A “online” EnKF-CGCM System

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PSU-UMD DA Workshop

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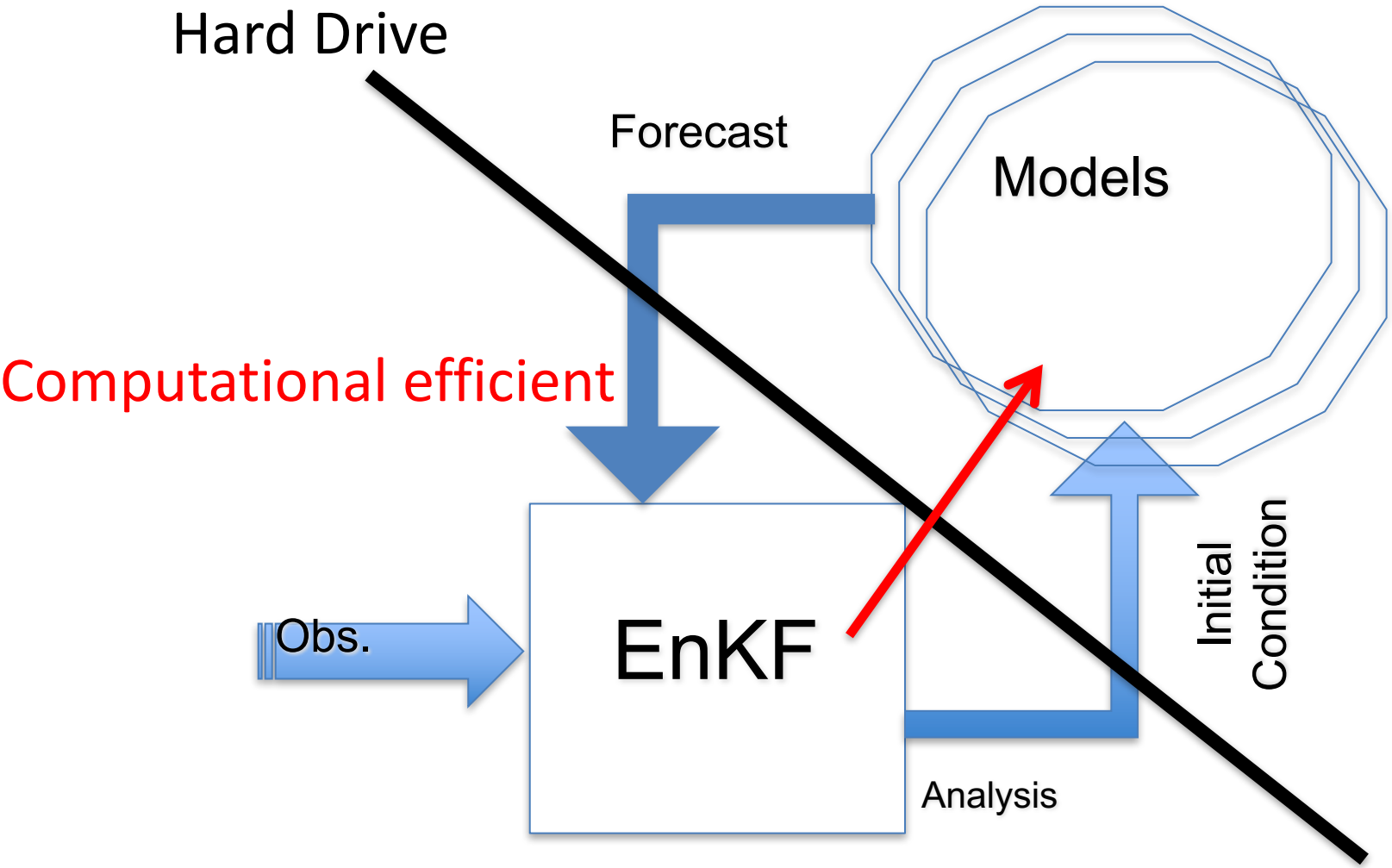
Outline

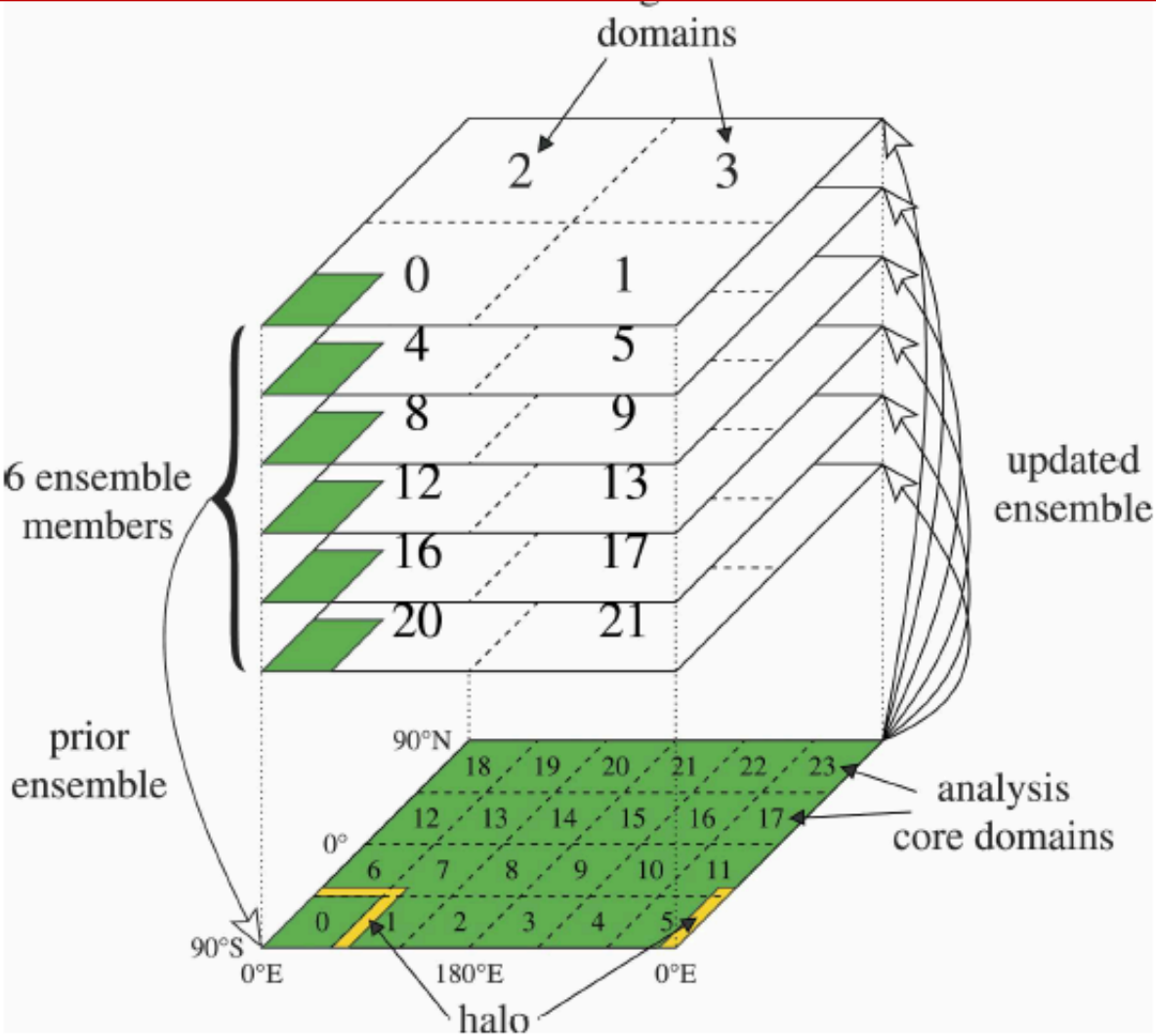
- Offline vs Online Ensemble data assimilation system
- An Online ECDA-FOAM system
- Ensemble parameter estimation with ECDA-FOAM
- Strongly Coupled data assimilation with ECDA-FOAM

Offline vs Online EnKF



Easy to implement and adapt

Online EnKF



Zhang et al 2007

Coupled Ensemble DA - FOAM

Model: **Fast Ocean Atmosphere model (FOAM)**

FOAM is developed jointly at the University of Wisconsin—Madison and the Argonne National Laboratory (Jacob, 1997).

The atmospheric model is a fully parallel version of the NCAR Community Climate Model version 2 (CCM2) with CCM3 physics at the R15 resolution with 18 levels;

The ocean model is a z-coordinate model similar to the GFDL MOM1.0 with a resolution of 1.4^{o}x2.8^{o} and 24 levels.

A simple thermodynamic sea ice model is incorporated.

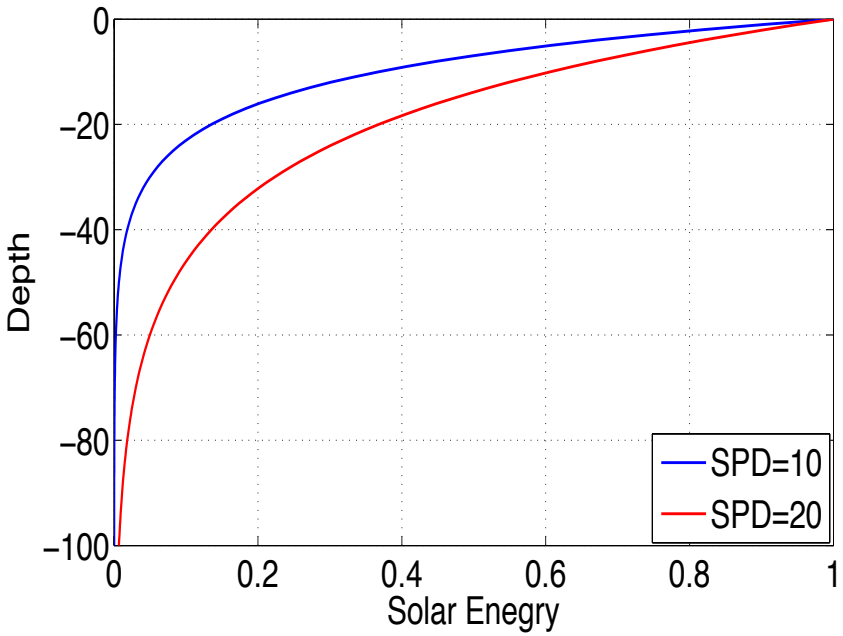
DA: Ensemble adjustment Kalman Filter (EAKF)

