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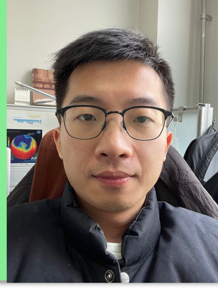
# Computational efficient global (2°×2.5°) and regional (0.5°×0.625°) $CO_2$ inversion using in-situ and OCO-2 B10 observations based on the COLA system

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## Abstract


Atmospheric inversion of carbon dioxide ($CO_2$) measurements to understand carbon sources and sinks has made great progress over the last two decades. However, most of the studies, including four-dimension variational (4D-Var), Ensemble Kalman filter (EnKF), and Bayesian synthesis approaches, obtains directly only fluxes while $CO_2$ concentration is derived with the forward model as post-analysis. Kang et al. (2012) used the Local Ensemble Transform Kalman Filter (LETKF) that updates the $CO_2$, surface carbon fluxes (SCF), and meteorology field simultaneously. Following this track, a system with a short assimilation window and a long observation window was developed (Liu et al., 2019). However, this DA system faces the challenge of maintaining carbon mass conservation. To overcome this shortcoming, here we introduce a Constrained Ensemble Kalman Filter (CEnKF) approach to ensure the conservation of global $CO_2$ mass. After a standard LETKF procedure, an additional assimilation is used to adjust $CO_2$ at each model grid point, and to ensure the consistency between the analysis and the first guess of global $CO_2$ mass. In the context of observing system simulation experiments (OSSEs), we show that the CEnKF can significantly reduce the annual global SCF bias from ~0.2 gigaton to less than 0.06 gigaton by comparing between experiments with and without it. Moreover, the annual bias over most continental regions is also reduced.

Based on this system, **Carbon in Ocean-Land-Atmosphere (COLA),** we present a global (2°×2.5°) to North America (0.5°×0.625°) daily surface $CO_2$ flux inferred from in-situ and OCO-2 B10 observations. COLA is one of the OCO2MIP-v10 model, and it is well consistent with the space-based and ground-based estimations. COLA fully takes the advantages of EnKF that significantly reduced the computational costs compared with traditional methods. For example, using 20 cores of CPU, the 5 years of 4°×5° global inversion takes only 3 days and the 5 years of 0.5°×0.625° North America inversion takes ~30 days. We believe that the native resolution global inversion could be possible on the HPC using the methods proposed in COLA.


## Framework of the Carbon of Ocean, Land, and Atmosphere (COLA) data assimilation system

| Model | |
|---|---|
| *Model* | GEOS-Chem v13.0.2 |
| *Horizontal resolution* | 2×2.5: global<br>0.5×0.625: NA/EU/AS |
| *Priori fluxes* | Fossil: ODIAC<br>Land: VEGAS<br>Ocean: oc-2021 |

| Assimilation Stretegy | |
|---|---|
| *DA module* | 4D-LETKF+CEnKF |
| *Assimilation window (AW)* | 1 day |
| *Observation window (OW)* | 6 days |
| *Ensemble member* | 20 ~ 50 |
| *Inflation method* | SCF: additive inflation<br>$CO_2$: relaxation to prior spread (RTPS) |

