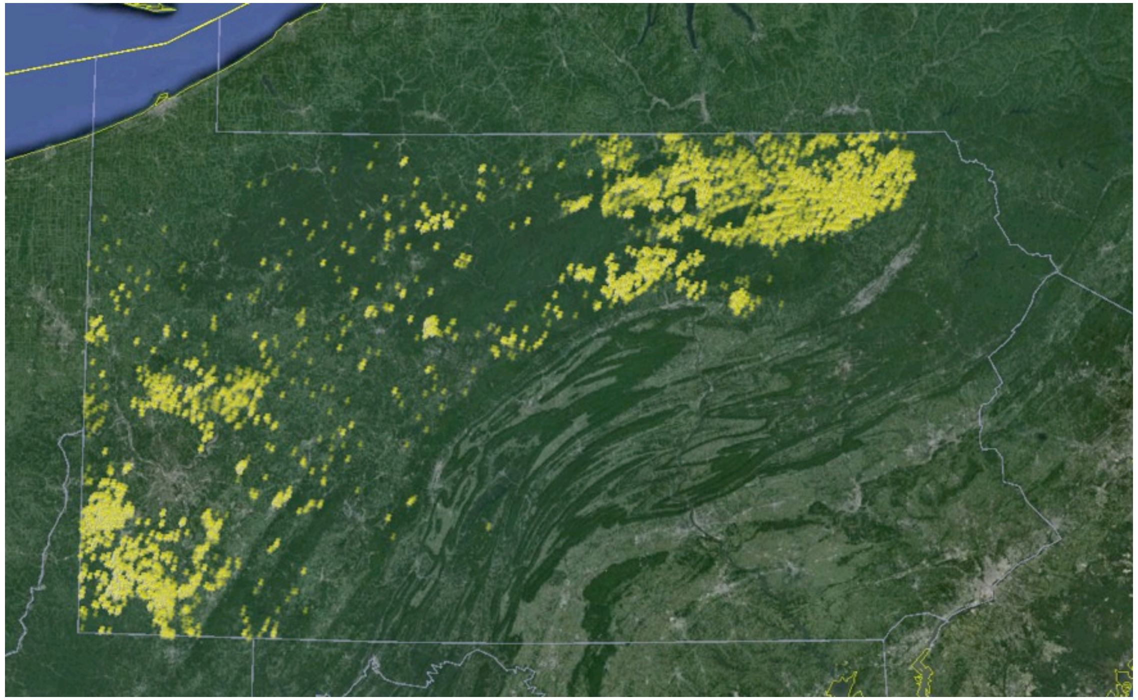
Quantifying Upstream Emissions from Natural Gas Production in Northeastern Pennsylvania



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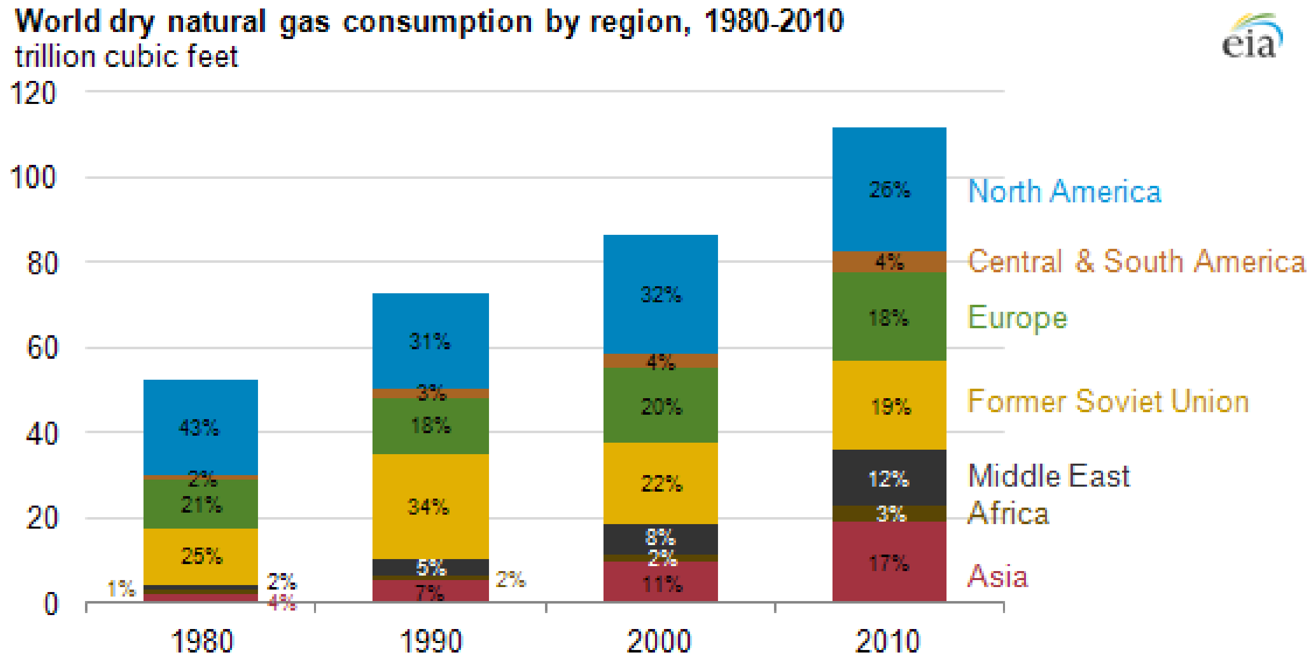
Motivation

- Natural gas is often praised as being a cleaner energy source compared to coal.
- However, leaks in infrastructure lead to the release of natural gas into the atmosphere.
- Methane (CH_4), the main component of natural gas, is a greenhouse gas 28 times more potent than CO_2 over a 100 year period
- An emission rate of ~3% would cancel out any short term environmental gains associated with reduced CO_2 emissions compared to coal.



How much is leaking?

- EPA estimates 1-2% of production leaks into atmosphere using a **bottom-up methodology.**

- **Top-down methodologies** disagree. Tend to result in higher emission rates.

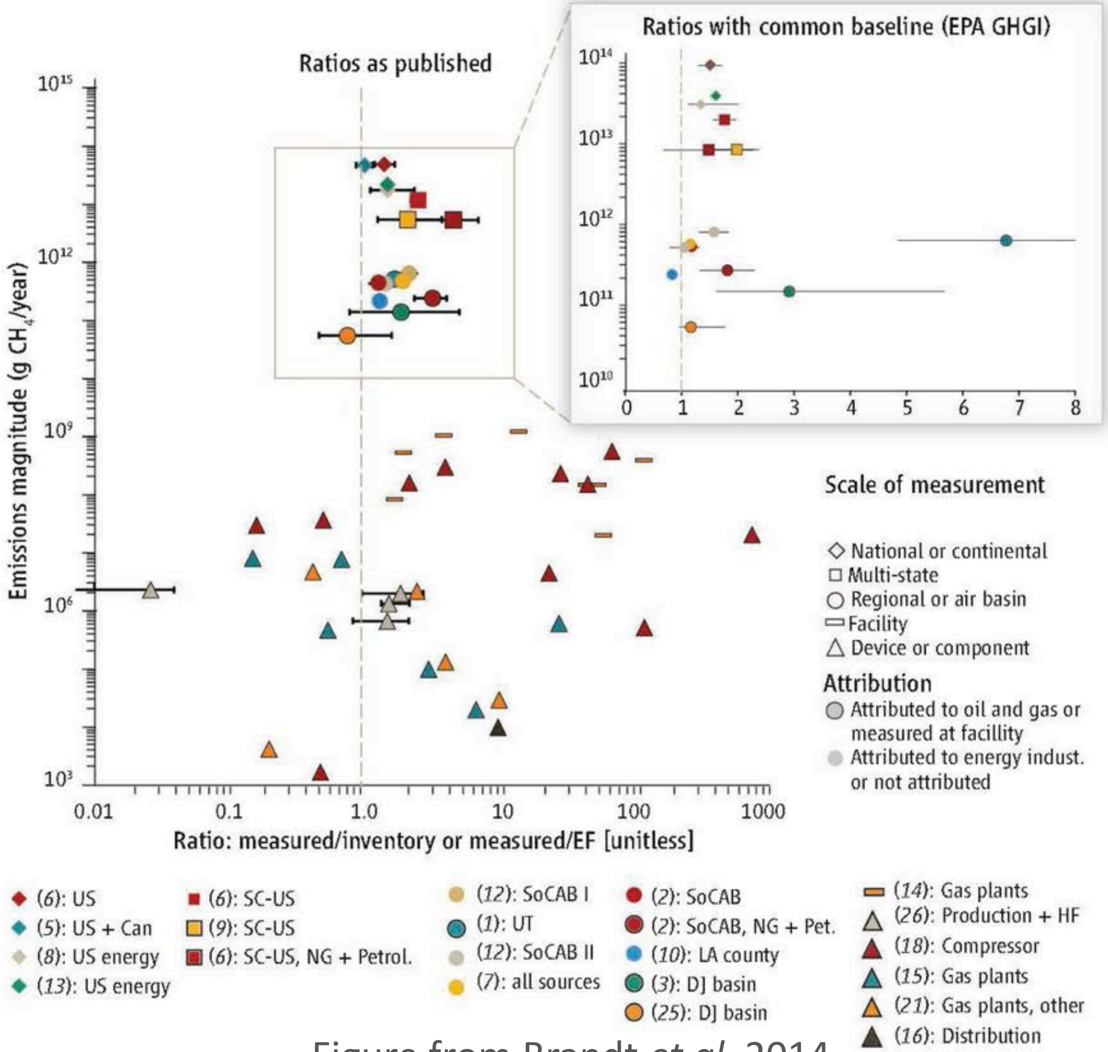


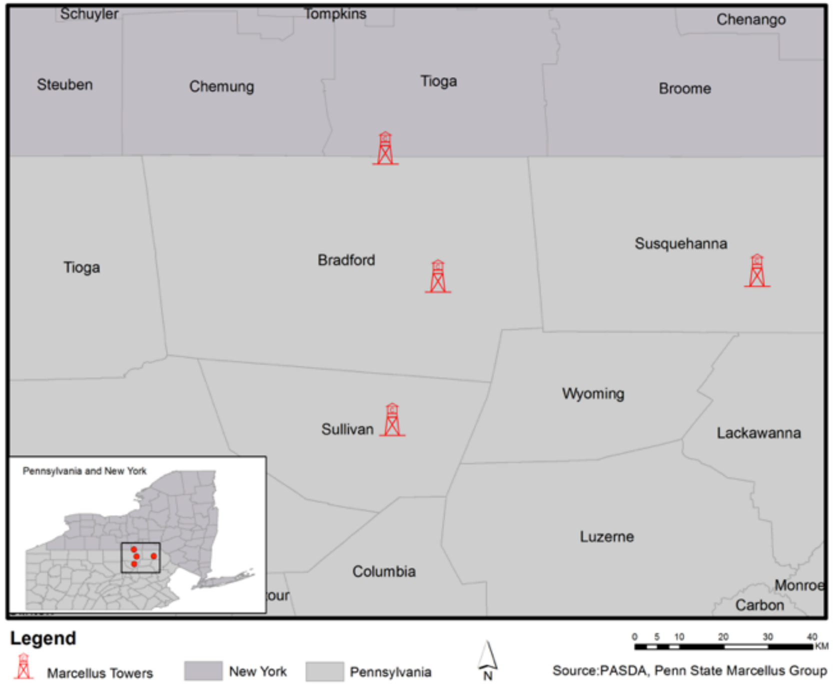
Figure from Brandt *et al.* 2014

The Marcellus Projects

Aircraft Campaign

- Short term project
- 10 flights in May 2015 measuring methane concentrations upwind and downwind of gas production in NEPA.
- Objective: To create a first-guess approximation of The natural gas emission rates from Marcellus activity.

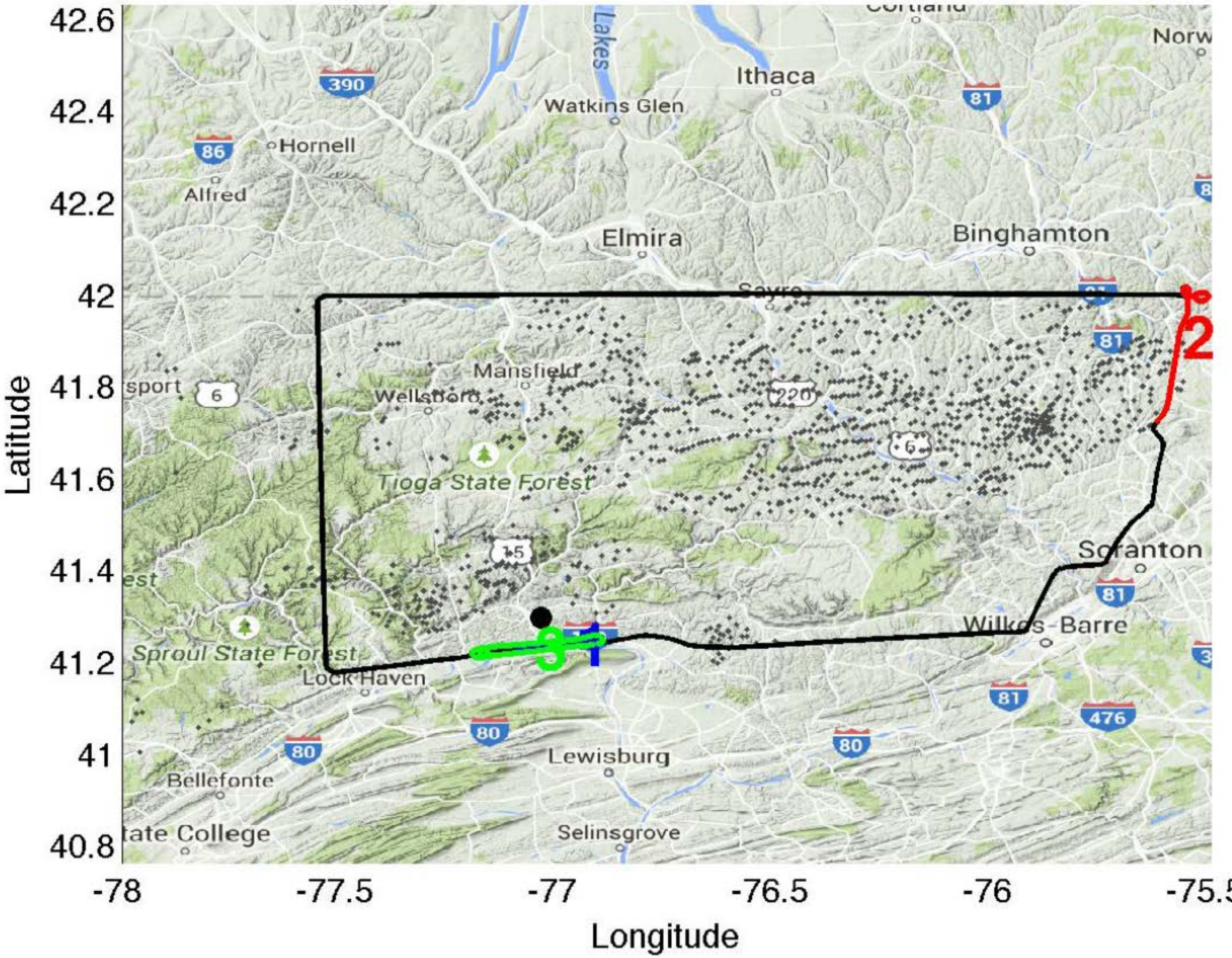
Atmospheric Inversion



- Long term project
- 2 years of methane and isotopic data from a tower network across four locations
- Objective: To observe spatial and temporal properties of methane emissions from natural gas production.