Parameter Estimation in a CGCM (FOAM)

- **Single parameter estimation**
- **Multiple parameter estimation**

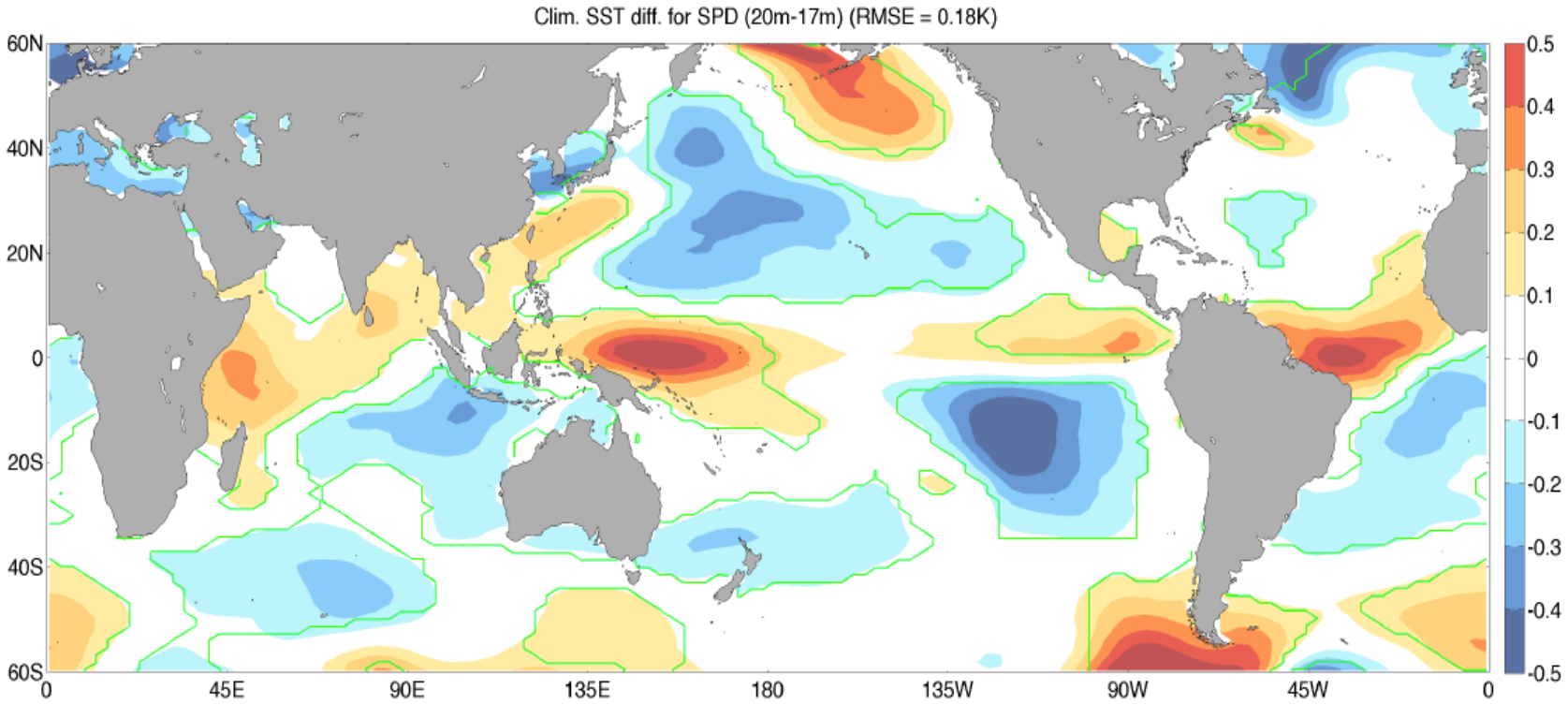
Single Parameter Estimation: Solar Penetration Depth

$$I(z) = I(0)\gamma \exp(-z / SPD)$$



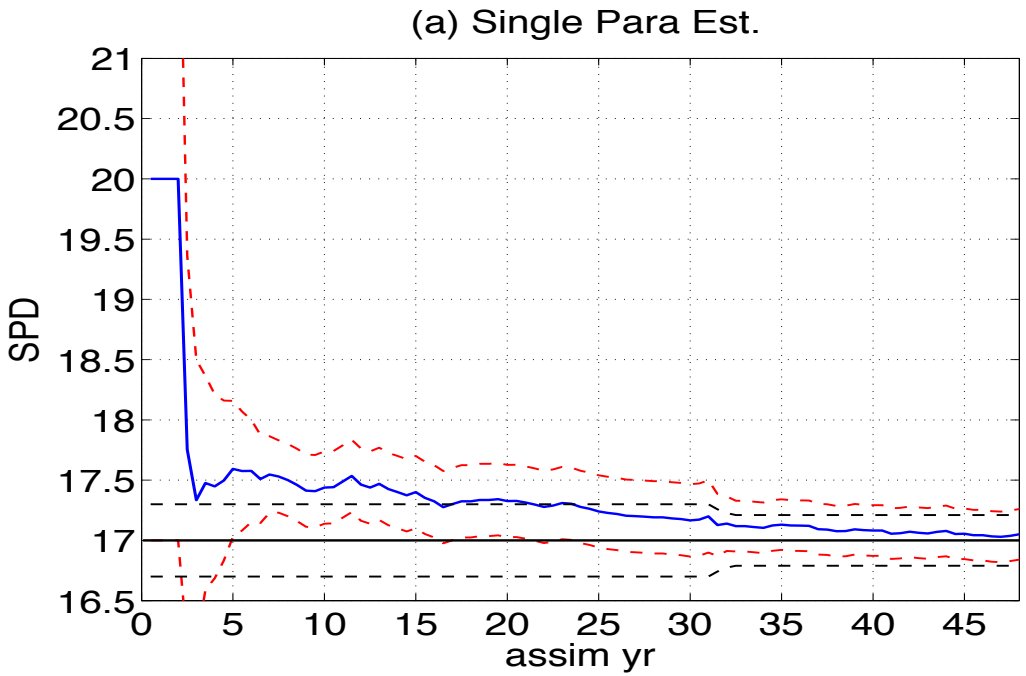
The solar penetration depth (SPD) is assumed as a global-uniform parameter.

SST Response to SPD Change



- The SST climatology difference between two simulations with the same initial conditions but different SPD (20m - 17m).

The First Successful Parameter Estimation with EnKF in a CGCM



The EnKF with ASA successfully estimates the parameter SPD. The SPD error decreases from 3-m to 0.2-m after 40 years of assimilation.

Multiple Parameter Estimation

Parameter	Comp.	Truth	initial
Solar penetration depth (SPD)	ocean	17m	20m
A linear multiplier of the momentum flux (m_d)	coupler	1.0	1.2
A linear multiplier of the latent heat flux (m_q)	coupler	1.0	1.2

Bulk Formulas:

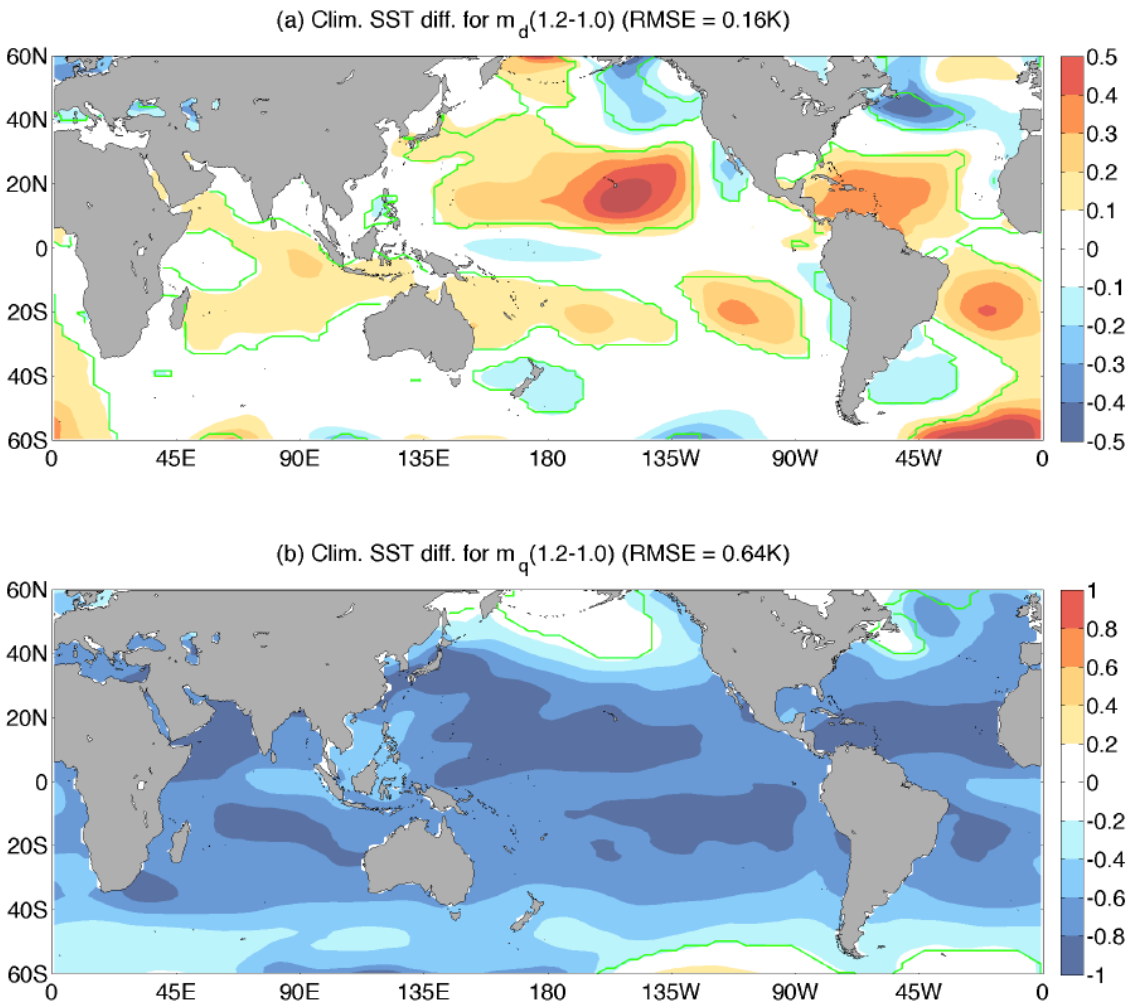
$$F = \rho C_d U_{10}^2$$

$$Q_L = \rho L C_q U_{10}(q_s - q_a)$$

$$F = m_d \rho C_d U_{10}^2$$

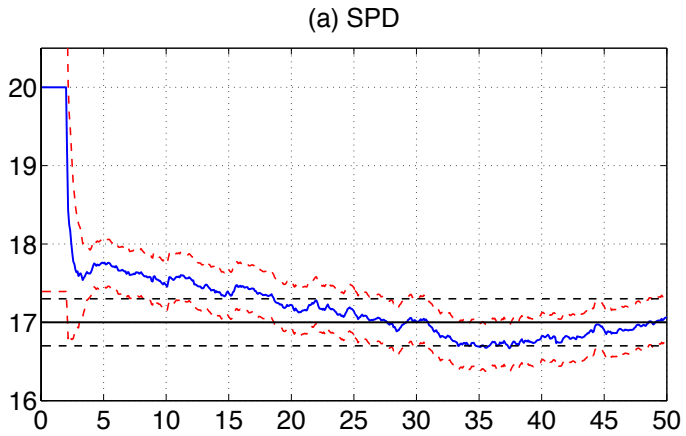
$$Q_L = m_q \rho L C_q U_{10}(q_s - q_a)$$

