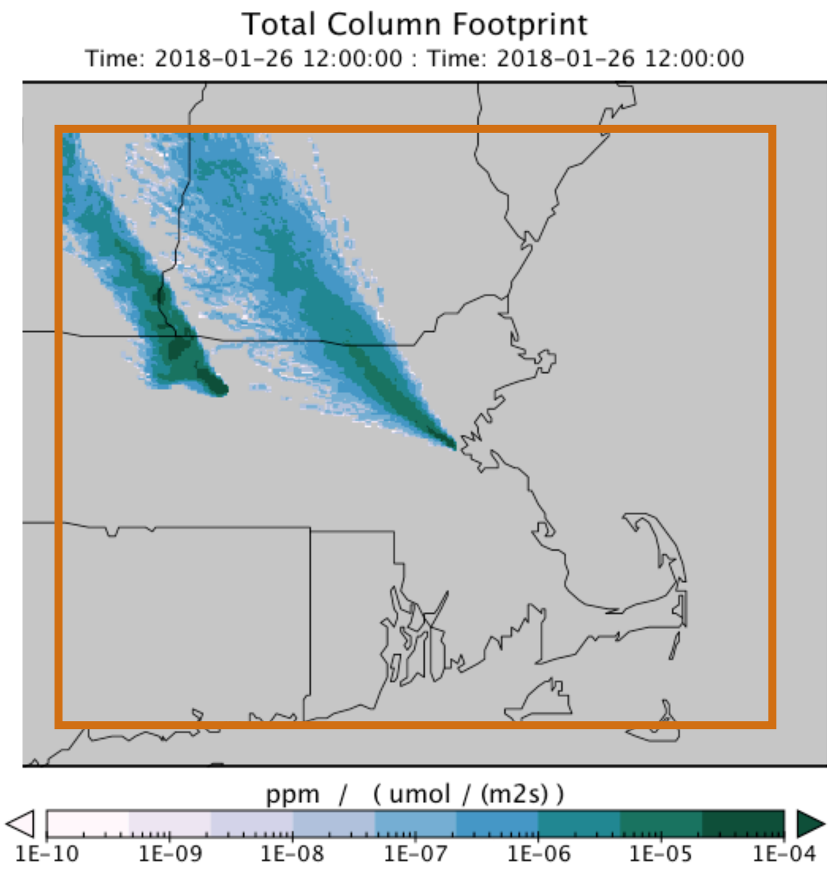
The hourly-resolved ACES inventory was used as the prior and for the spatial distribution.

Hourly scaling factors for emissions, as well as a background concentration time-series, were solved for using a Bayesian framework.

(Footprints x inventory)

