Estimating CO2 as state and surface carbon flux as time evolving parameter using 4D-LETKF with constrains by CEnKF: results from assimilating ground and GOSAT observations

Zhiqiang Liu[1], Ning Zeng[2,1]

[1]*Institute of Atmospheric Physics, China*

[2]*University of Maryland, USA*

Introduction:

Unlike traditional CO2 inversion studies that using very long assimilation window (AW). We sequentially estimating the Surface carbon flux (SCF) every 3 days by taking advantage of the future 12 days of observations (Liu et al, 2019). The model and observations are paired every 1 hour.

In a sequential data assimilation system. Instead of reversing back and using the optimized SCF run again. The optimized SCF are taken as the forcing for the next AW. <u>Thus the error covariance are transport between times</u>.

Since the state of CO2 are updated, the mass conservation between CO2 and SCF are broken. Such imbalance are common in weather data assimilation that energy, entropy are usually disturbed after assimilation. In CO2 data assimilation, the mass conservation is the first order problem. To overcome this, we introduce a constrained ensemble kalman filter (CEnKF) that maintain the balance between CO2 and SCF. The CEnKF take advantage the analysis covariance structure of LETKF and make a addition analysis,

$$\mathbf{x}^{\mathbf{a}+} = \mathbf{x}^{\mathbf{a}} + \widetilde{\mathbf{P}}^{\mathbf{a}}\mathbf{H}^{\mathbf{T}}\left(\mathbf{H}\widetilde{\mathbf{P}}^{\mathbf{a}}\mathbf{H}^{\mathbf{T}} + \mathbf{R}\right)^{-1}(\mathbf{M} - \mathbf{H}\mathbf{x}^{\mathbf{a}})$$

Where **M** is the CO2 global total mass of first guess. Note that **R** is zero matrix. Because there is no error from the global mass.