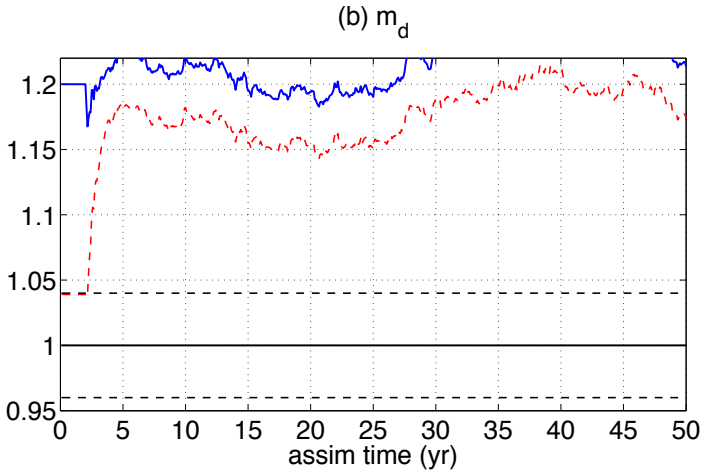
Climate Sensitivity of m_d & m_q

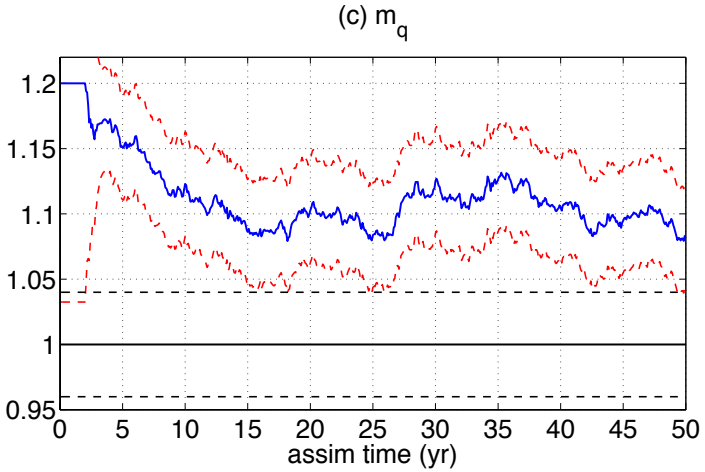


- The SST climatology difference between two simulations with the same initial conditions but different parameters: (a) the different m_d (1.2 - 1.0); (b) the different m_q (1.2 - 1.0).

Estimated Parameters with Oceanic Observation





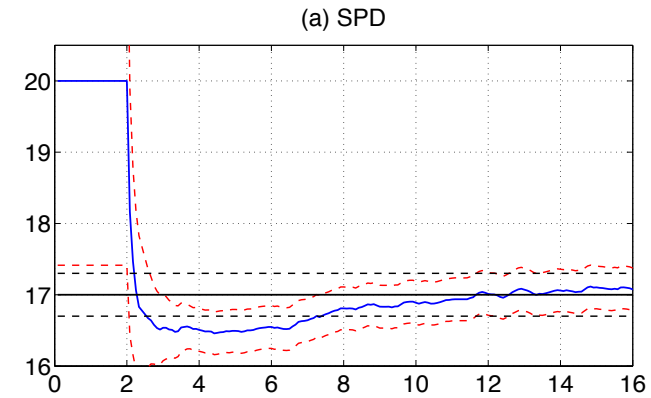


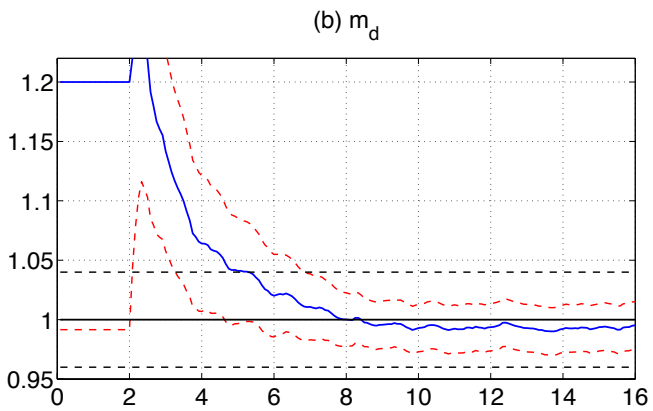
Observations:
monthly SST, SSS

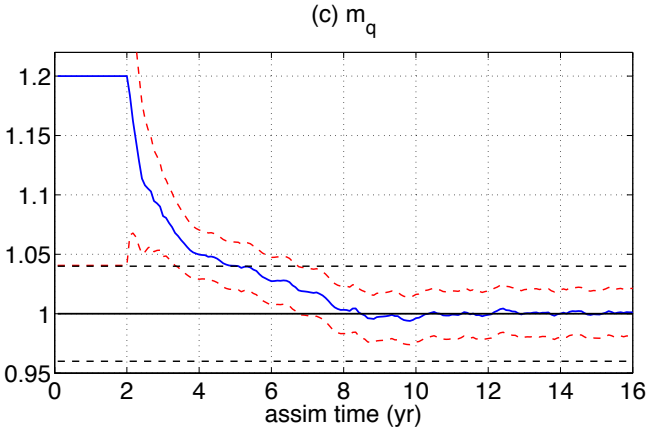
Estimated Parameters with both Oceanic and Atmospheric Observation

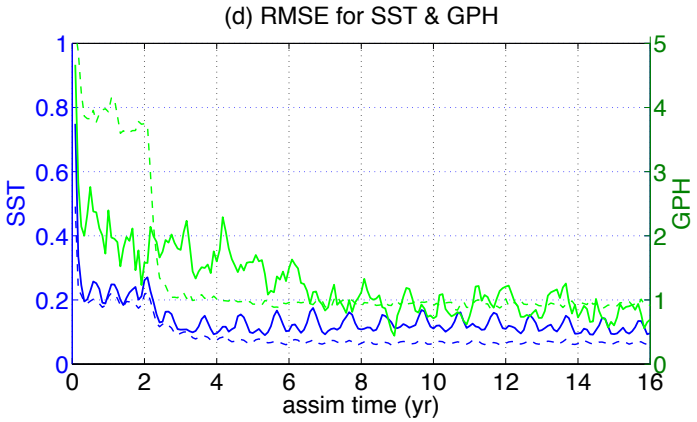
Observations

- Ocean: monthly SST, SSS
- Atmosphere : daily U,V,T









Liu et al. 2014 JCl

Summary (1)

Our study demonstrates the first successful ensemble based parameter estimation in a CGCM in a twin model framework for both single parameter estimation and multiple parameter estimation, which suggests the feasibility of the ensemble based parameter estimation in a fully coupled general circulation model.

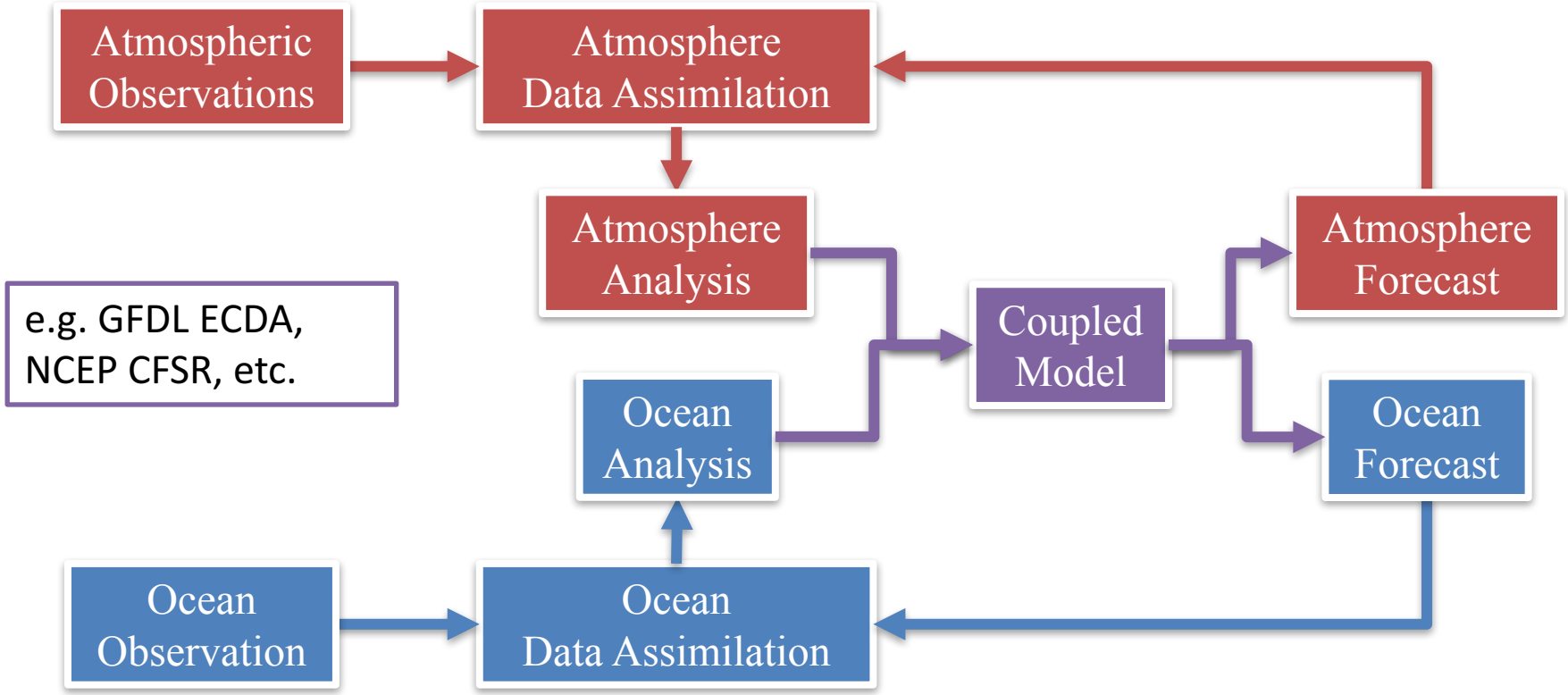
Liu et al. 2014 JCl

Strongly coupled DA in FOAM

- Leading Averaged Coupled Covariance method for Strongly coupled DA in a CGCM (Lu et al. 2015 MWR)