$$\mathbf{y} = \mathbf{A}\mathbf{x} + \boxed{background} + \varepsilon$$

Total Column Concentrations — hourly scaling factors — error



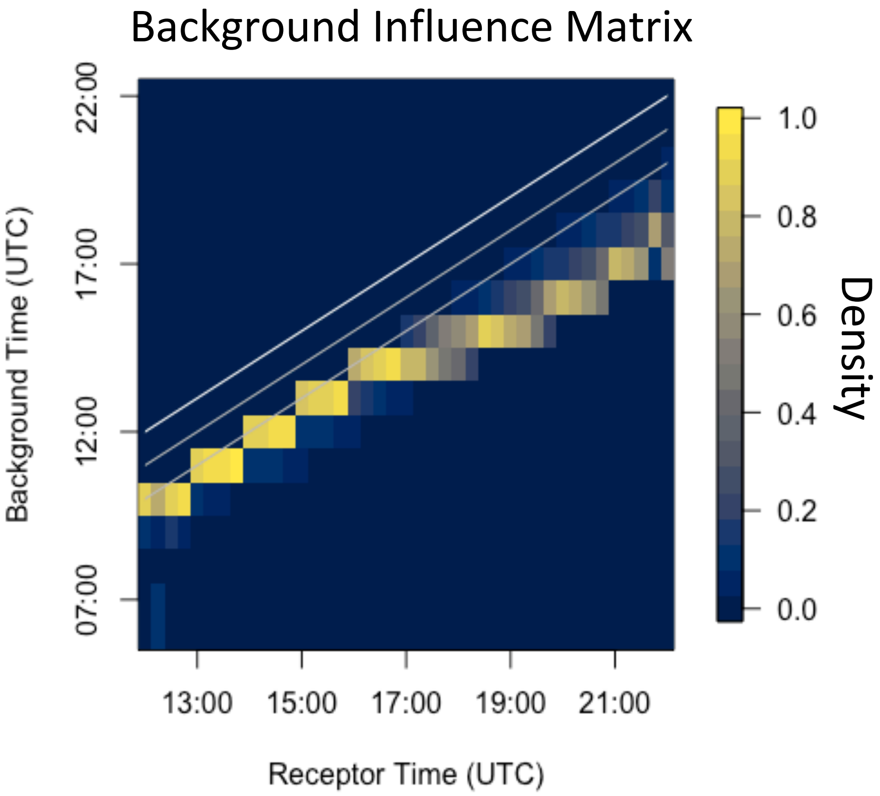
Background Influnce

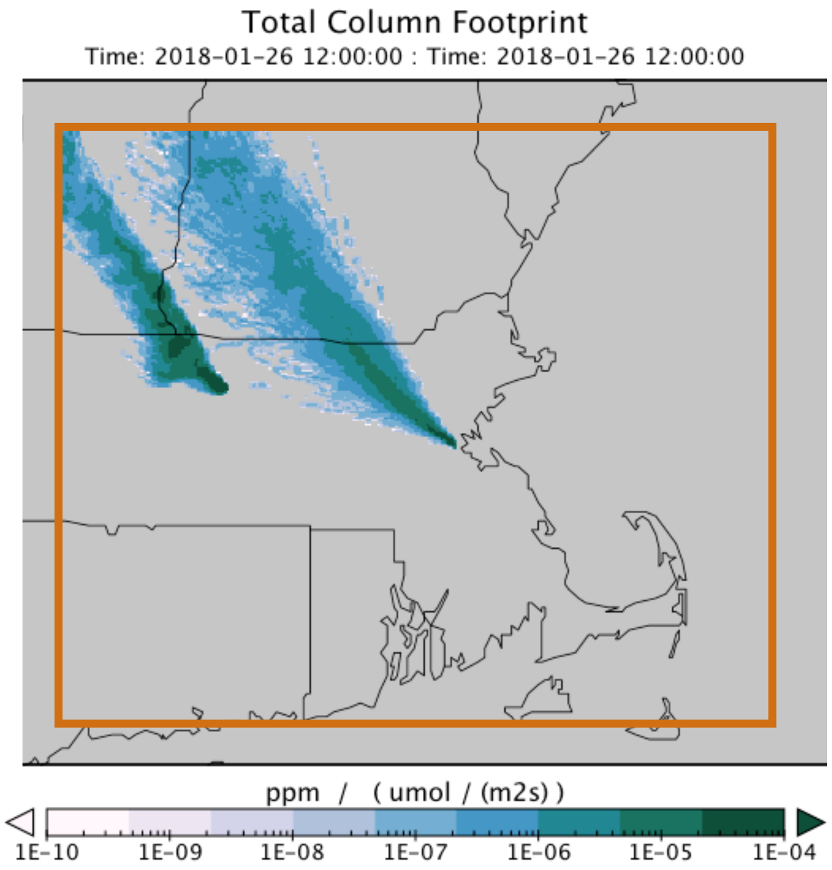
STILT particles were tracked as they entered the domain, and this information was used to populate a background influence Matrix.

Background influence matrix

$$\mathbf{y} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{b} + \varepsilon$$

Background time series





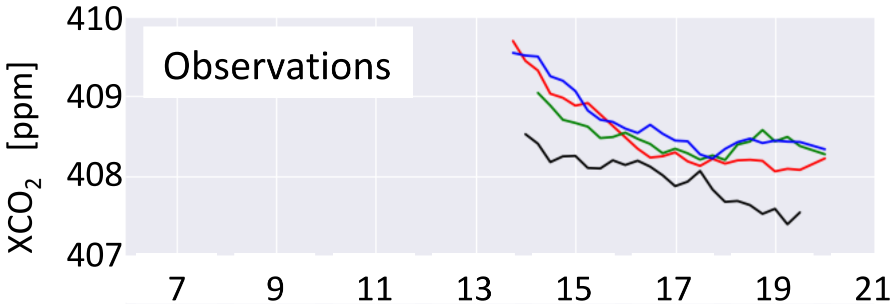
Advantages:

- Does not require a “true” upwind sensor
- Accurately propagates background plumes

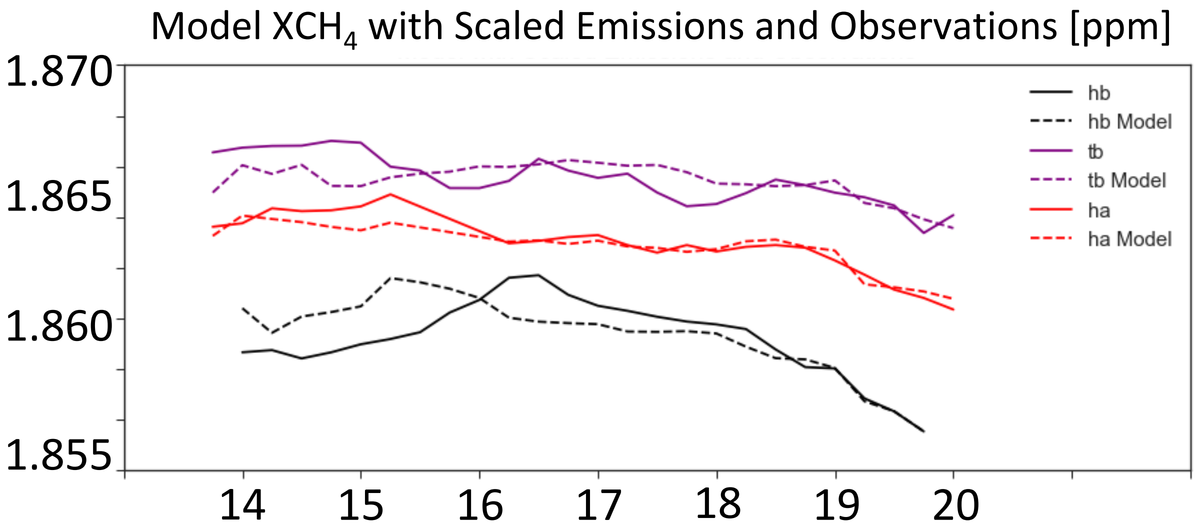
Caveats:

