Bias correction using analysis increment in an ensemble Kalman filter data assimilation

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Introduction

- There is no “perfect” model in reality
- **If a model providing an ensemble forecast as a background is **not perfect**, then...**
  - Capability to estimate background uncertainty can be degraded
  - Analysis can be contaminated by this unresolved model bias
- Methods to deal with the model bias
  - Inflation
  - Bias removal using O–B or A–B statistics
  - Bias estimation through the state vector augmentation (Kalnay, 2003; Li, 2007)
Methods

- For our **carbon cycle data assimilation system** which assimilates meteorological variables and carbon variables simultaneously,
  - We have applied **LDM** (Danforth et al., 2007) to the bias correction of meteorological variables, but not for CO₂
  - It is because LDM (Bias removal using A–B) requires another reference states (reanalysis data) to estimate bias of the forecast model
  - There are not enough knowledge about CO₂ (lack of observations, and no reliable analysis data yet)

  ➔ We have attempt to estimate bias correction using the analysis increment (A-B) within our own analysis cycle
Bias Correction Using Analysis Increments

- First, perform **the analysis without bias correction** (in this ppt, for seven months)
- **Average out the A-B** (dashed lines) for every month
  - We have **the estimated bias** as a monthly mean
- Now, perform **another analysis with the bias correction**
- Subtract the corresponding estimated bias from the forecast every analysis step
Experimental Setting

- **SPEEDY-C: Ensemble Forecast**
  - Atmospheric General Circulation Model (AGCM) with T30/7 levels
  - CO$_2$ (a passive tracer, C) is a prognostic variable in addition to (U, V, T, q, Ps)
  - Surface CO$_2$ fluxes (CF) are persistence-forecast

- **SPEEDY-VEGAS: Nature**
  - SPEEDY–C is coupled with SLand (Simple physical land model) and VEGAS (terrestrial vegetation and carbon model)
  - Evolving CO$_2$ fluxes over land every 6 hour
  - Monthly ocean CO$_2$ fluxes of −2PgC/yr (Takahashi et al., 2002)
Experimental Setting

- **1-way multivariate data assimilation**
  - Carbon variables do not affect the analysis of meteorological variables
  - Wind uncertainty is reflected to update atmospheric CO$_2$
  - Surface CO$_2$ fluxes (CF) are updated by the error covariance between (C, CF)

- **Adaptive inflation (Miyoshi, 2010)**
  - Inflation is adaptively computed at every grid point & every analysis time

- **Observations at every other grid point**
  - 25% coverage

- **20 ensemble members**

- **Seven-month analysis with every 6 hour cycle**
Three experiments

- **NoBC**: Analysis without bias correction
- **analincBC**: Analysis with a bias correction using the analysis increment
- **LDM**: Analysis with a bias correction using a difference between the forecast and the nature (truth)
Bias estimation of $U$ (left), $q$ (right)

- Comparison of estimated bias from NoBC (A-B) to that from LDM

![NoBC (A-B)](image1)

![LDM](image2)
Bias Estimation of CO₂

- **Bias of atmospheric CO₂**
  - Near the surface, it is strongly dependent on a spatial pattern of surface CO₂ fluxes
Results: RMS Error of Analysis

- **LDM** using the truth gives the **best** result
- **AnalincBC** results in very promising performance, close to the result of LDM
  - It reduces errors in **noBC**
Analysis error of \( U \) & \( \text{CO}_2 \)

- The last month mean of the seven-month analyses
Analysis of surface CO$_2$ fluxes

- The last month mean of the seven-month analyses
Summary

- **Preliminary results**
  - Good performance to estimate CO$_2$ bias in addition to other meteorological variables
  - Little improvement on CF should be explained
  - Observation network should be re-designed to be closer to the real case, as a next step

- Results depend on the quality of the analysis without the bias correction
  - Adaptive inflation benefits the estimation of bias and the analysis
Future Plan

- Apply this method to the case with CAM3.5/CLM + LETKF system → Estimate CO₂ model bias of CAM3.5

: Dr. Fung (U.C. Berkeley) mentioned that the CO₂ forecast in CAM3.5 has serious bias in terms of the vertical convection, which is highly related to the problem of estimating surface CO₂ fluxes in the carbon cycle data assimilation.

+ This is very important issue to assimilate satellite CO₂ observations whose averaging kernel has a peak at midlevel.
The End

Thank you