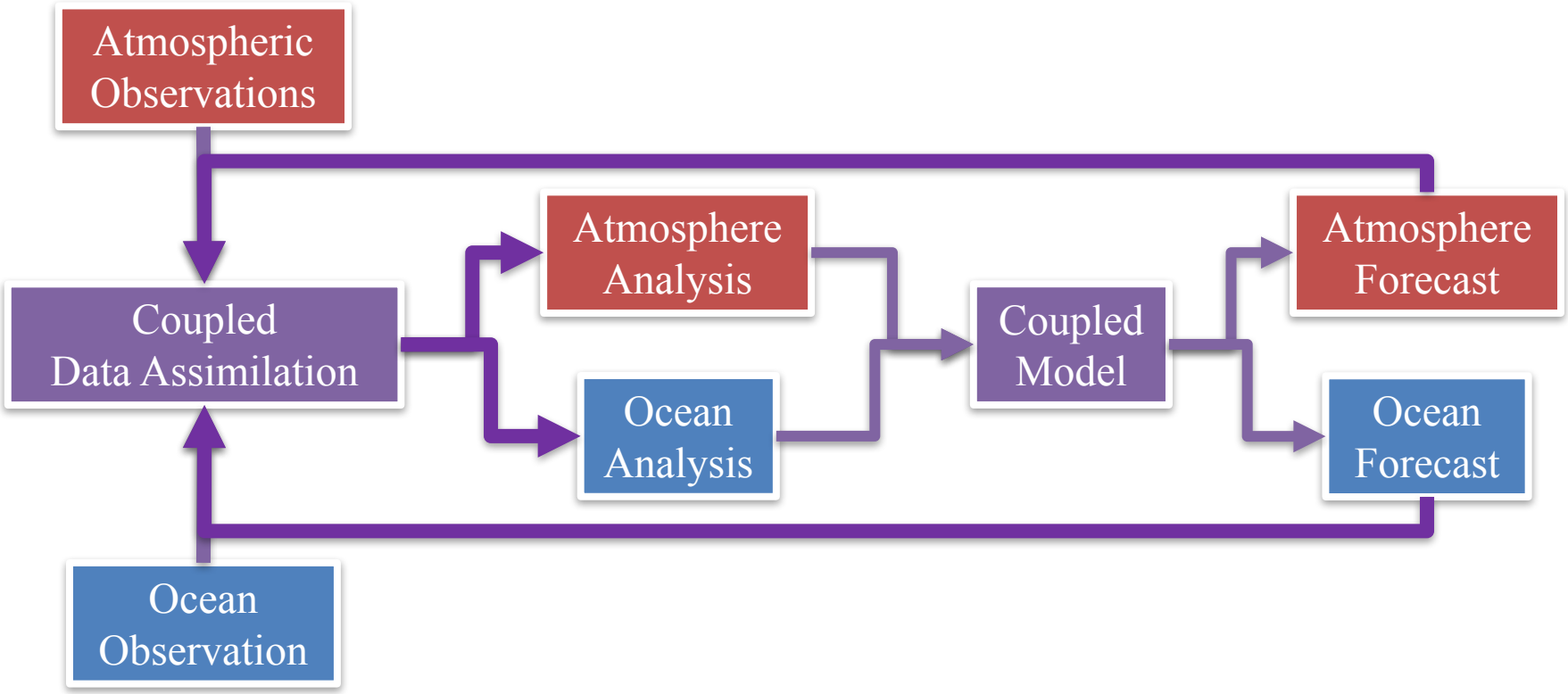
Lu et al. 2015 MWR

Weakly Coupled Data Assimilation (WCDA)



- Better forecast fields for multiple model components
- Exchange of observational information among components
- Balanced initial conditions for coupled model forecast

Strongly Coupled Data Assimilation



- Instant exchange of observational information through statistical update
- Observations are unevenly distributed among components
- More balanced analysis and initial conditions

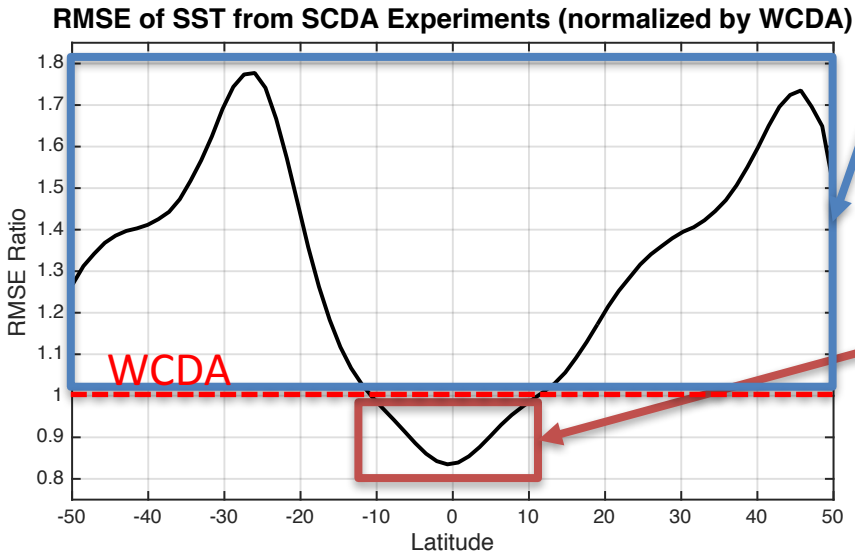
Example: Simultaneous SCDA in FOAM

Simultaneous SCDA

Low-level air temperature

↓ ADA frequency

SST



Outside of Deep Tropics:

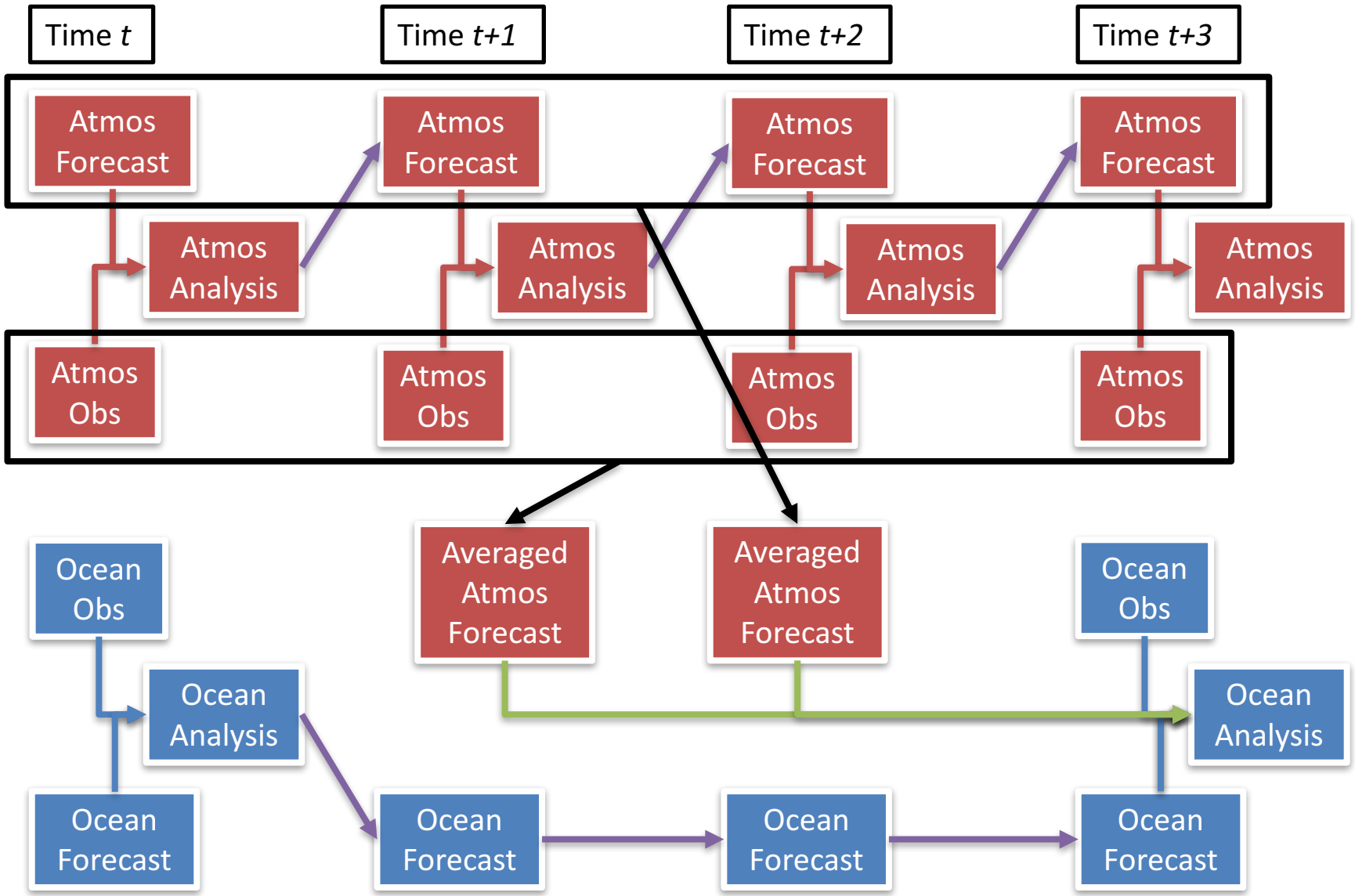
- Large atmosphere noise
- Weaker coupling (Atmosphere forcing ocean)
- Lower simultaneous T_a & T_o correlation