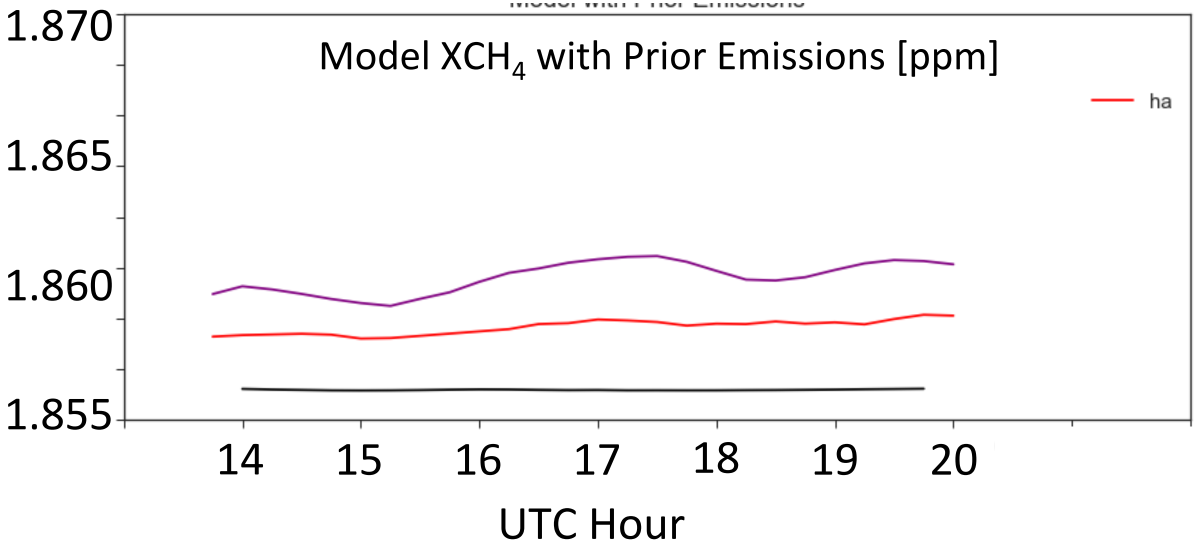
- Assumes uniform background for a given time.
- Does not work well with strong heterogeneous emissions immediately upwind

