Simulation of Tall Tower CO$_2$ concentration using WRF-STILT Model

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Outline

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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 been 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 the 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:

1. **Global CO₂ background data**
2. **Tall Tower CO₂ observations**
3. **Background CO₂**
4. **Tall Tower CO₂ enhancement**
5. **Bayesian inversion method**
6. **Carbon Tracker**
7. **Modeled CO₂ enhancement**
8. **Carbon Balance in Corn Belt**

**Steps:**
- **WRF (3 domains)**
- **STILT Model**
- **Footprint**

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)
In the Bayesian inverse method, the optimal solution is to minimize the cost function $J(\Gamma)$, 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 $J(\Gamma)$ is as follows:

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

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

$$\Gamma_{\text{post}} = (K^T S_e^{-1} K + S_a^{-1})^{-1} (K^T S_e^{-1} y + S_a^{-1} \Gamma_a)$$
Sensitivity tests for Bayesian inversion

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

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: \( 0.5+0.1y; \quad 0.5+0.2y \)

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\(\times\)4\(\times\)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.
Blue line represents the sum of CO₂ emissions or source for every 3 hours, and black is the accumulated CO₂ since the first hour in 2008.

Net CO₂ balance in 2008 for the corn belt is 1610 Tg CO₂ 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