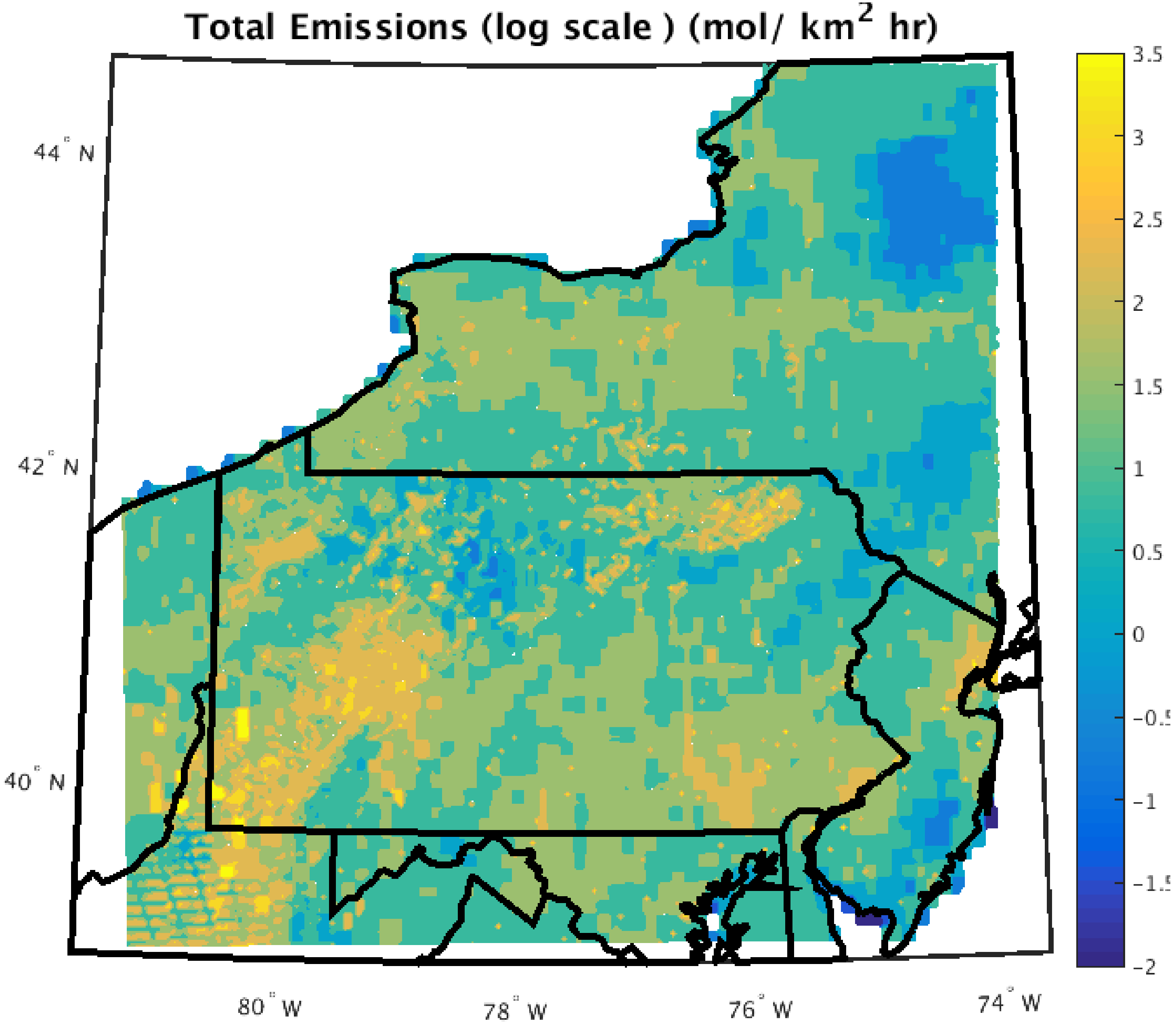
Aircraft Campaign: May 2015

- NOAA Twin Otter Aircraft flying at altitudes ~1000m above ground.
- Picarro Trace Gas Analyzer and Ethane sensor on board
    - Measured CH_4, CO_2, CO, H_2O, C_2H_6
- 10 successful flights from May 14th-June 3rd
- Observations were compared to projected enhancements from WRF-Chem simulation
- Modeling methane? Need methane inventory!

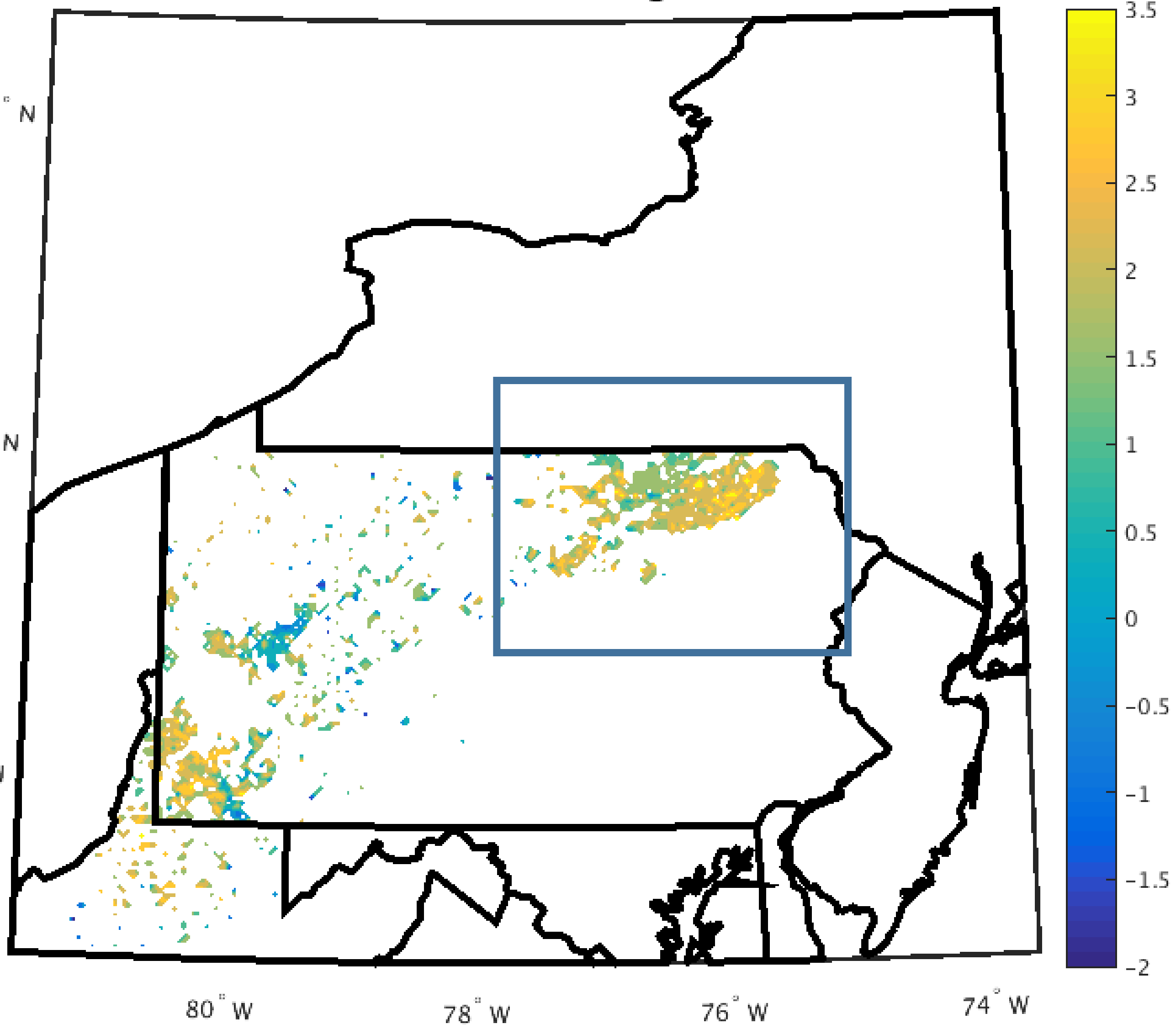


Inventory

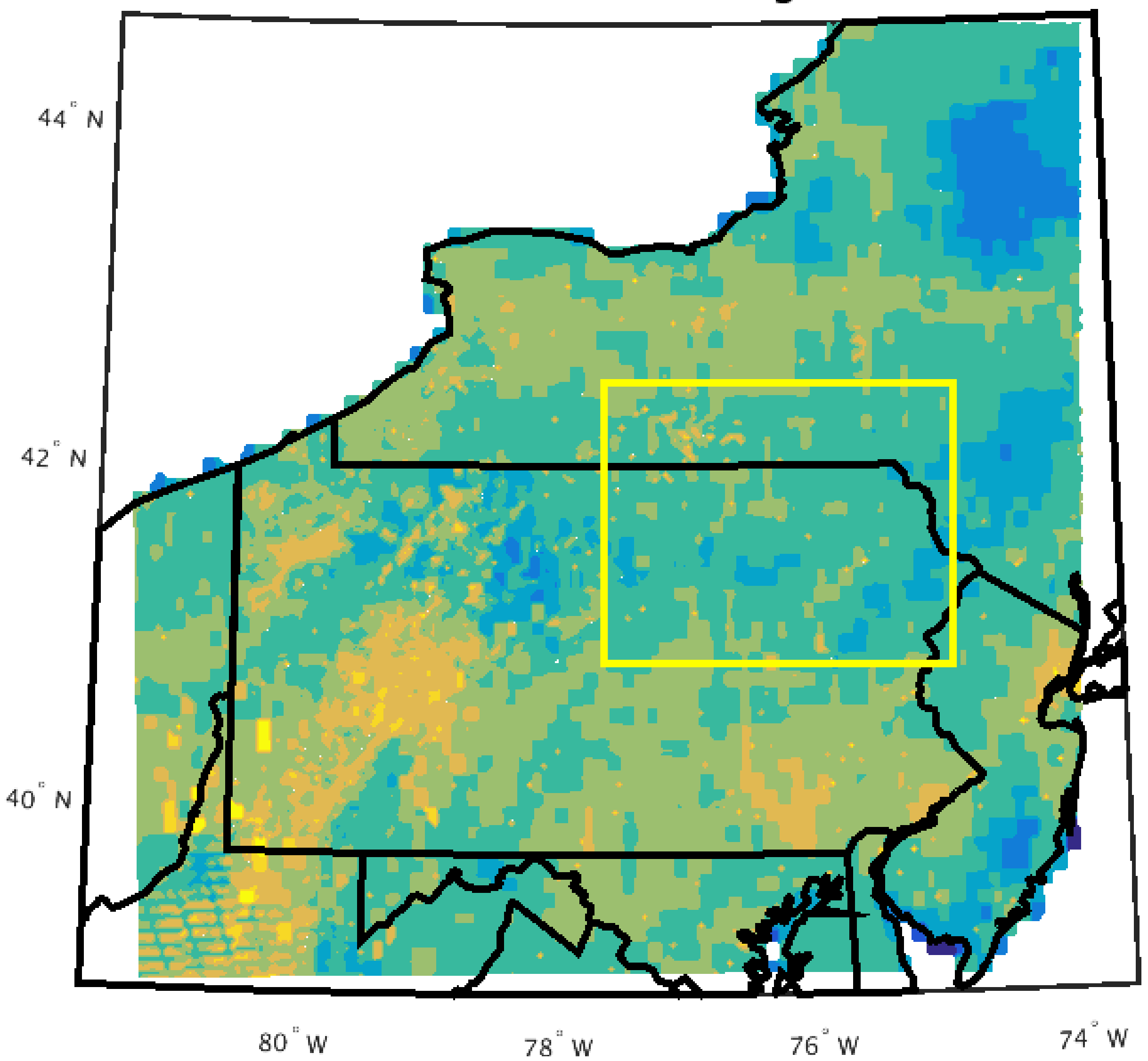
- **Unconventional Wells**: 6000+. High production. 0.13% first guess rate. SOLVING FOR THIS
- **Conventional Wells**: 60000+. Low production. 11% leakage rate?
- **Compressors/Storage/ Pipelines/Distribution** sources included but not solved for
- **Landfills:** Few but large emitters
- **Coal Mines:** Enormous emitters located in southwestern PA
- **Industrial Sources:** Localized concerns
- **Enteric Fermentation:** Everyone in PA owns a cow, but everyone in Lancaster County owns 100.