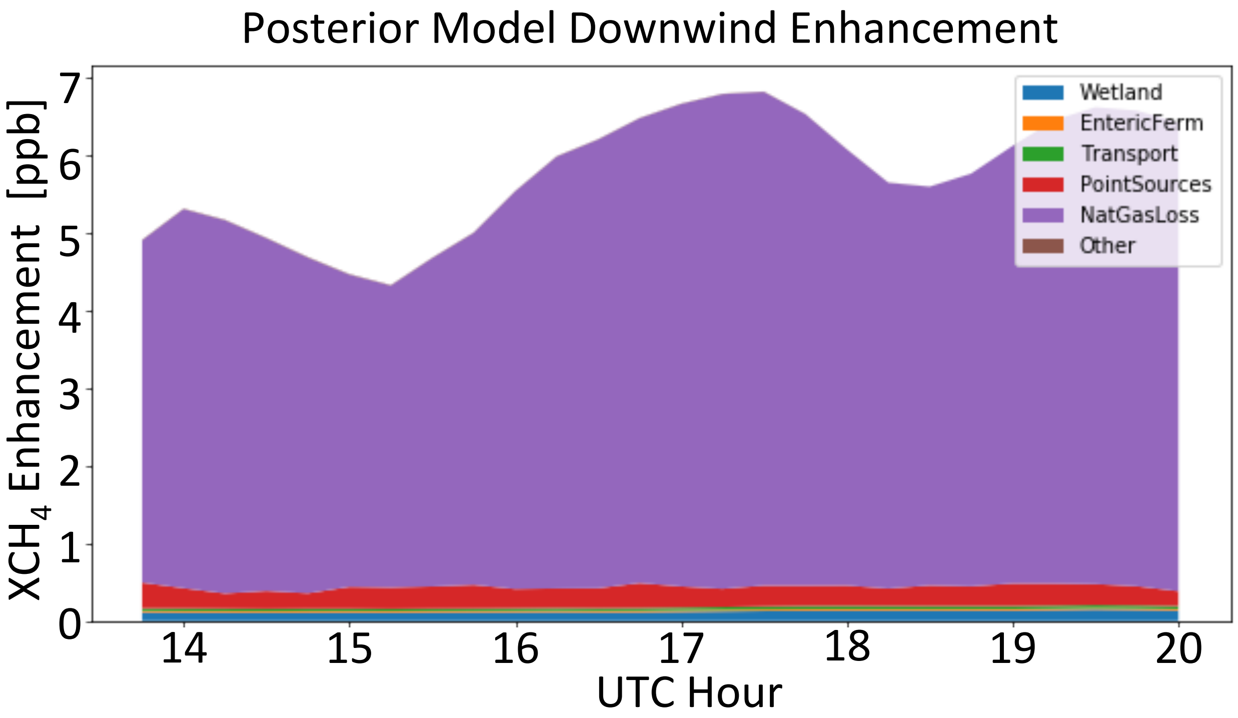
Inversion Method – Results



Boston Methane







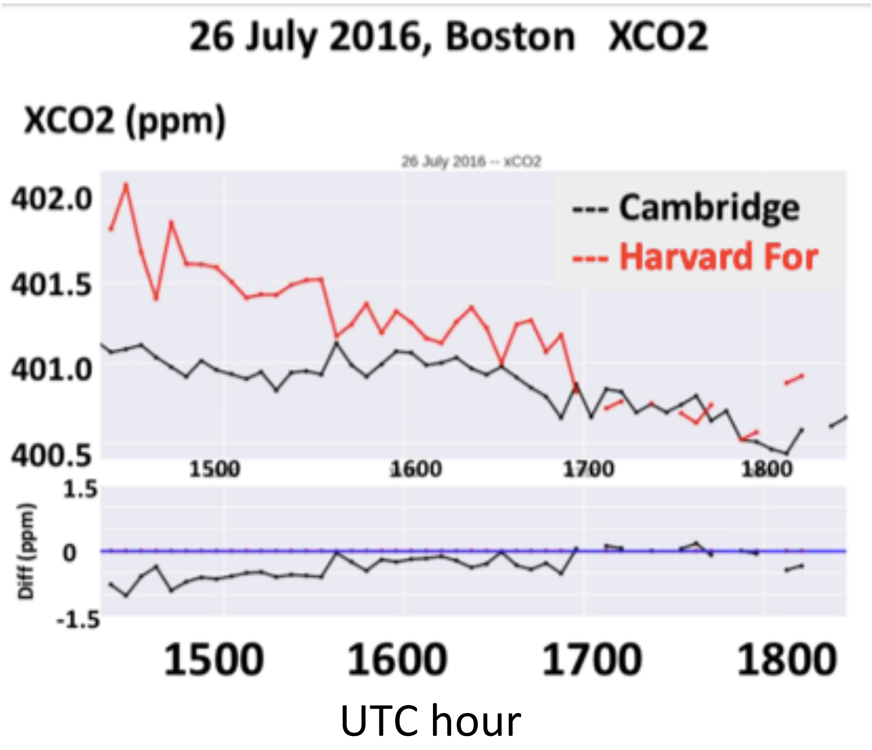
Our inverse model estimates scaling factors for existing inventories of these sectors.

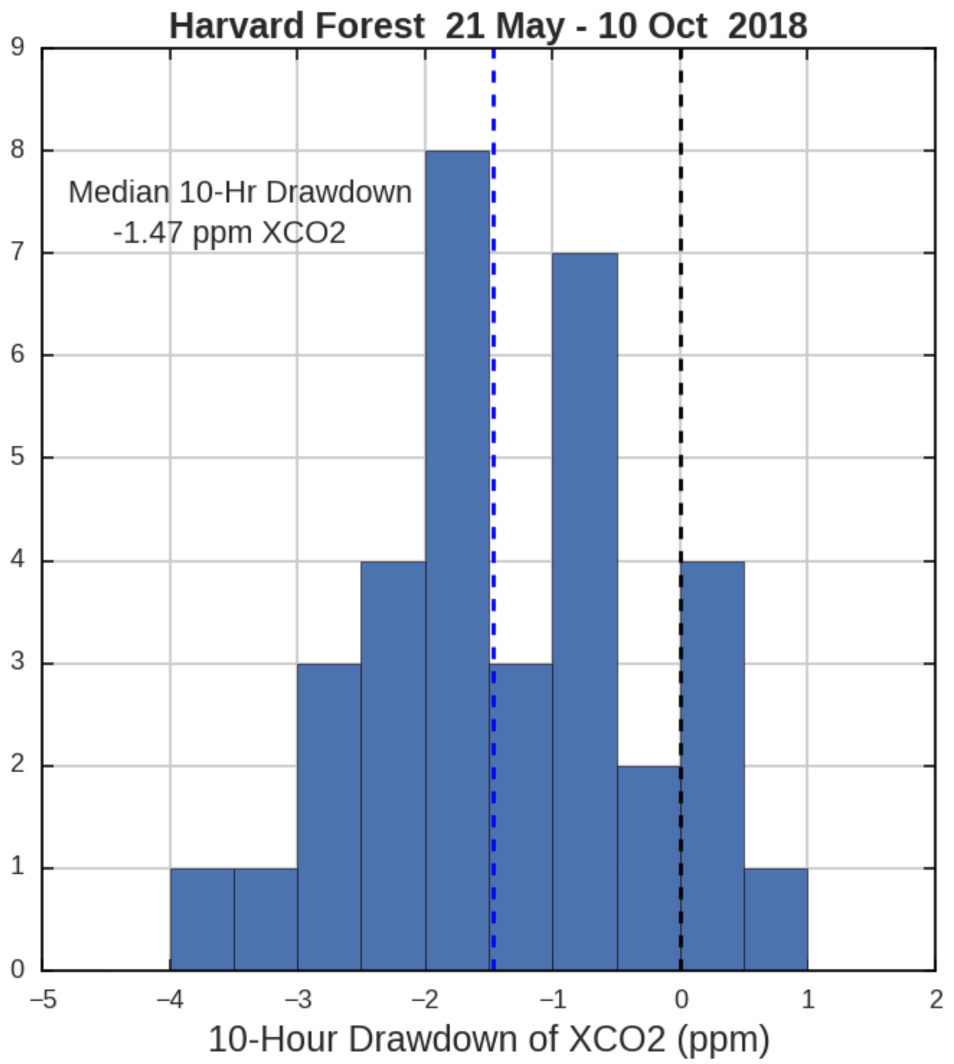
- Fluxes related to natural gas losses were estimated at **27% higher** than the inventory.
- Flux estimates from other sectors could not be made.