Deep Tropics:

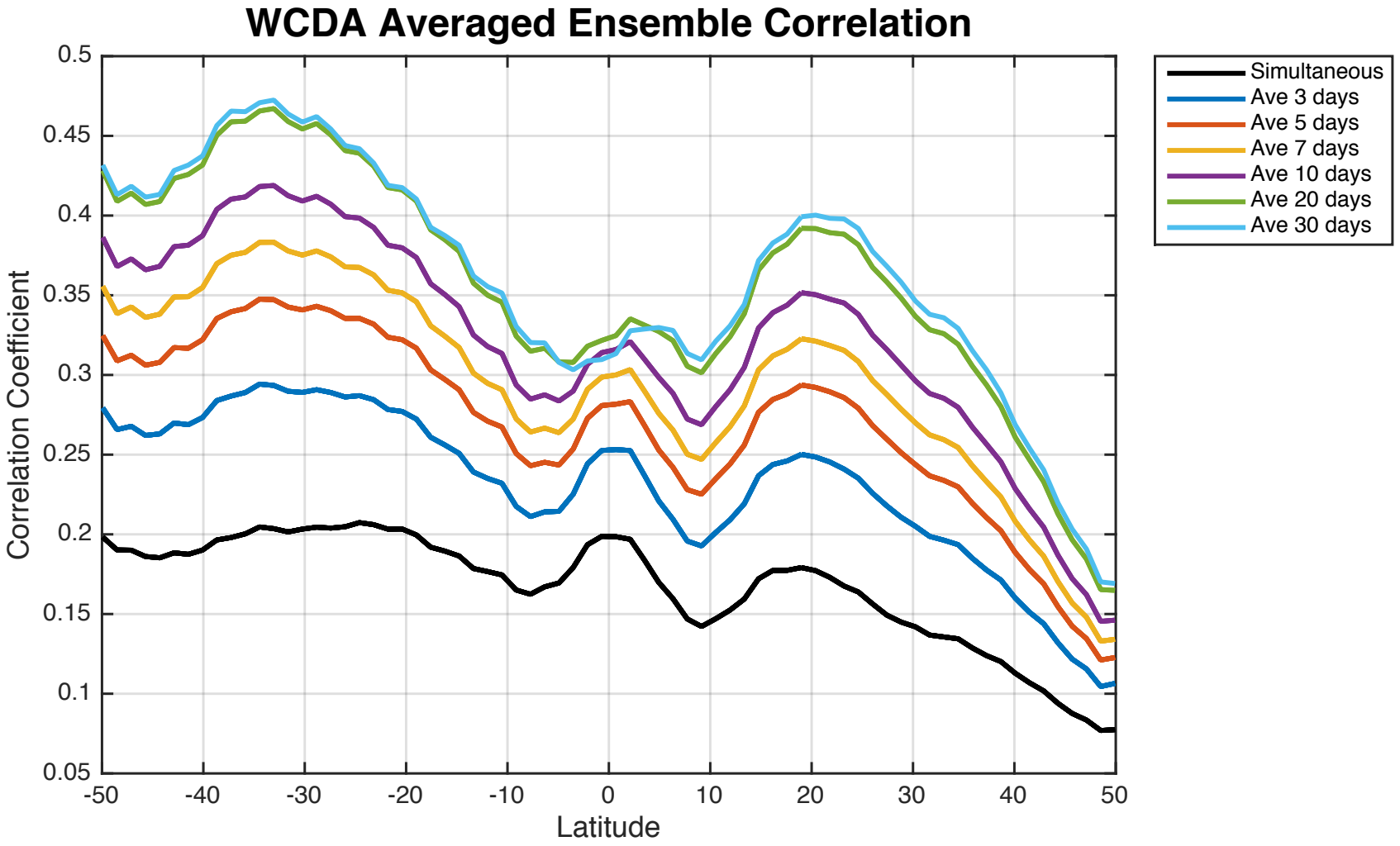
- Small atmosphere noise
- Stronger coupling (oceanic feedback on atmosphere)
- Higher simultaneous T_a & T_o correlation

Lu et al. 2015 MWR

Leading Averaged Coupled Covariance(LACC) Method

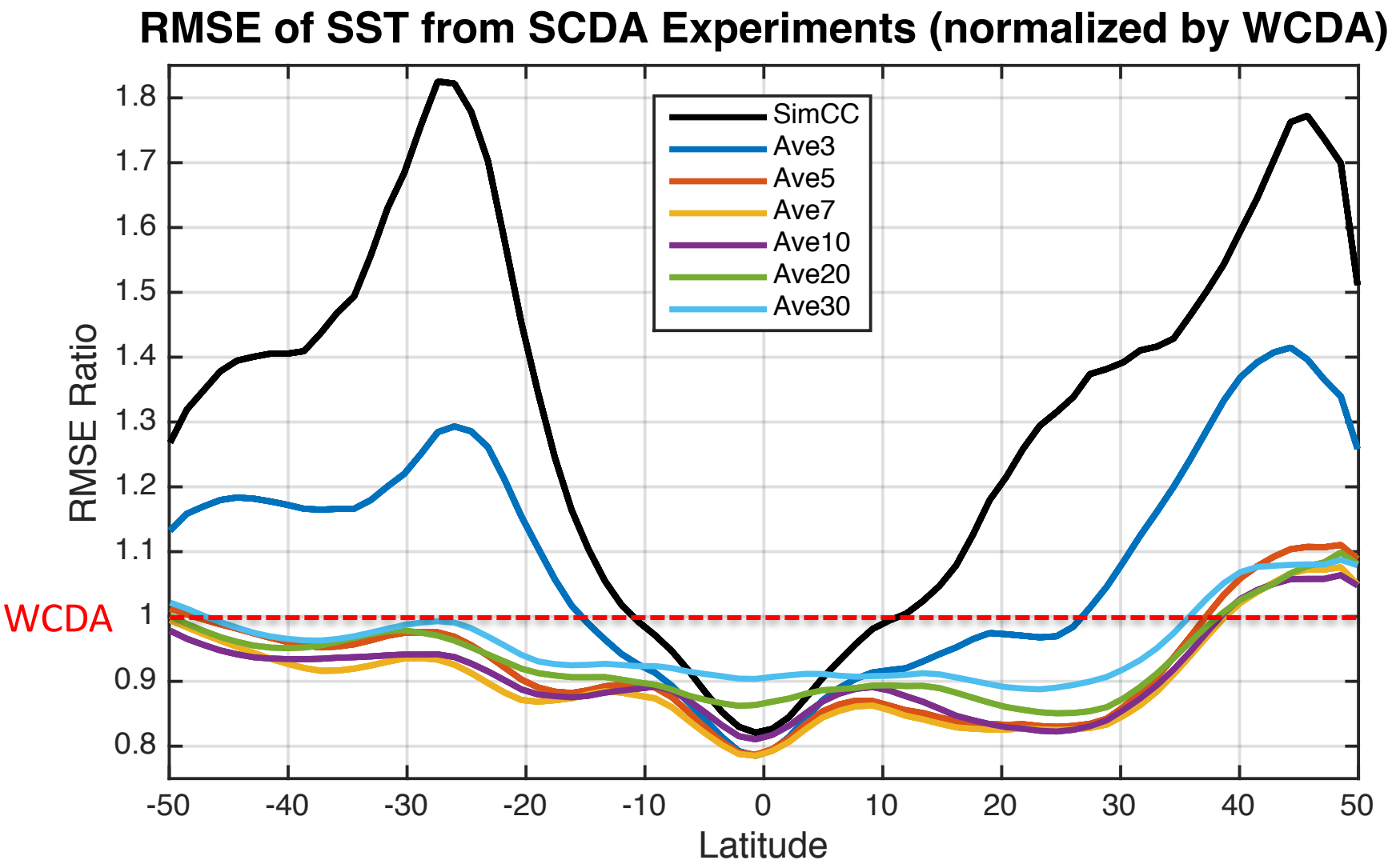


Leading Averaged Coupled Correlation



Lu et al. 2015 MWR

SCDA with LACC



Summary (2)

LACC improves SST (**slow component**) analysis in a CGCM by boosting the **signal-to-noise ratio** in cross-component update

