Ensemble Kalman filter data assimilation for Carbon Cycle

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◆ Introduction

Quantifying the temporal and spatial pattern of **CO_2 sources and sinks** at the Earth's surface is very important in order to understand carbon cycle and to project the atmospheric CO_2 concentrations and future climate.

We have performed a **simultaneous data assimilation** of surface CO_2 fluxes (CF) and atmospheric CO_2 concentrations (C) along with meteorological variables (U, V, T, q, Ps) using the Local Ensemble Transform Kalman Filter (LETKF, Hunt et al., 2007).

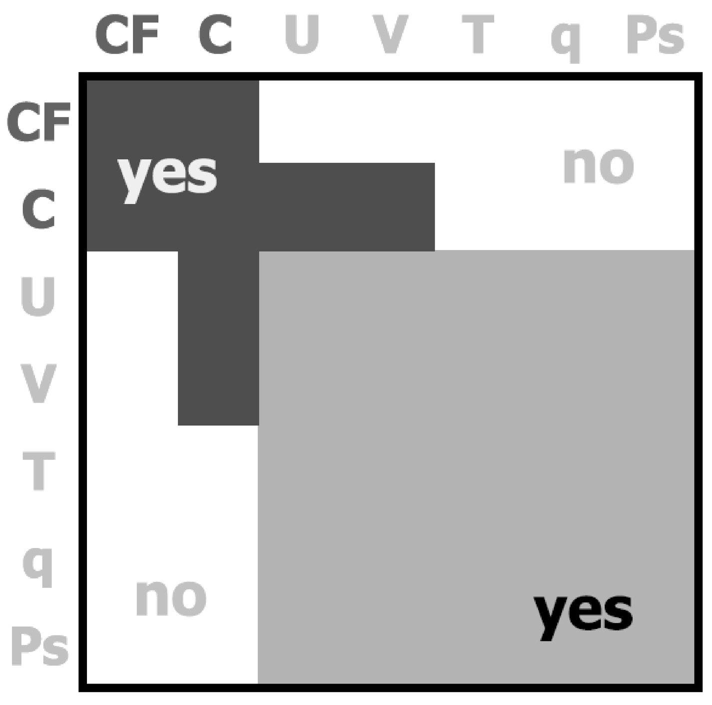
Surface CO_2 fluxes are not observed, but estimated as "parameters", augmenting the state vector of atmospheric CO_2 concentrations with the surface fluxes, and using the ensemble Kalman filter to estimate the **multivariate error covariance**. The "**variable localization**" method (Kang et al., 2011) has been applied to reduce sampling errors in the CO_2 LETKF multivariate analysis system. With **advanced inflation methods**, we are able to obtain encouraging multiseasonal analyses of surface CO_2 fluxes in addition to atmospheric CO_2 and meteorological analyses.

◆ Observing System Simulation Experiments

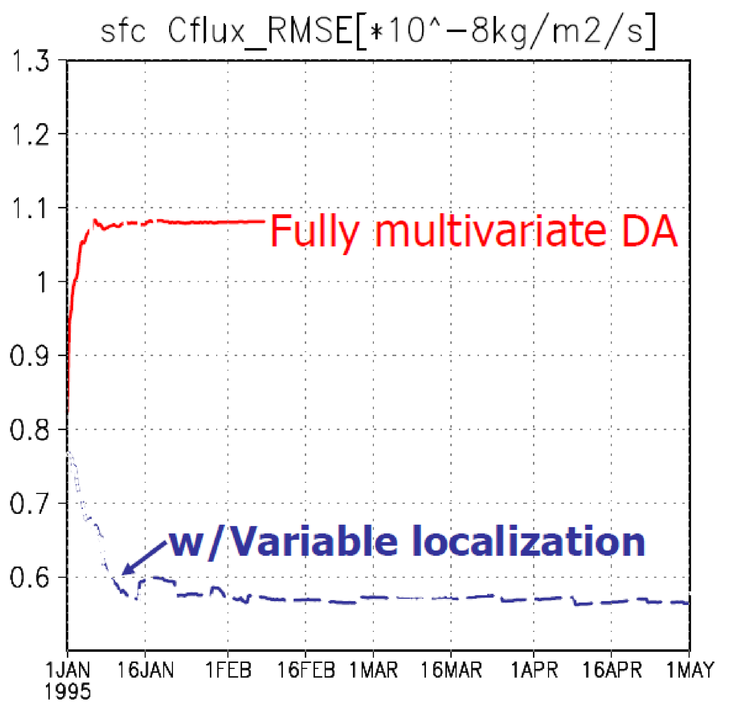
- Model: SPEEDY model with CO_2 as a trace gas (T30L7 resolution)
- Observations: rawinsonde data for (U, V, T, q, Ps)
  + surface station, GOSAT, and AIRS data for C
- CF in Nature run:
  A constant fossil fuel emission (Andres et al., 1996) + time-evolving CASA terrestrial CO_2 fluxes (Gurney et al., 2004) + Oceanic CO_2 fluxes (Takahashi et al., 2002)
- Persistence-forecast of CF: CF is updated only by the data assimilation
- Initial conditions: random (**no *a-priori* information**)
- 20 ensembles, every six hour analysis for one year