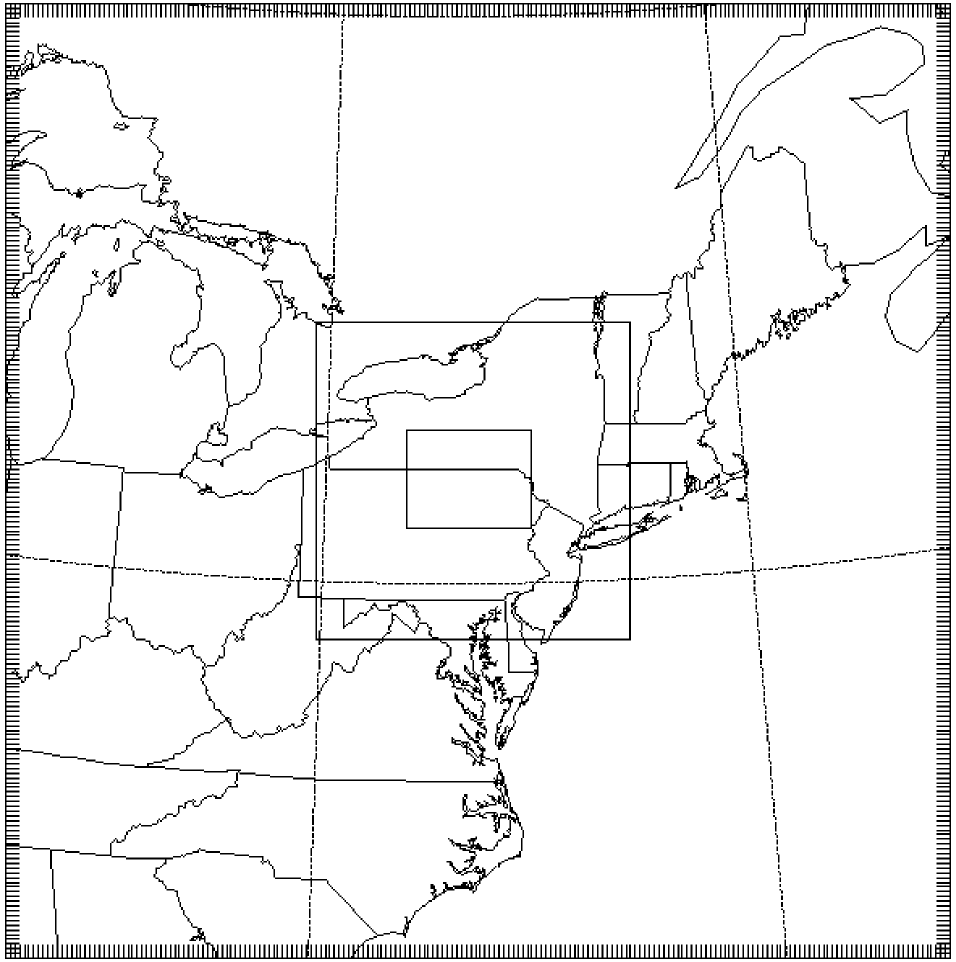
What we're solving for



What we're not solving for



WRF-Chem Modeling



- 9km res grid with 3km nested grid centered around wells in northeastern PA
- Tracers are created for the different sources of methane, and concentration fields are mapped for each of the flight days
- Emission rates from upstream production in model are adjusted to best match aircraft observations.

Emission Rate Optimization

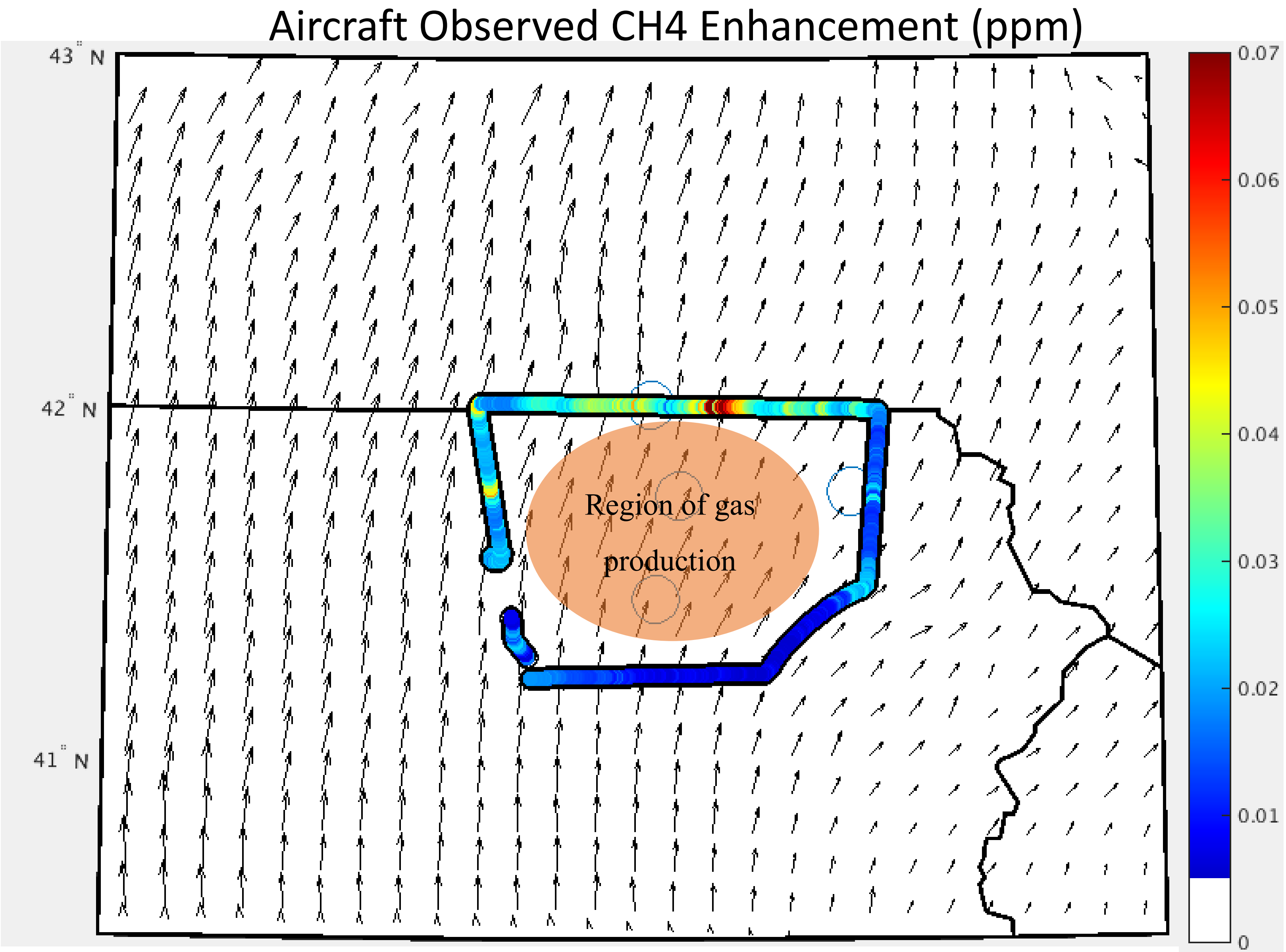
1. Select appropriate background methane value for flight and subtract from obs to create "observed methane enhancement".

    -Use observation in lowest 3rd percentile as background. Add

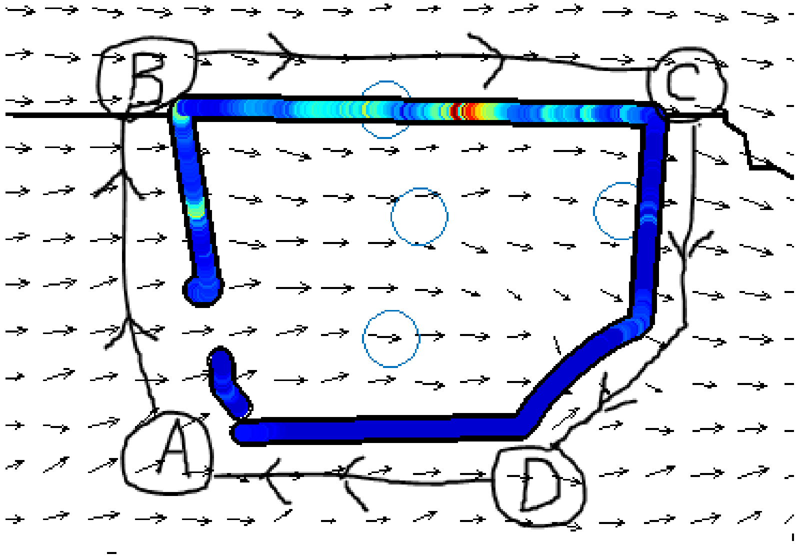
2. Subtract off non-natural gas enhancements from the observed methane enhancement to create an "observed natural gas enhancement
3. Adjust natural gas emission rate in model to minimize error between observed natural gas enhancement and modeled natural gas enhancement.

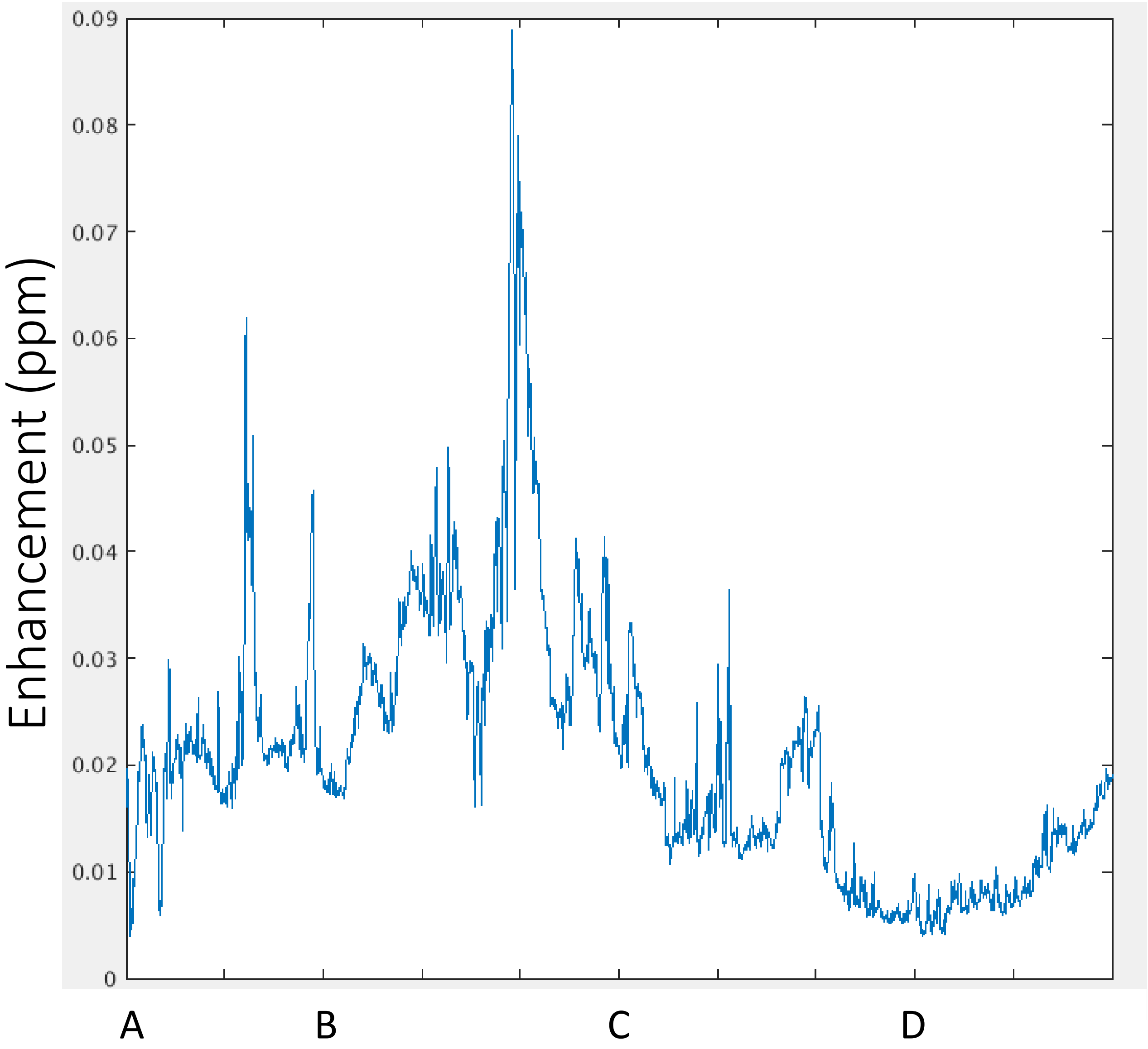
EXAMPLE: May 29th, 2015

May 29th 2015: A good day.