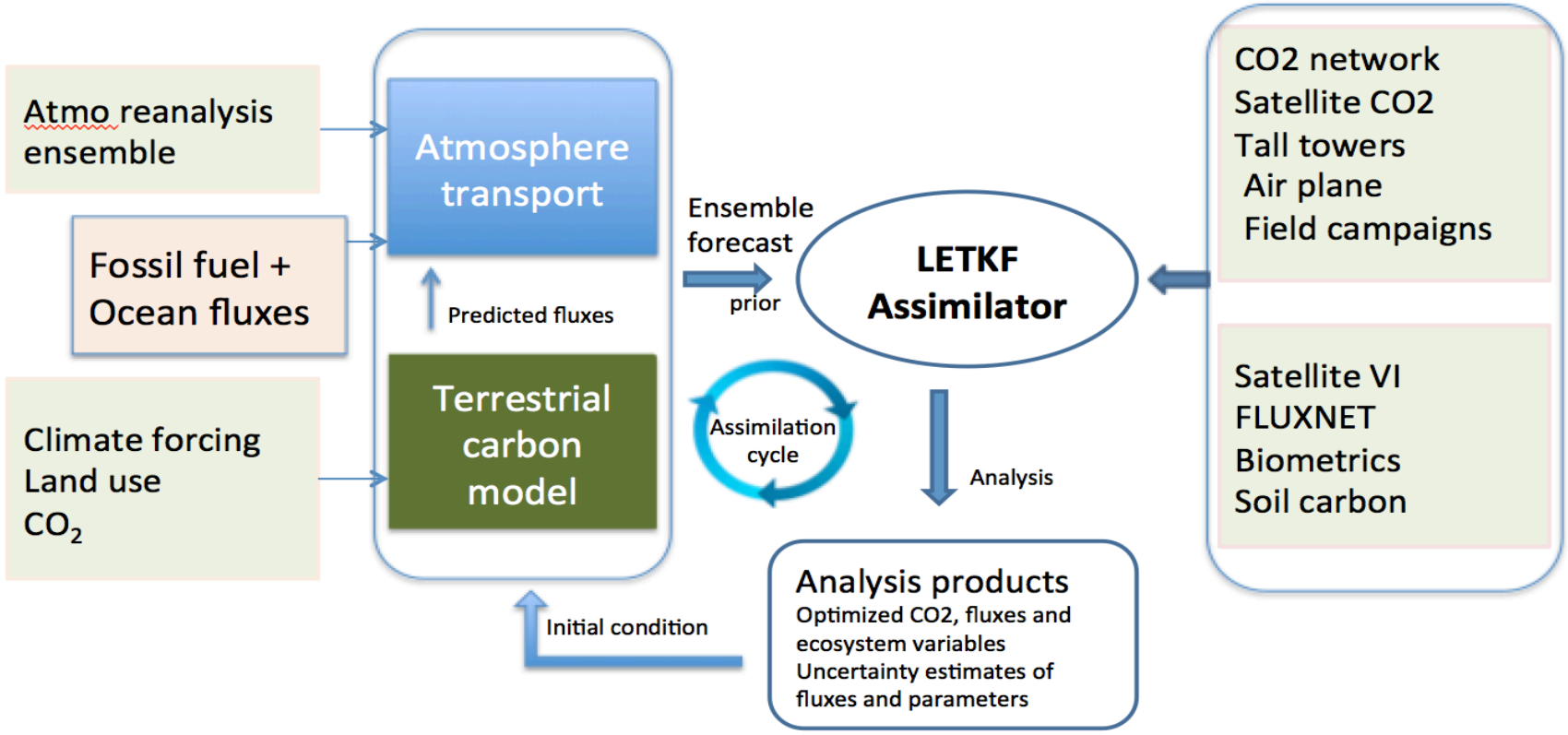
- Increase cross correlation (leading and averaging)
- Reduce atmosphere noise (averaging)

LACC makes use of the principles of **climate dynamics** (extratropical ocean driven by atmosphere) to improve **coupled data assimilation**

- We developed Online ECDA-FOAM system
- The system have been used for ensemble parameter estimation and SCDA studies.

Thank you!

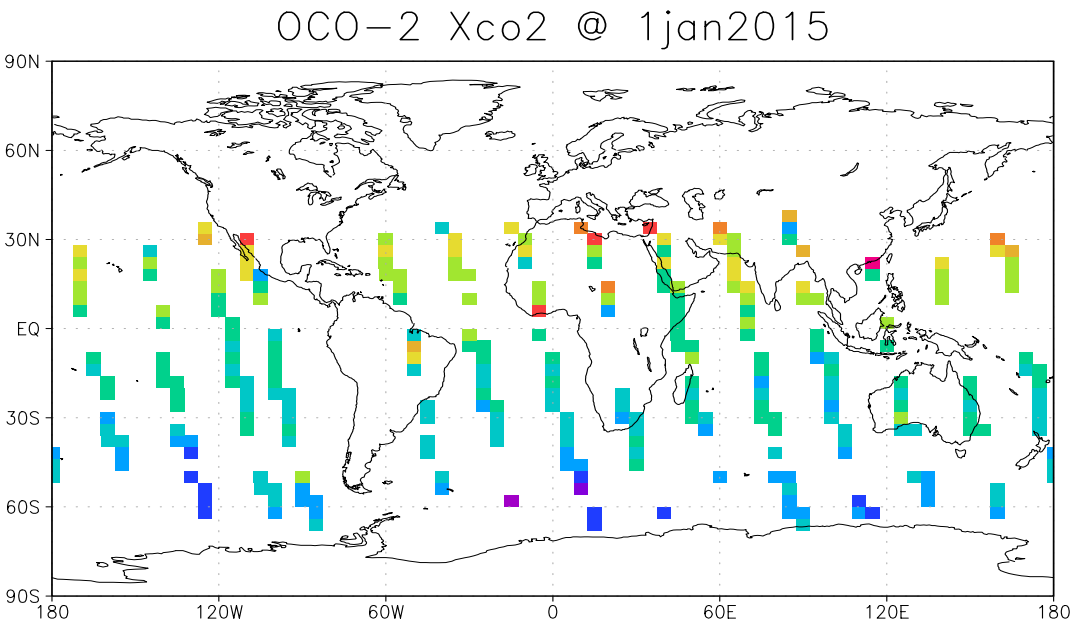
Coupled land-atmos-carbon data assimi-lation system (Zeng, Liu, Kalnay, Asrar)

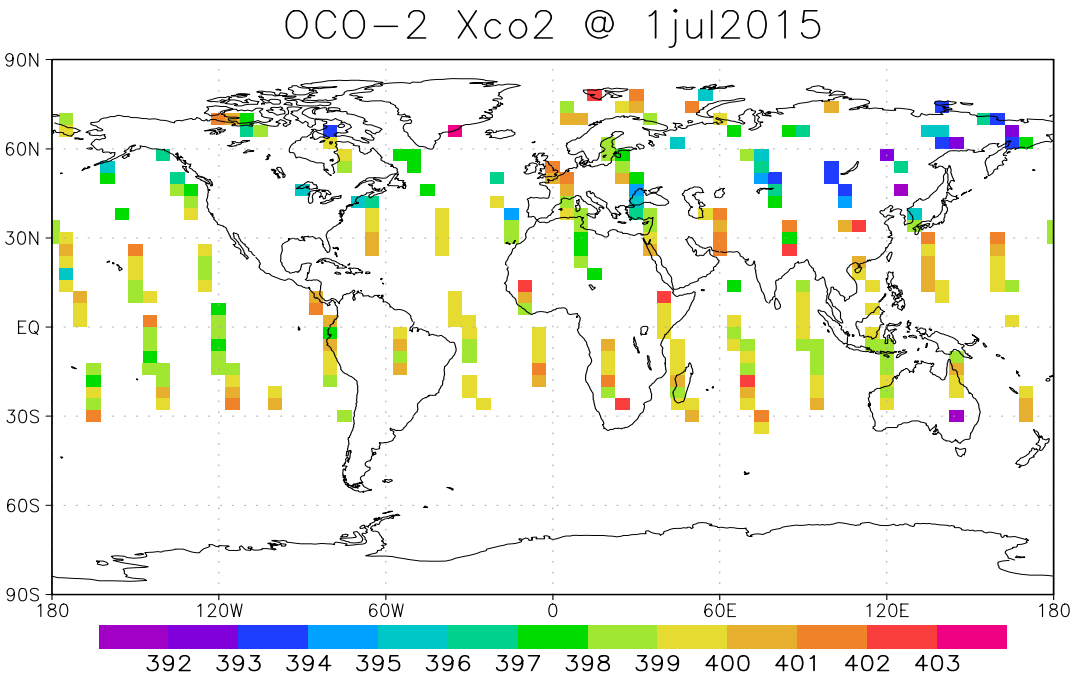


Top Down approach

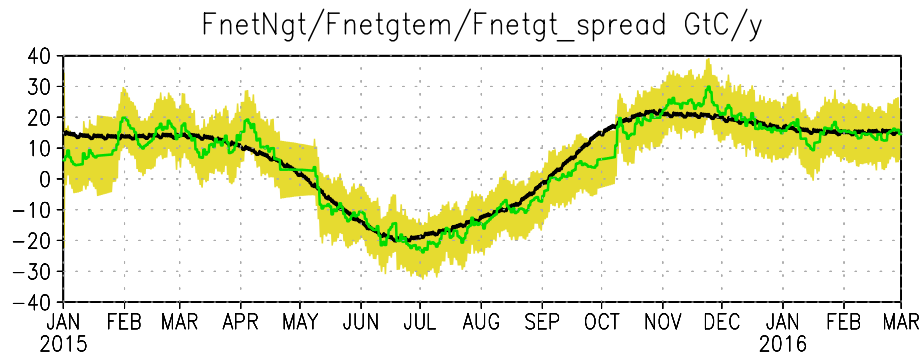
- **Short assimilation windows are more accurate than long assimilation windows.**
- **Short assimilation windows combined with long *observation* windows give the best results.**

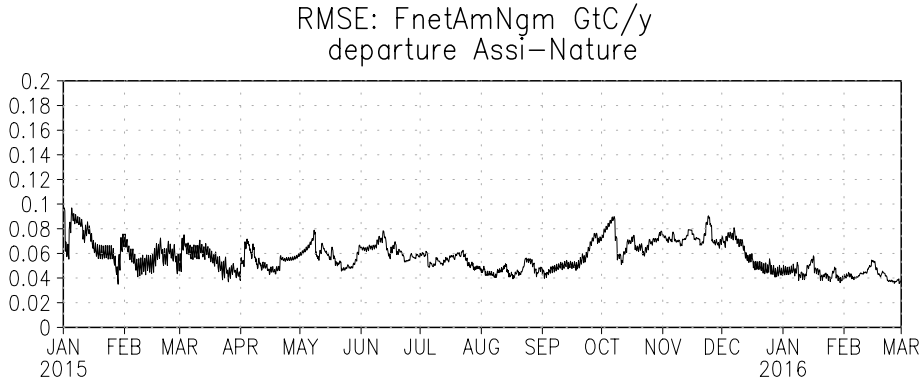
OSSE OCO-2


OCO−2 Xco2 @ 1jan2015
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180

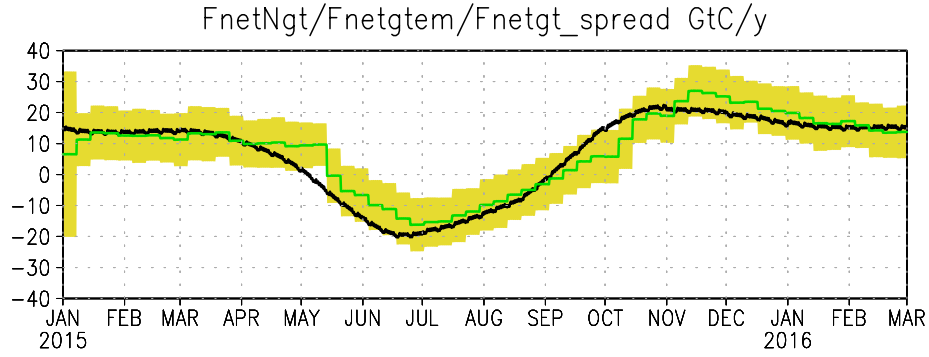

OCO−2 Xco2 @ 1jul2015
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
392 393 394 395 396 397 398 399 400 401 402 403

