Simulation of Tall Tower CO_2 concentration using WRF-STILT Model

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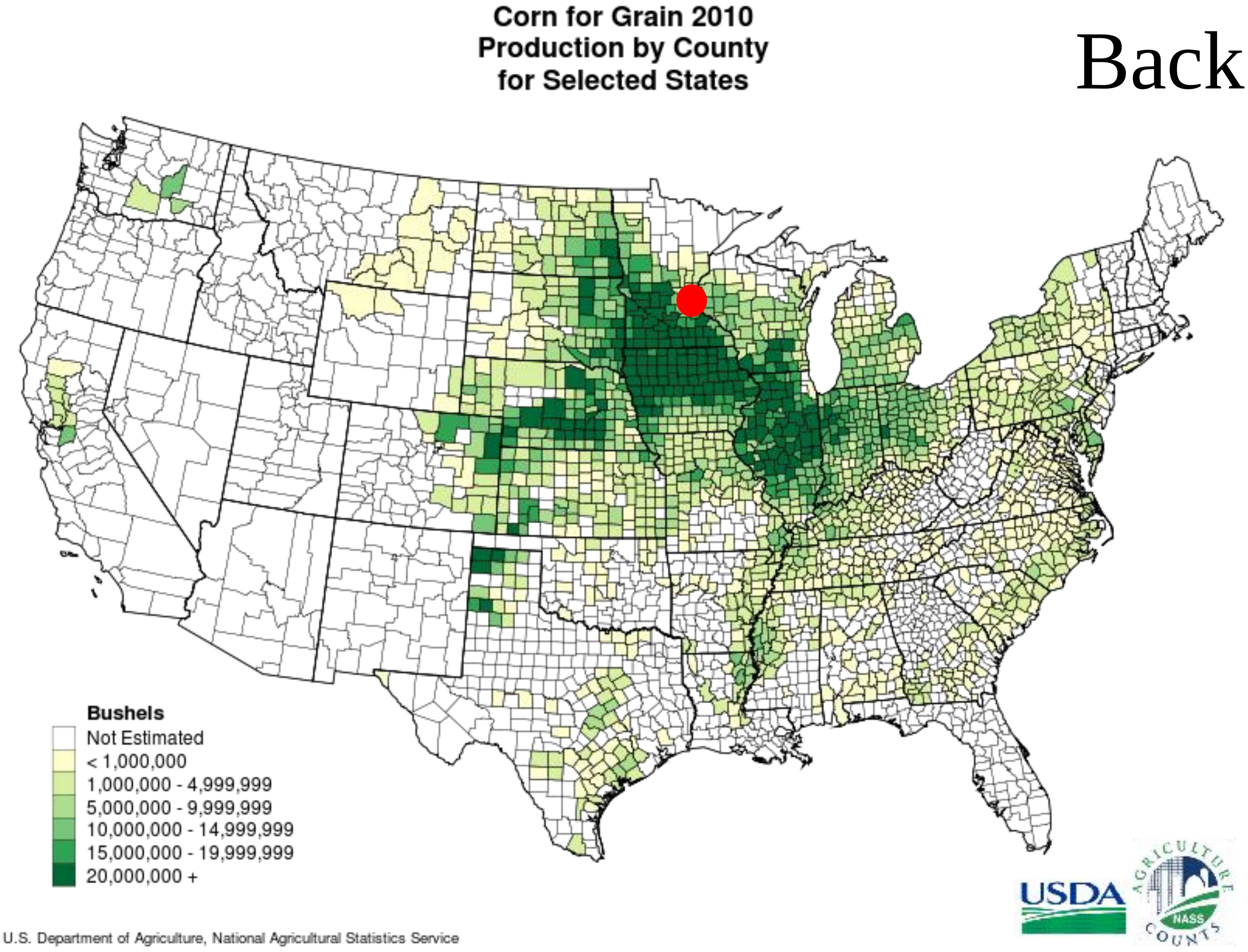
Outline

- Background
- Motivations
- Methods
- Preliminary results
- On-going work

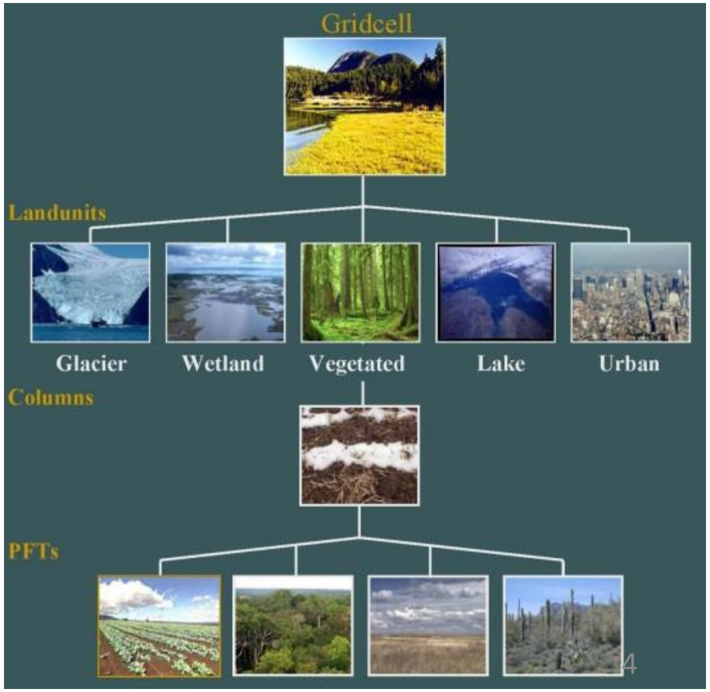
Background



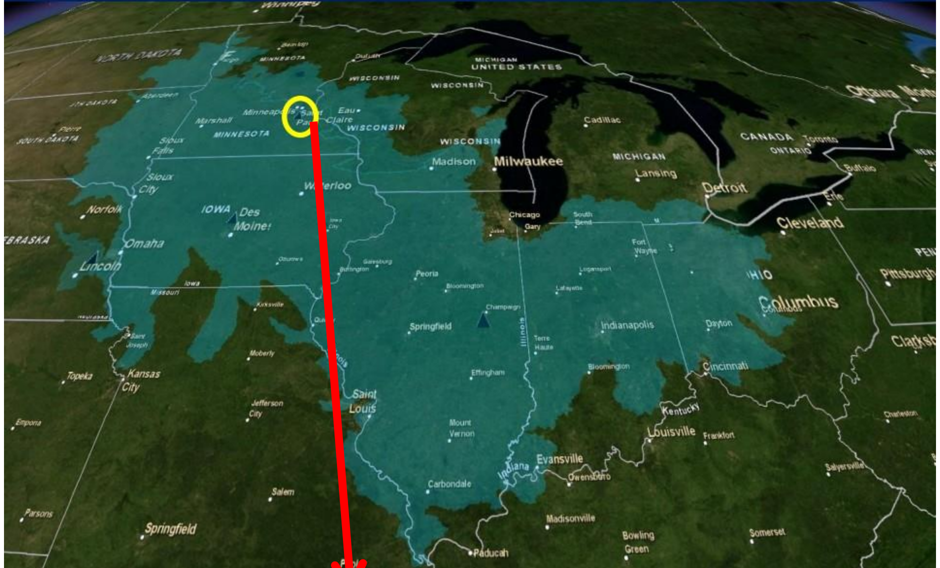
2010 production of corn in the United States
Figure from *https://en.wikipedia.org/wiki/Corn_Belt*

- US Midwest/Corn Belt, one of the most productive agricultural land around the world, is essential CO_2 sink for its role of food products base and lateral transport of harvested products [West et al., 2011].

- Several methods have be applied to measure or estimate regional scale CO_2 flux. Bottom-up methods: Eddy Covariance, Chamber methods, IPCC or model-based inversion products(Carbon Tracker [Peter et al., 2007]; EDGAR), and crop-phenology based Community Land Model (CLM).



- Top-down method: STILT inversion model based on Tall Tower concentration measurement, it can help us with the atmospheric view of the connection between surface processes and concentration at measurement .



The tall tower trace gas observatory (TGO, Minnesota Public Radio communications tower, KCMP) is located approximately 25 km to the south of Minneapolis-St. Paul(44°41’19’’N, 93°4’22’’W)

View of the land use at the top of tall tower.