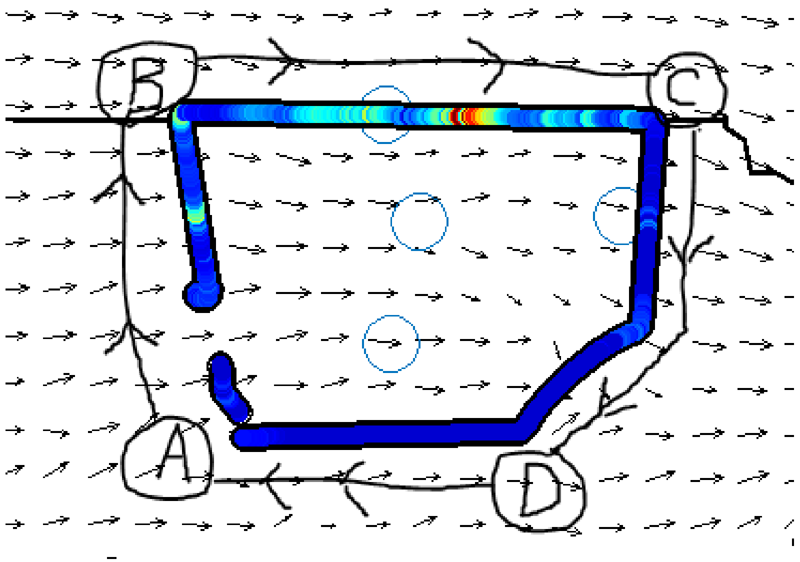


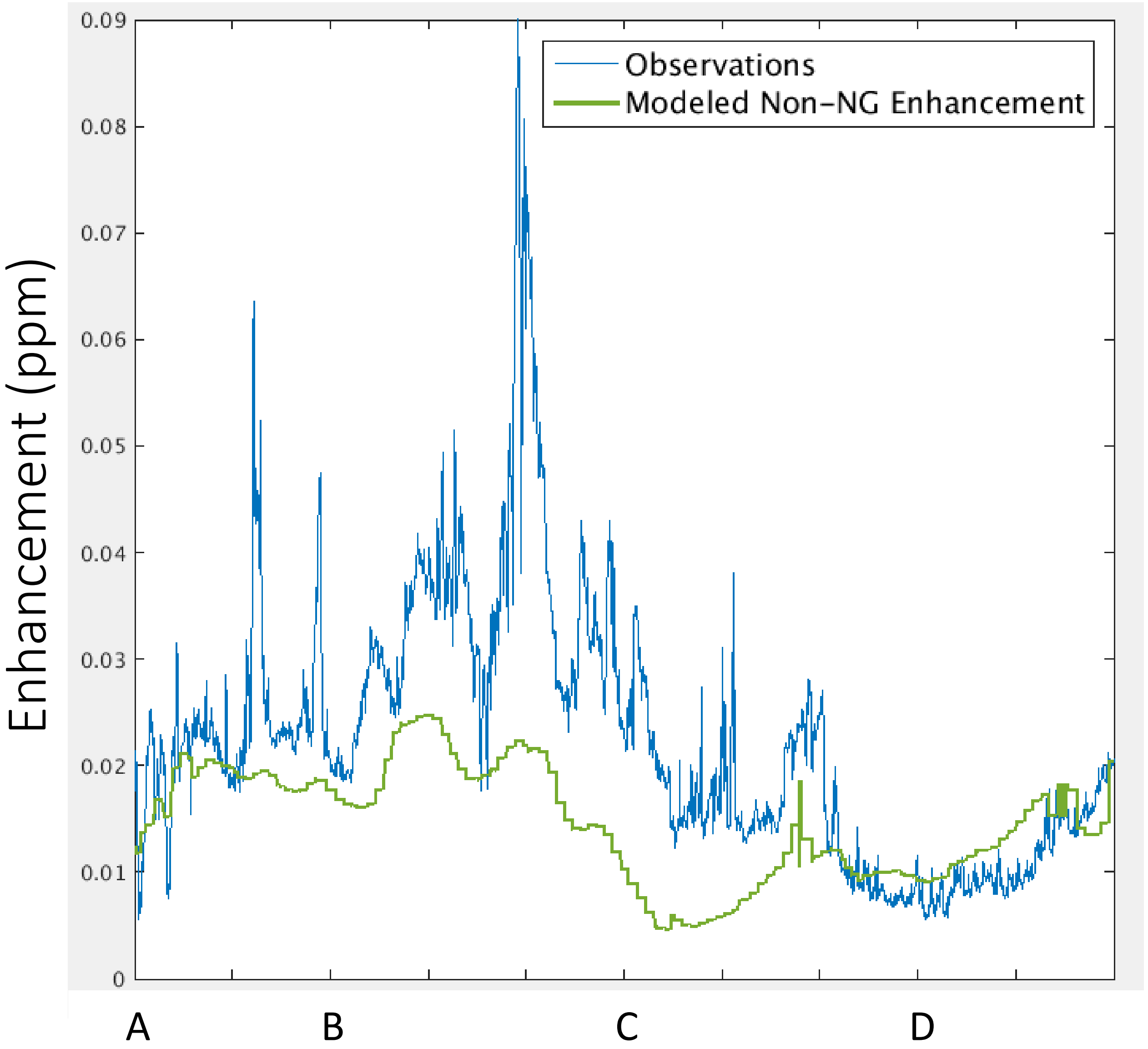
Observed Methane Enhancement

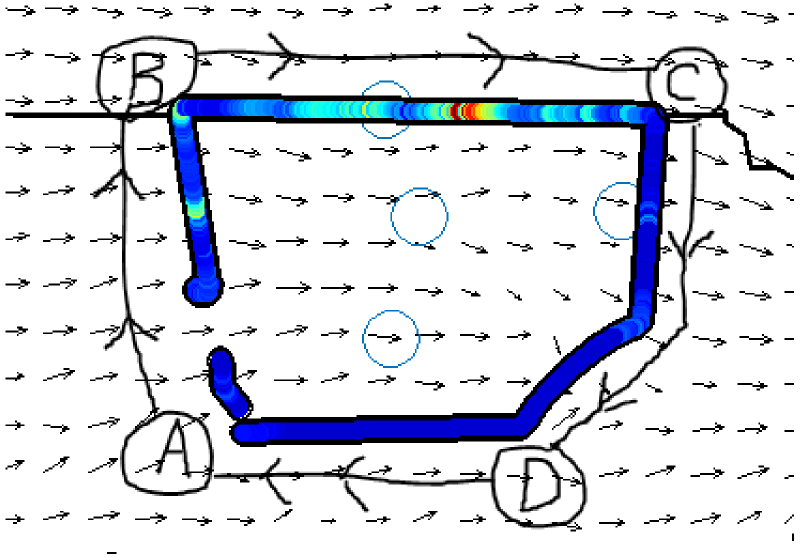




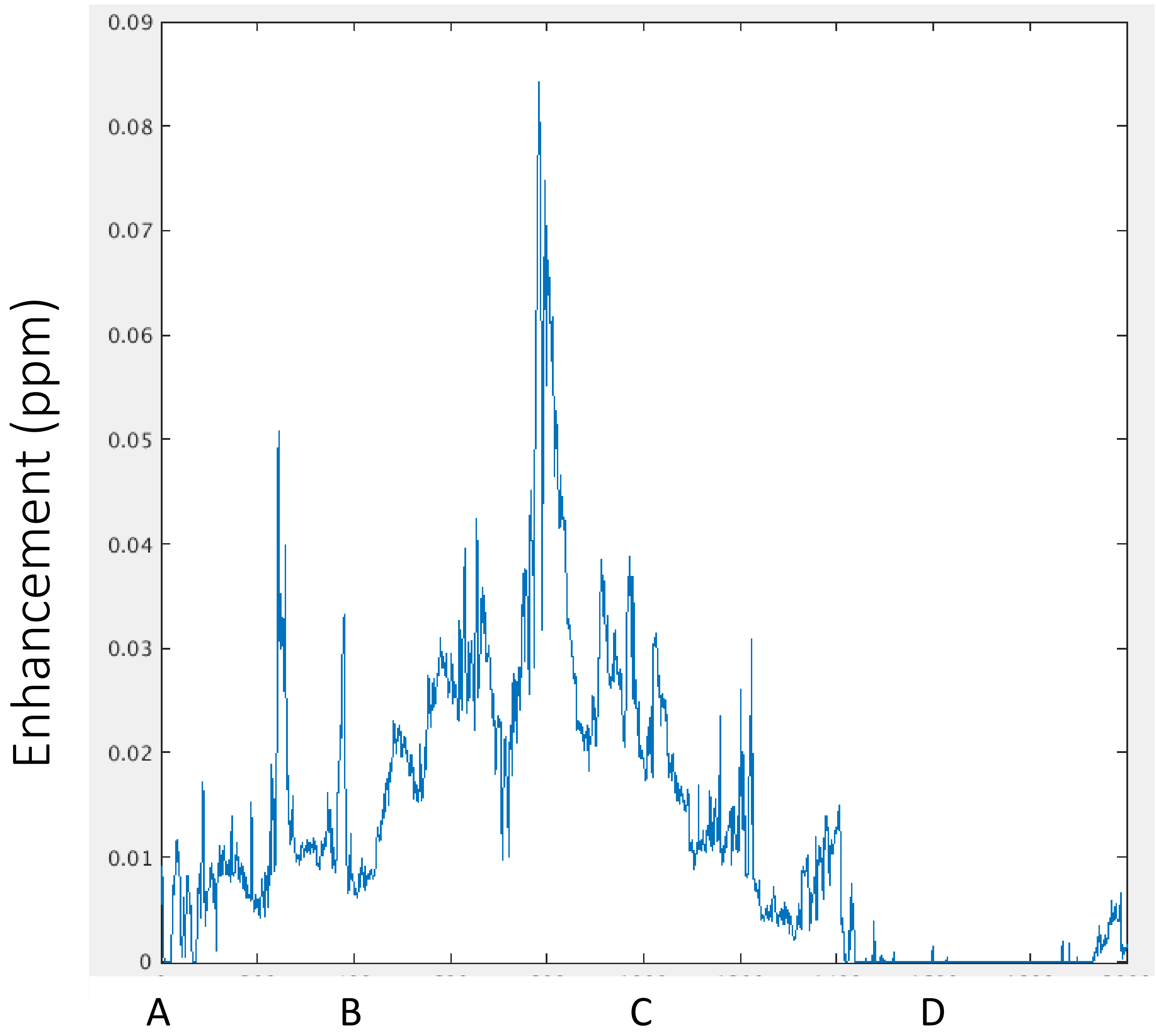
Observed Methane Enhancement

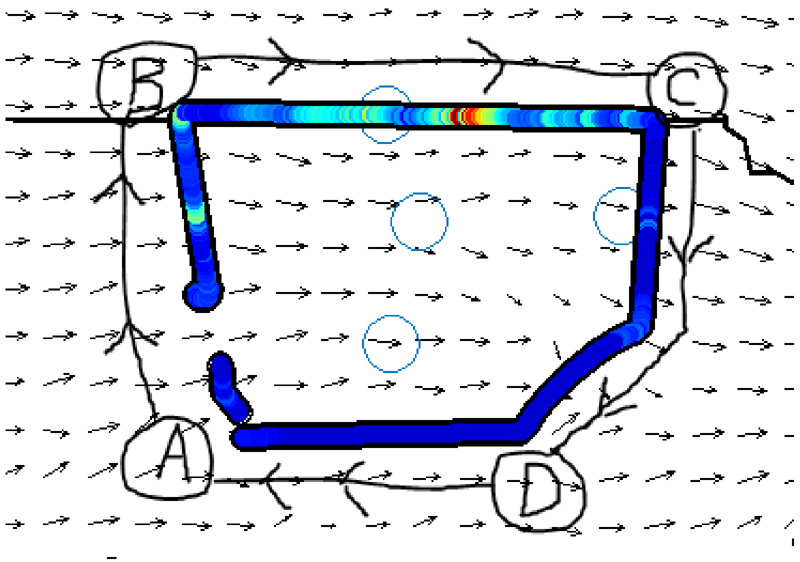




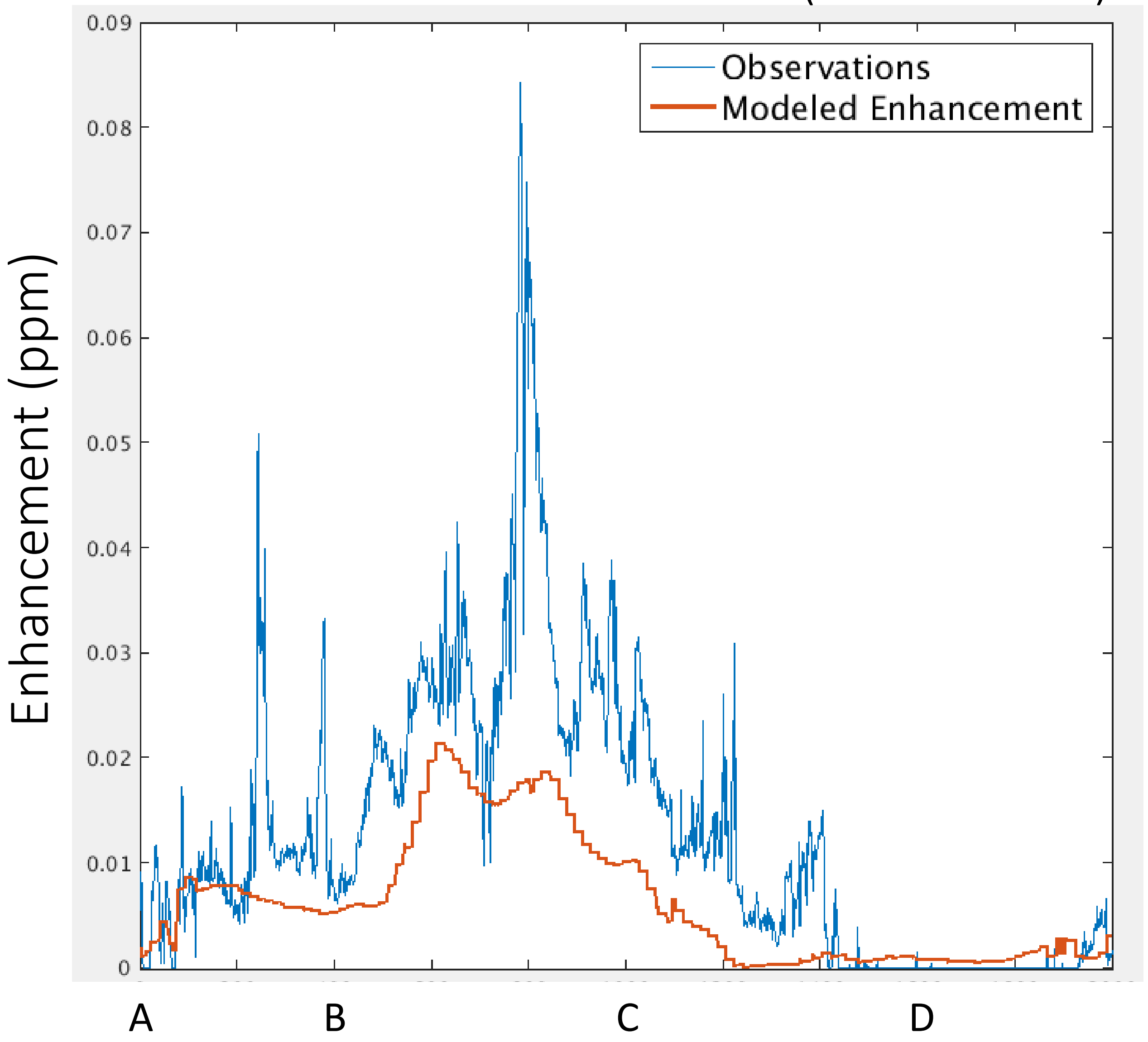


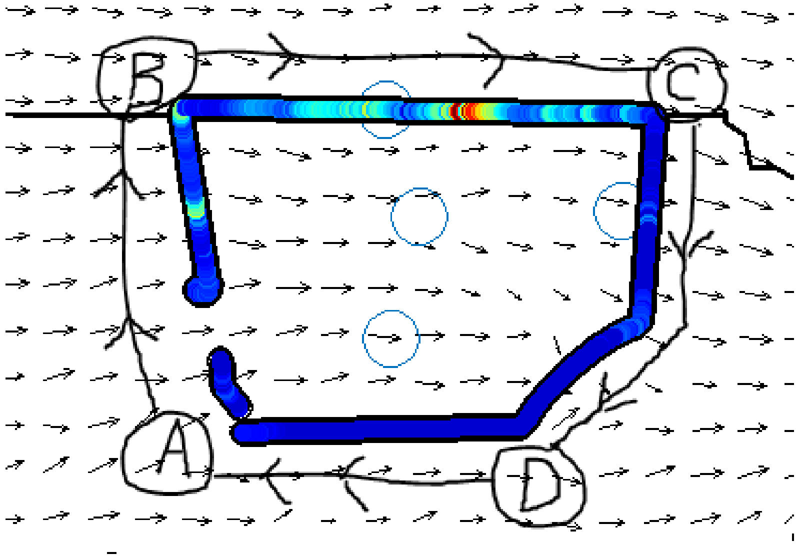
Observed Natural Gas Enhancement

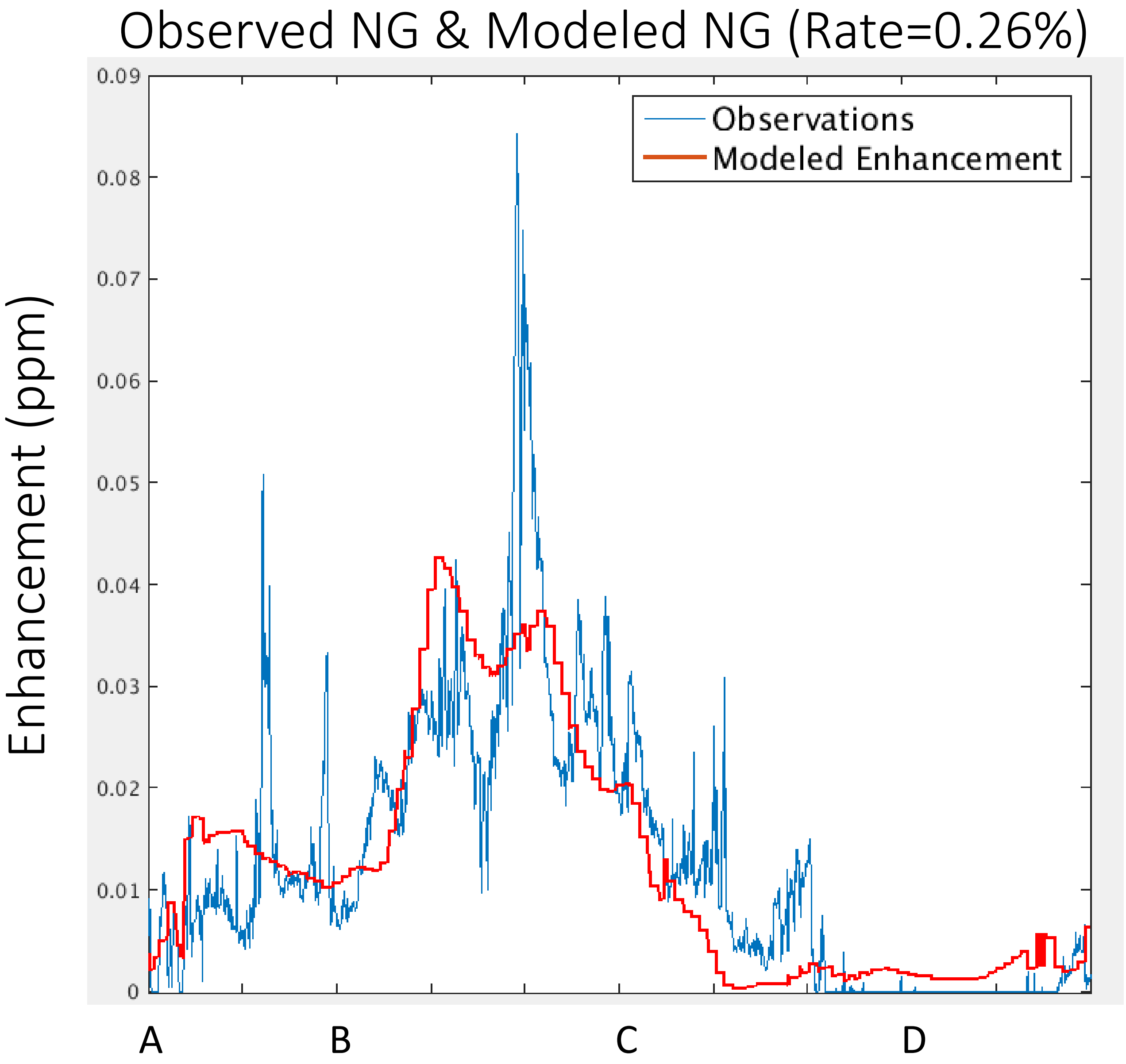




Observed NG vs Modeled NG (Rate=0.13%)




B
C
A
D

