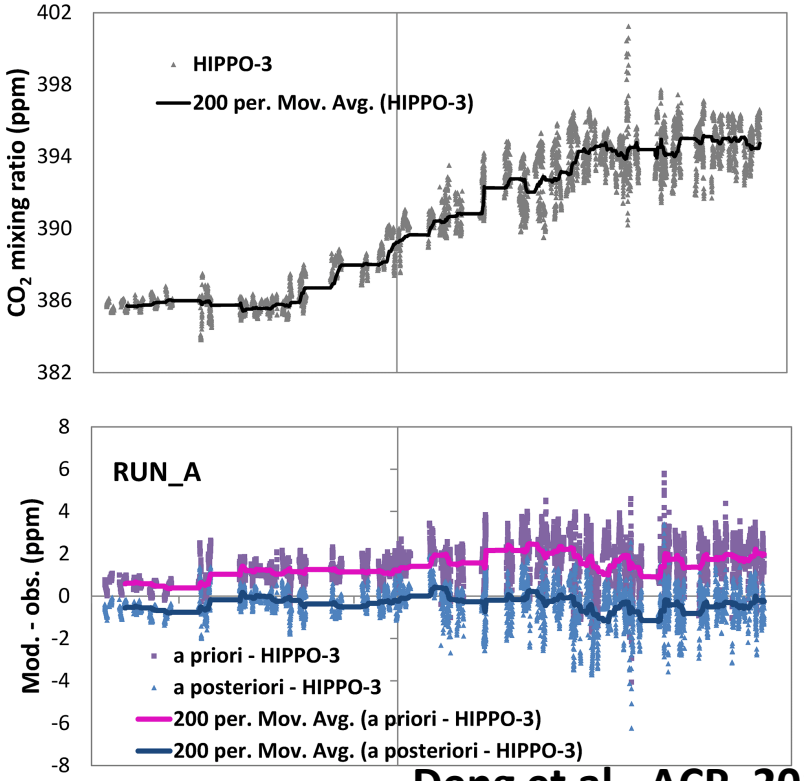
A method for independent validation of surface fluxes from atmospheric inversion: application to CO_2

Junjie Liu[1]

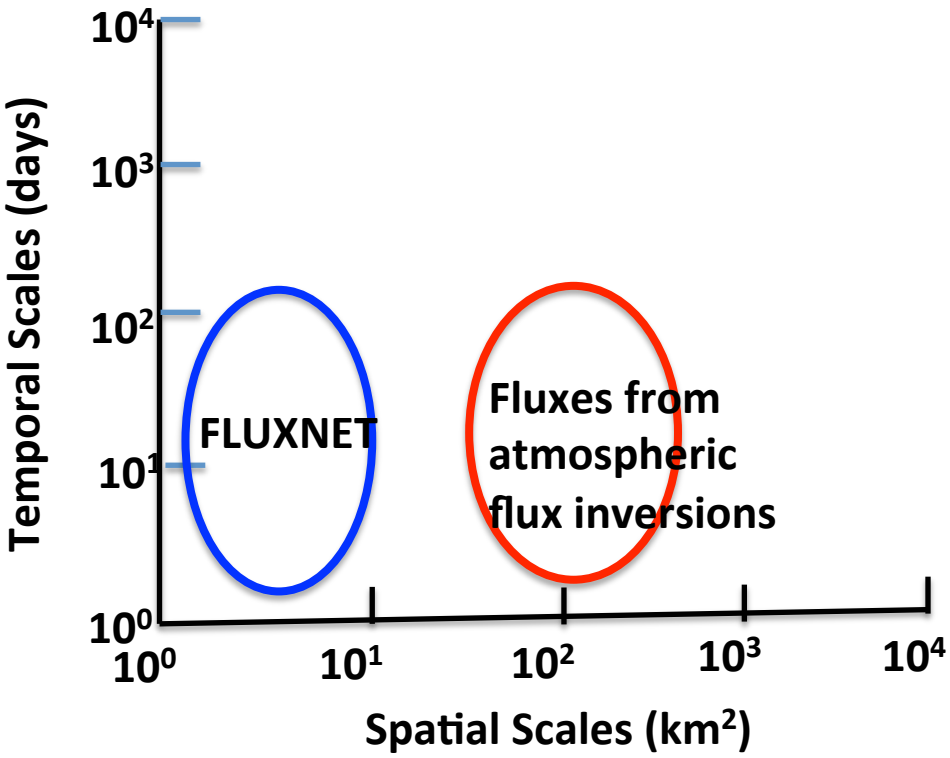
[1.] Jet Propulsion Lab (JPL), Caltech

Liu and Bowman (GRL, 2016, accepted)

Motivation



Deng et al., ACP, 2014



- No direct flux measurements at comparable spatiotemporal scales.
- We propose a methodology to project the changes of CO_2 concentration errors relative to independent observations to the differences between posterior and prior fluxes.

