Coupled data assimilation using a low order coupled atmosphere-ocean model

Maxime Tondeur[1,2], Alberto Carrassi[2], Stephane Vannitsem [3]& Marc Bocquet[4]

(1) MINES ParisTech (France) - (2) NERSC (Norway) - (3) Royal Meteorological Institute of Belgium - (4) Ponts Paristech (France)

maxime.tondeur@mines-paristech.fr

OUTLINE

The finite-size Ensemble Kalman Filter (EnKF-N) is used on a low order coupled atmosphere-ocean model. The model has two different time scales of evolution with the atmosphere being faster than the ocean. The goal is to study coupled data assimilation. Stability of analysis is done to study model dynamical properties and to choose a set up as a benchmark. Different observational distribution as well different size of ensemble are considered with strongly coupled assimilation. We finally compare the strongly and weakly formulation.

Model description

The model is the Modular Arbitrary-Order Ocean-Atmosphere Model (MAOOAM) developed by Stephane Vannitsem and collaborators ([2]). The system is described by the evolution of the temperatures and the streamfunctions of the ocean and the atmosphere. These quantities are expanded into a Fourier basis of variable length. The resulting model used in the present study possesses 36 ODEs of which, 20 dimensions are assigned to the atmosphere and 16 to the ocean.

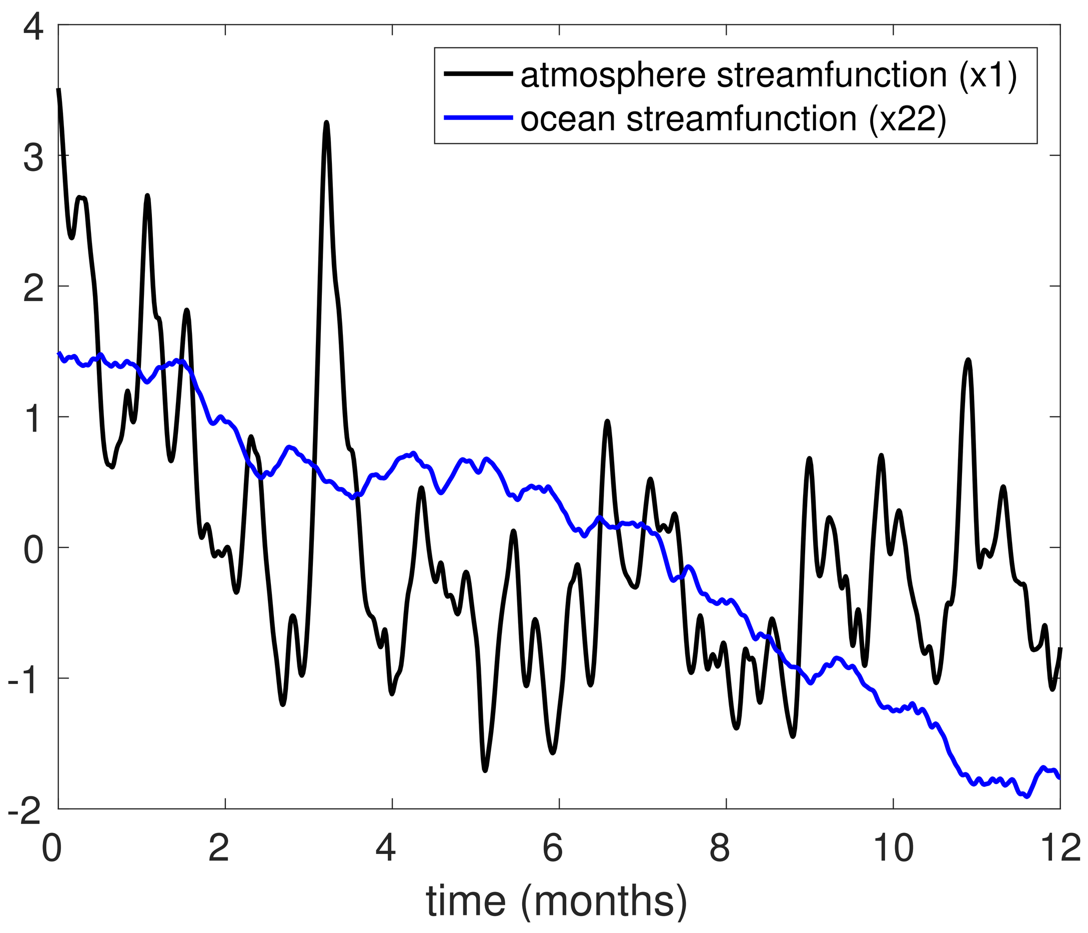

Figure 1: Model evolution - Normalized time series of the 1st and 22th component of MAOOAM during one year. The different of time scale between the ocean and the atmosphere are visible.

