Data Assimilation Experiments using a Simple Coupled Ocean-Atmosphere Model

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INTRODUCTION

Coupled ocean-atmosphere data assimilation can be used for advancing and improving coupled model forecasts numerical weather prediction, and seasonal and interannual predictions. Challenges of coupled ocean-atmosphere data assimilation include differing time and spatial scales of the atmospheric and oceanic system vast range of growing instabilities of the system. We seek to investigate the performance of sequential and variational data assimilation methods using a simple coupled ocean-atmosphere model of different time scales and amplitude.

To study this problem, we consider a very simple triple coupled Lorenz (1963) model that includes a slow "ocean" component strongly coupled with a fast "tropical atmosphere component" in turn weakly coupled with a fast "extratropical atmosphere".

Simple Coupled Ocean-Atmosphere Model (Peña and Kalnay, 2004)

Extra-tropical Atmosphere

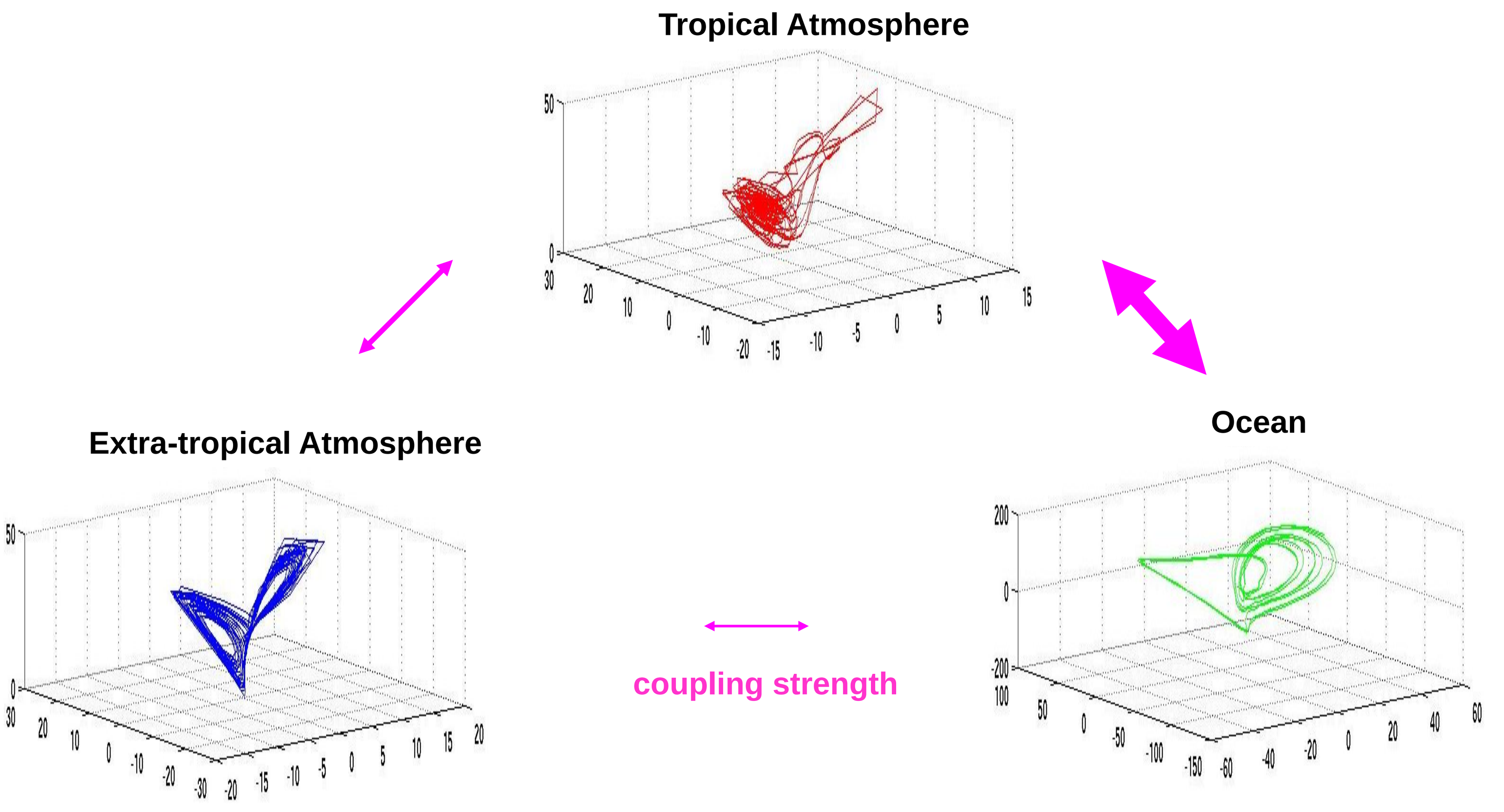
$$\dot{x}_e = \sigma(y_e - x_e) - c_e(Sx_t + k_1)$$
$$\dot{y}_e = rx_e - y_e - x_e z_e - c_e(Sy_t + k_1)$$
$$\dot{z}_e = x_e y_e - bz_e$$