Methodology

We first define two cost functions that measure the posterior CO_2 (C_{post}) and prior CO_2(C_{prior}) errors relative to independent observations (O):

$$J_{post} = (\mathbf{C}_{post} - \mathbf{O})^T (\mathbf{C}_{post} - \mathbf{O})$$

$$J_{prior} = (\mathbf{C}_{prior} - \mathbf{O})^T (\mathbf{C}_{prior} - \mathbf{O})$$

$$\mathbf{C}_{post} = M(\mathbf{f}_{post})$$

Where *M* is a transport model, and f_{post} is the posterior fluxes

Methodology (continued)

- **We then define the difference between these cost functions:**

$$\Delta J = J_{post} - J_{prior}$$

- **It can be rewritten as:**

$$\Delta \tilde{J} = \left\langle (\mathbf{f}_{post} - \mathbf{f}_{prior}), \mathbf{M}^T (\mathbf{C}_{post} - \mathbf{O} + \mathbf{C}_{prior} - \mathbf{O}) \right\rangle$$

where f_{post} and f_{prior} are the posterior and prior fluxes, and M^T is the adjoint of the transport model. The above equation projects the changes of CO_2 errors to the spatiotemporal differences between posterior and prior fluxes.

Methodology (continued)

- **Equation (4) can also be written as:**

$$\Delta\tilde{J} = (\mathbf{f}_{post} - \mathbf{f}_{truth})^T \mathbf{M}^T \mathbf{M} (\mathbf{f}_{post} - \mathbf{f}_{truth}) - (\mathbf{f}_{prior} - \mathbf{f}_{truth})^T \mathbf{M}^T \mathbf{M} (\mathbf{f}_{prior} - \mathbf{f}_{truth})$$

- **where $\mathbf{f}_{truth}$ is the true fluxes. The above equation shows that the posterior fluxes are more accurate than the prior fluxes over a region restricted by $\mathbf{M}^T\mathbf{M}$ when $\Delta\tilde{J}$ is smaller than zero.**

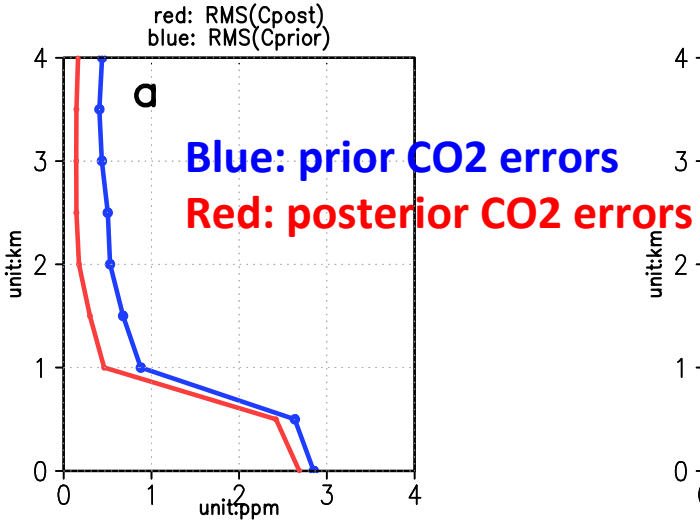
Two questions can be addressed:

- **What are the magnitude and sign of the CO_2 error changes from the differences between posterior and prior fluxes at each grid point?**
- **Within what spatial domain the posterior fluxes are more accurate than the prior fluxes when the posterior CO_2 concentrations are more accurate than the prior CO_2 concentrations relative to independent observations?**