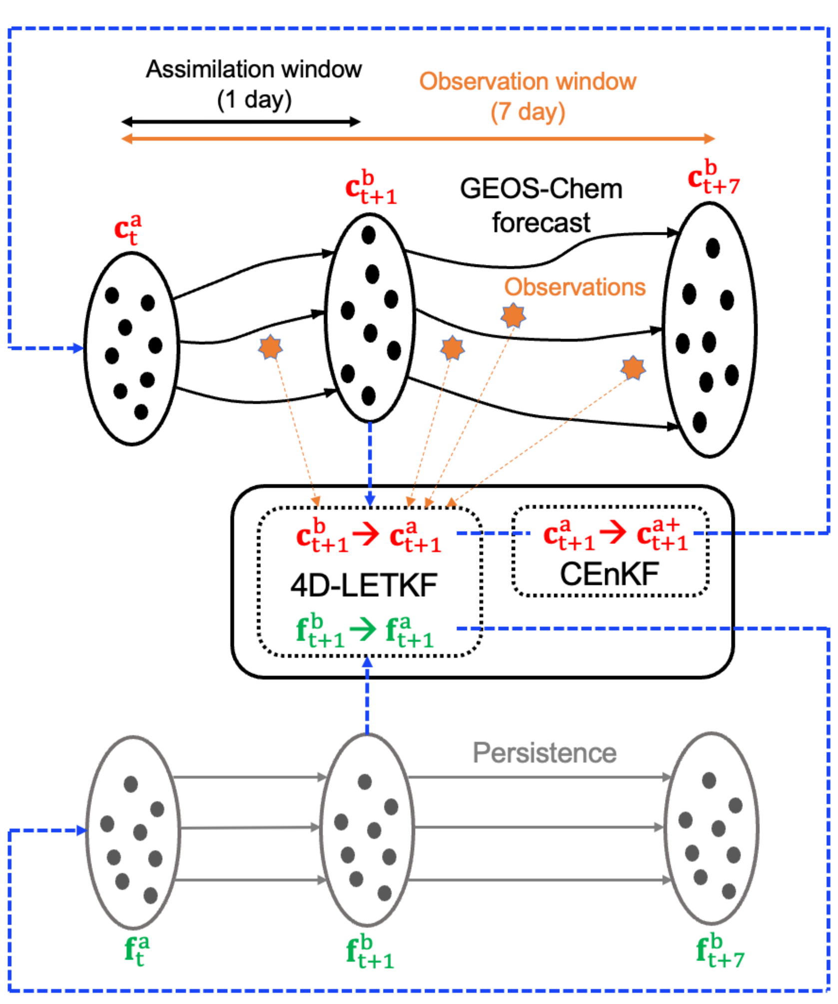



**Figure 2: Framework of COLA system**

| Observations | |
|---|---|
| *Surface* | GLOBALVIEW-CO2 v7.0 (back-corrected to X2007) |
| *Satellite* | OCO-2 B10 |

## Global (2°×2.5°) inversion results

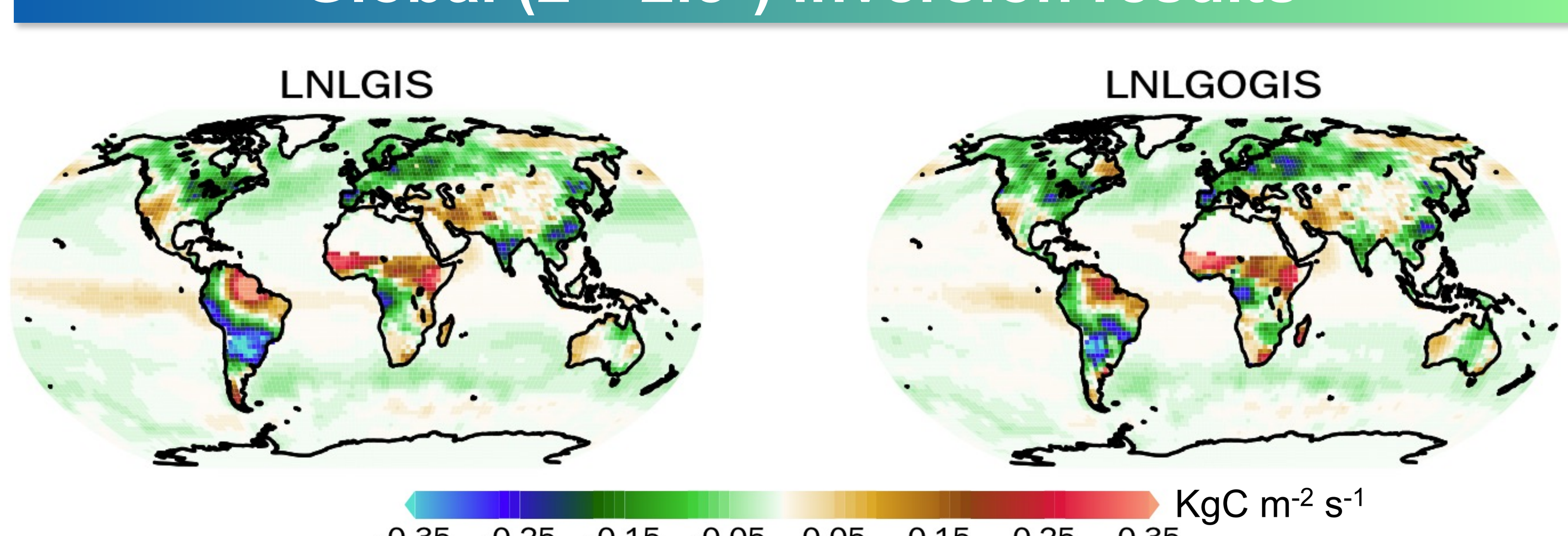



**Figure 1: Annual mean fluxes averaged from 2015 to 2019 using insitu together with OCO-2 LNLG data (LNLGIS), and insitu together with OCO-2 LNLGOG data.**


**Reference**

Liu, Z., Zeng, N., Liu, Y., Kalnay, E., Asrar, G., Wu, B., Cai, Q., Liu, D., and Han, P.: Improving the joint estimation of $CO_2$ and surface carbon fluxes using a Constrained Ensemble Kalman Filter in COLA (v1.0), Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2021-375, accepted, 2021.