Continuing Boston Total Column Observations

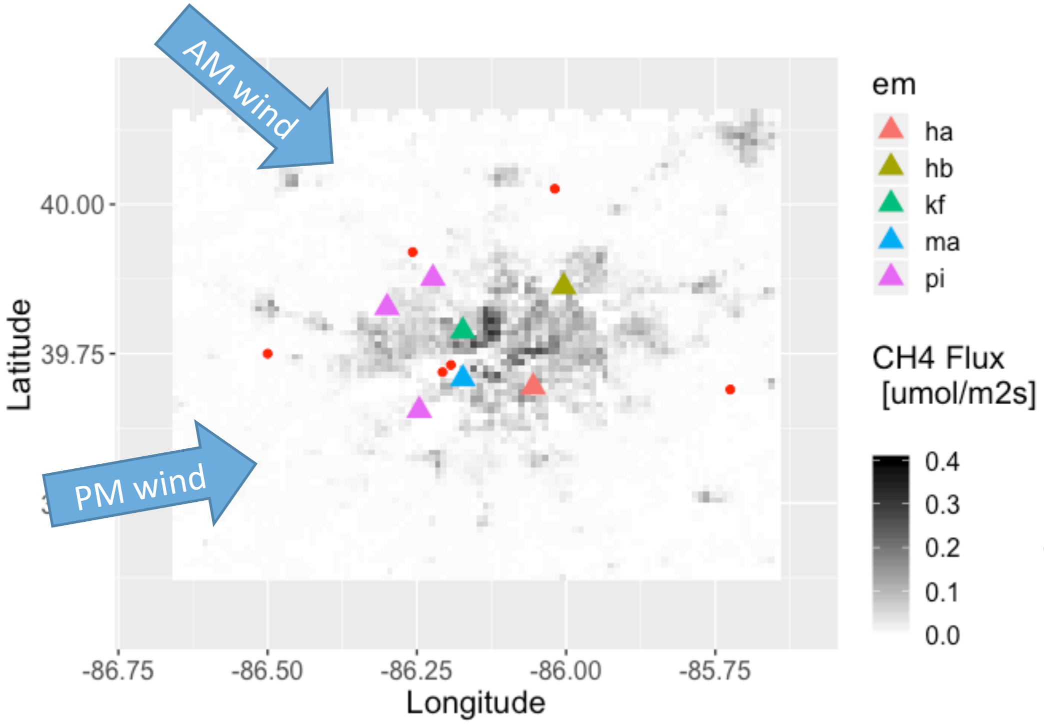
FTIRs are now autonomous at Harvard Forest and Cambridge, and measuring on all clear sunny days.

Summertime measurements are showing consistent drawdown from the biosphere over the course of the day, and this can eliminate the XCO_2 gradient between sites.