OSSE experiment to test the method

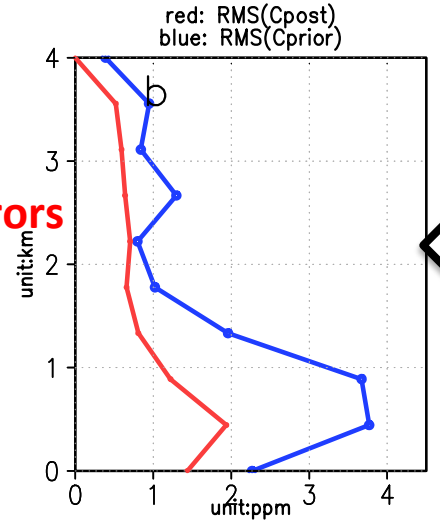
- **Observing System Simulation Experiments (OSSE)**
  - ✓ **The prior flux and posterior fluxes have different seasonal and diurnal cycle, but the same annual total fluxes**
- **ACOS-GOSAT observation coverage**
- **Independent data: simulated aircraft observations at three aircraft sites (CAR, SGP, and TGC) over North America, four aircraft sites (SAN, TAB, ALF, and RBA) over Amazonia, one TCCON site at Lauder,Australia**

Validating against simulated aircraft obs



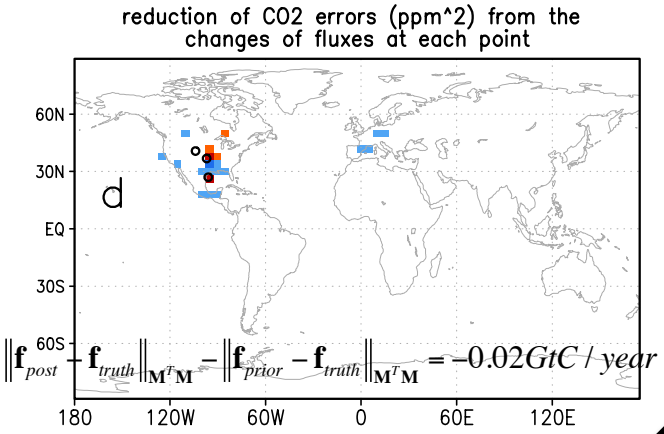
Blue: prior CO2 errors

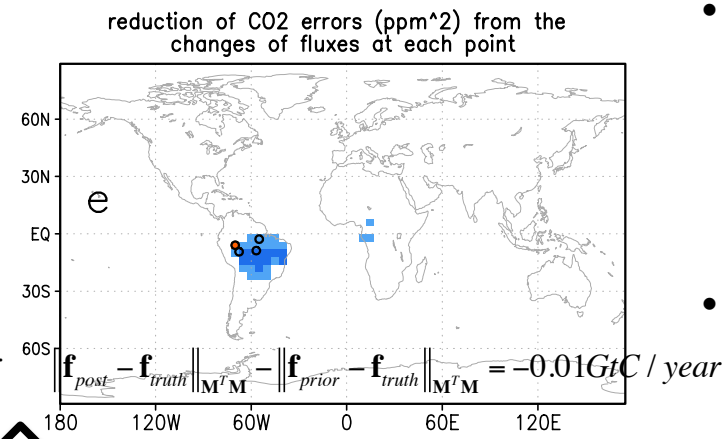
Red: posterior CO2 errors



- Posterior CO2 is more accurate than the prior CO2 concentration

$$\Delta J = J_{post} - J_{prior}$$

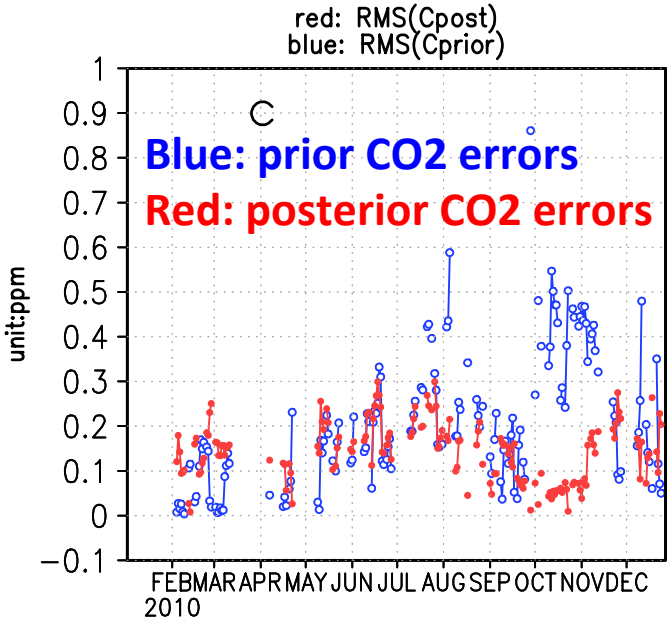




- Attribute the CO2 error changes to the contributions from the flux changes at each grid point
- Where the fluxes are more accurate