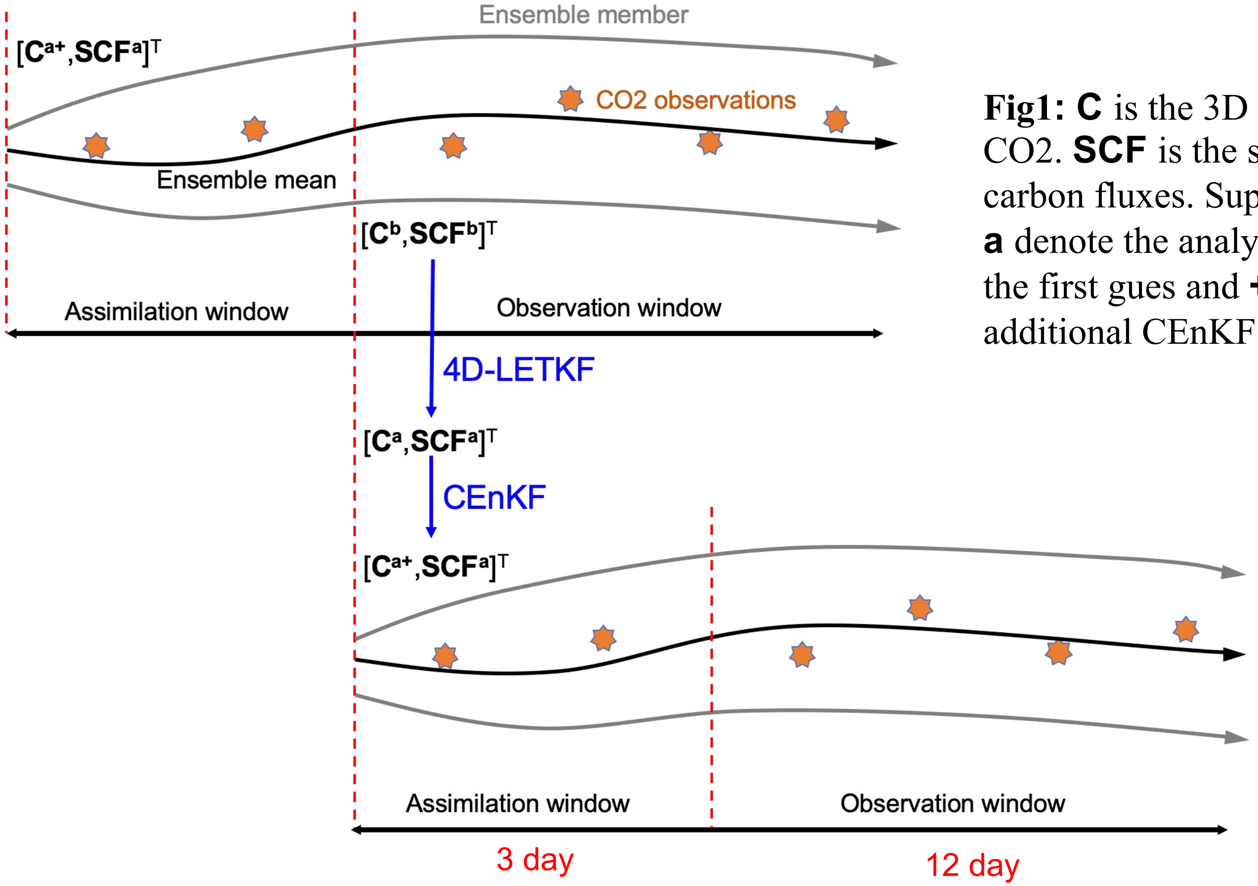

Fig1: **C** is the 3D state CO2. **SCF** is the surface carbon fluxes. Superscript **a** denote the analysis, **b** is the first gues and **+** is the additional CEnKF analysis.

Assimilation set-up:

Transport model : GEOS-Chem v13.0.2 run at 4x5 degree resolution driven by MERRA2.

Assimilation module : 4D-LETKF + CEnKF

Prior Fluxes : Unlike other inversion system, the prior fluxes are not directly put into the model. It works as the additive inflation samples. The temporal evolution of SCF are updated by LETKF. (Fossil fuel emissions: 1 hourly ODIAC, Land fluxes: daily VEGAS, Ocean fluxes: daily Rodenbeck)

Inflation : For state CO2, we apply relaxation to prior spread method. For parameter SCF, we apply adaptive additive inflation by randomly sampling the SCF field from prior SCF centered at assimilation time within 4 month.

Localization : For surface flask observations we did not apply localization for it has better representation of large scale CO2 variablity. For other ground based observations, we apply a 3000km to 9000km horizontal radium (HR) based on the representativeness of the observations. (note that the HR is very large considering the long-lived property of CO2). For GOSAT, we applied a 6000km HR. Vertically, we apply a 200hpa localization radium.

Ensemble size : 20

Observations : GLOBALVIEW-CO2 5.0+, AMES, GOSAT ACOS v9

Experiments:

E1 : GLOBALVIEW-CO2 5.0+, AMES (4/2009 ~ 12/2016)

E2 : GLOBALVIEW-CO2 5.0+, AMES, GOSAT ACOS v9 (1/2001~12/2016)

E1: Benchmark evaluation of the flux history from 2001 to 2016

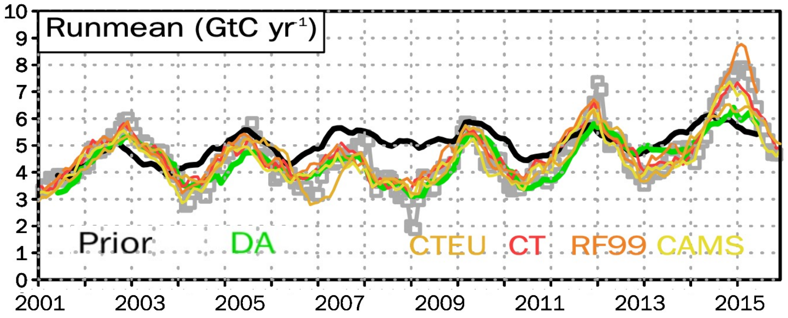

Fig2: Interannual variability (IAV) of SCF and compare with other products. Grey line is the NOAA GL CO2. After assimilating the surface data, the bias of IAV were fixed.