Column Observations - Indianapolis

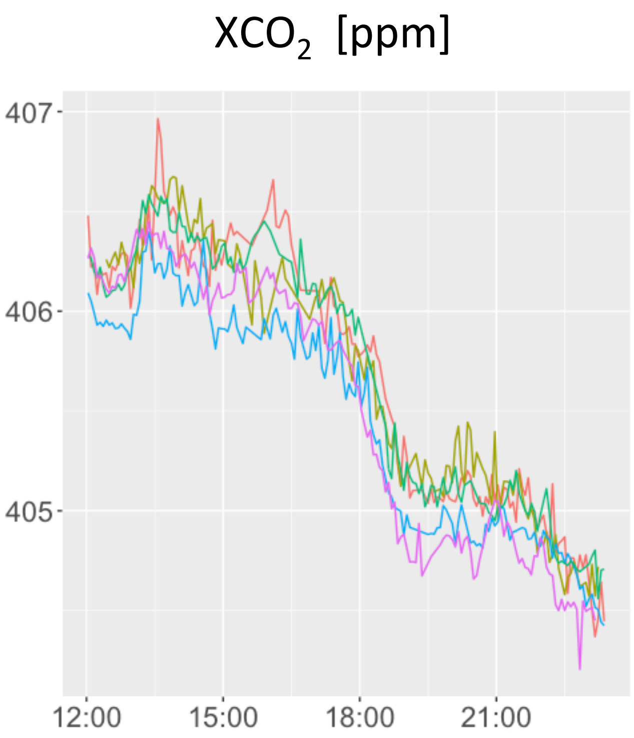


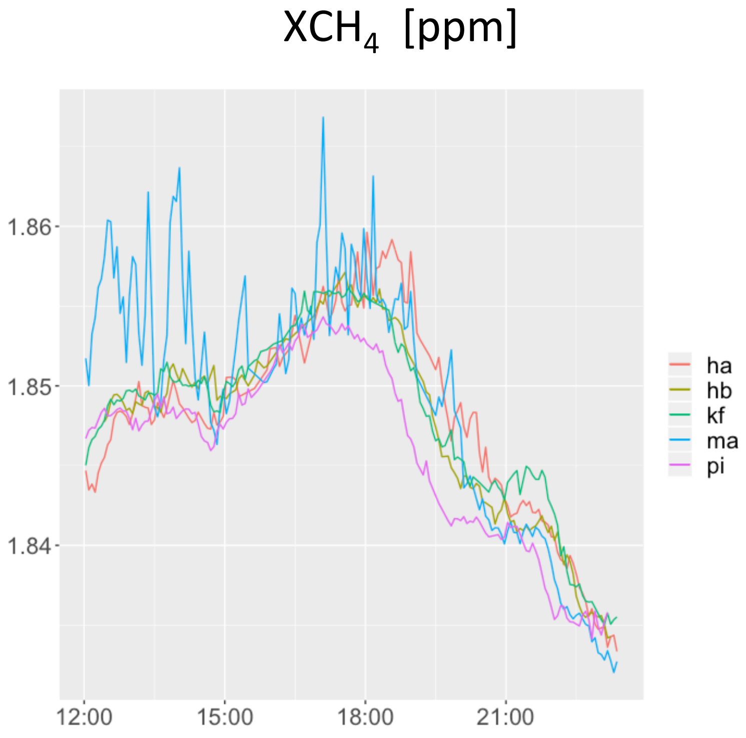
1 km^2 CH_4 inventory distribution based on HESTIA CO_2 associated with natural gas end use, plus point sources (red circles)

-Lamb et al, 2016

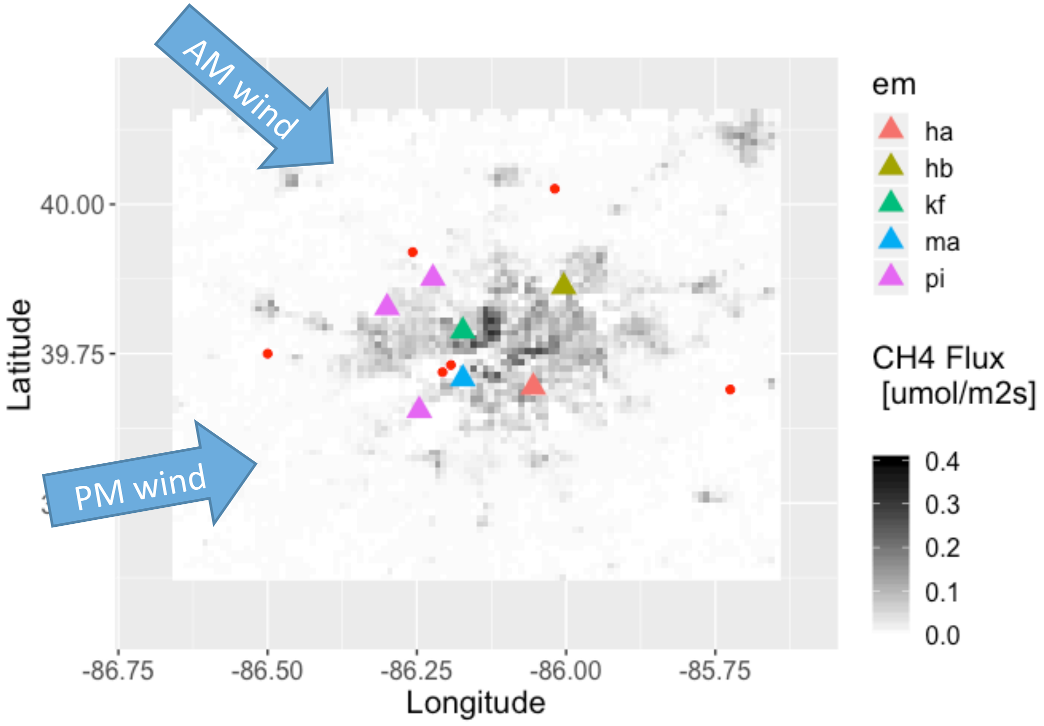
A field campaign in May 2016 brought five FTIRs to Indianapolis for five days of data.