Figure from http://biometeorology-dev.umn.edu/research/tall-tower

Motivations

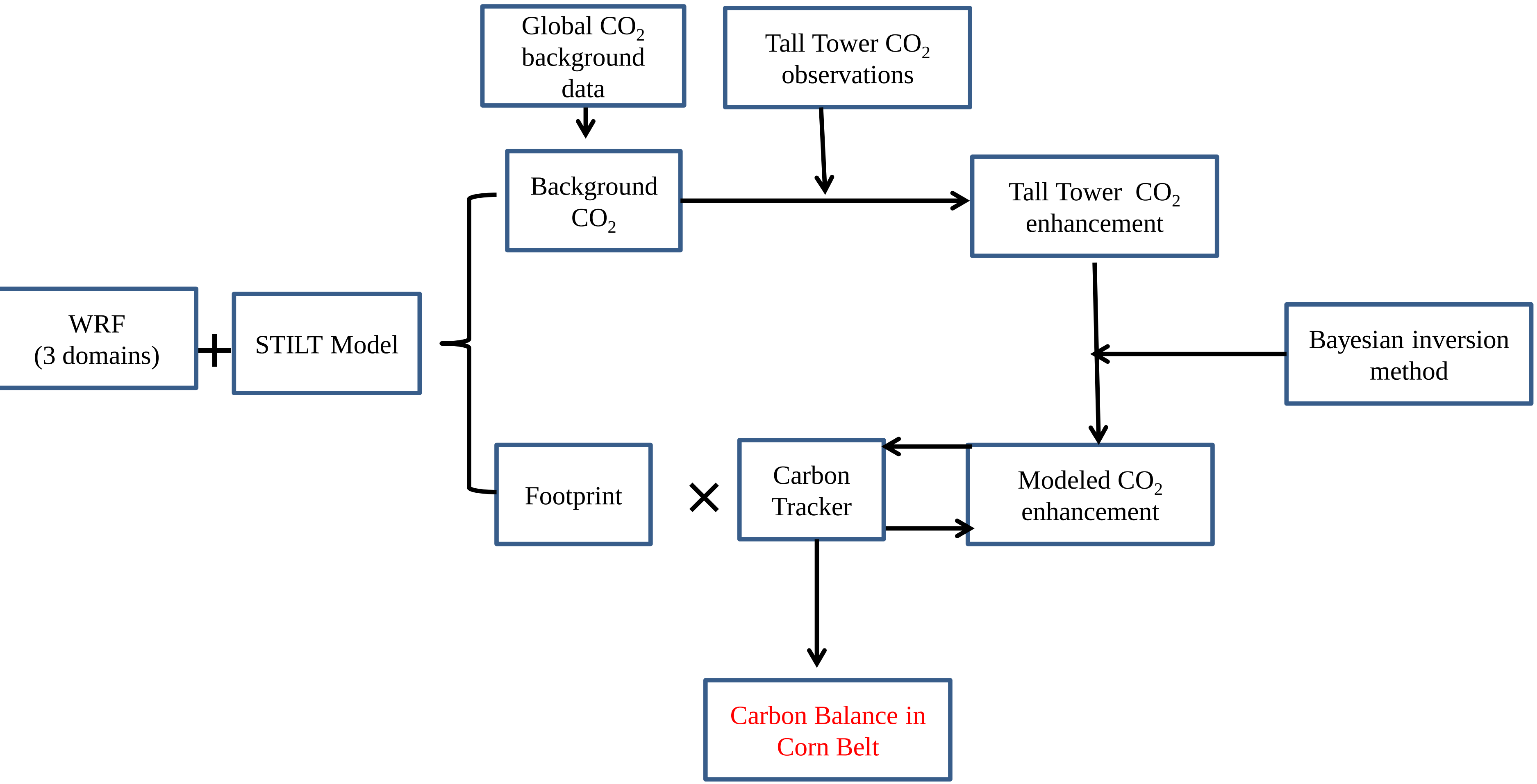
- 1) Whether the diurnal variation of Tall Tower CO_2 concentration at the agriculture dominating lands can be simulated?

- 2) Whether the Bayesian inversion method can be used to optimize the CO_2 fluxes?

- 3) What's the Carbon balance in the Corn Belt?

Methods

Brief framework of this study:



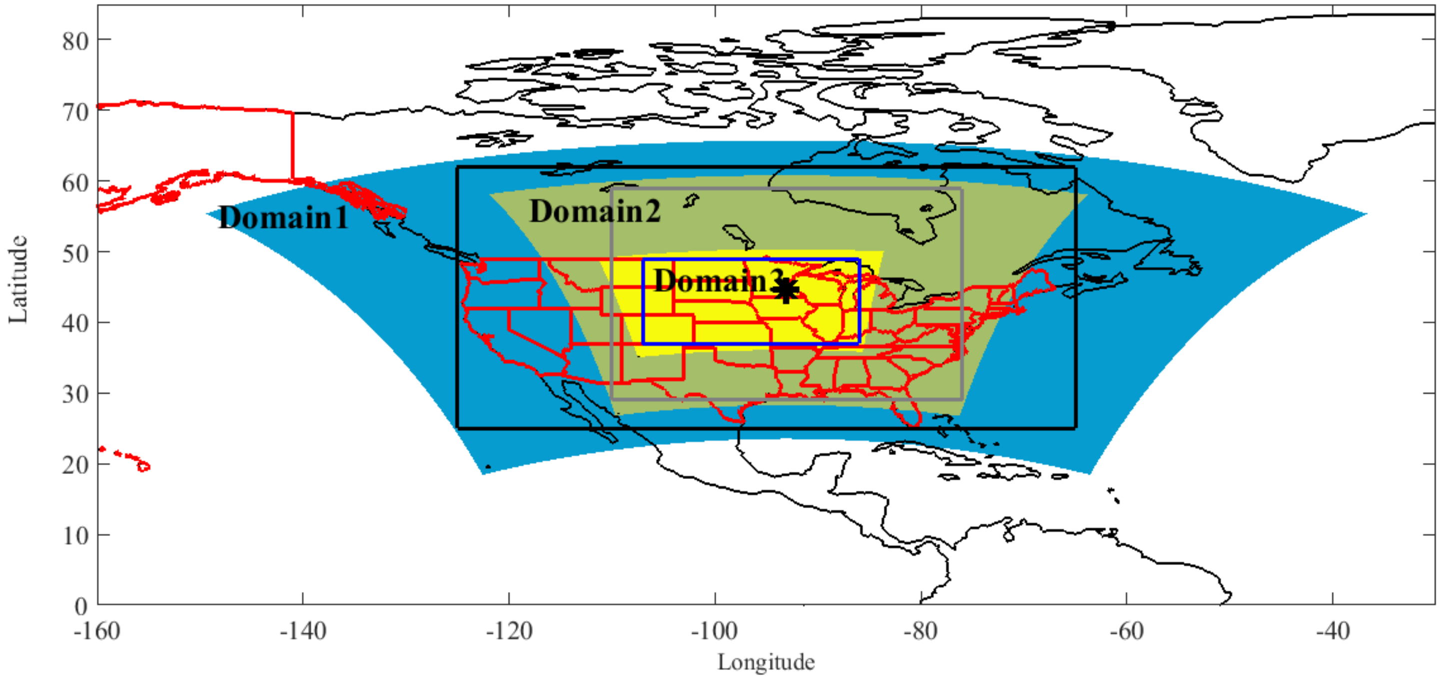
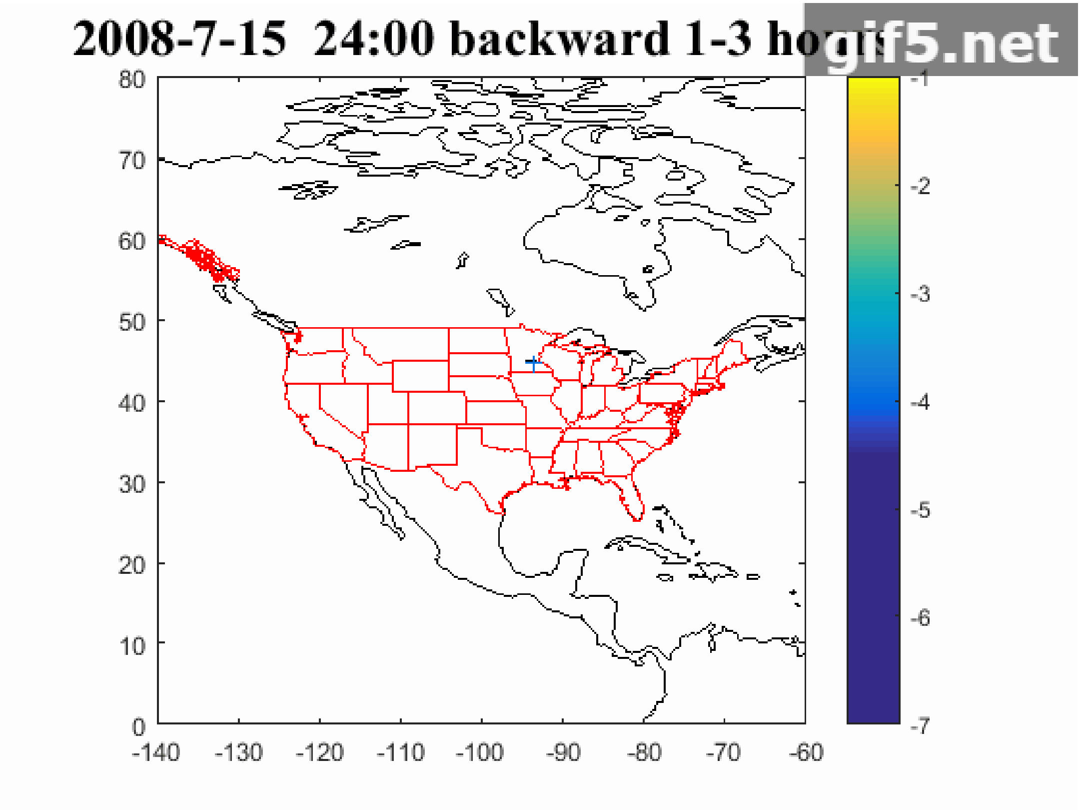


Figure: 3 Domains used in WRF(Blue, light-yellow, and deep-yellow indicates the area for Domain1, Domain2, and Domain3, respectively) and STILT (in different rectangular regions) .