◆ Advanced methods in LETKF carbon cycle system

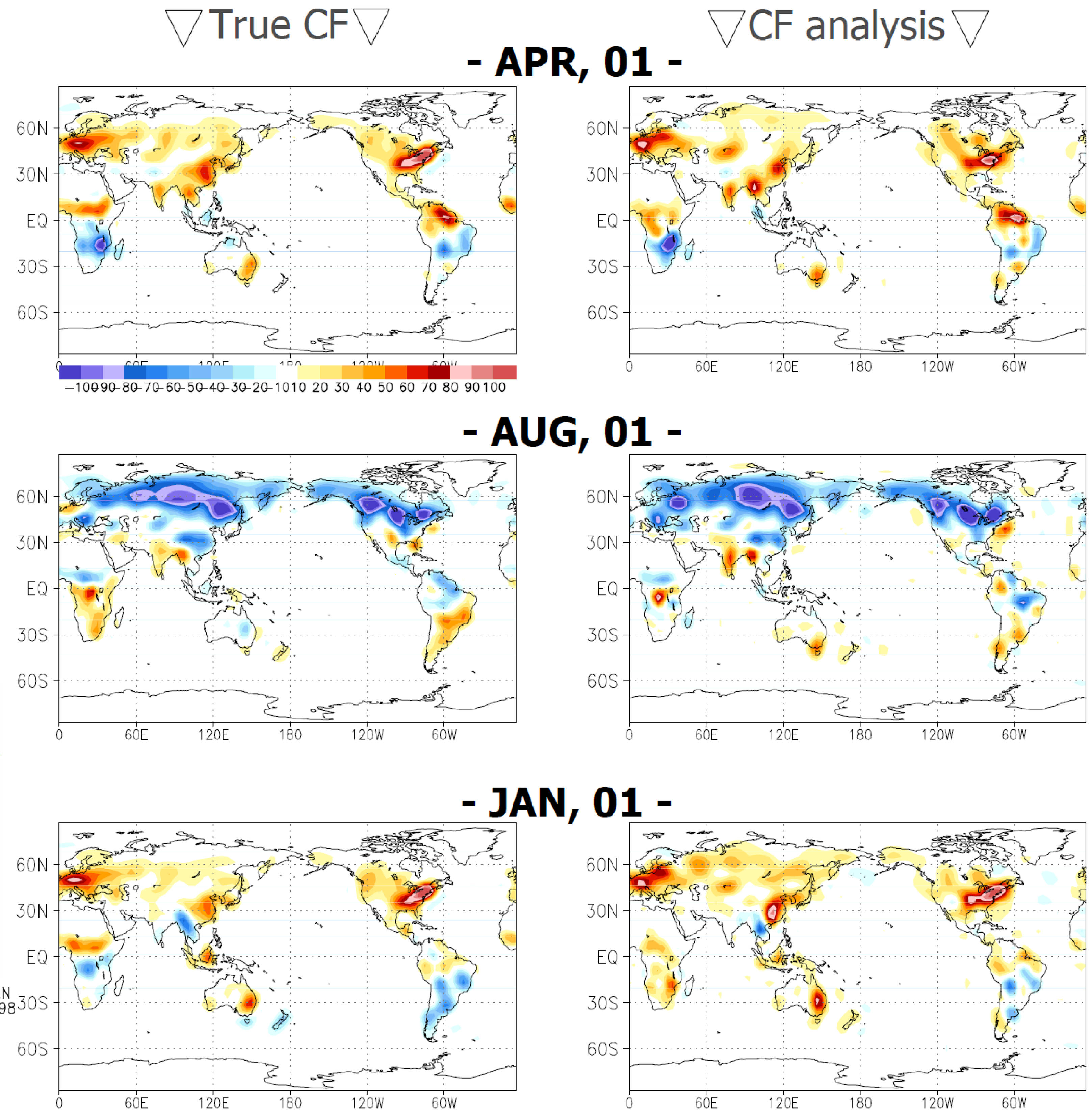
- **Variable localization** zeros out unphysical error covariance between the variables
- Inflation: **adaptive** multiplicative inflation (Miyoshi, 2011) for (U, V, T, q, Ps, C)
  + additive inflation for (C, CF)
- **Vertical localization** on column CO_2 data of GOSAT: updating lower tropospheric CO_2