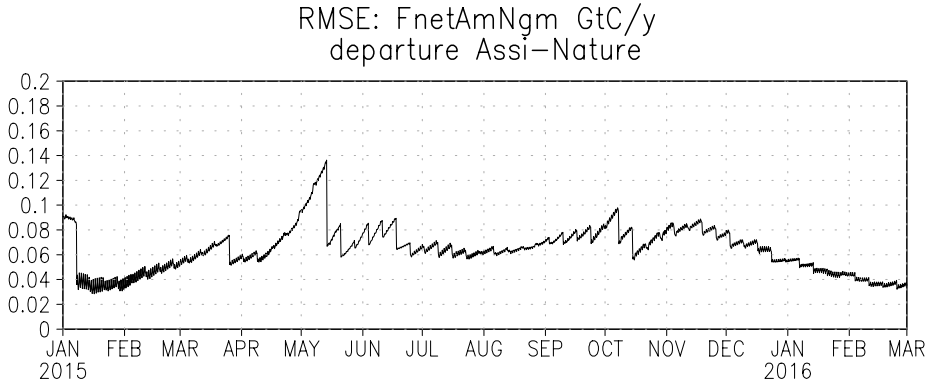
1 day: good results



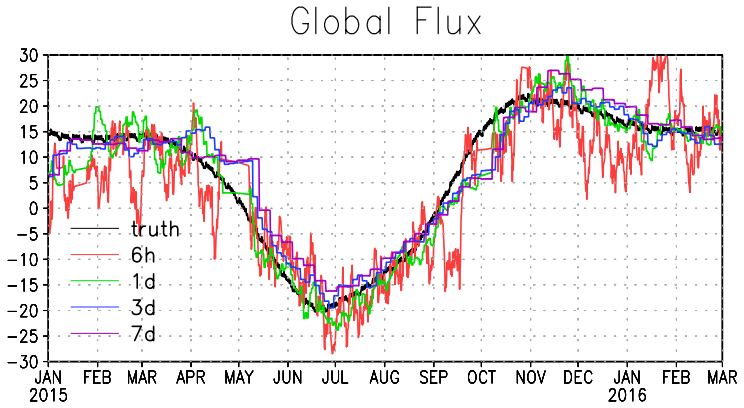


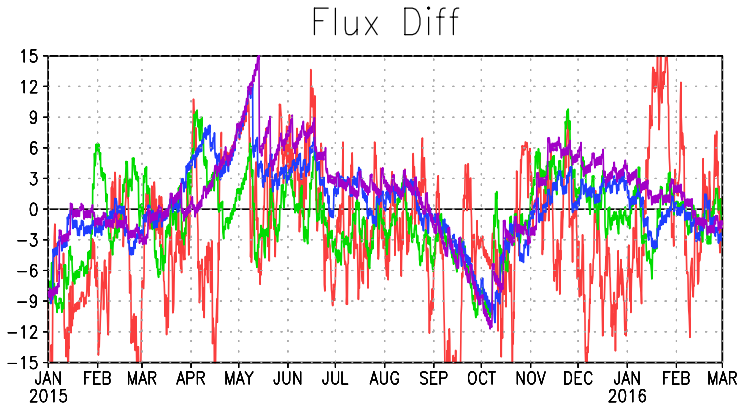
7 days: worse results

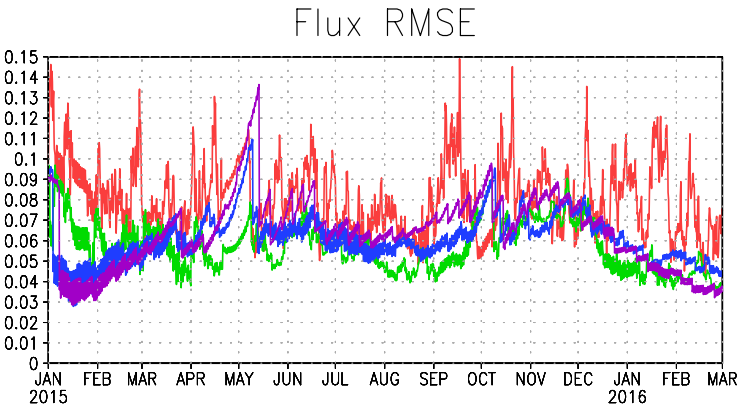


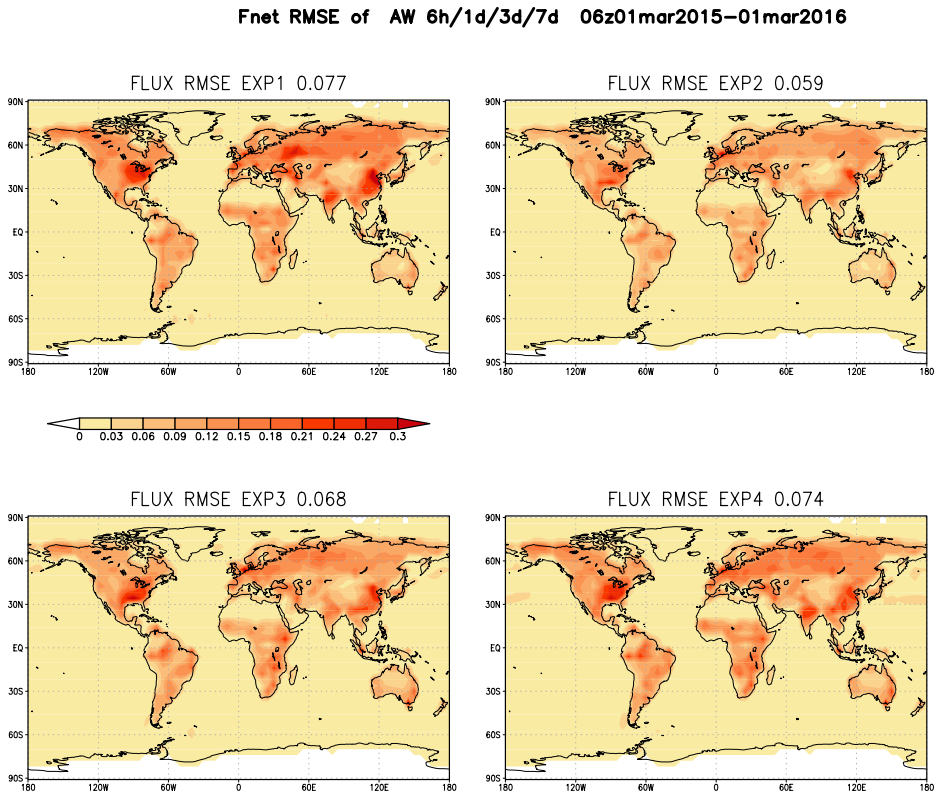


Sensitivity for assimilation window



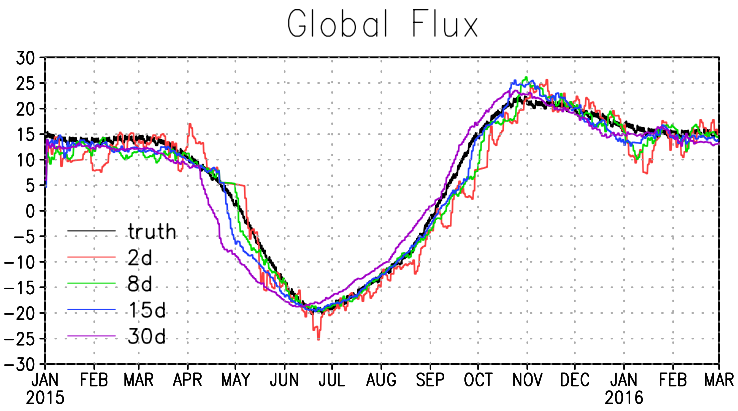


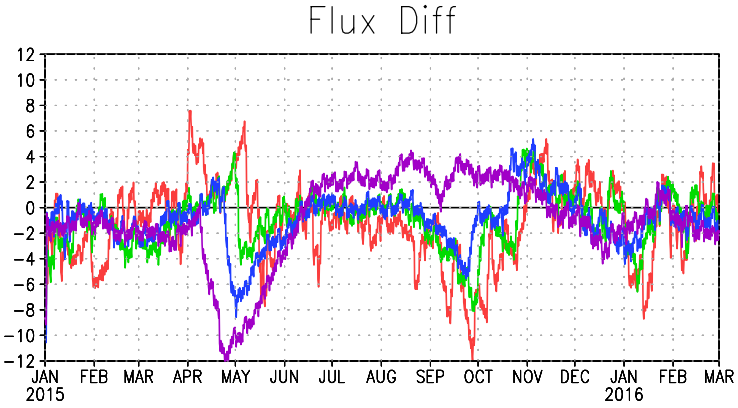


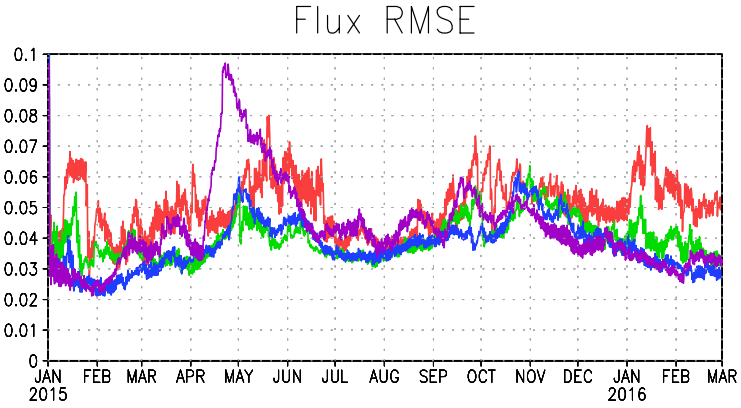


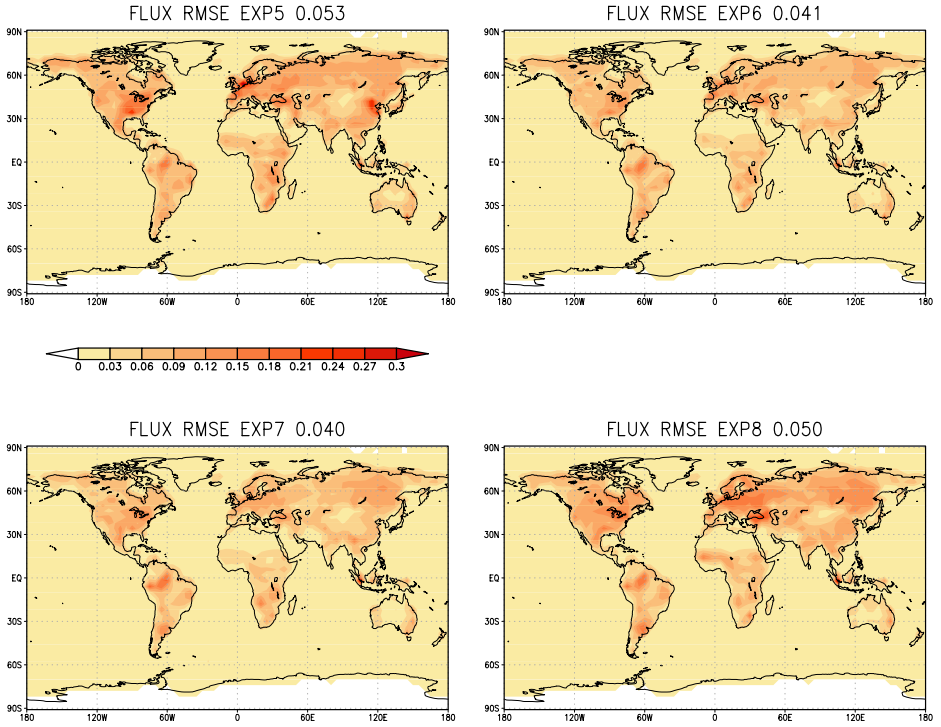
1-day assimilation window produce best results.

Sensitive of Observation window



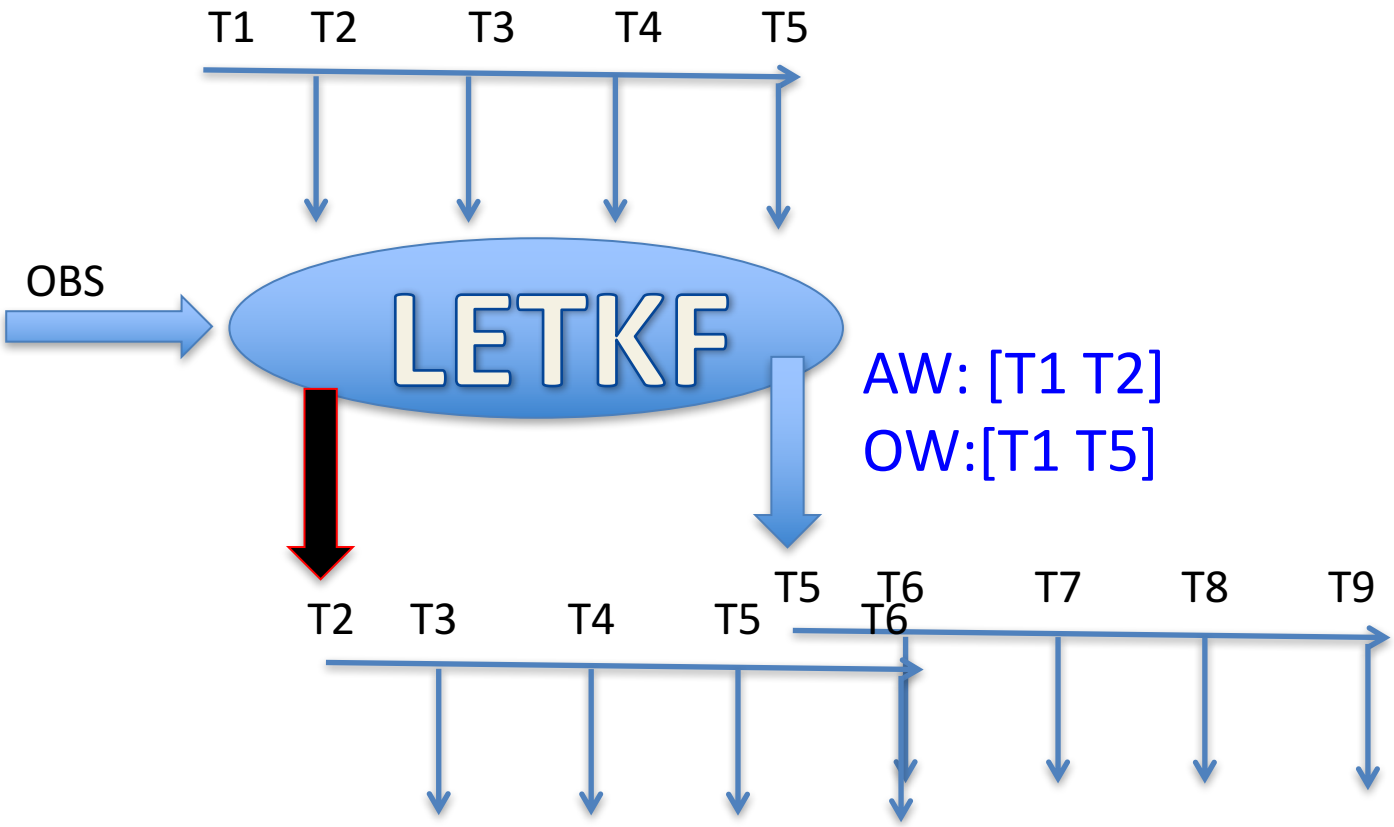