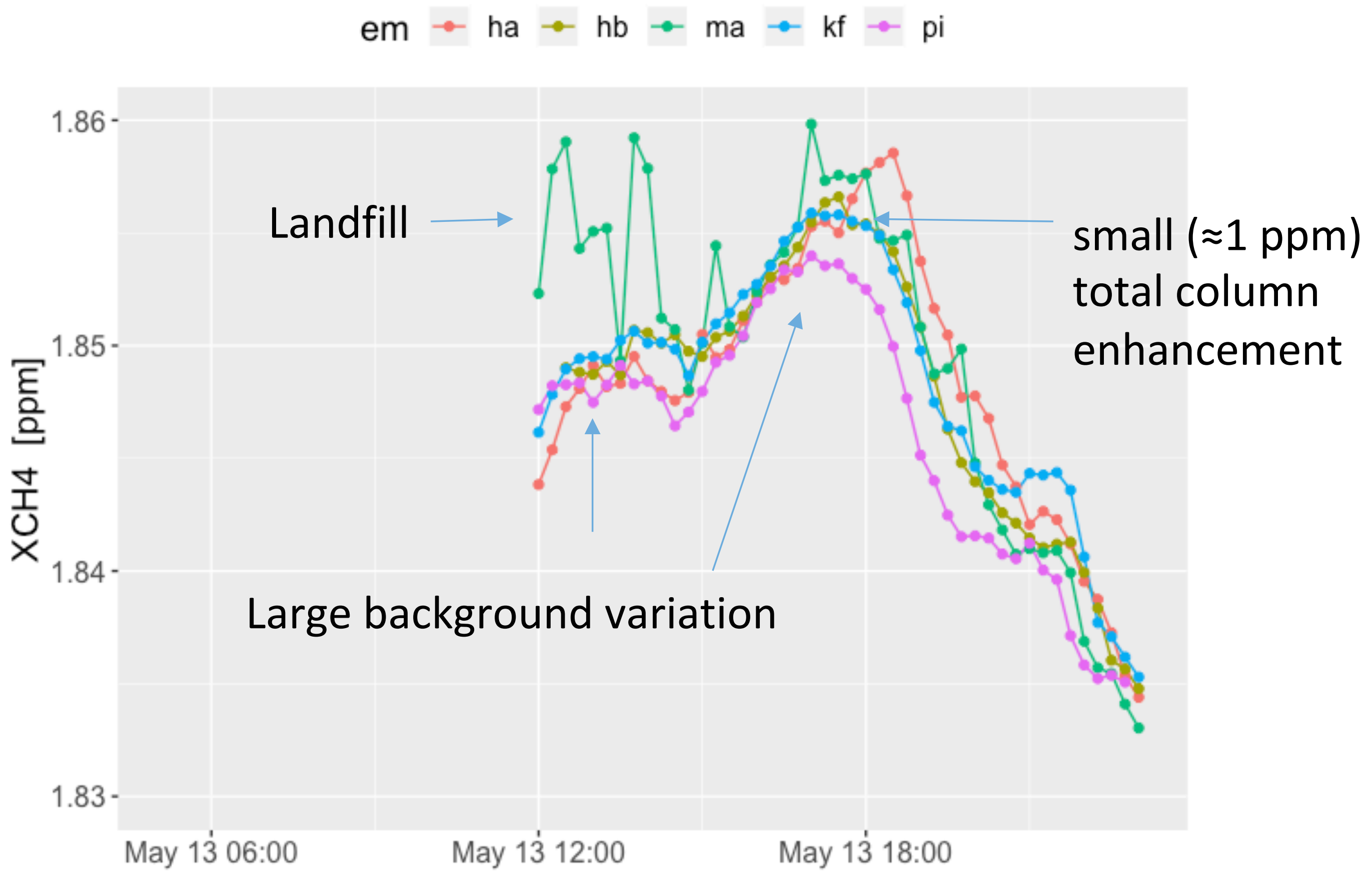
The data showed low XCO_2 and XCH_4 enhancements across the city compared to Boston.





Indianapolis Column Methane





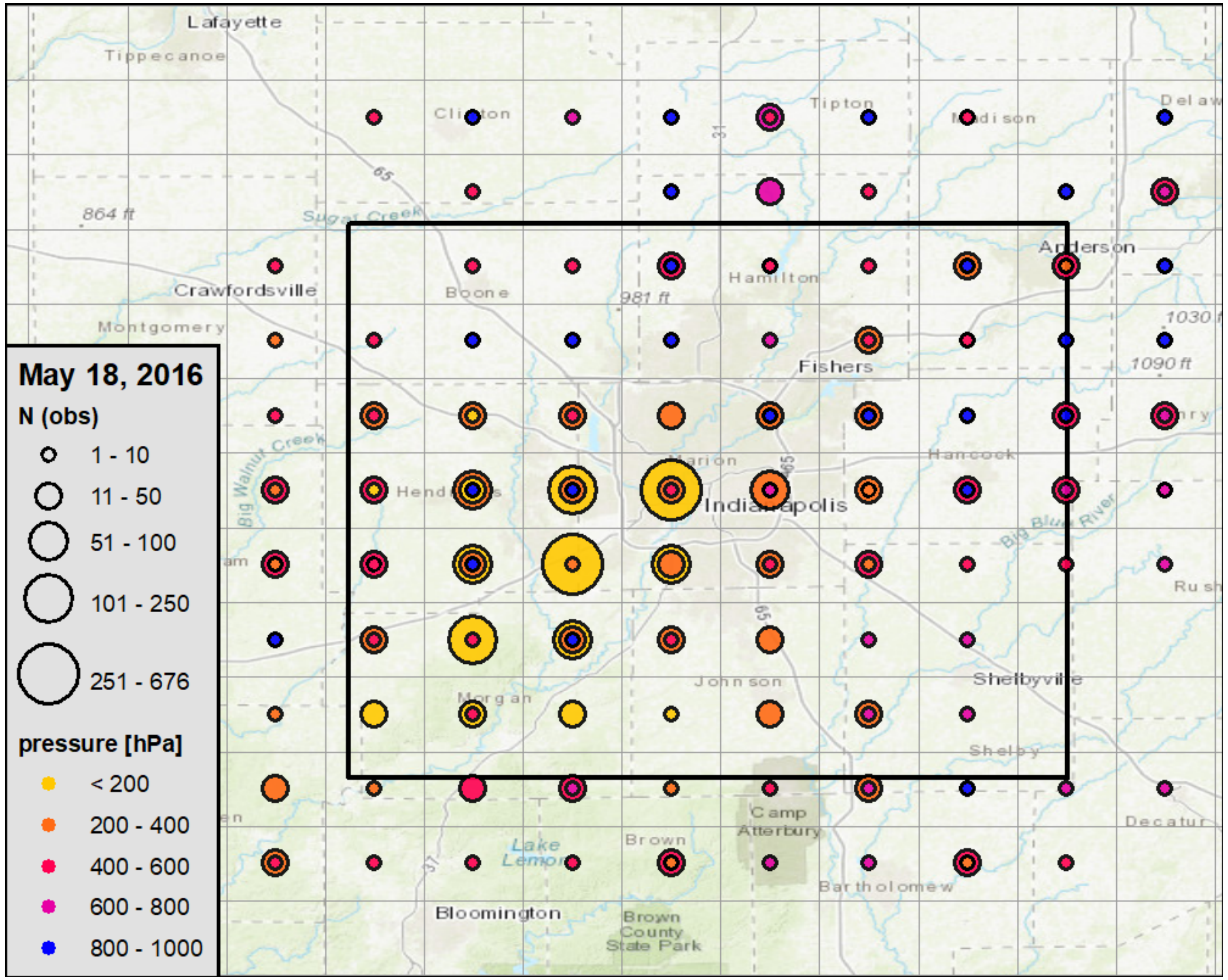
Daily methane inversions were performed, but observations with footprints over point sources were discarded.