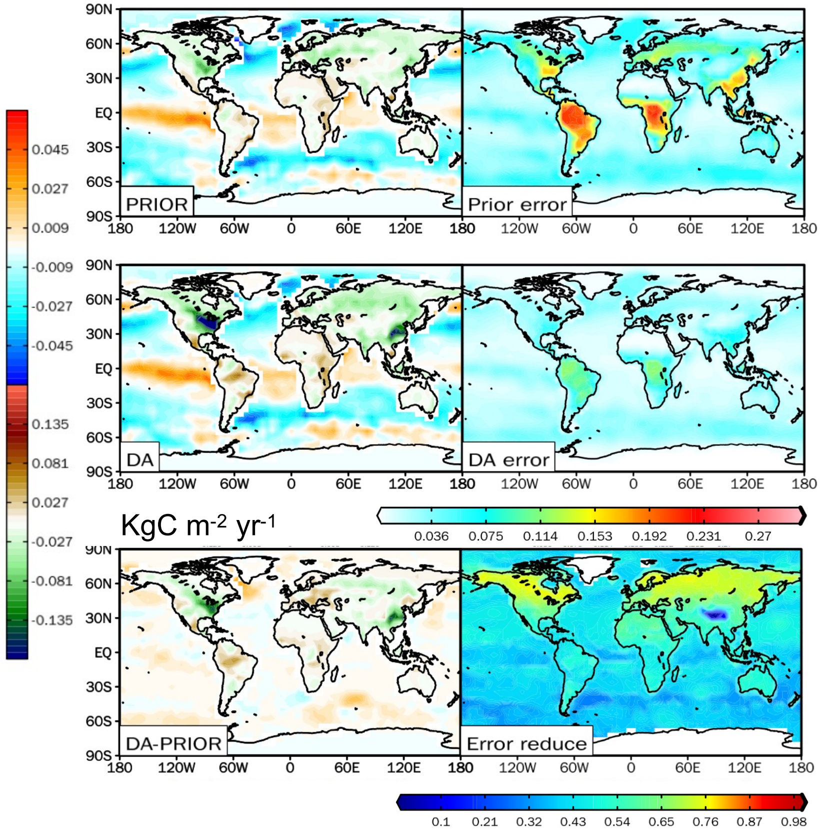

Fig3: The left panel are the mean carbon sink compare between prior and posterior. The right panel indicate the prescribed SCF error and the error reduction.