Stability Analysis

We compute the spectrum of Lyapunov exponents for different values of parameters. Figure 2 shows the number of positive, negative and null exponents for four different values of d the friction coefficient between the ocean and the atmosphere. In yellow there are the positive values, in green the null values and in blue the negative values.

There are the same studies for 2 other physical coupling parameters :

- C_o which is the net short-wave radiation input for the ocean
- λ heat exchange between the ocean and the atmosphere

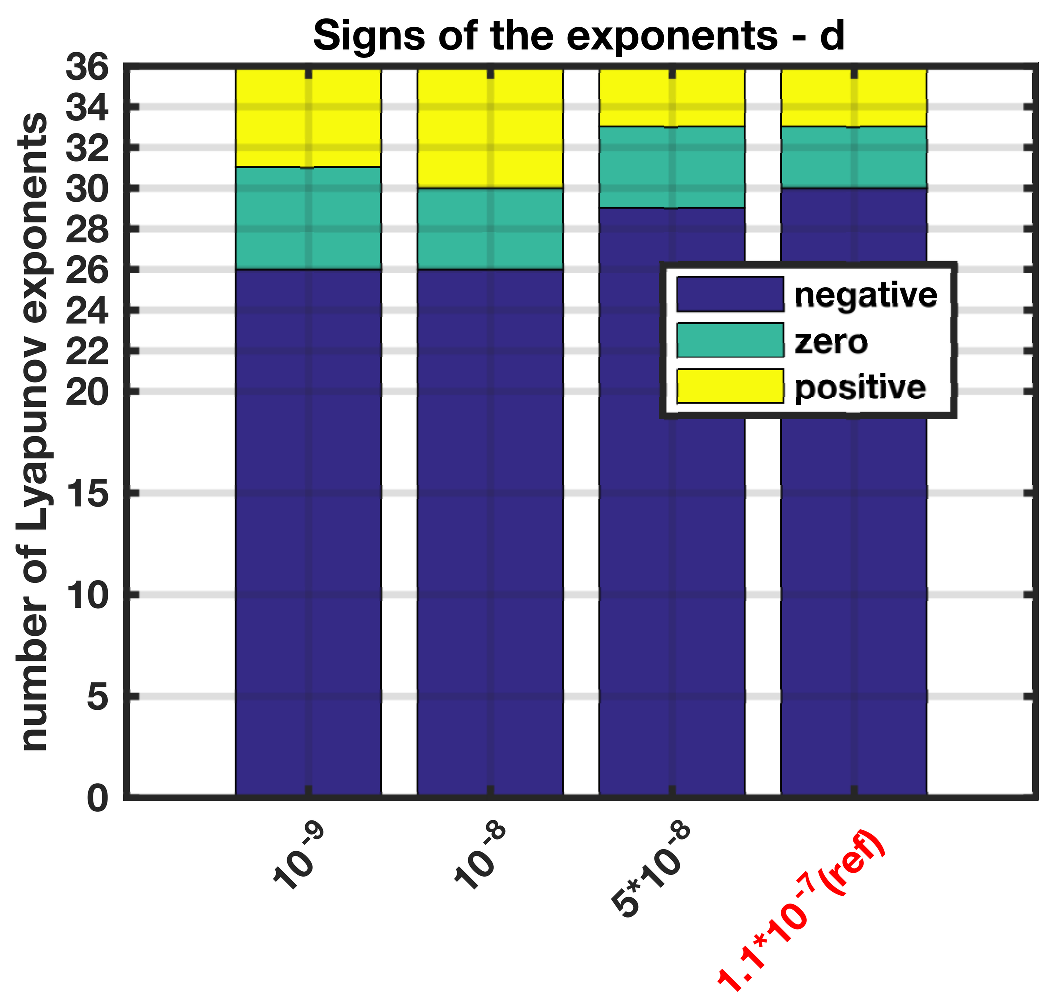

Figure 2: Signs of the Lyapunov exponents as a function of the physical parameter d - Signs of Lyapunov exponents for different values of the physical parameter d. Yellow for positive, green for null values and blue for negative values. The red value of d is the reference for the stability analysis. If we decrease d, there are more positive Lyapunov exponents, so the system is more chaotic.

The higher the Lyapunov exponents are, the more chaotic the system is. To study the spectrum, we compute the signs, the Kolmogorov entropy and the Kaplan-Yorke dimensions. We deduce that if we want to be more chaotic, we have to decrease d, increase C_o or decrease λ. C_o seems to be the most influential parameter. Finally we take a specific set of parameters with $d = 6*10^{-8}s{-1}$ with an error doubling time of 2 days and 11 non-negative Lyapunov exponents.