- A short assimilation window (1 day) with a long observation window of (8-15days) produce best results

AW and OW


T1
T2
T3
T4
T5
OBS
LETKF
AW: [T1 T2]
OW:[T1 T5]
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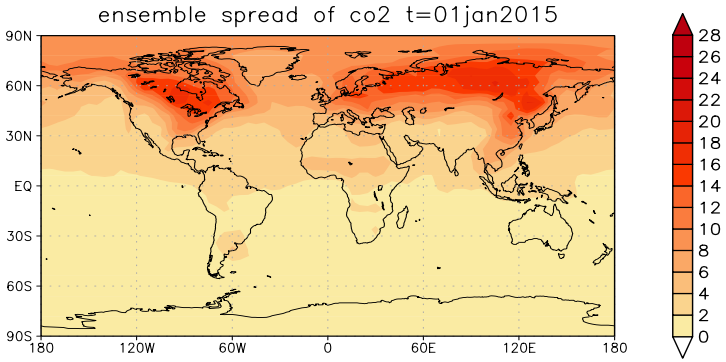
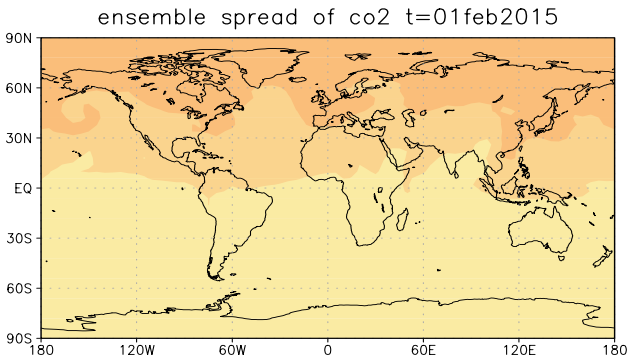
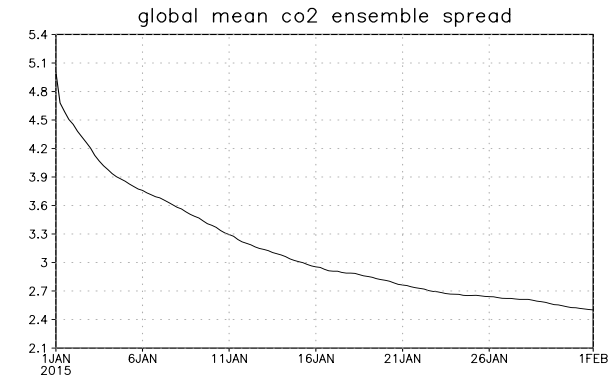
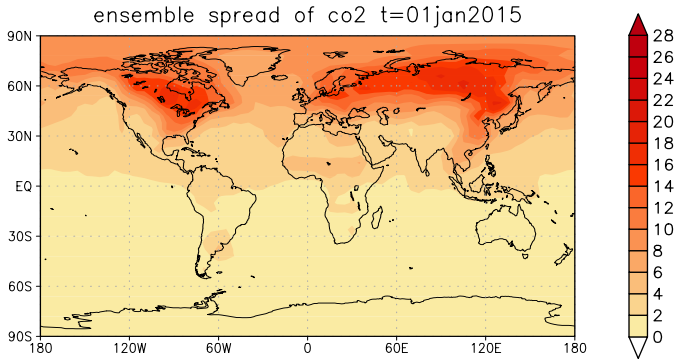
T5
T6
T6
T7
T8
T9

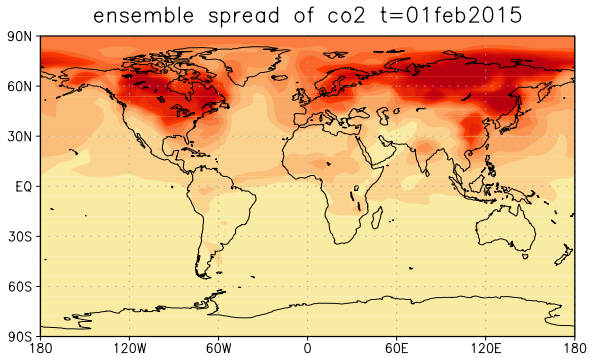
forward sensitive experiments (Ensemble spread)

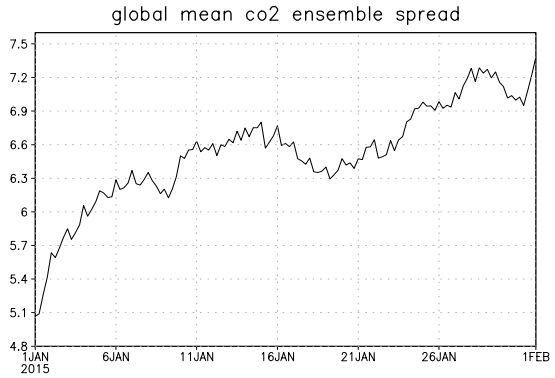












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