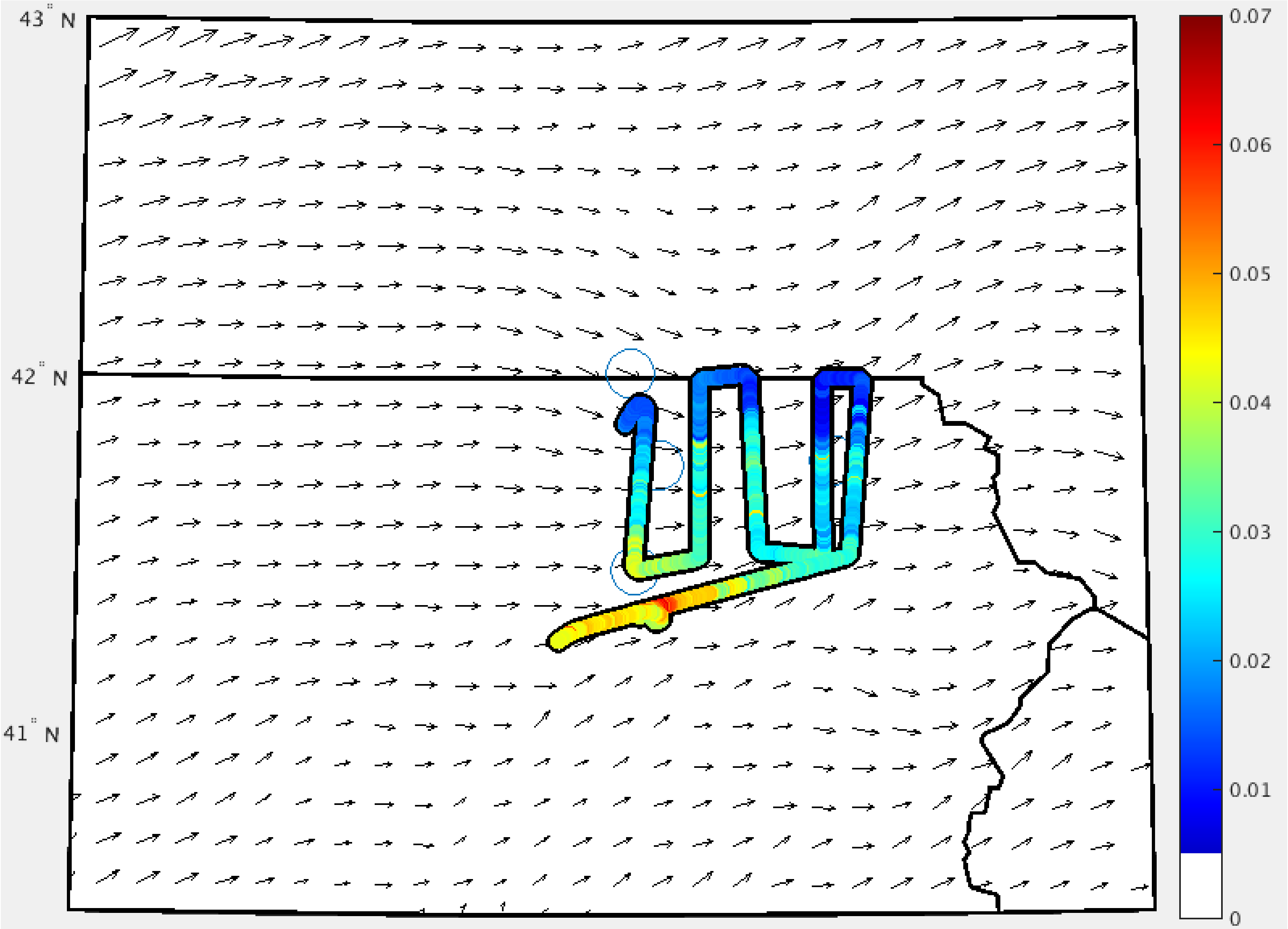

Observed NG & Modeled NG (Rate=0.26%)
Observations
Modeled Enhancement
Enhancement (ppm)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
A
B
C
D

CASE STUDY: MAY 24th, 2015

The Importance of a Good Methane Inventory

The Importance of a Good Methane Inventory

Aircraft Observed CH4 Enhancement (ppm)

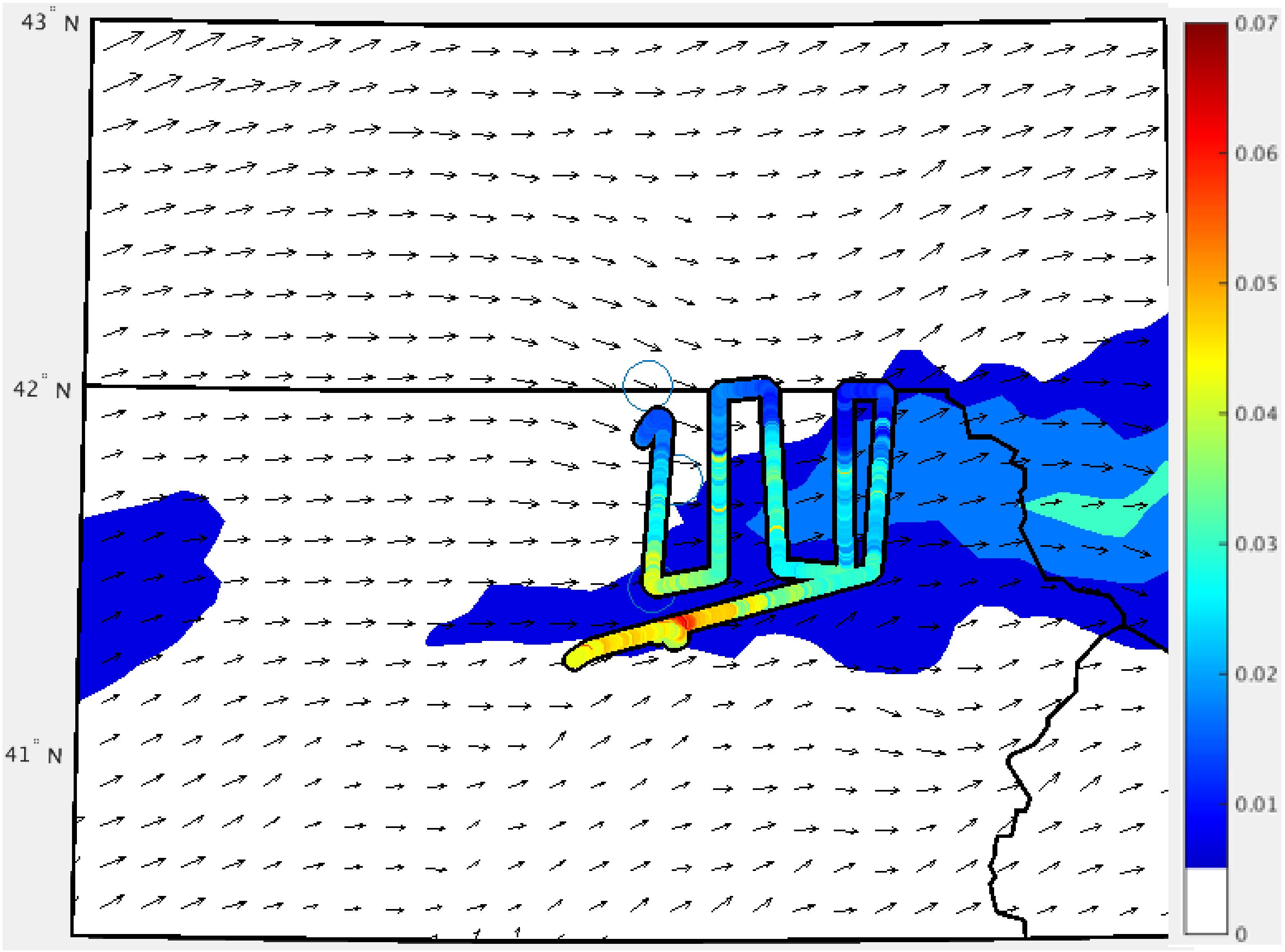


May 24th, 2015: Late flight observations

Observed CH_4 enhancement appears to be a function of latitude.