<Variable localization>

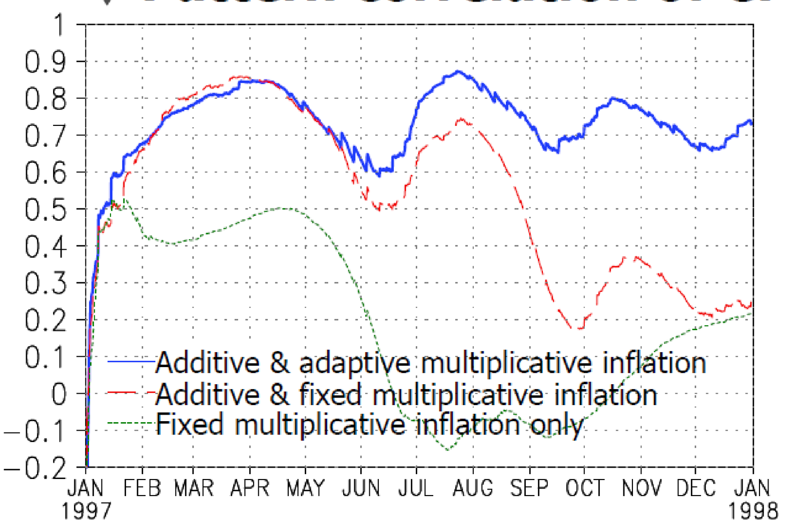


Impact of variable localization on CF estimation

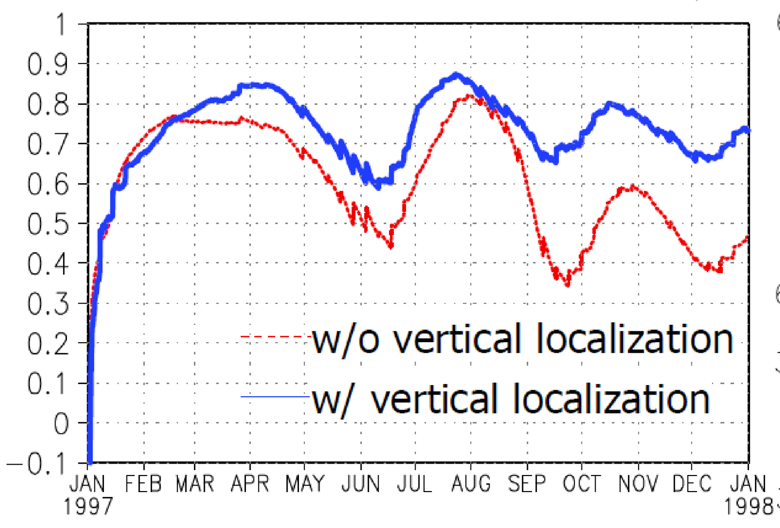


▲ Comparison of CF estimation with true seasonal CF ▲

▼Pattern correlation of CF estimation over the land▼



Impact of advanced inflation methods on CF estimation



Impact of vertical localization on CF estimation

◆ Summary

Our simultaneous analysis system **accounts for wind uncertainties** during the analysis cycle of carbon variables and there is no need to run the transport model additionally as an observation operator.

Additive inflation improves CO_2 analysis remarkably, solving a problem of CF stuck in time, and the **adaptive inflation method** provides further improved convergence of CF analysis to the true CF in terms of both a spatial pattern and an amplitude.

In principle, this methodology could be extended to the estimation of **surface moisture/heat fluxes** from the assimilation of observations of humidity/temperature in the atmosphere, another major challenge in current models.