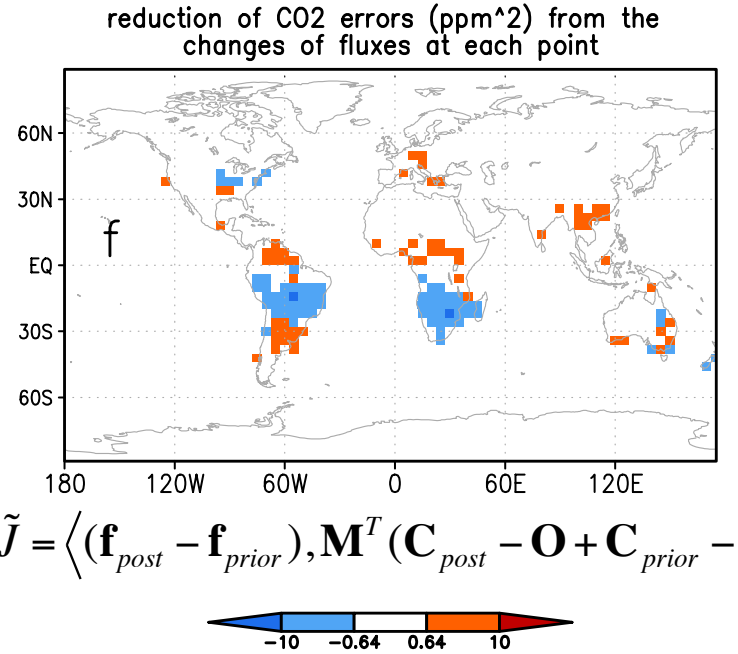
$$\Delta\tilde{J} = \left\langle (\mathbf{f}_{post} - \mathbf{f}_{prior}), \mathbf{M}^T (\mathbf{C}_{post} - \mathbf{O} + \mathbf{C}_{prior} - \mathbf{O}) \right\rangle$$

Validating against simulated TCCON at Lauder



- **Posterior CO2 is more accurate than the prior CO2 concentration**

$$\Delta J = J_{post} - J_{prior}$$



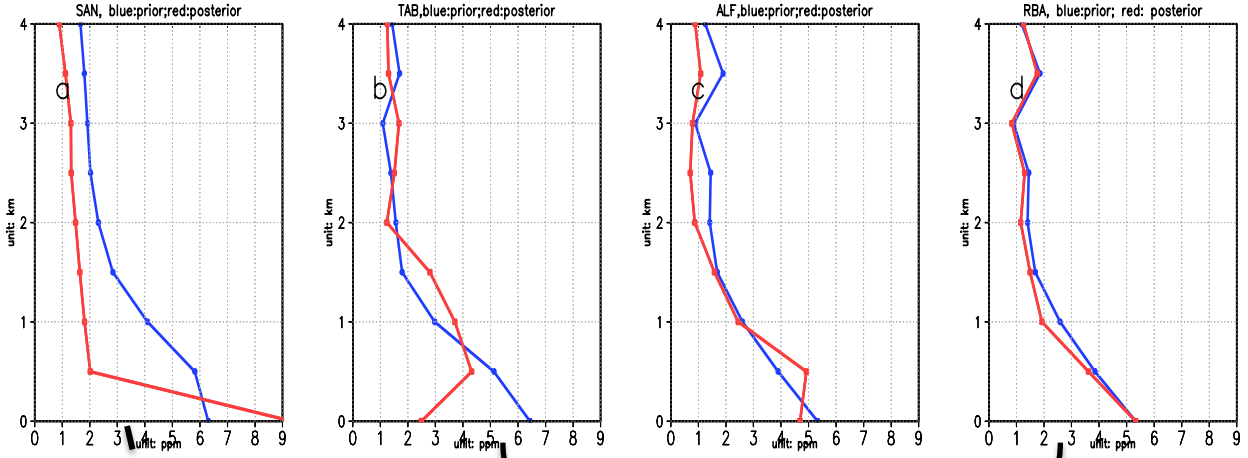
$$\Delta\tilde{J} = \left\langle (\mathbf{f}_{post} - \mathbf{f}_{prior}), \mathbf{M}^T (\mathbf{C}_{post} - \mathbf{O} + \mathbf{C}_{prior} - \mathbf{O}) \right\rangle$$

$$\left\| \mathbf{f}_{post} - \mathbf{f}_{truth} \right\|_{\mathbf{M}^T\mathbf{M}} - \left\| \mathbf{f}_{prior} - \mathbf{f}_{truth} \right\|_{\mathbf{M}^T\mathbf{M}} = -0.01 GtC / year$$