The Importance of a Good Methane Inventory

Projected natural gas enhancement (ppm)

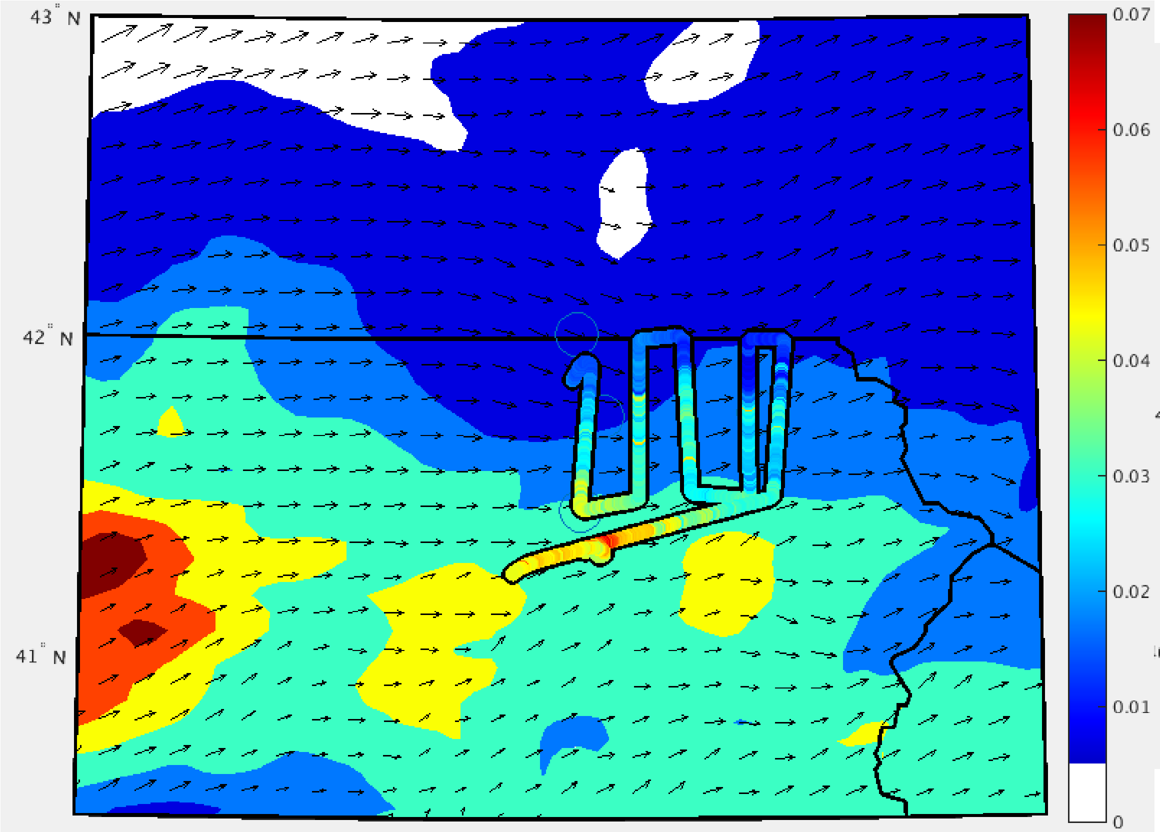


May 24th, 2015: Late flight observations

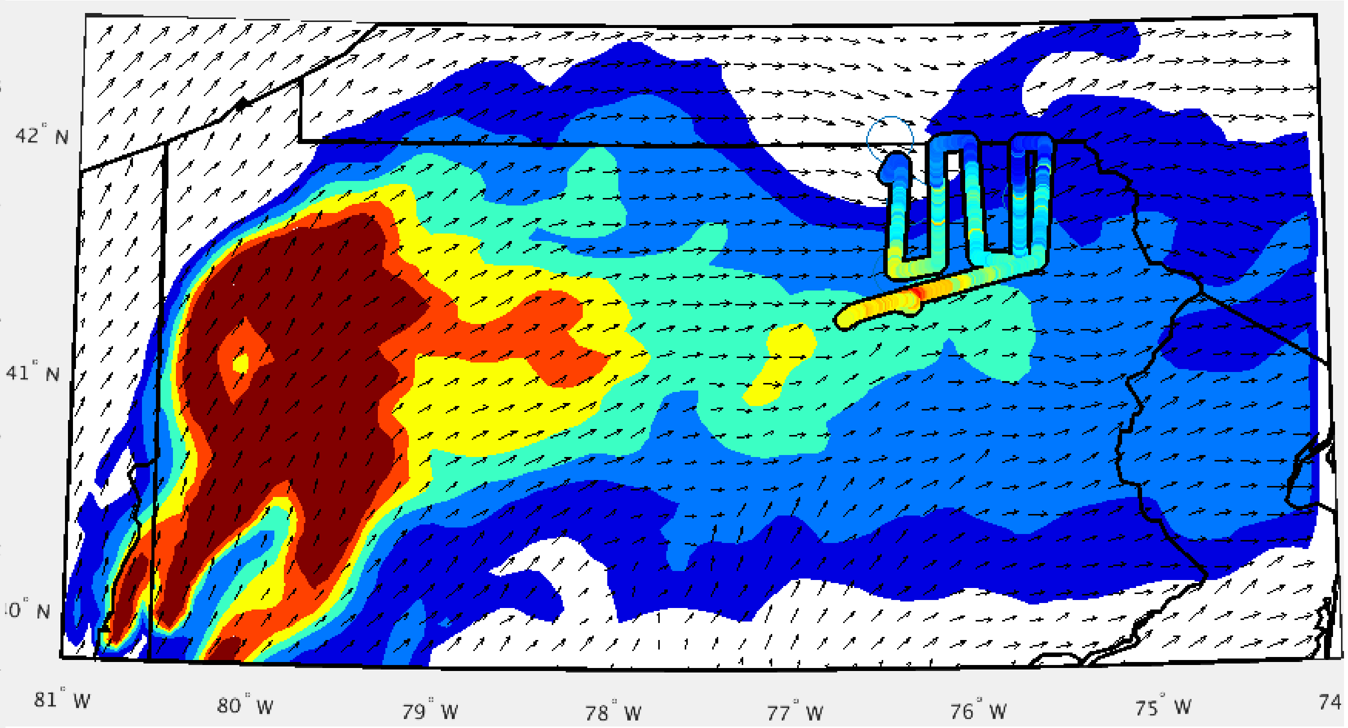
Wells cannot explain north/south methane gradient ☹

The Importance of a Good Methane Inventory

Projected Enhancement from Coal/Conventional Wells

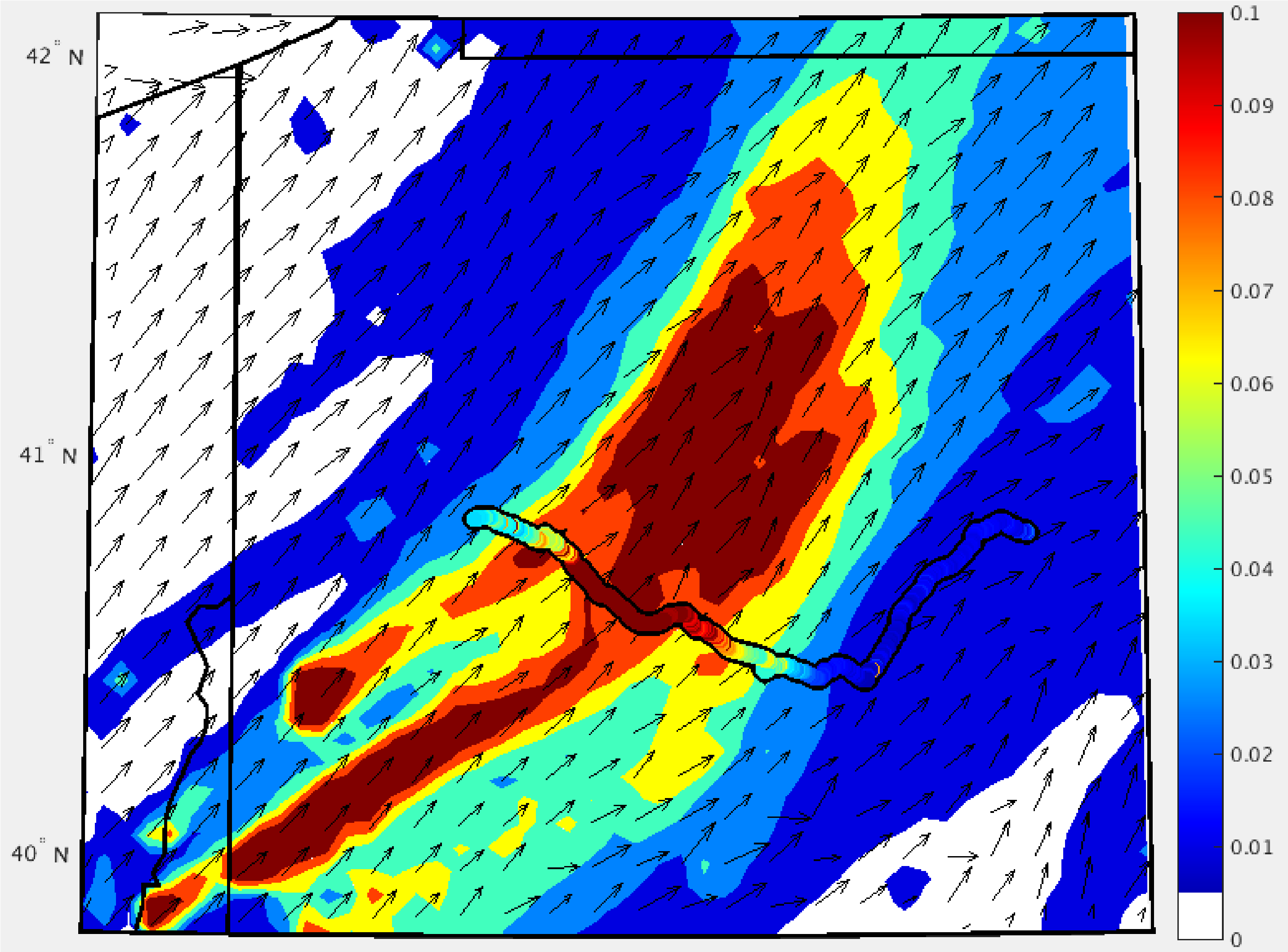


May 24th, 2015: Late flight observations



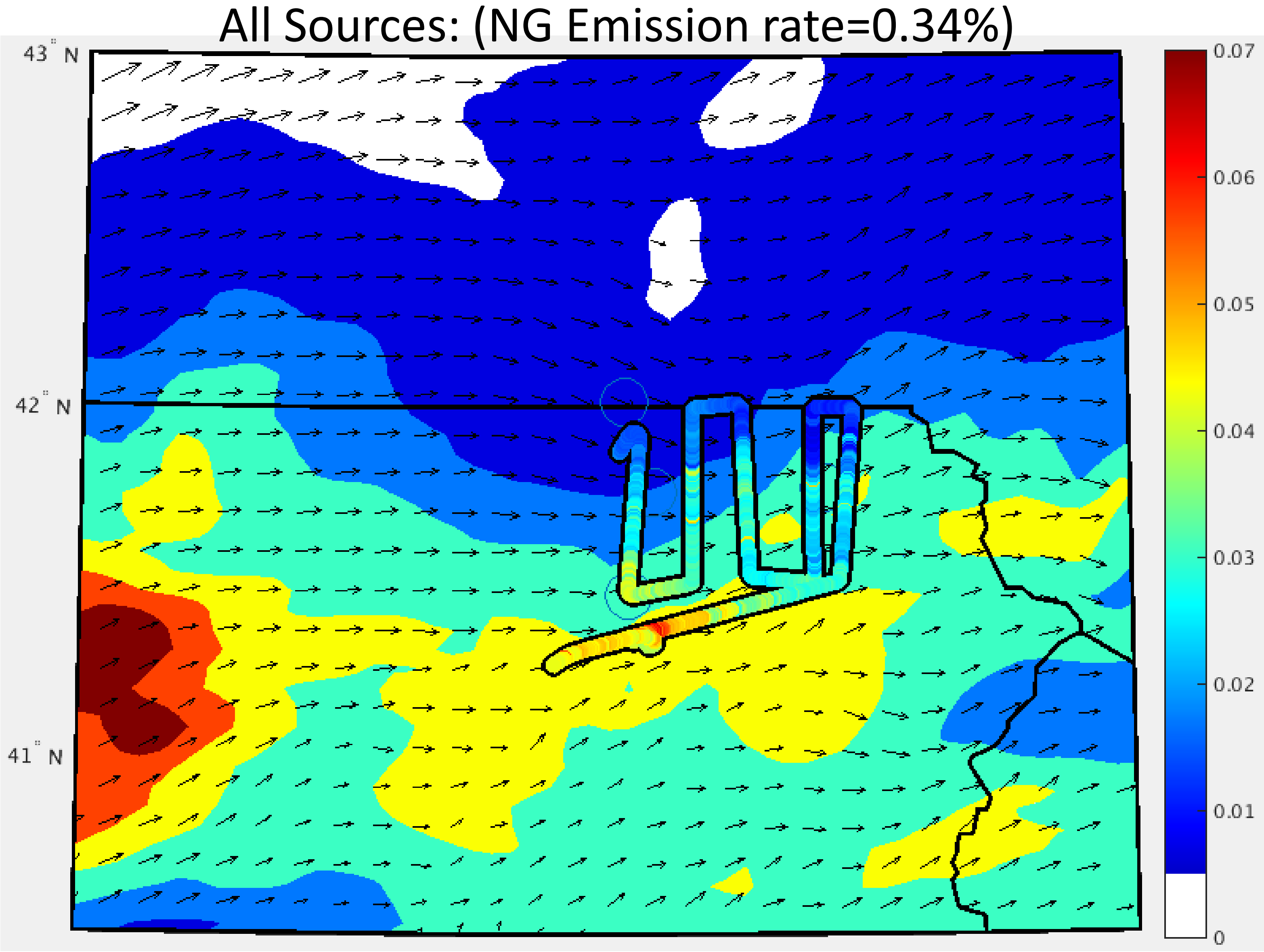
Emissions from coal and conventional wells from southwestern PA do explain pattern ☺