WRF setup: 3 domains, 2-way feedback, Yonsei University PBL schemes, 27 levels

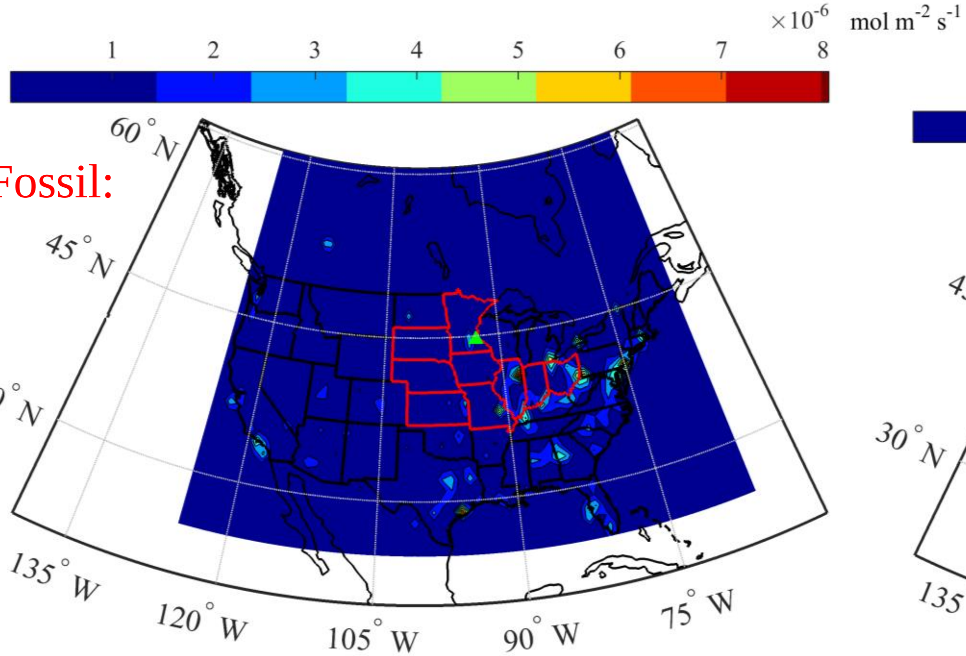


In the STILT setup, we release 500 particles every hour at the height of 100 m

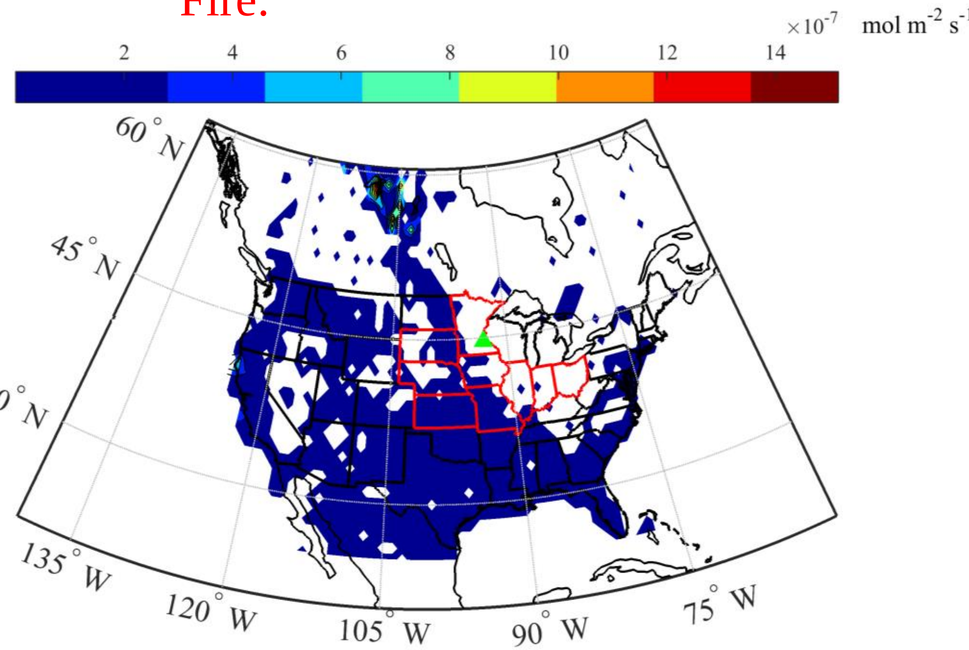
Hourly Modeled Tall Tower CO_2 concentration enhancement= $\sum_{i=1}^{168}[(foot_i \times (Carbon\ Tracker\ CO_2\ flux)_i]$

Initial background CO_2 concentration: Global 3D CO_2 fields(TM3 products with optimized CO_2 flux)

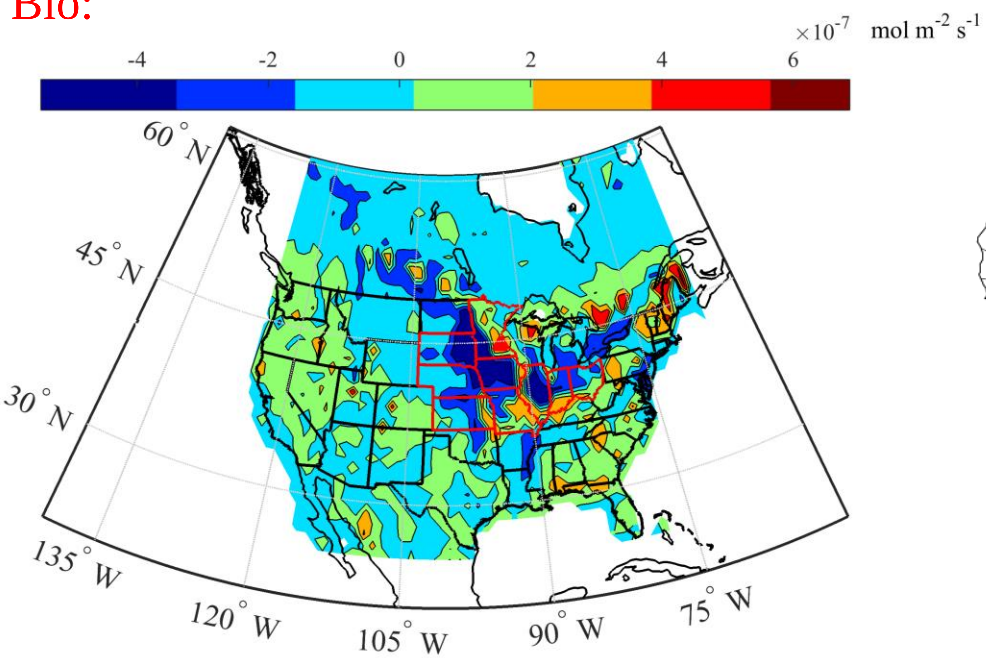
Fossil:

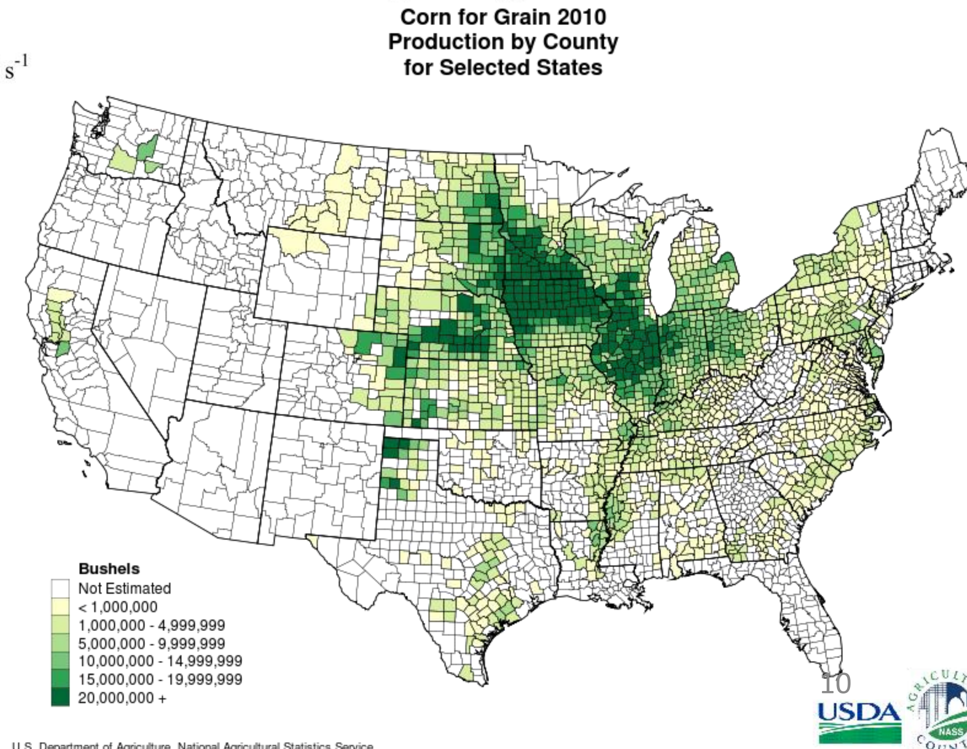


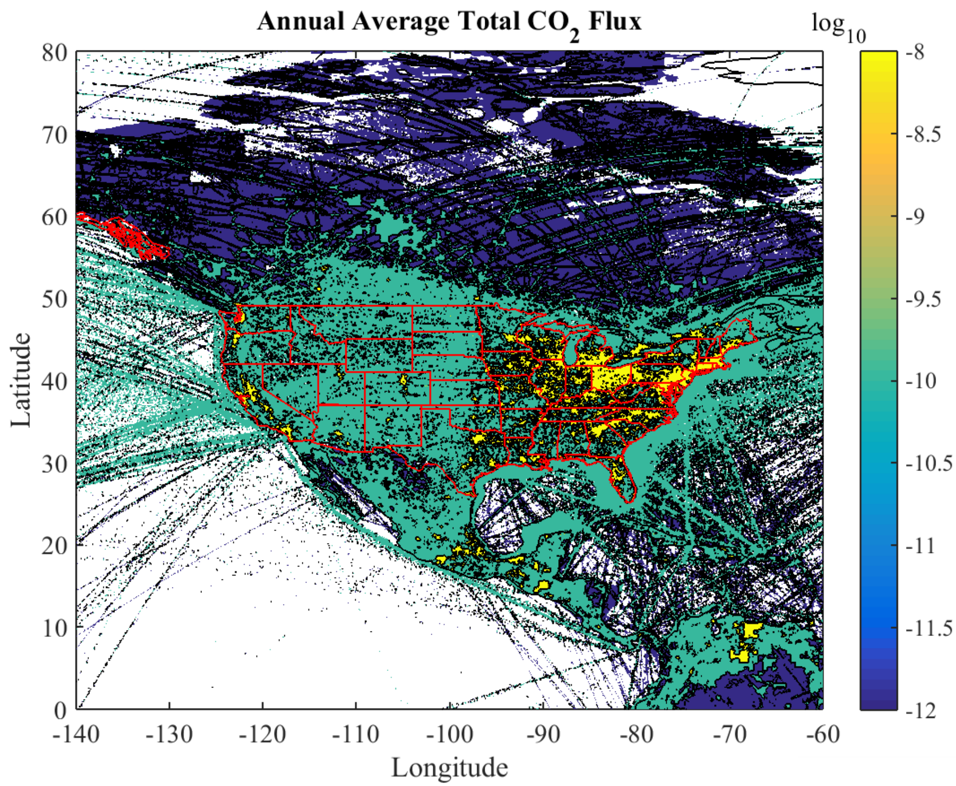
Fire:



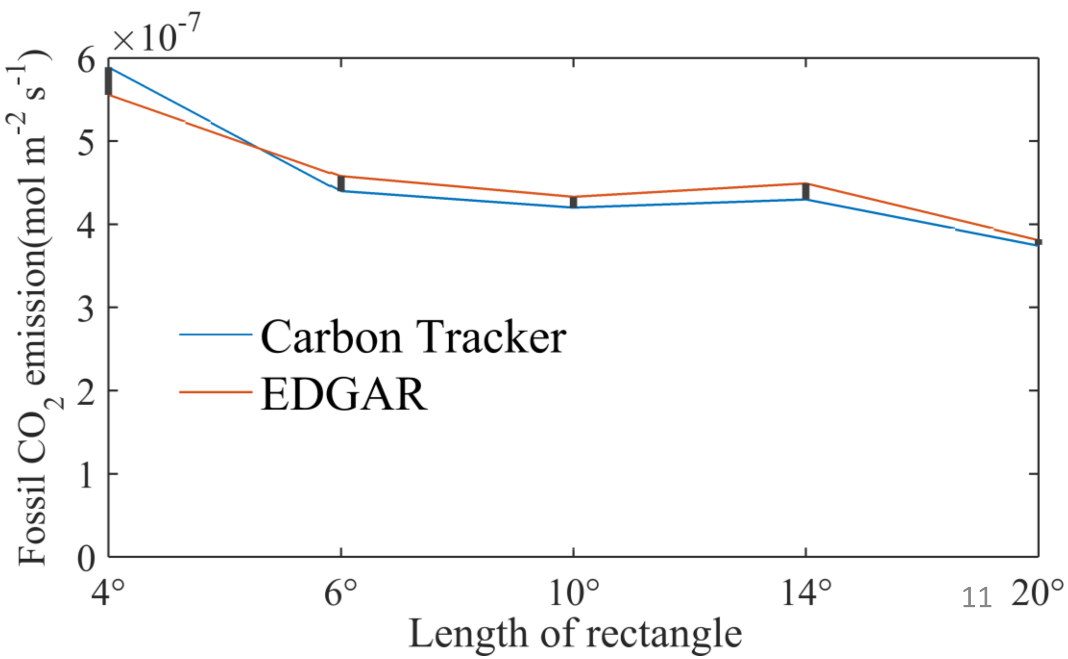
Bio:



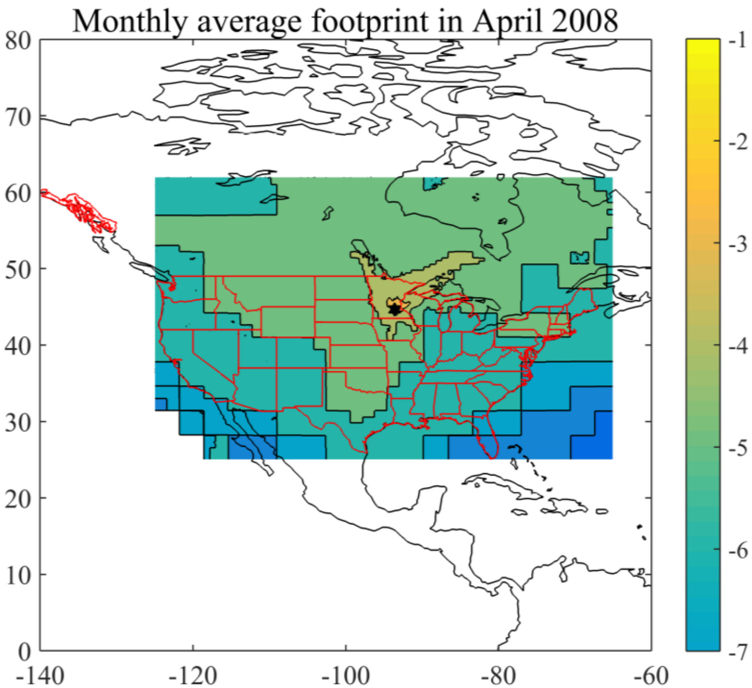


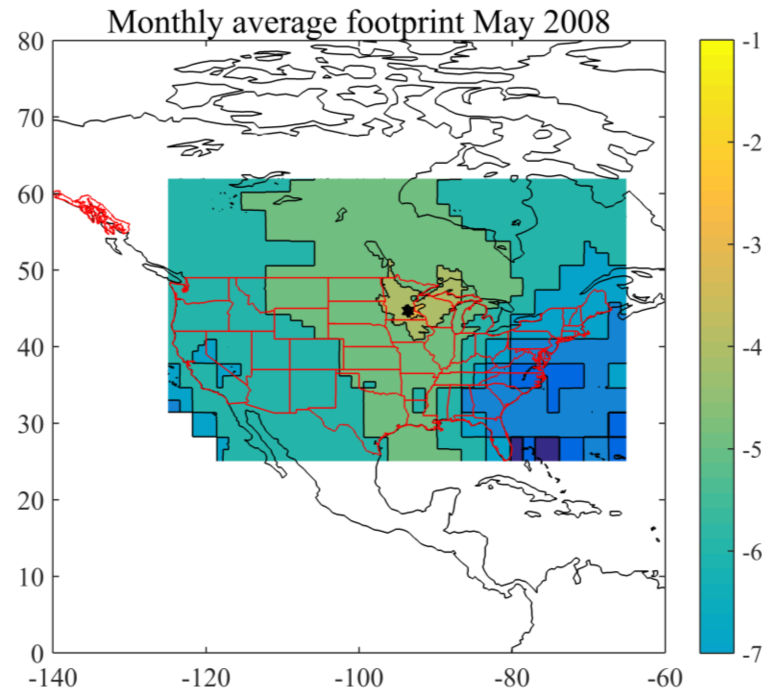


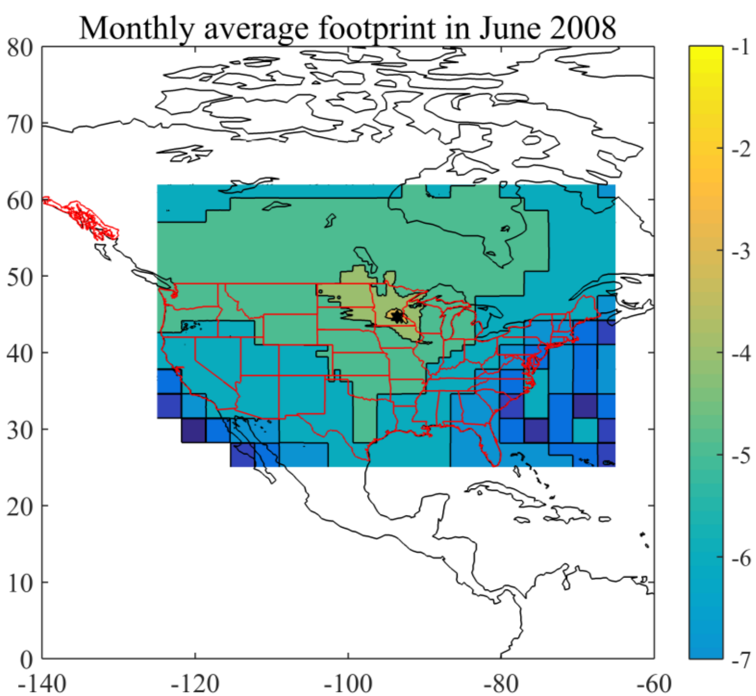
Annual Average Total CO_2 Flux
$\log_{10}$
Latitude
Longitude