Impact of GOSAT observation on estimating the SCF from 2010 to 2016

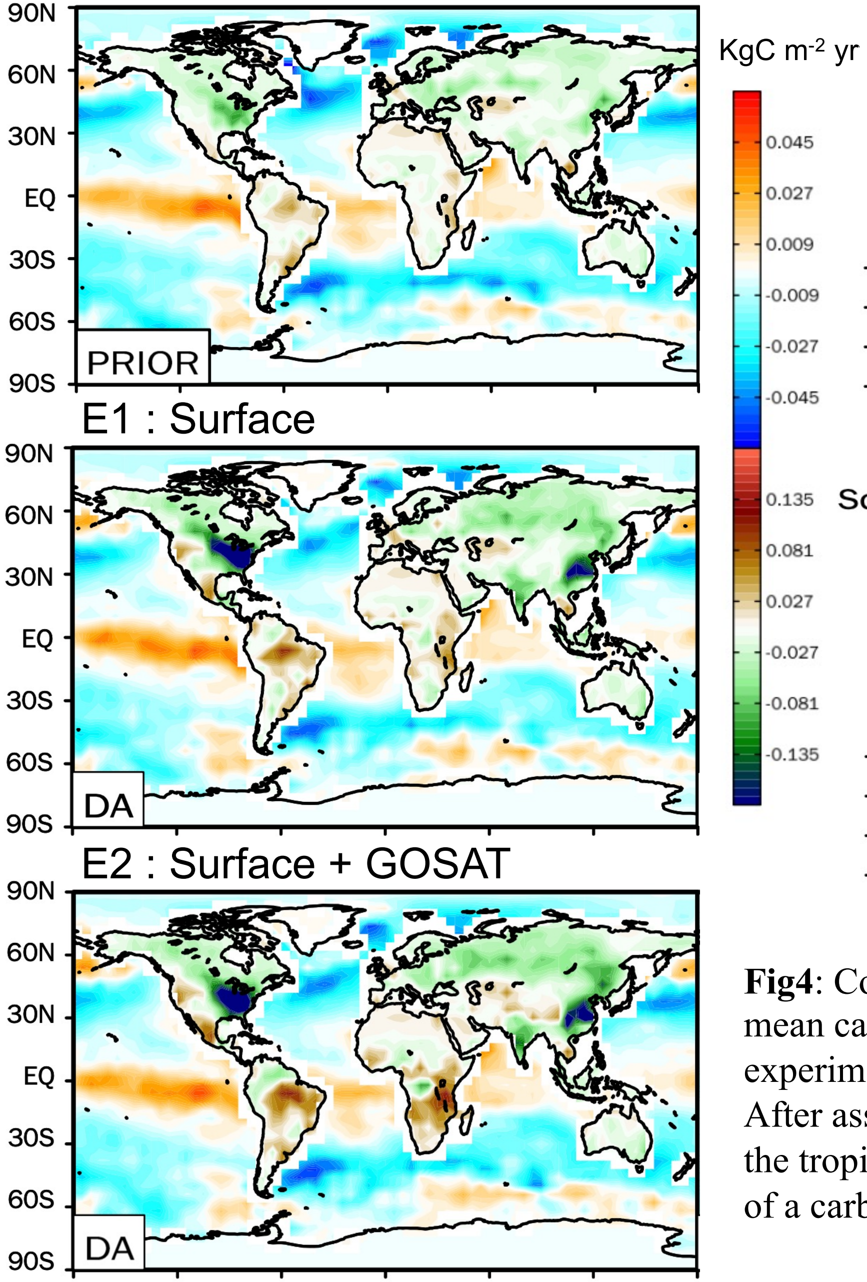

Fig4: Comparision of the mean carbon sink between experiment E1 and E2. After assimilating GOSAT, the tropical region are more of a carbon source.

E2 : The climatology seasonal cycle of regional SCF (2010~2016)

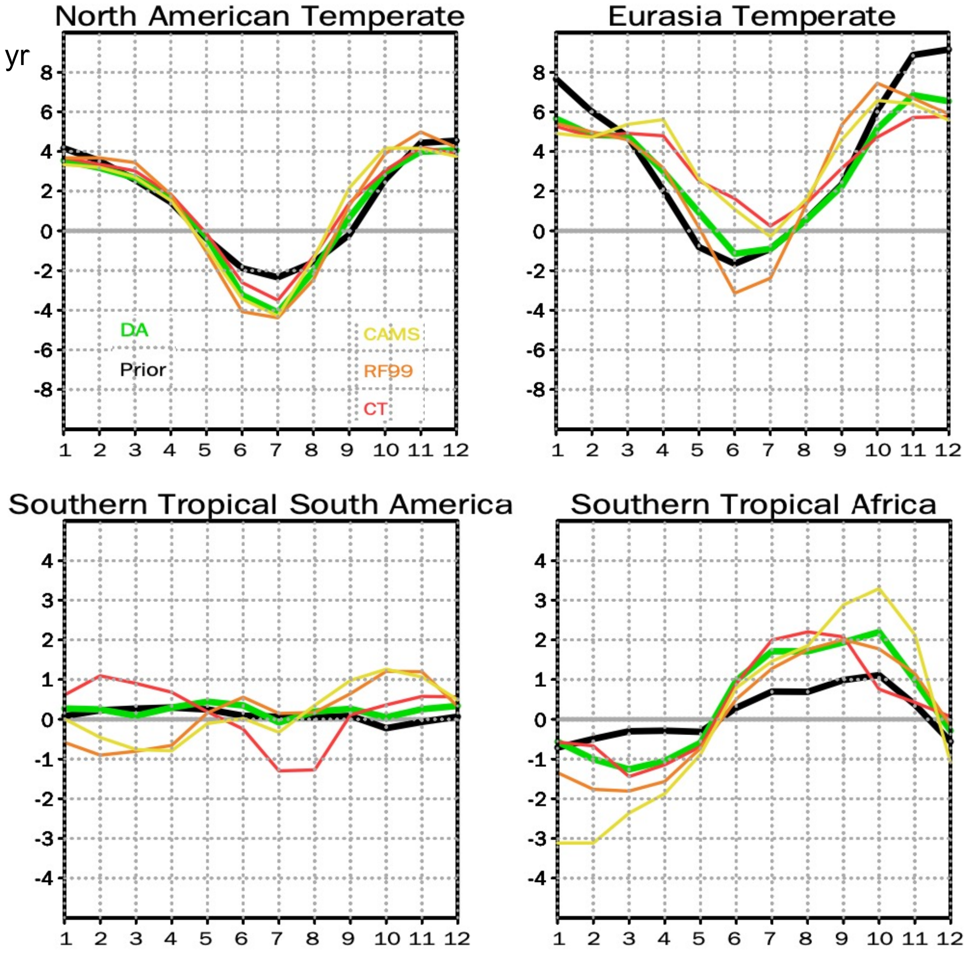

Fig5: Climatology seasonal cycle at different continental region

Conclusion:

- In our preliminary results. It shows that we can reproduce the reasonable interannual variability and seasonal cycle compared with other inversion products.
- The long term mean SCF shows that from 2010 to 2016 north America and southern China shows a large sink, while the tropical land shows a large spread source.
- Comparing the CO2 concentration with the assimilated GOSAT data. It shows that large discrepancy still showed at tropical Africa during winter, which indicate that there are some issues need to be fixed.
- In the next few days, we will modify the assimilation set-up and try to find out the underlying problems. After this we would like to participate in the MIPs like OCO2MIP and RECCAP.

Appendix : CO2 time series compared with observation