- **Flux changes over a much broader region contribute to the changes of CO2 error at TCCON site at Lauder.**

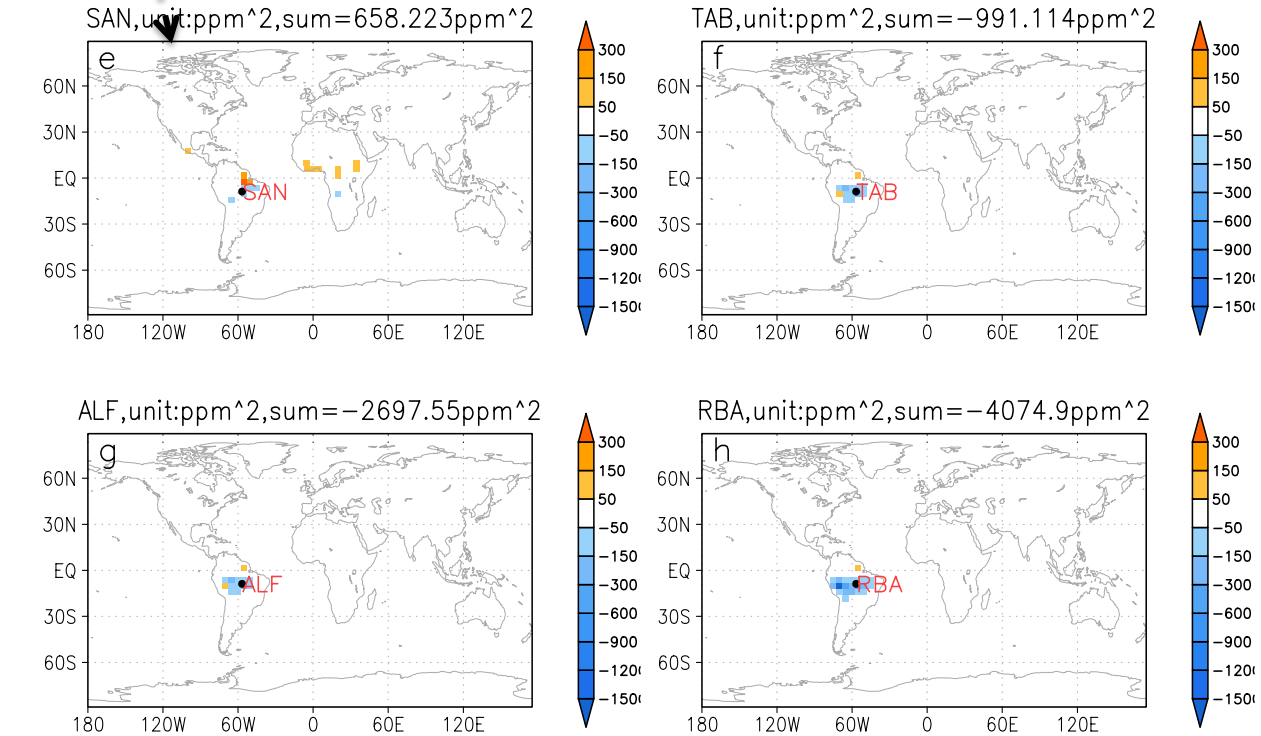
Real data experiment

- **Optimize 2010 and 2011 monthly mean biosphere fluxes assimilating ACOS-GOSAT B3.5 land nadir good-quality observations**
- **4D-Var flux inversion with GEOS-Chem adjoint model**
- **Independent data: 2010 and 2011 bi-weekly aircraft observations over Amazonia (Gatti et al., 2014).**



$$\Delta J = J_{post} - J_{prior} > 0$$

$$\Delta J = J_{post} - J_{prior} < 0$$



Blue: prior CO2 errors

Red: posterior CO2 errors

- **The degradation of posterior fluxes contributing to the increase of CO2 errors may result from bias in observations, transport errors, or inversion setup.**

Summary

- **We propose a validation method that project the changes of CO2 errors relative to independent observations to the spatiotemporal differences between posterior and prior fluxes with an atmospheric transport adjoint model.**
- **We show that the posterior fluxes are more accurate than the prior fluxes over the regions restricted by M^TM when posterior CO2 is more accurate.**
- **The method can be applied to any inversions where the direct measurements are not available.**
- **The method is not limited to variational flux inversion.**
- **Limitation: the method is limited by the existence of transport errors.**