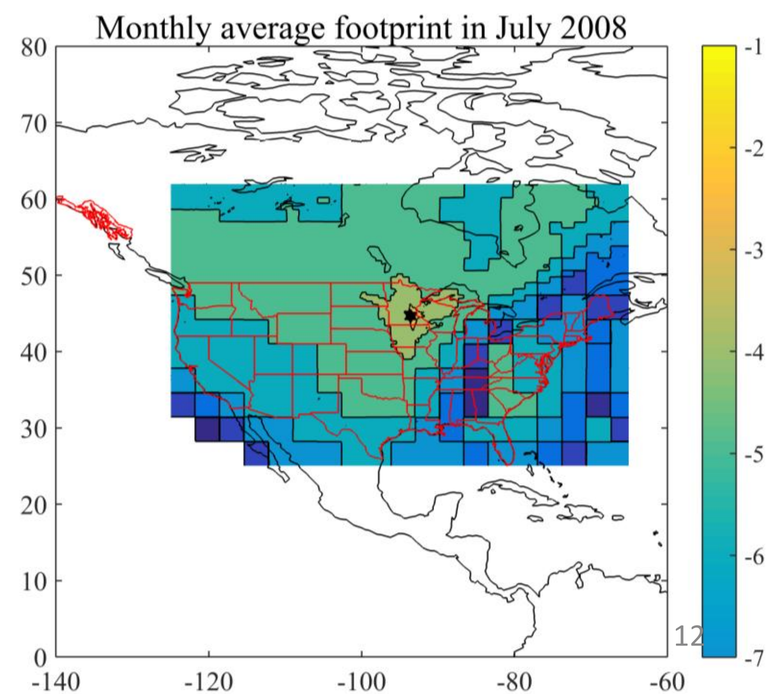


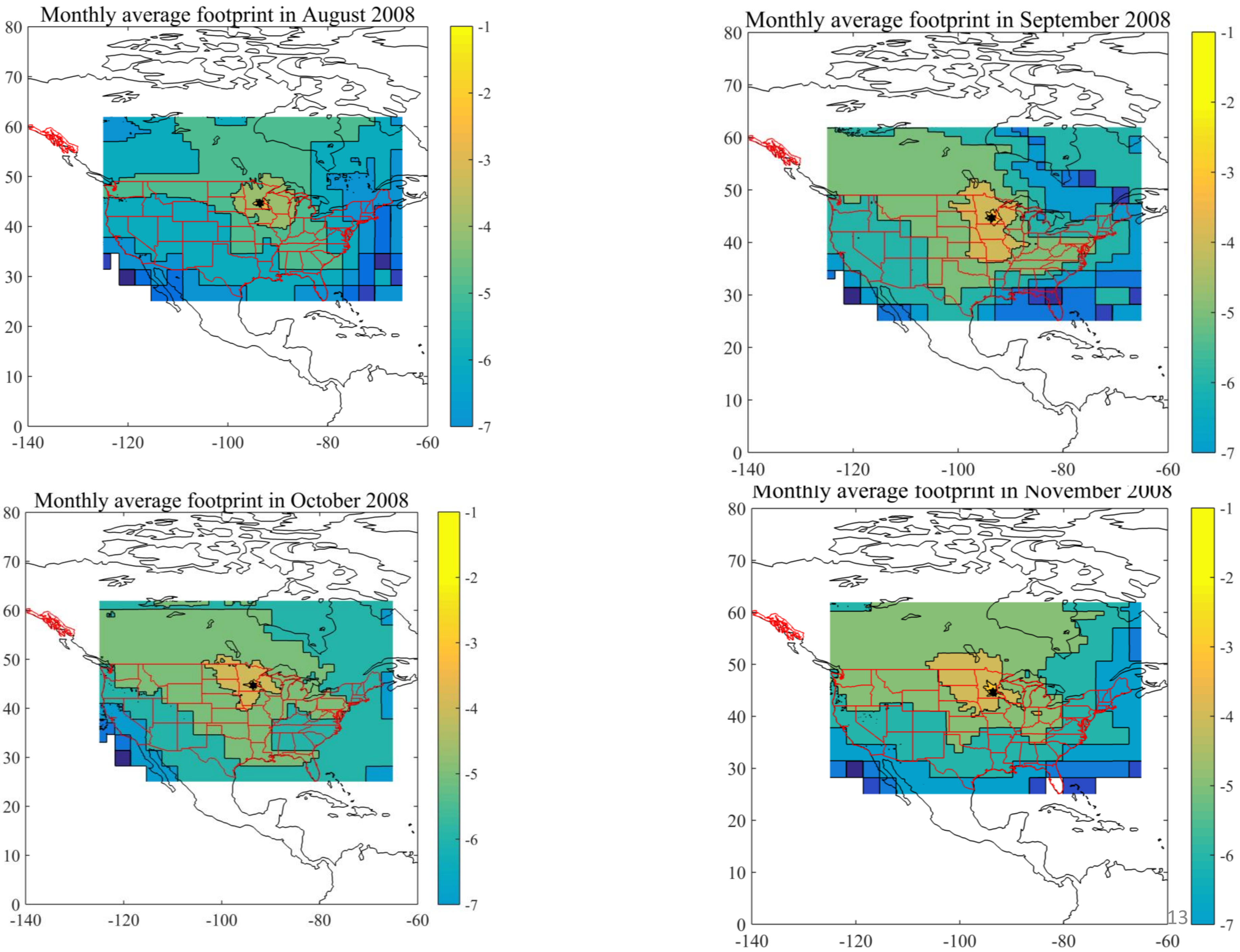
$\times 10^{-7}$
Fossil CO_2 emission(mol m^{-2} s^{-1})
Carbon Tracker
EDGAR
Length of rectangle