Data Assimilation

In Data Assimilation, the Ensemble Kalman Filter method (EnKF) seeks to mimic the analysis step of the Kalman filter with an ensemble of limited size to simulate the covariance matrices. The version we use (named EnKF-N [1]) does not require multiplicative inflation meant to counteract sampling errors is used.

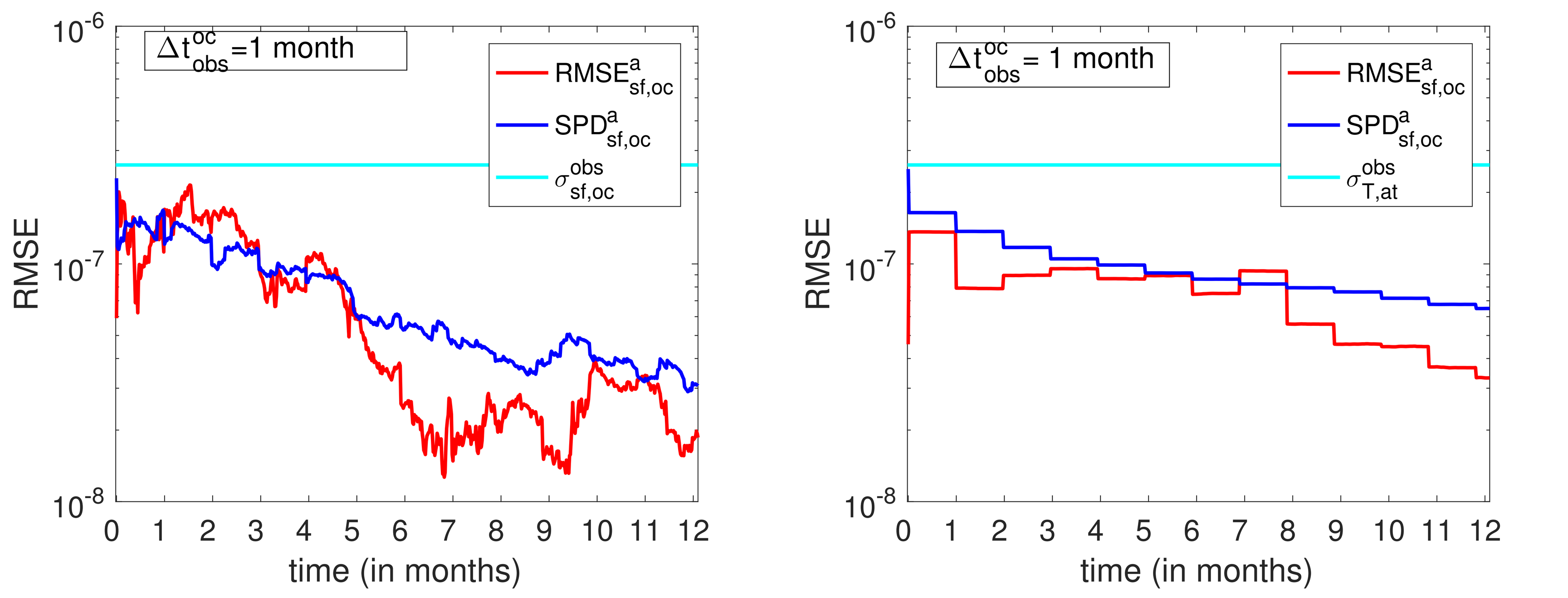

Figure 3: RMSE as a function of time with strongly and weakly formulation with N=15 - Ocean streamfunction assimilation during one year (X-axis). The standard error is in cyan, the RMSE and the Spread are under it in both case. The atmosphere observation frequency is 12 hours and the ocean 1 month. Weakly and Strongly assimilation has different patterns but the trends seem to be the same.

With the set of parameters, we launch twin experiments with an observation error of 1% of the climate variance. We compute the Root Mean Square Error (RMSE) and the spread (SPD) during 1 year. Figure 3 and Figure 4 compare the strongly and the weakly formulation.