Tropical Atmosphere

$$\dot{x}_t = \sigma(y_t - x_t) - c(SX + k_2) - c_e(Sx_e + k_1)$$
$$\dot{y}_t = rx_t - y_t - x_t z_t - c(SY + k_2) + c_e(Sy_e + k_1)$$
$$\dot{z}_t = x_t y_t - bz_t + c_z Z$$

Ocean

$$\dot{X} = \tau\sigma(Y - X) - c(x_t + k_2)$$
$$\dot{Y} = \tau rX - \tau Y - \tau SXZ + c(y_t + k_2)$$
$$\dot{Z} = \tau SXY - \tau bZ - c_z z_t$$



DATA ASSIMILATION METHODS

Sequential Methods

Method	Assimilating	Observations
ETKF	Fast and slow variables together	At analysis time
4D-ETKF *4-dimensional*	Fast and slow variables together	Throughout an assimilation window
ETKF-QOL *With quasi-outer loop*	Fast and slow variable together	At analysis time
LETKF *Submodel localization*	Fast and slow variables separately	At analysis time
4D-LETKF *4-dimensional with quasi-outer loop*	Fast and slow variables separately	Atmos: At analysis time Ocean: Throughout an assimilation window

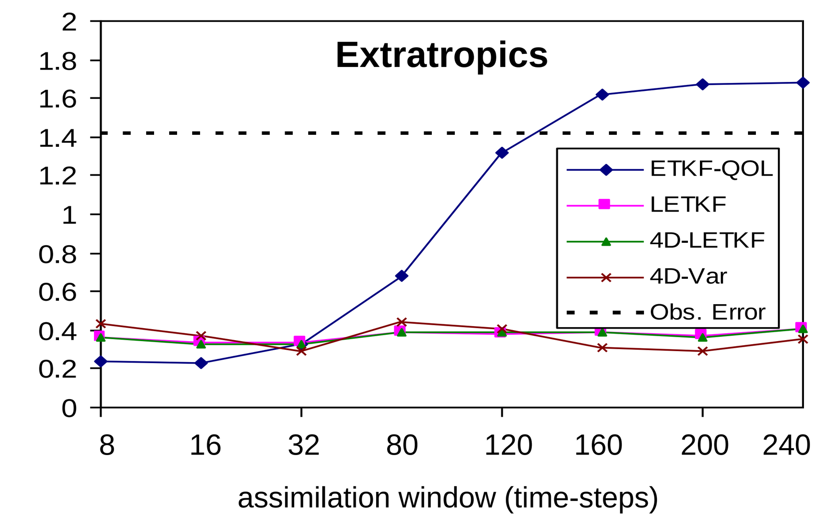
Variational Methods

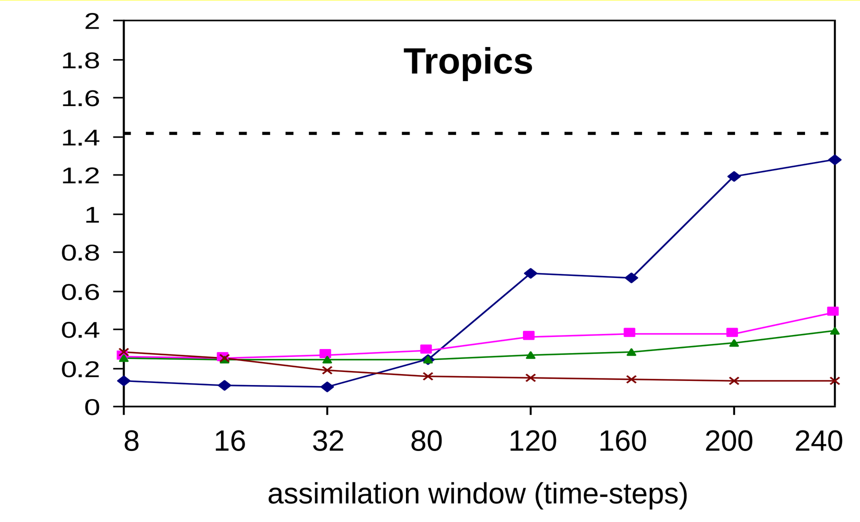
Method	Control Variables	Forecast Model
Fully Coupled 4D-Var	Initial model state	Simple coupled ocean-atmosphere model
ECCO-like 4D-Var	Initial ocean model state and trp-ocn fluxes	Ocean model forced by fluxes
Ocean 4D-Var	Initial ocean model state	Ocean model forced by fluxes