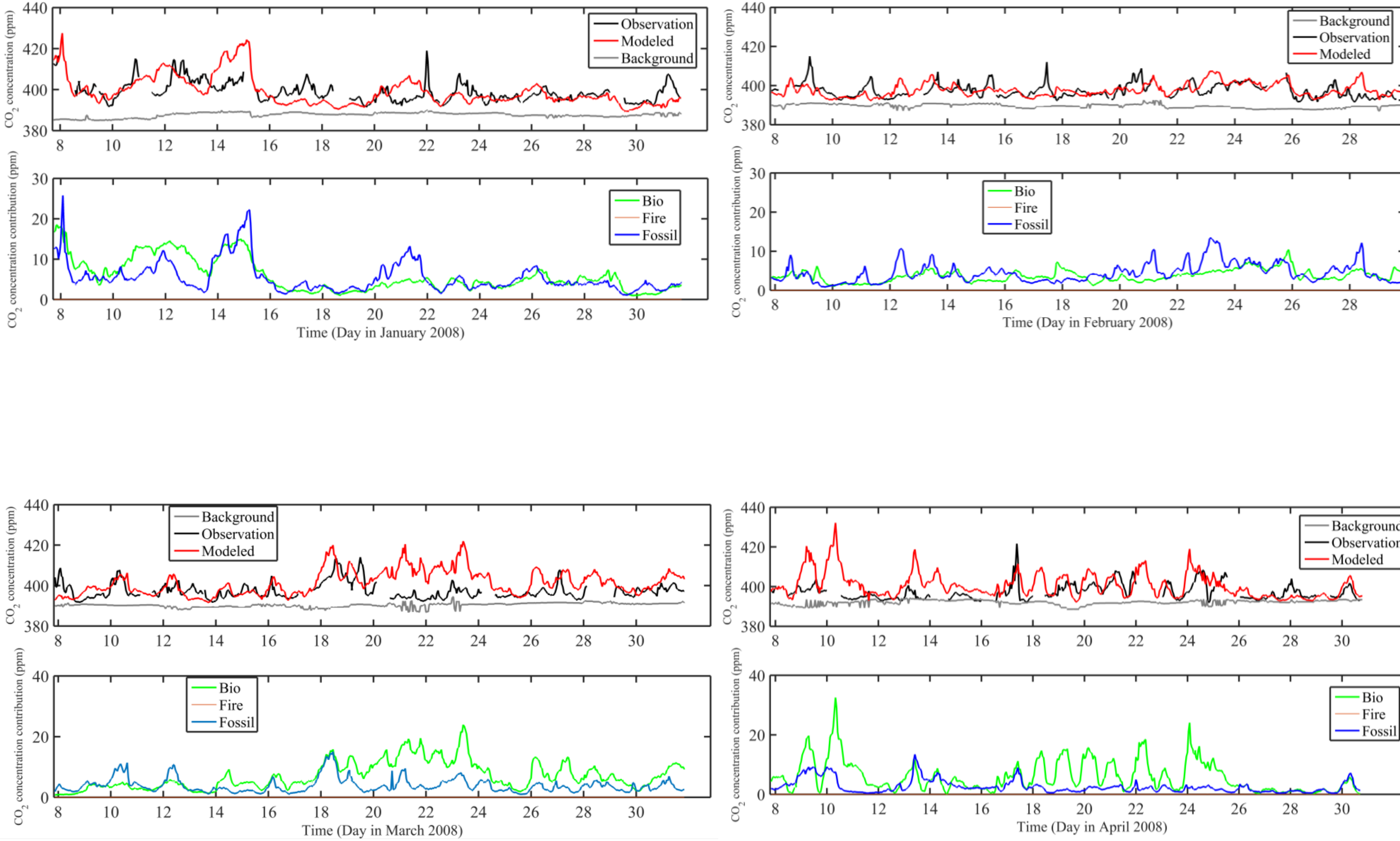

Monthly average footprint in April 2008
80 70 60 50 40 30 20 10 0
-140 -120 -100 -80 -60
-1 -2 -3 -4 -5 -6 -7


Monthly average footprint May 2008
80 70 60 50 40 30 20 10 0
-140 -120 -100 -80 -60
-1 -2 -3 -4 -5 -6 -7

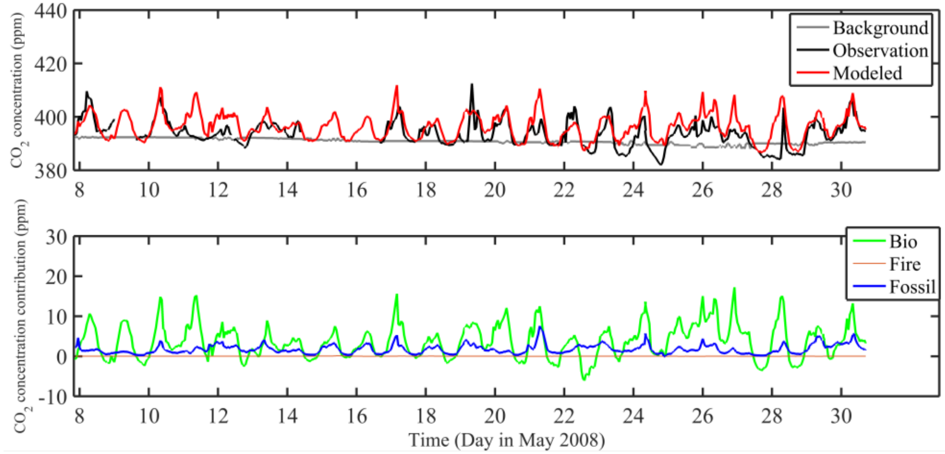

Monthly average footprint in June 2008
80 70 60 50 40 30 20 10 0
-140 -120 -100 -80 -60
-1 -2 -3 -4 -5 -6 -7

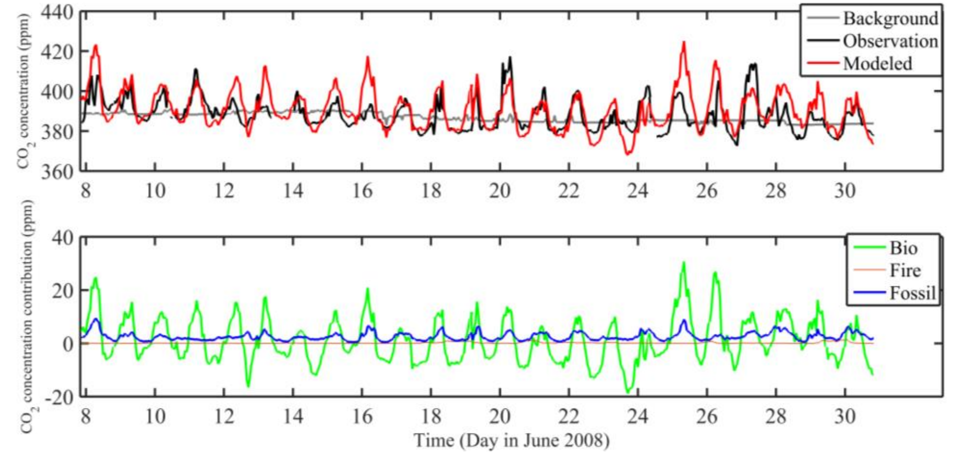

Monthly average footprint in July 2008
80 70 60 50 40 30 20 10 0
-140 -120 -100 -80 -60
-1 -2 -3 -4 -5 -6 -7

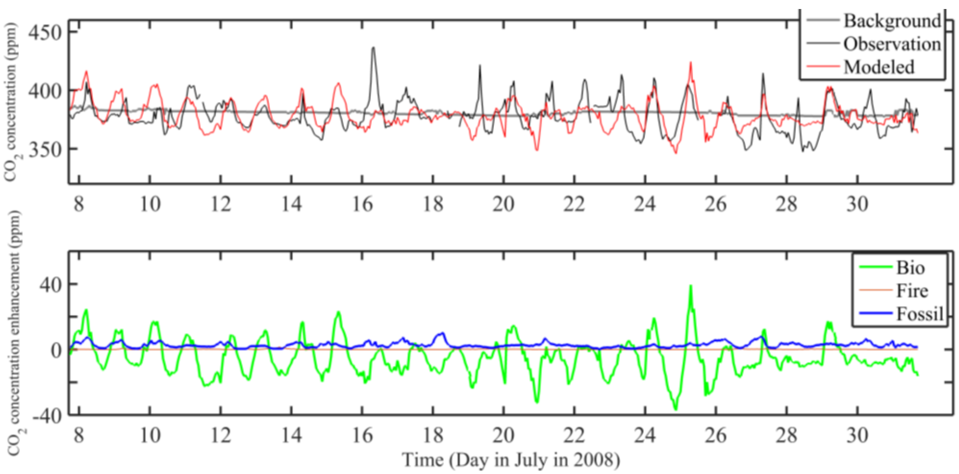

Monthly average footprint in August 2008
Monthly average footprint in September 2008
Monthly average footprint in October 2008
Monthly average footprint in November 2008
80
70
60
50
40
30
20
10
0
-140
-120
-100
-80
-60
-1
-2
-3
-4
-5
-6
-7

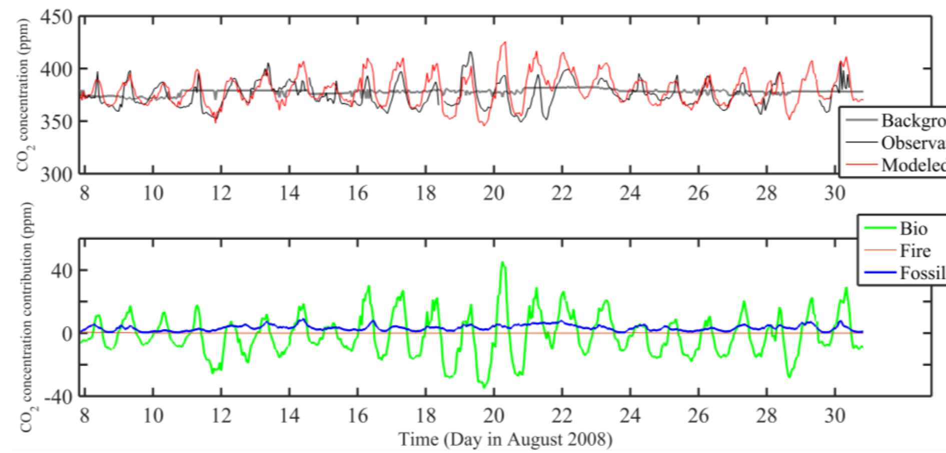


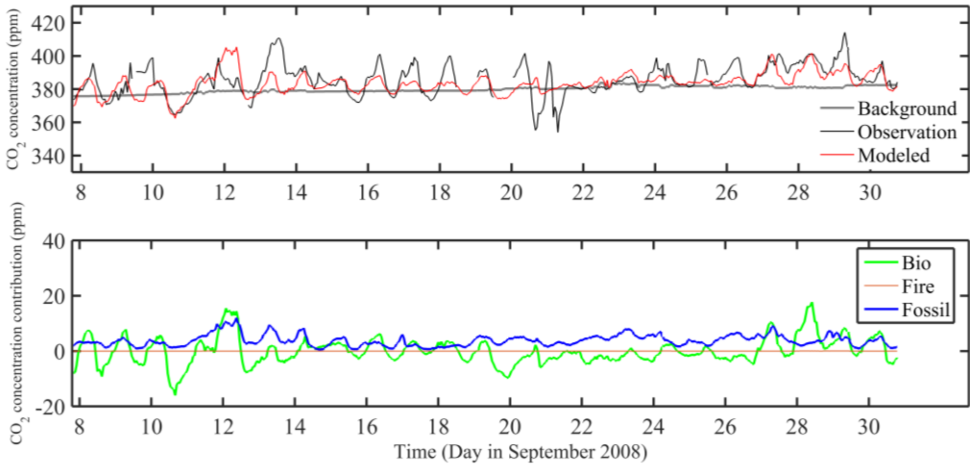
CO2 concentration (ppm)
Observation
Modeled
Background
CO2 concentration contribution (ppm)
Bio
Fire
Fossil
Time (Day in January 2008)
Time (Day in February 2008)
Time (Day in March 2008)
Time (Day in April 2008)