Aside: Coal Plume is a big player in PA



Driving campaign on May 27th, 2015

The Importance of a Good Methane Inventory

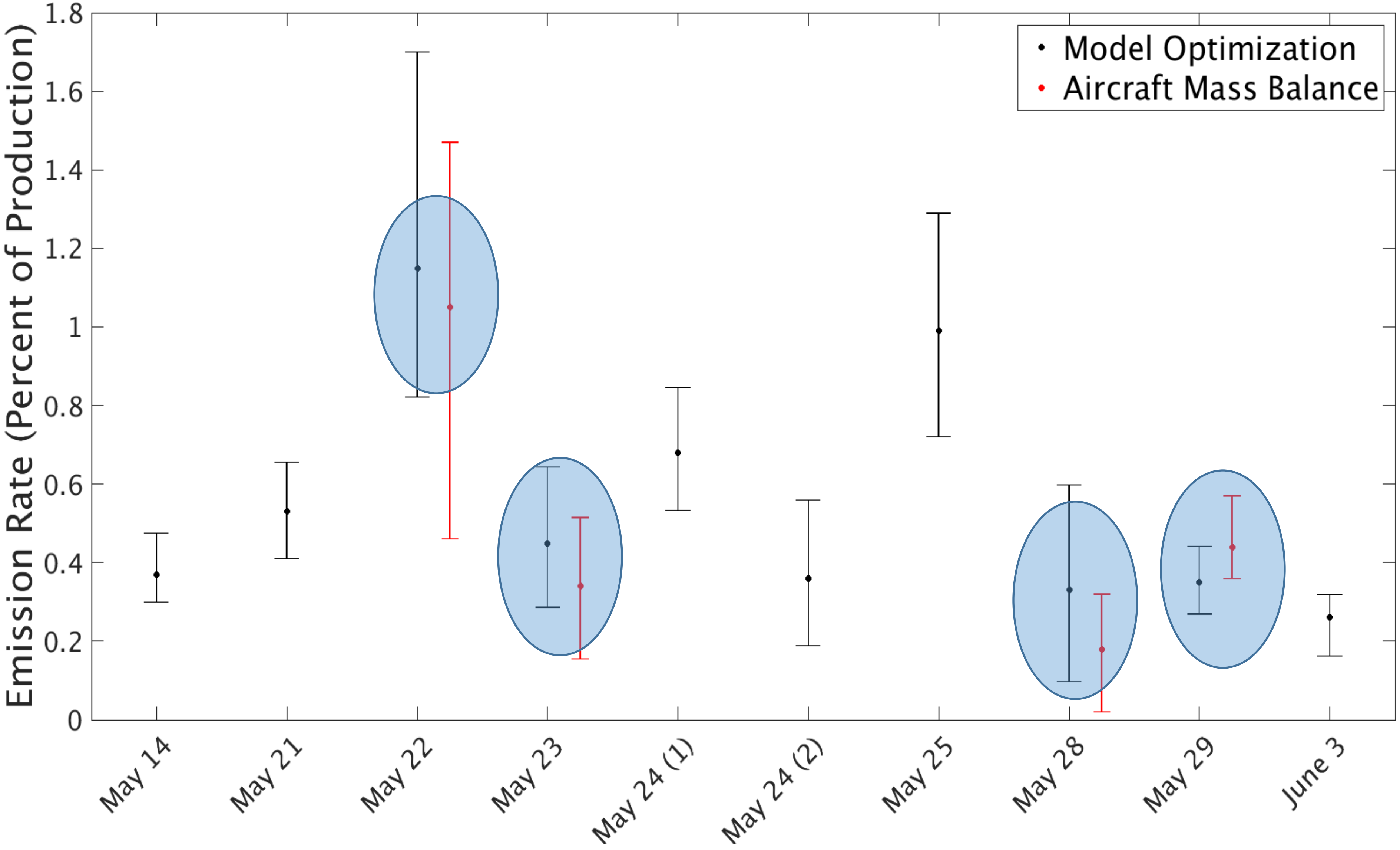


May 24th, 2015: Late flight observations

Modeling methane concentrations allows us to separate out enhancements from NG and solve for an emission rate on even the messiest days.

EMISSION ESTIMATES

Best-guess upstream emission estimates



Mean rate: 0.55%

Conclusions

- Natural gas emissions in Marcellus region from upstream processes are ~0.5%
  - Study accounts for production and gathering of natural gas. Distribution is nonexistent in the area.
- WRF-Chem can be an effective tool for calculating natural gas emission rates.
  - Previous studies using mass balance techniques struggle to account for non-NG sources intruding into box. WRF can identify and separate these plumes.
- Thorough study, but performed over a single month.
  - Data obtained from tower network during the next two years will answer whether emissions rates vary in time.

Extra Material

CASE STUDY: MAY 14th, 2015

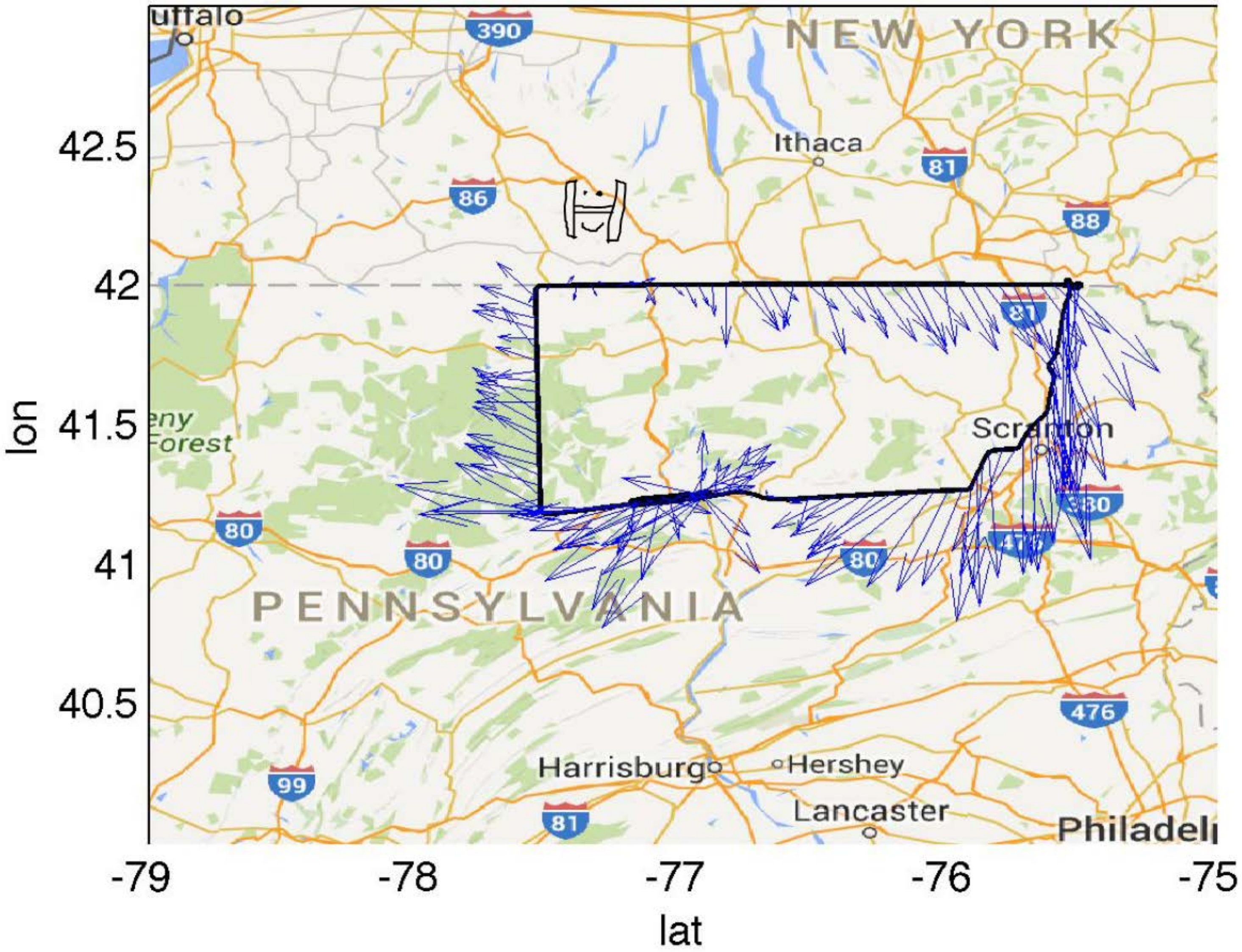
Addressing the issue of transport error

Transport Errors

-High pressure located near flight path creates a “swirly wind” pattern around well sources