**Figure 2: Annual mean fluxes anomaly from 2015 to 2019 for the LNLGIS inversion. The anomaly is defined by subtracting the annual mean of each year with the 5 year mean.**

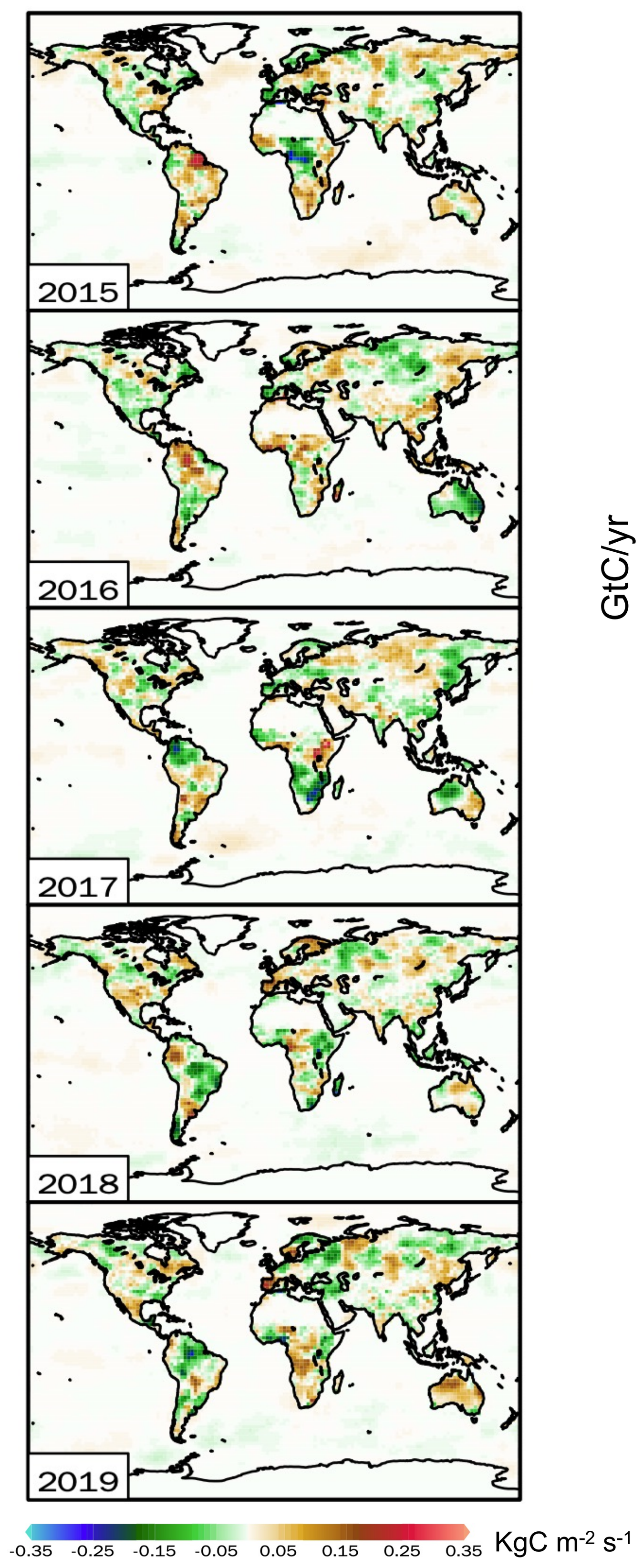
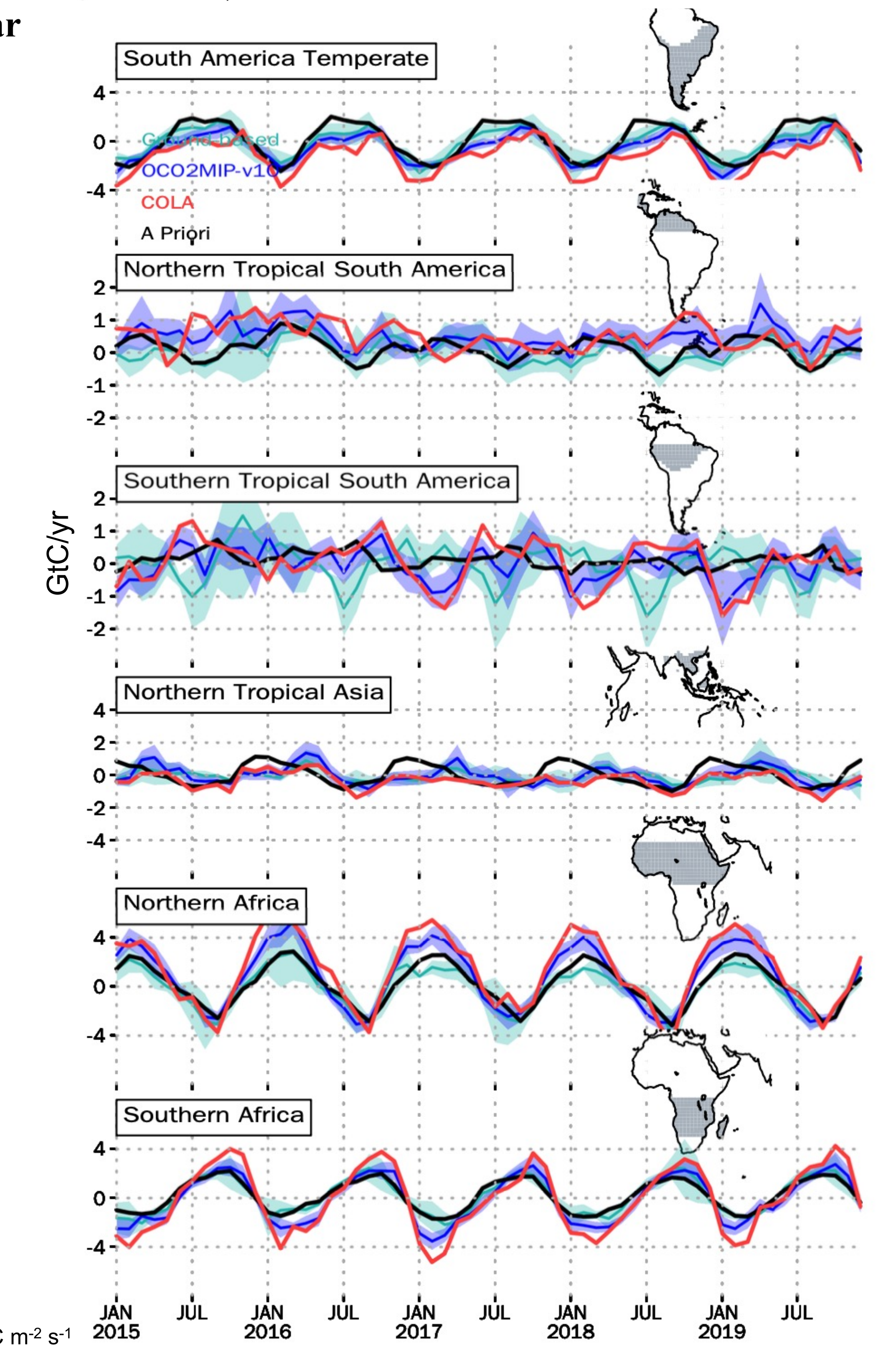