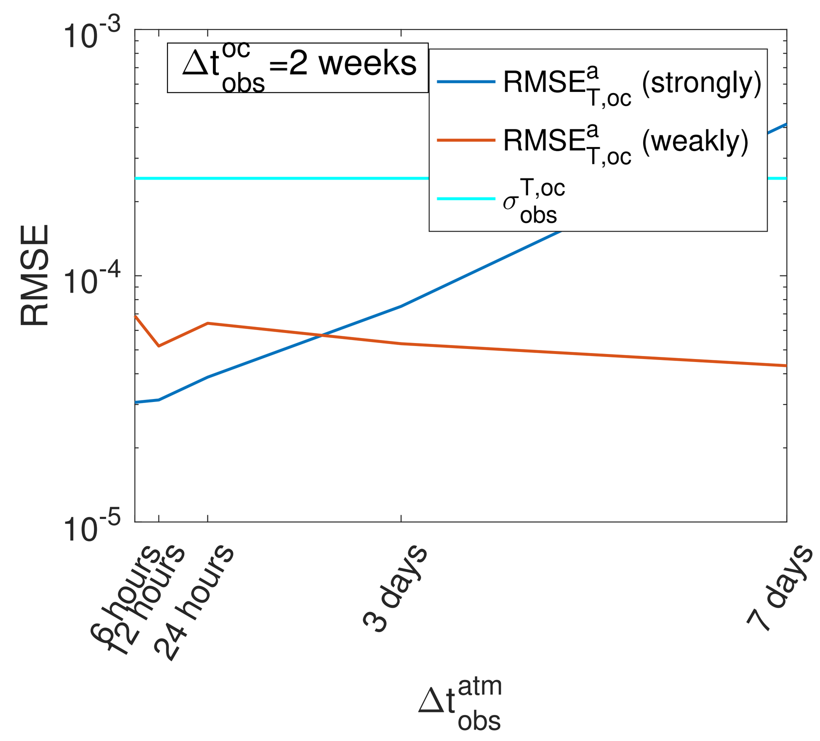

Figure 4: RMSE as a function of the atmospheric observation frequency The analysis error for weak (red) and strong (blue) coupled data assimilation is displayed vs the observation frequency in the atmosphere. The horizontal line (cyan) depicts the observation error level.

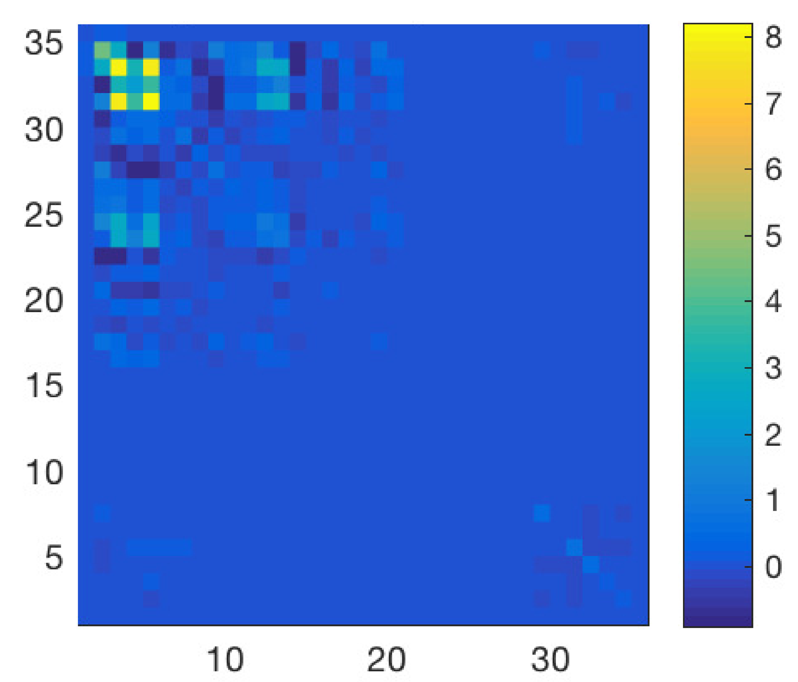

Figure 5: Analysis covariance matrices at t=12 months with $\Delta t^{full}_{obs} = 24 hours$ and N=15 (strongly coupled) - The coupled terms does not seem enough correlated.

Summary

- RMSE and SPD are both under the initial error given to the system and SPD is under RMSE for an observation frequency.
- The performances are improving for bigger ensemble size N of the ensemble with a good compromise for N=11 the number of non-negative Lyapunov exponents.
- If we observe only the ocean (resp. only the atmosphere), we loose the control of the atmosphere (resp. the ocean).
- Covariance matrices have not big values, the ocean and the atmosphere are maybe not enough correlated as shown in Figure 5.
- strongly formulation seems to be better than weakly formulation in the majority of the cases.

References

[1] M Bocquet, PN Raanes, and A Hannart. Expanding the validity of the ensemble kalman filter without the intrinsic need for inflation. *Nonlinear Processes in Geophysics*, 22(6):645, 2015.

[2] S Vannitsem and L De Cruz. A 24-variable low-order coupled ocean–atmosphere model: Oa-qg-ws v2. *Geoscientific Model Development*, 7(2):649–662, 2014.

Acknowledgments

Maxime Tondeur and Alberto Carrassi have been funded by the Nordic Centre of Excellence EmblA of the Nordic Countries Research Council, NordForsk.