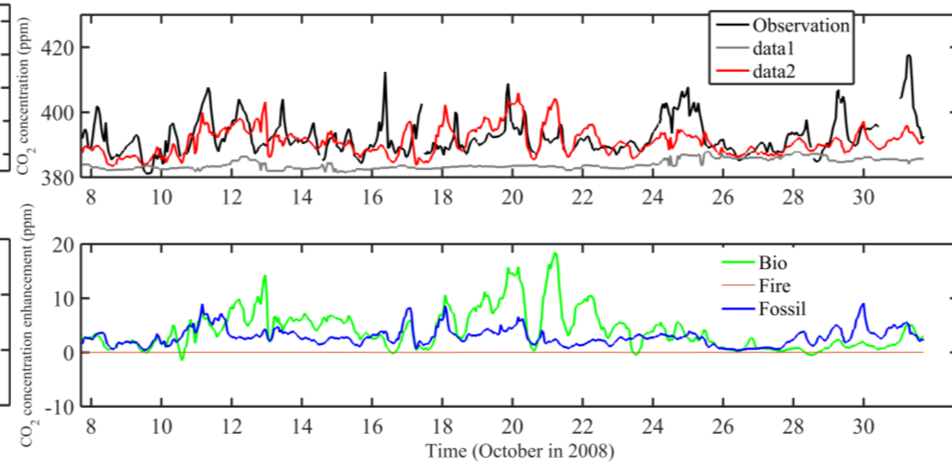

Background
Observation
Modeled
CO2 concentration (ppm)
Bio
Fire
Fossil
CO2 concentration contribution (ppm)
Time (Day in May 2008)

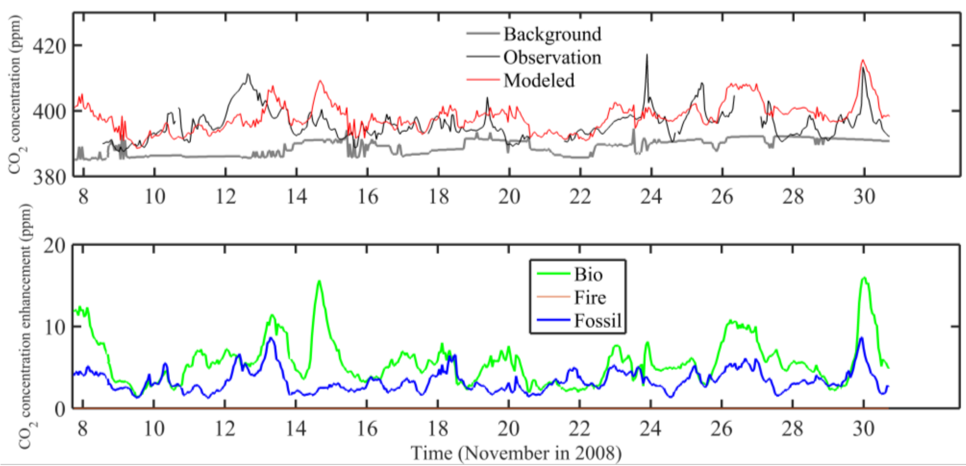

Background
Observation
Modeled
CO2 concentration (ppm)
Bio
Fire
Fossil
CO2 concentration contribution (ppm)
Time (Day in June 2008)

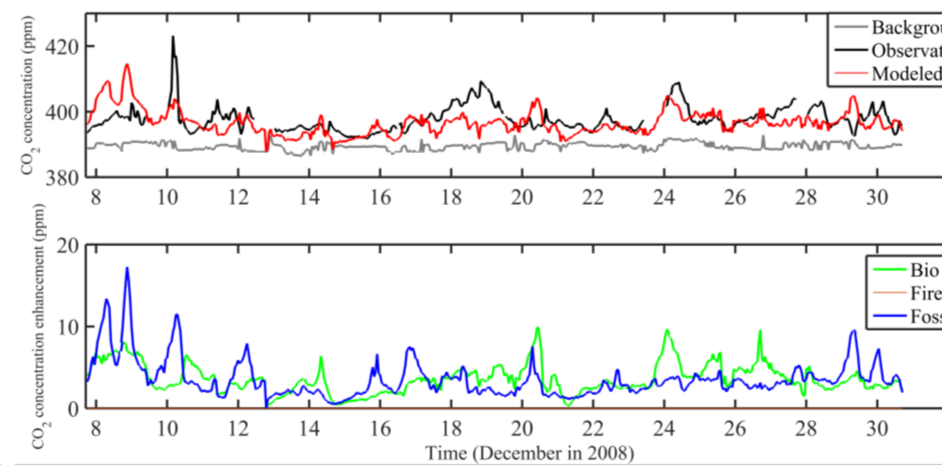

Background
Observation
Modeled
CO2 concentration (ppm)
Bio
Fire
Fossil
CO2 concentration enhancement (ppm)
Time (Day in July in 2008)


CO2 concentration (ppm)
Bio
Fire
Fossil
CO2 concentration contribution (ppm)
Time (Day in August 2008)


CO2 concentration (ppm)
Background
Observation
Modeled
CO2 concentration contribution (ppm)
Bio
Fire
Fossil
Time (Day in September 2008)


CO2 concentration (ppm)
Observation
data1
data2
CO2 concentration enhancement (ppm)
Bio
Fire
Fossil
Time (October in 2008)


CO2 concentration (ppm)
Background
Observation
Modeled
CO2 concentration enhancement (ppm)
Bio
Fire
Fossil
Time (November in 2008)


CO2 concentration (ppm)
CO2 concentration enhancement (ppm)
Bio
Time (December in 2008)

In the Bayesian inverse method, the optimal solution is to minimize the cost function J(Γ), which represents the mismatch between measured and simulated CO_2 concentrations, and the mismatch between a priori and posteriori scaling factors. Both of these are weighted by the corresponding error terms. The equation for J(Γ) is as follows:

$$2J(\Gamma) = (\mathrm{y} - \mathrm{K}\Gamma)^T {S_e}^{-1}(y - K\Gamma) + (\Gamma - \Gamma_a)^T {S_a}^{-1}(\Gamma - \Gamma_a)$$

Therefore the solution for minimizing this cost function and obtaining the posteriori scaling factors is to solve $\nabla_\Gamma J(\Gamma) = 0$, which can be resolved as:

$$\Gamma_{post} = (K^T {S_e}^{-1} K + {S_a}^{-1})^{-1}(K^T {S_e}^{-1} y + {S_a}^{-1} \Gamma_a)$$

Sensitivity tests for Bayesian inversion

$$2J(\Gamma) = (\mathrm{y} - \mathrm{K}\Gamma)^T {S_e}^{-1}(y - K\Gamma) + (\Gamma - \Gamma_a)^T {S_a}^{-1}(\Gamma - \Gamma_a)$$

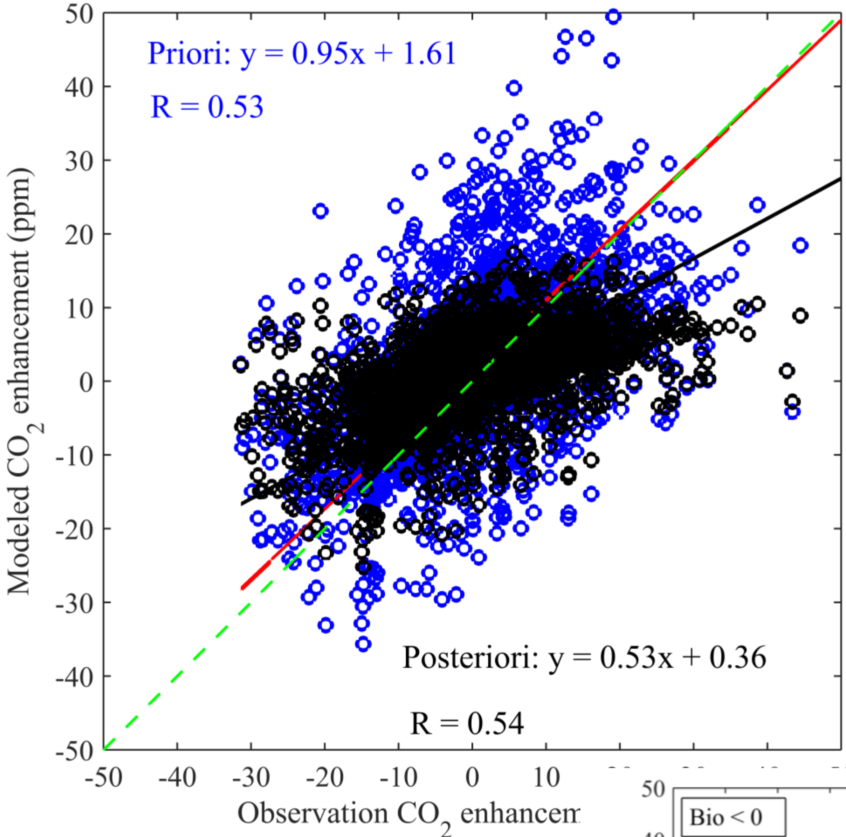
a). Uncertainty in y contains both instrument precision and background uncertainty, so value of 0.5 ppm for CO_2 is used as the instrument precision, while the uncertainty in background is more complex which mainly come from the uncertainty of background products and the choice of air flow as background. Here I apply the relative uncertainty of 0.1 and 0.2 in y as the prior uncertainty. Here are 2 choices: 0.5+0.1y; 0.5+0.2y

2) The prior uncertainty for Fossil : 60%, 80%, 100%, 120%.