**Figure 3: Regional and seasonal flux from 2015 to 2019 for the LNLGIS inversion and compared with ground-based inversions (CT, CT-EU, CAMS) and other OCO2MIP-v10 inversions.**




## North America (0.5°×0.625°) inversion results

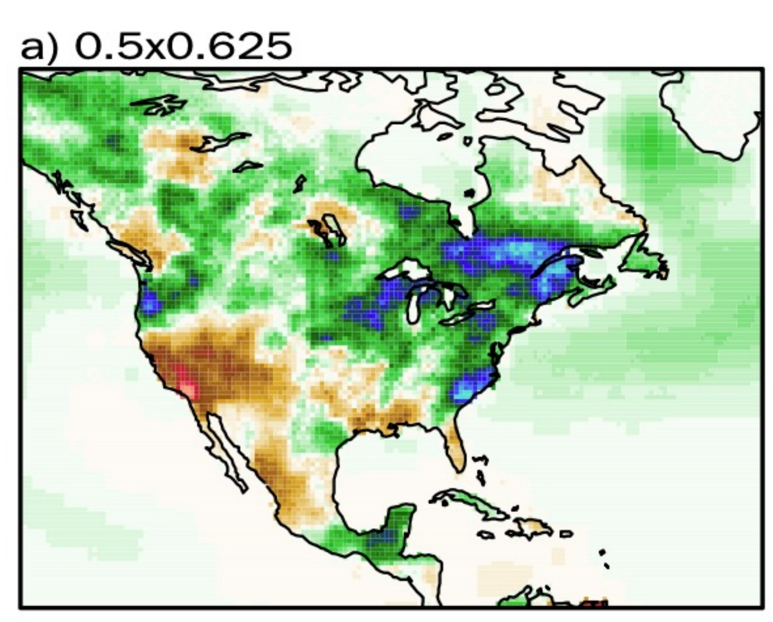
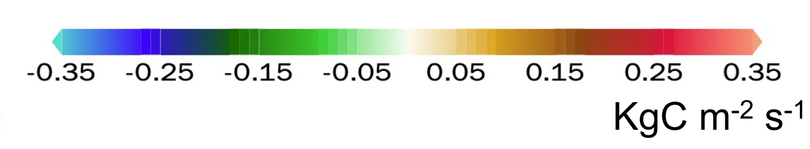
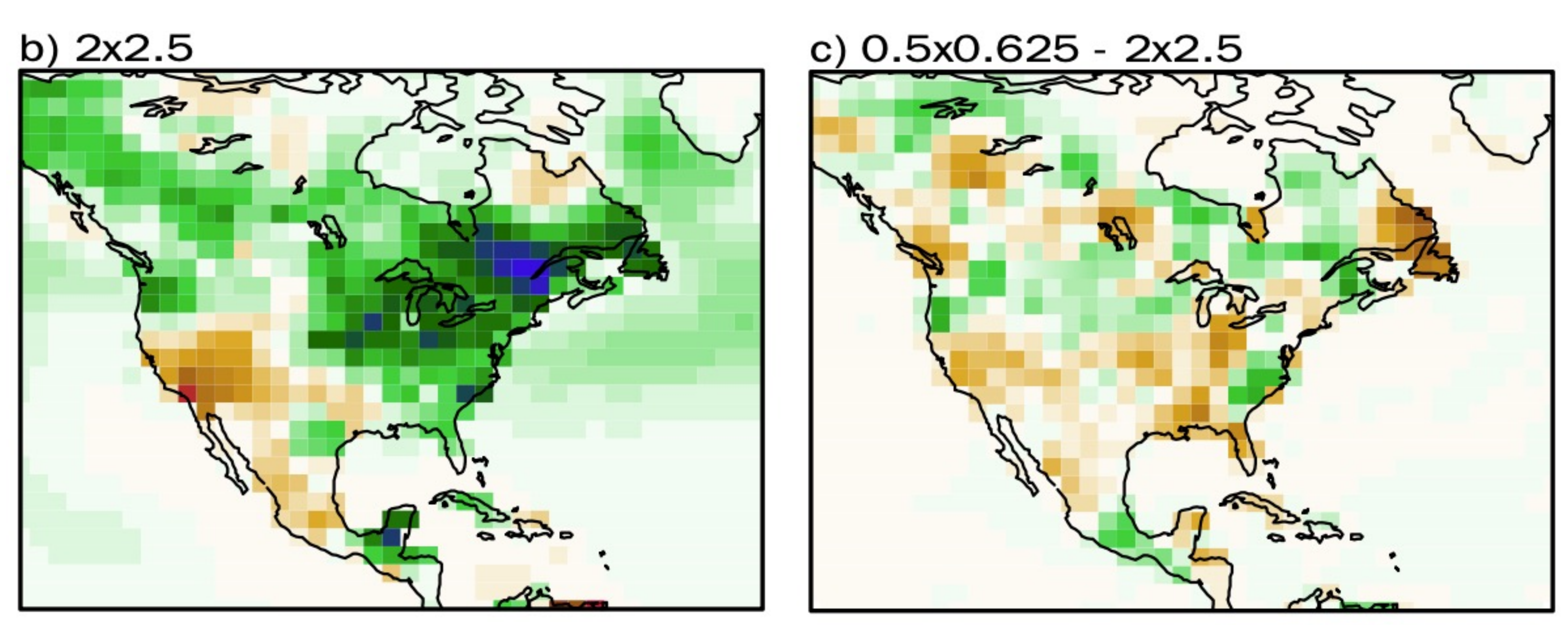