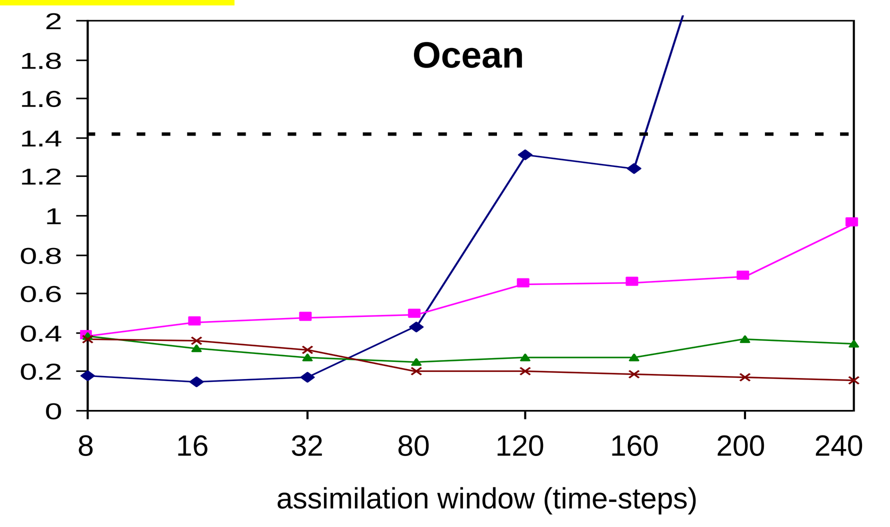
RESULTS

EnKF-Based Methods & Fully Coupled 4D-Var

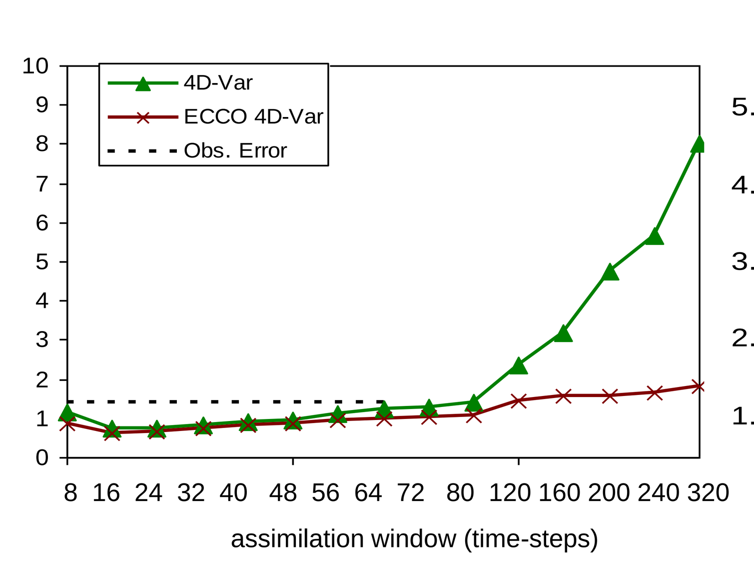
Mean RMSE

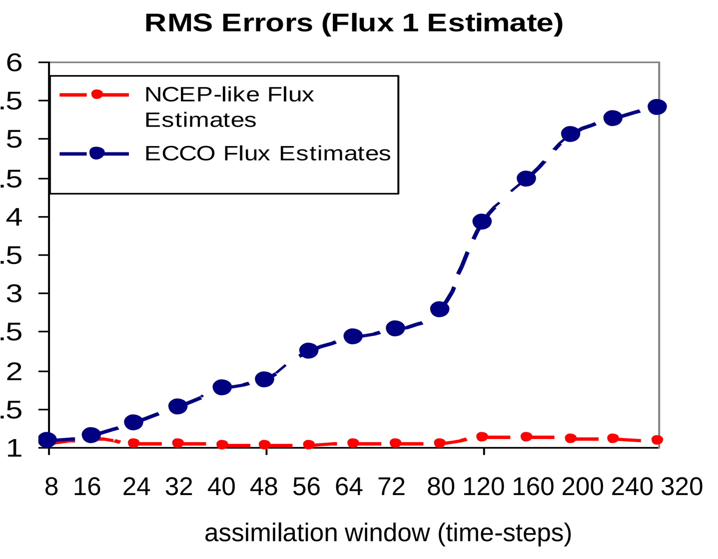


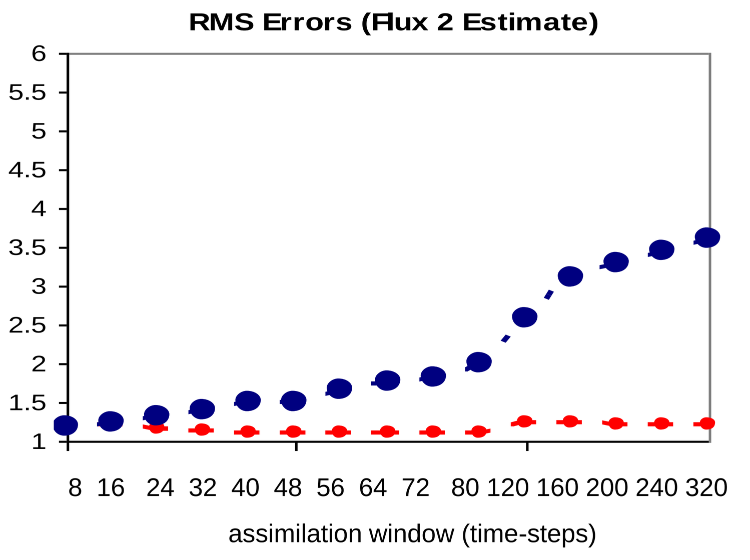


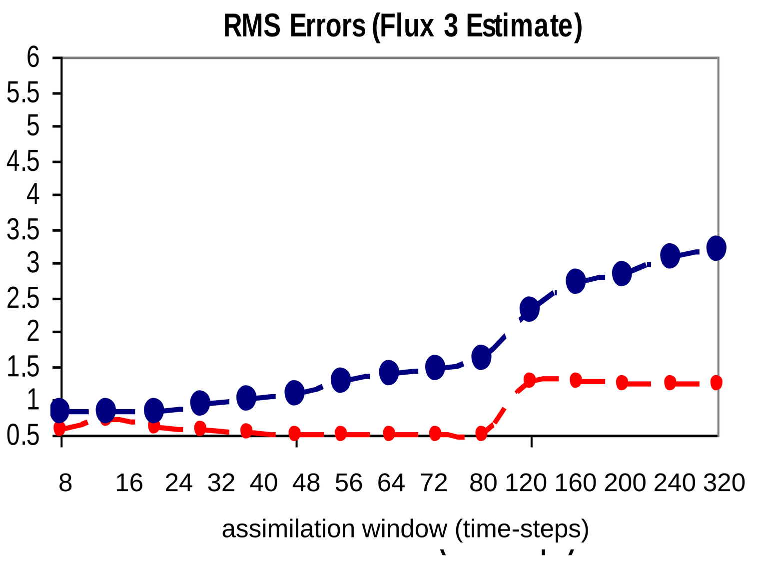


ECCO-like 4D-Var & Ocean 4D-Var









DISCUSSION

•EnKF-based algorithms without a quasi-outer loop or model localization experience filter divergence for long assimilation windows. As expected, their accuracy depends on the covariance inflation and number of ensemble members (we used a full-rank ensemble of 9 members.

• The fully coupled 4D-Var analyses provided a good estimate of the model states, but required the implementation of the Quasi-static Variational Analysis (QVA) as well as the tuning of the amplitude of the background error covariance.

• The best results for coupled EnKF were for short assimilation windows, whereas the best results for 4D-Var coupled assimilation were for long windows.

• The ECCO-like 4D-Var improves the 4D-Var ocean analysis that only use the initial ocean state as control variables, at the expense of improving the flux estimates that became progressively worse.

•Ocean only 4D-Var analyses became worse for very long windows.

Conclusions

The data assimilation experiments offer insight on developing and advancing sequential and variational data assimilation systems for coupled models.

Future work includes

- Performing data assimilation experiments with model errors
- Applying a QOL to 4D-ETKF and 4D-LETKF
- Applying adaptive inflation to EnKF-based methods (Li et al, 2009; Miyoshi, 2011
- Extend ECCO-like 4D-Var to much longer assimilation windows

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