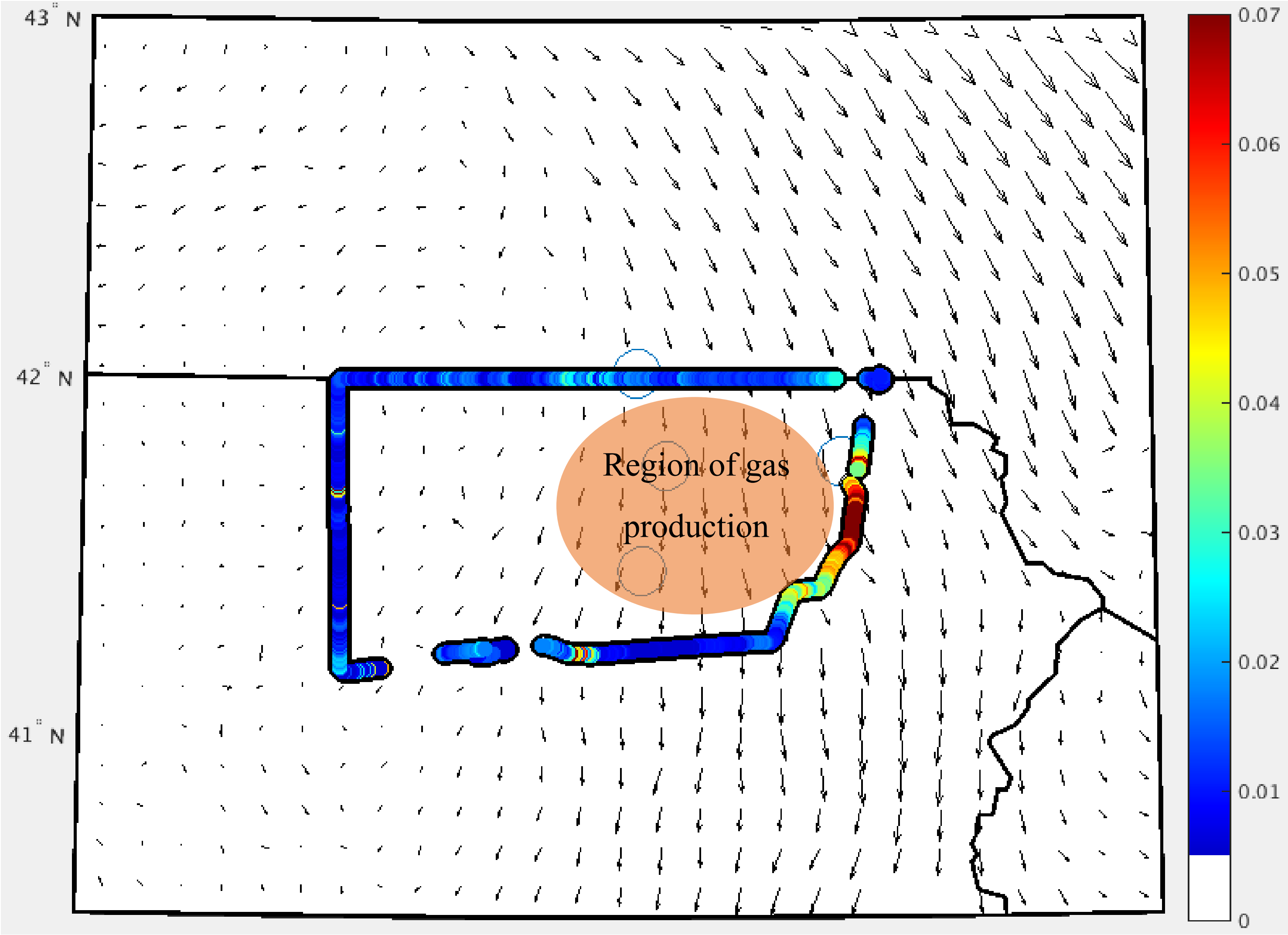
-Presents modeling challenge

Corrected Aircraft Wind



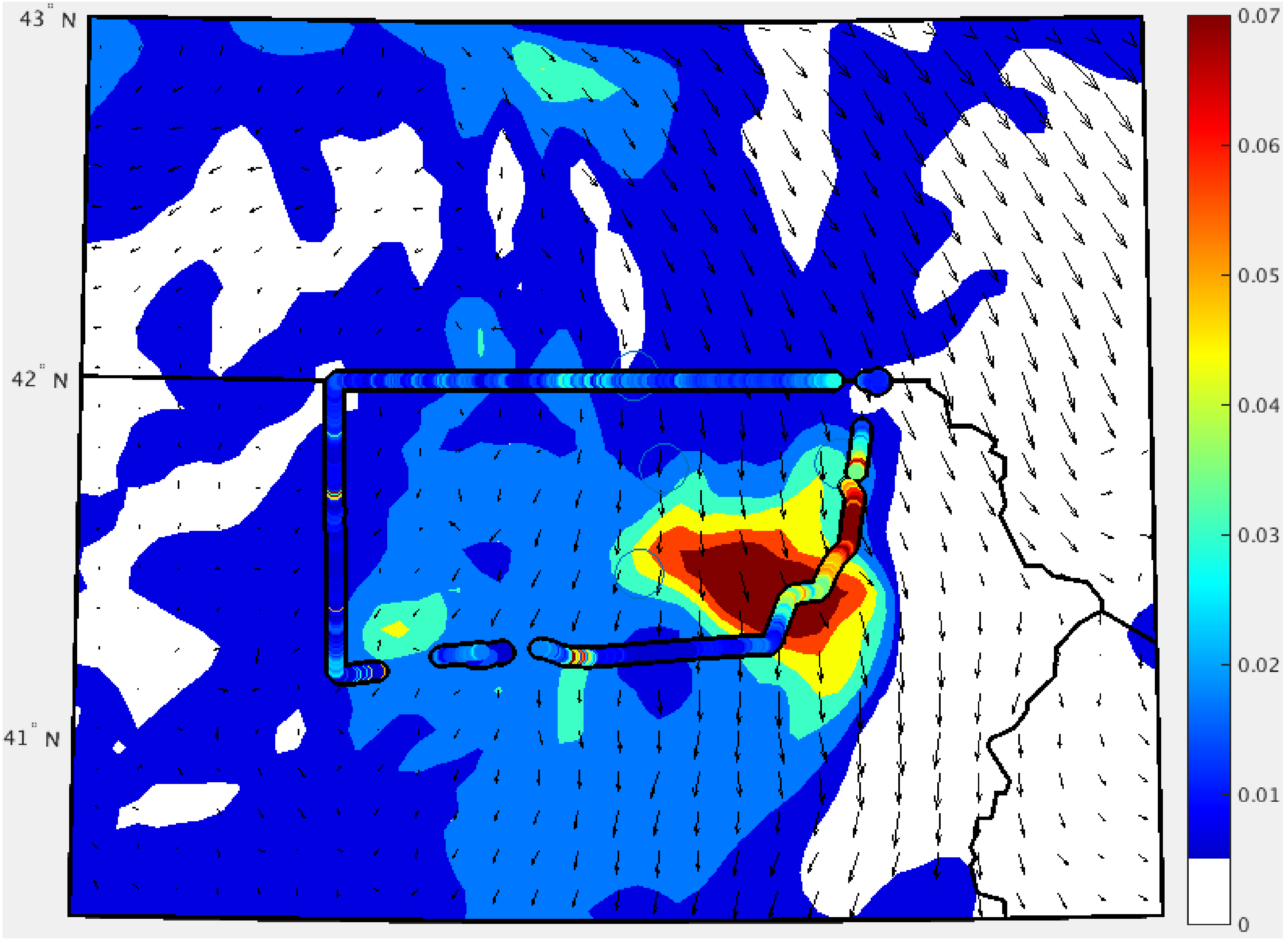
Transport Errors

Clearly defined natural gas plume along eastern transect



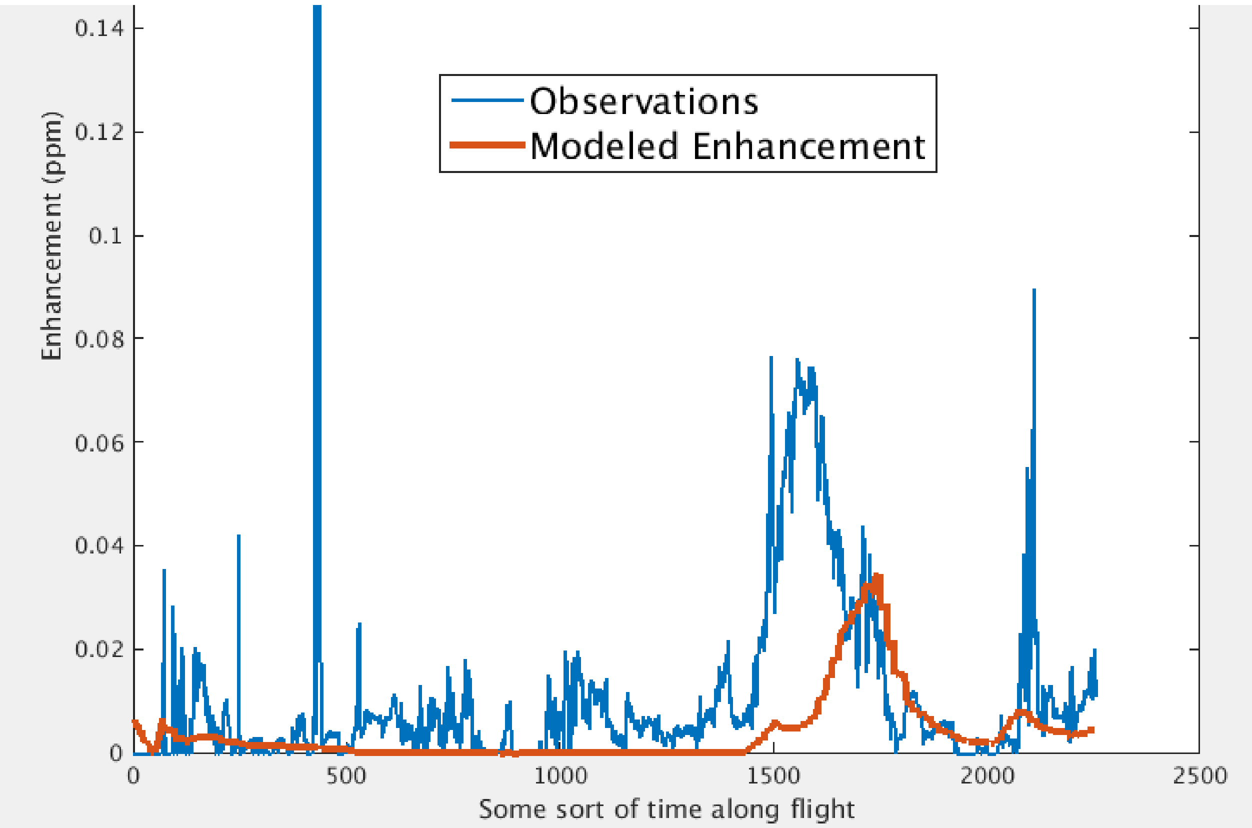
Transport Errors

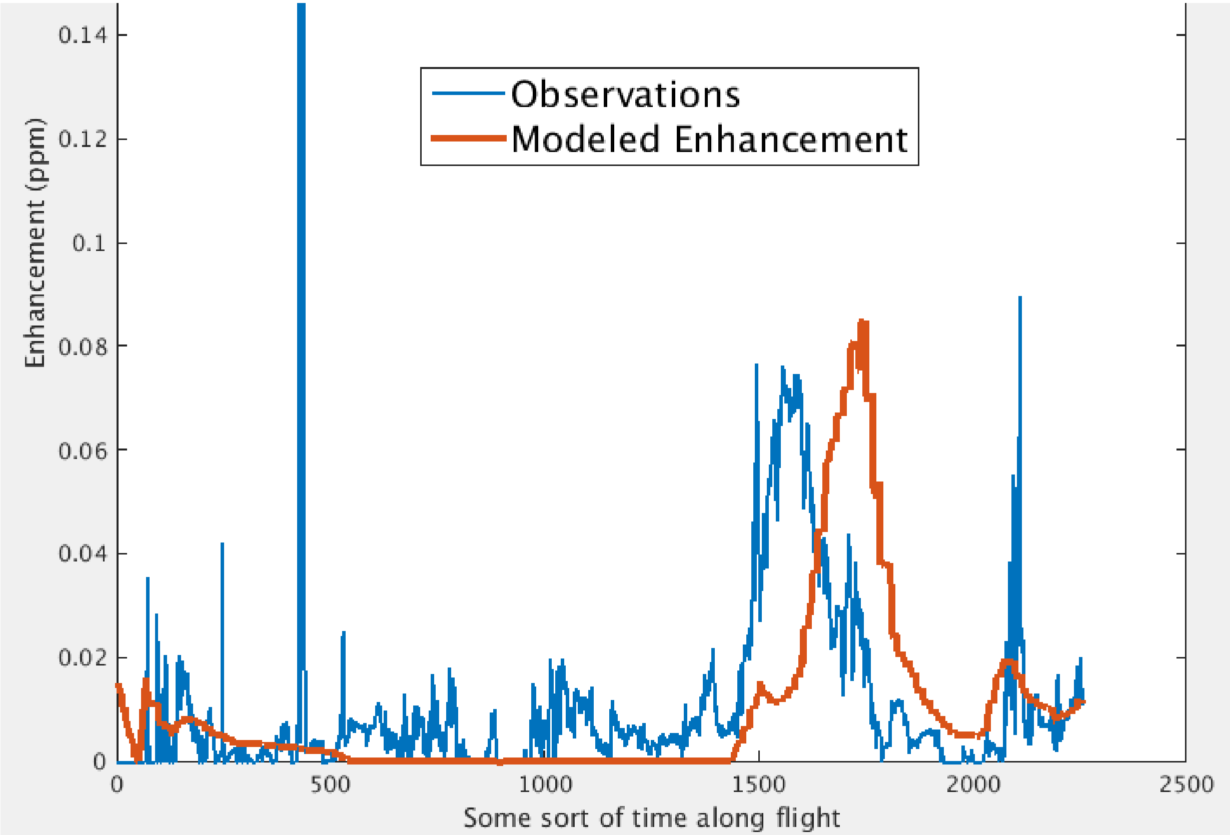
Model winds are lacking westerly component along east transect. Model plume goes south of intended location



Transport Errors

2 Strategies





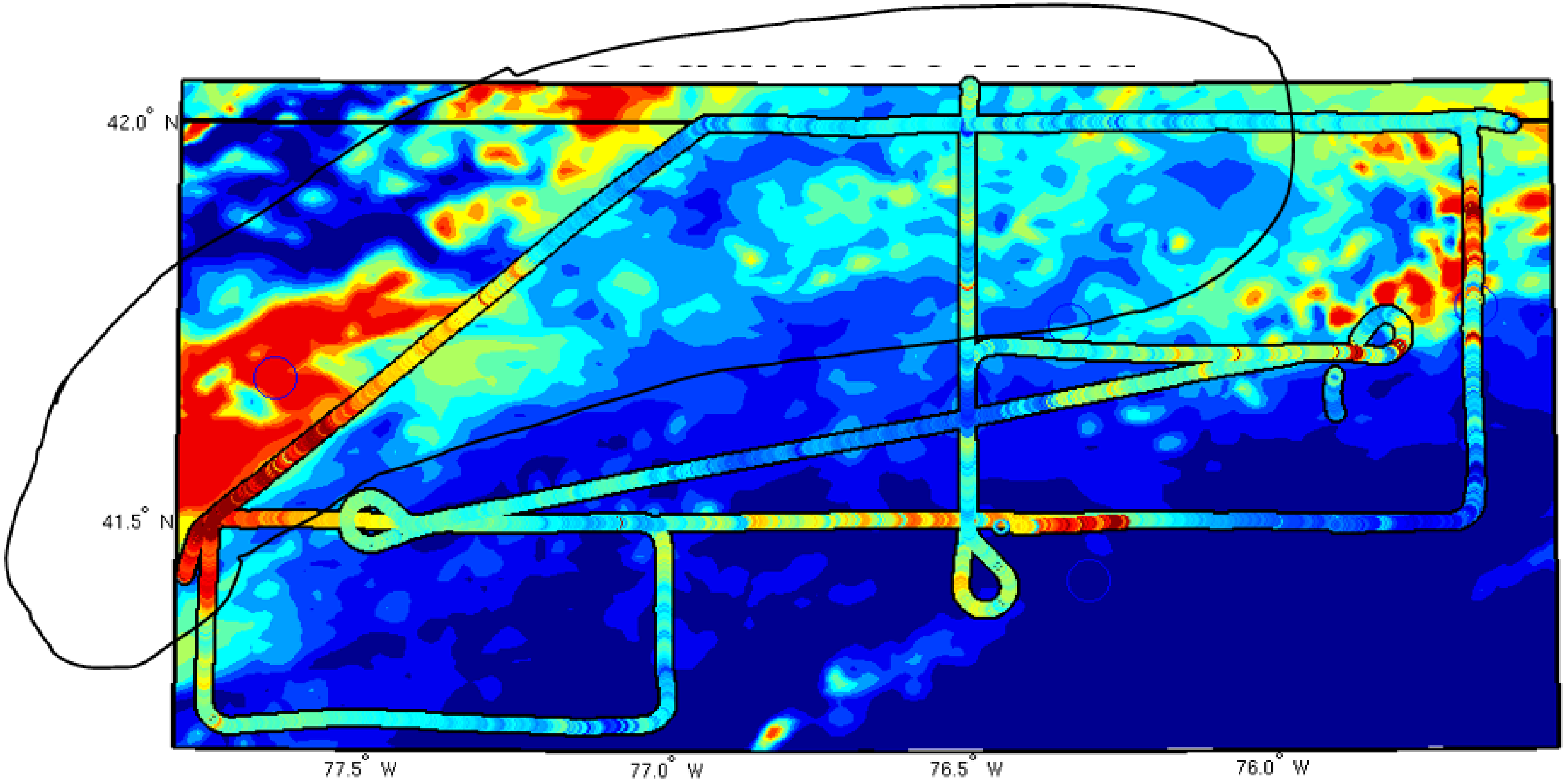
Find emission rate which minimizes ABSOLUTE error

Strict approach which aims for the closest match between the model and observations

Find emission rate which minimizes SUMMED error

An approach which allows for errors between observations and the model to be compensated elsewhere

Aside: Coal Plume is a big player in PA



July 2013 flight in Peischl et al 2015