Incorporating Wind Data

The NAM forecast product can be compared to wind measurements from the ACARS system.

These data are aggregated by day to compute error statistics for wind at each model pressure level.

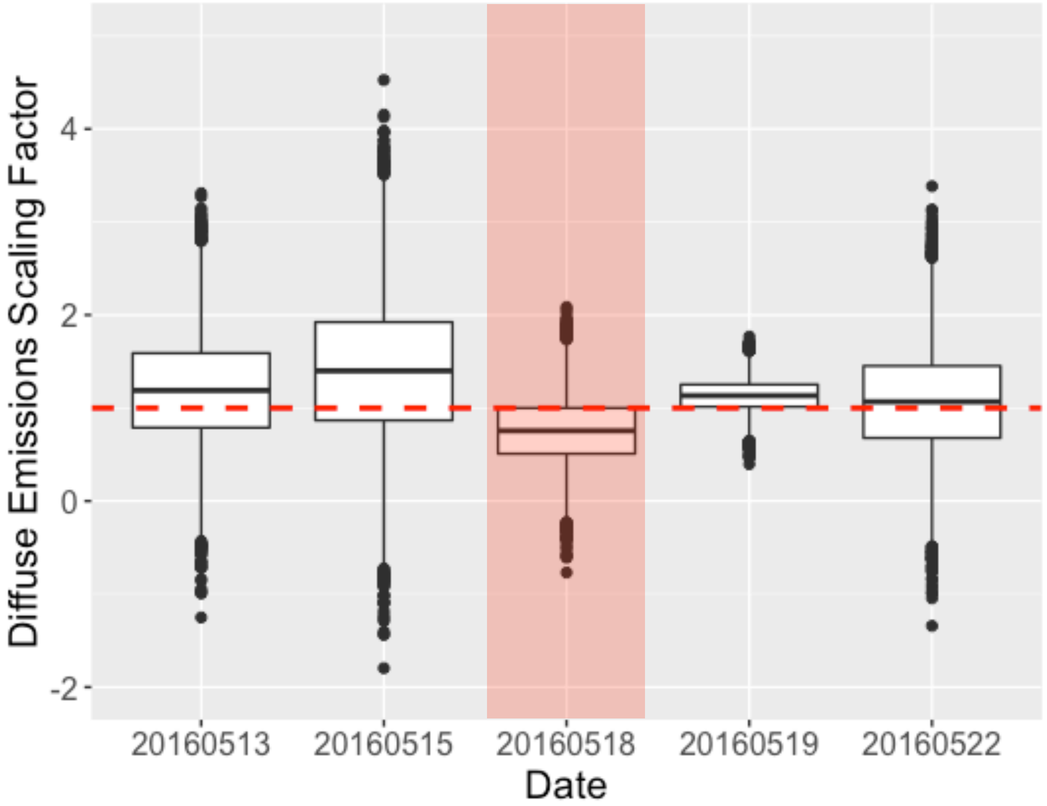
These error statistics can be propagated through STILT to compute values for the model covariance matrix.



Indianapolis Column Methane

Average scaling factor of **1.19** is found for diffuse methane emissions.

We are currently working on improving our uncertainty analysis, including the handling of wind errors.



Wind direction errors on 5/18 were particularly bad.

Inverse Modeling Challenges at Urban Scales

- Tower networks, combined with careful inventories and transport models, are a proven way to quantify urban carbon fluxes.

- There are still some areas where improvements can be made
  - characterizing the “background”
  - vertical mixing and boundary layer dynamics uncertainty
  - other transport errors
  - difficulty accounting for point sources
  - cost, speed, flexibility
  - Ability to validate current and future satellites.

- Portable, ground-based, total column spectrometers have real potential to address some of these issues.

Contact:
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Thank you!

EDF ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

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