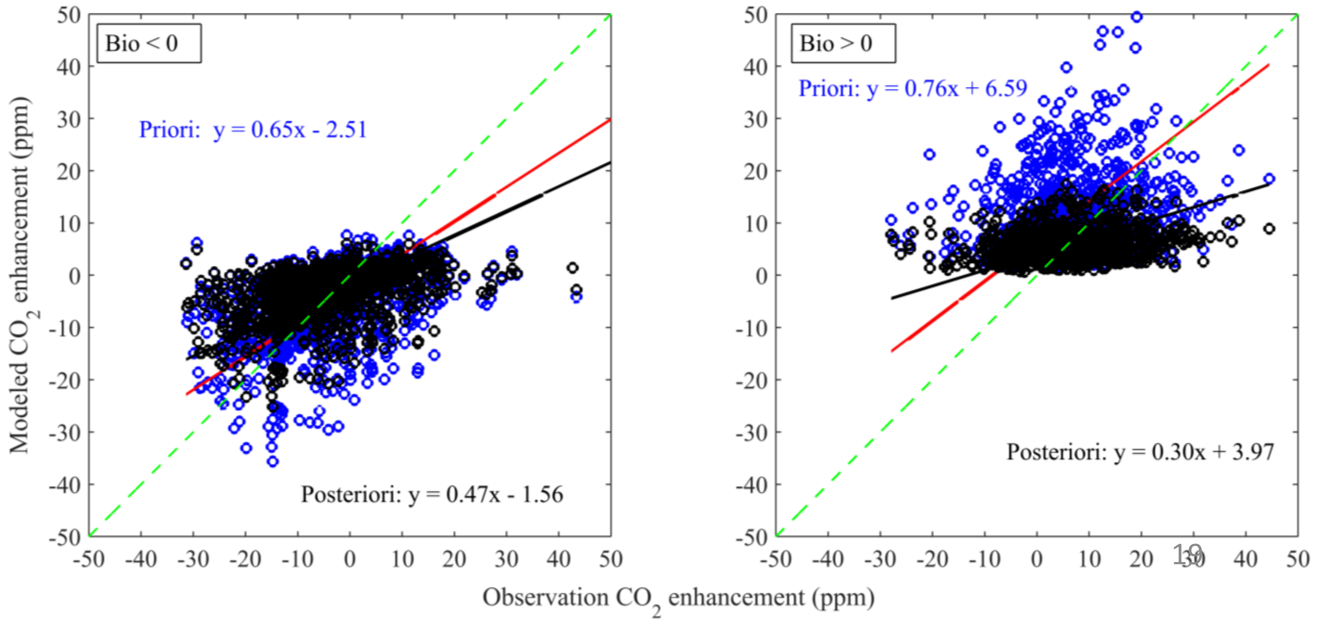
The prior uncertainty for Bio: 40%, 50%, 60%, 70%.

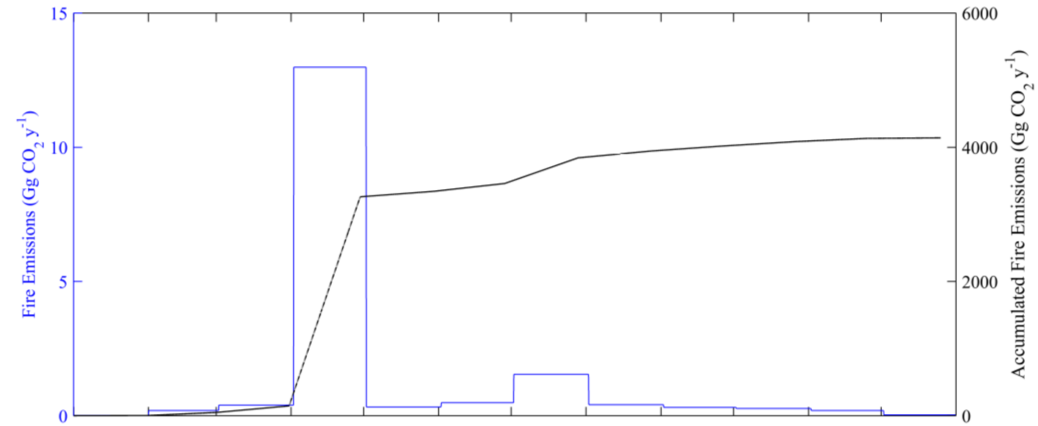
Then 32 different combinations in prior uncertainty were performed for the Bayesian sensitivity tests (2×4×4=32) for November, 2008) .

Bayesian inversion results

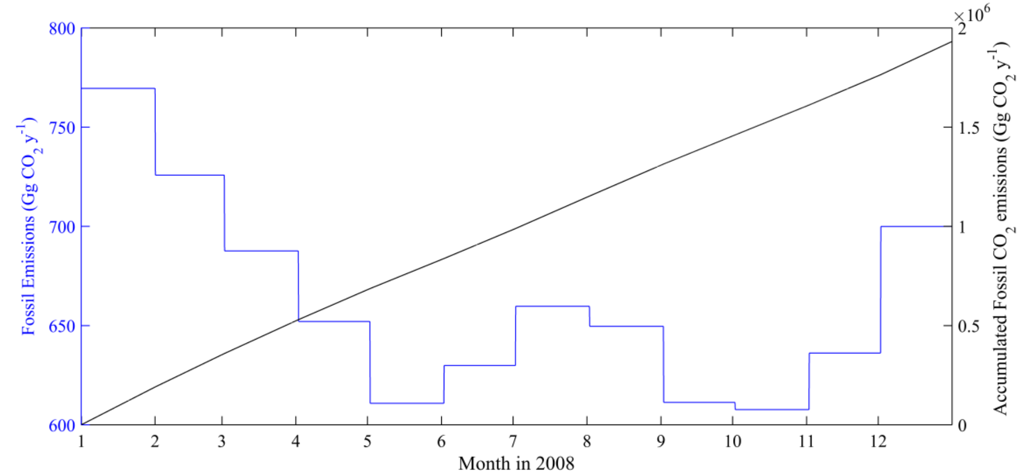


All enhancement data in 4 months (June, July, August, and September), when the absorption of CO_2 occurs.



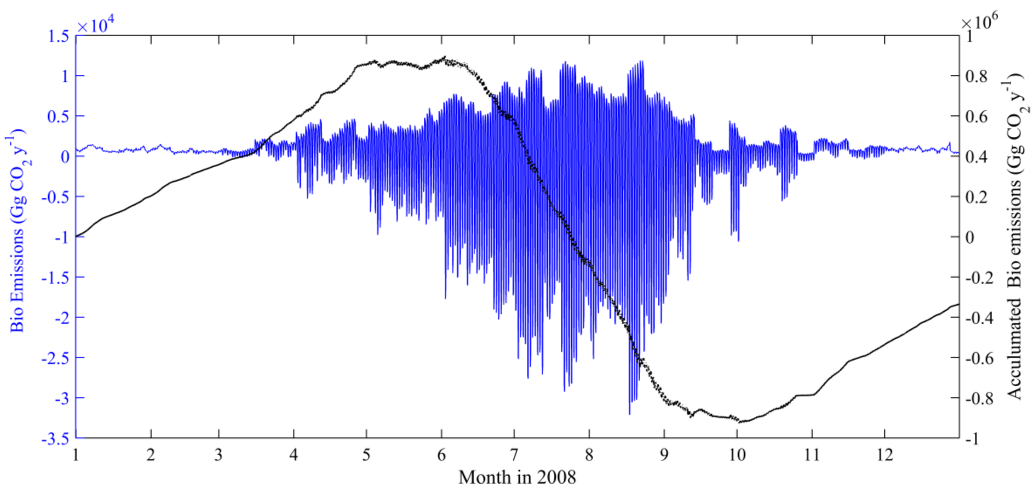


Fire:



Fossil:

Blue line represents the sum of CO_2 emission or source for every 3 hours, and black is the accumulated CO_2 since the first hour in 2008



Bio:

Net CO_2 balance in 2008 for the corn belt is 1610Tg CO_2 as shown in Carbon Tracker Products.

On-going work

- Take ^{13}C into consideration to separate CO_2 information from Bio and Fossil flux.

- Continue running the WRF-STILT model for other years(2009,2011,2012), and try to analyze the Bio flux effect to the CO_2 diurnal or seasonal amplitude.

Any advice is welcome.

End