**Figure 4: Annual mean fluxes at 0.5°×0.625° and 2°×2.5°resolution averaged from 2015 to 2016 using insitu together with OCO-2 LNLG data (LNLGIS).**



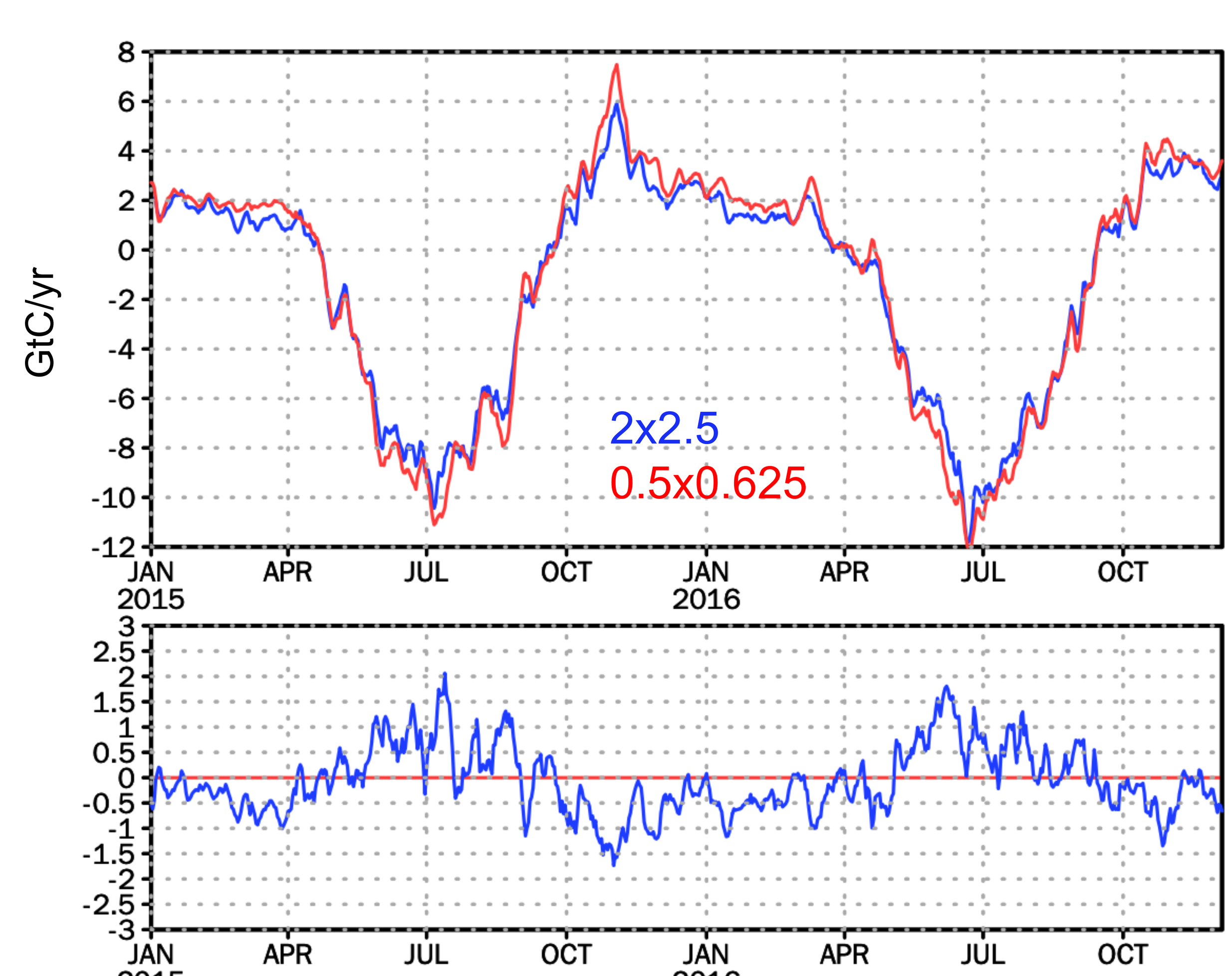




**Figure 5: Daily NA total flux at 0.5°×0.625° and 2°×2.5°resolution and their difference.**

## Summary

- We built a robust Carbon of Ocean, Land, and Atmosphere data assimilation system COLA. It involves several novel techniques for ensemble-based $CO_2$ data assimilation including CEnKF and RTPS.
- COLA is computational very efficient.
- COLA is a new model in the OCO2MIP-v10.