Reduced dimension Kalman filter for fast regional ocean weather forecasting

Imperial College London

César Quilodrán, Ralf Toumi and Nathan Sparks
Space and Atmospheric Physics, Department of Physics, Imperial College London

Motivation Data assimilation (DA) methods are highly valuable in climate sciences, whether to reduce model uncertainties and to have a better representation of the observed real world. Nevertheless, since the high dimensionality and nonlinearity of these models, this can be extremely computationally expensive. The project aims to solve this cost-benefit problem by using fast DA in dimensional-reduced regional ocean models, in order to improve ocean weather forecasting.

The Method Daily outputs from variables are obtained from a 10 km resolution ROMS model (full space: FS), which spans from 2001 to 2010. The procedure consists of two stages (Frolov et al. 2009). During the first stage, an Empirical Orthogonal Function (EOF) analysis is applied on FS to reduce its high dimensionality. To save memory, the grid is divided into sub grids where the EOF analysis is done individually. The compound of these subproblems creates the reduced space (RS). An adequate amount of EOFs are retained. To replicate the physical model, the RS is trained using an autoregressive artificial neural network (ANN). An Ensemble Kalman Filter (EnKF) is utilised during the second stage, where the ANN provides short range forecasts from the ensembles (Fig. 2).

The Region Comprises the area between 45-64W and 2S-12N. The area is dominated by the North Brazil Current; and the Orinoco and Amazon rivers. The NBC originates from NEC, and travels NW bordering the South American continent. When this current weakens, it changes direction feeding the NEUC and superficial anticyclonic eddies known as the "NBC rings" are created. The rings advect until the Lesser Antilles where they are destroyed.

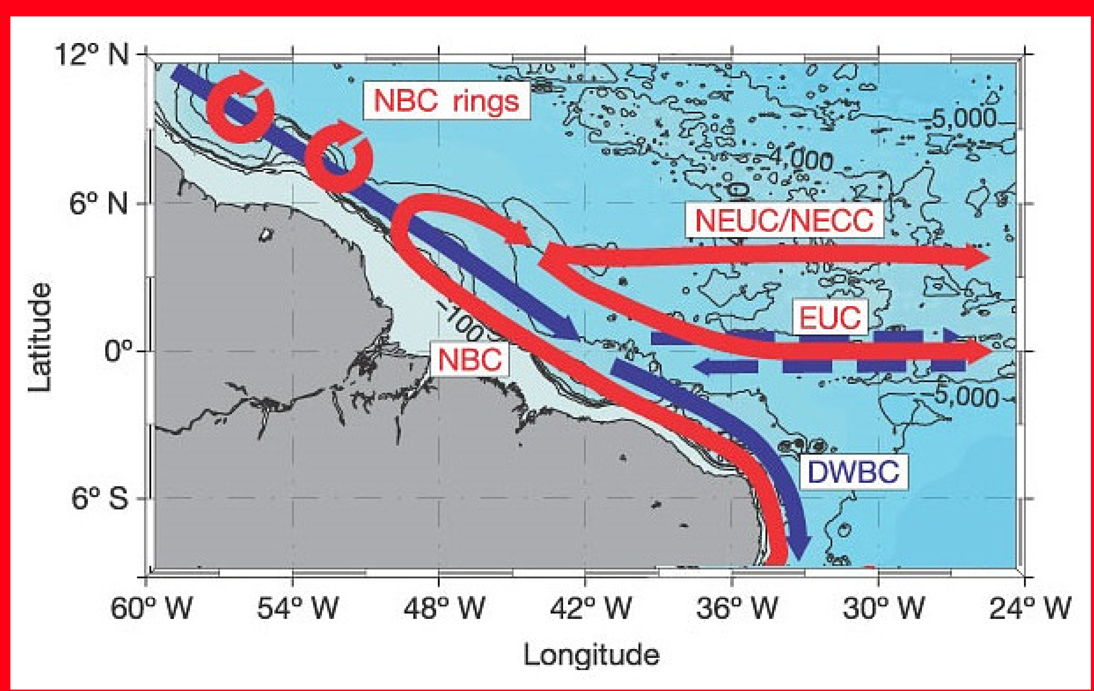

Fig. 1 Schematic flow paths in North Brazil. Warm water paths (red): the North Brazil current (NBC), the Equatorial undercurrent (EUC), the North equatorial undercurrent/countercurrent (NEUC/NECC). Cold water paths (blue) include the deep water boundary current (DWBC). Modified from Dengler et al. (2004)

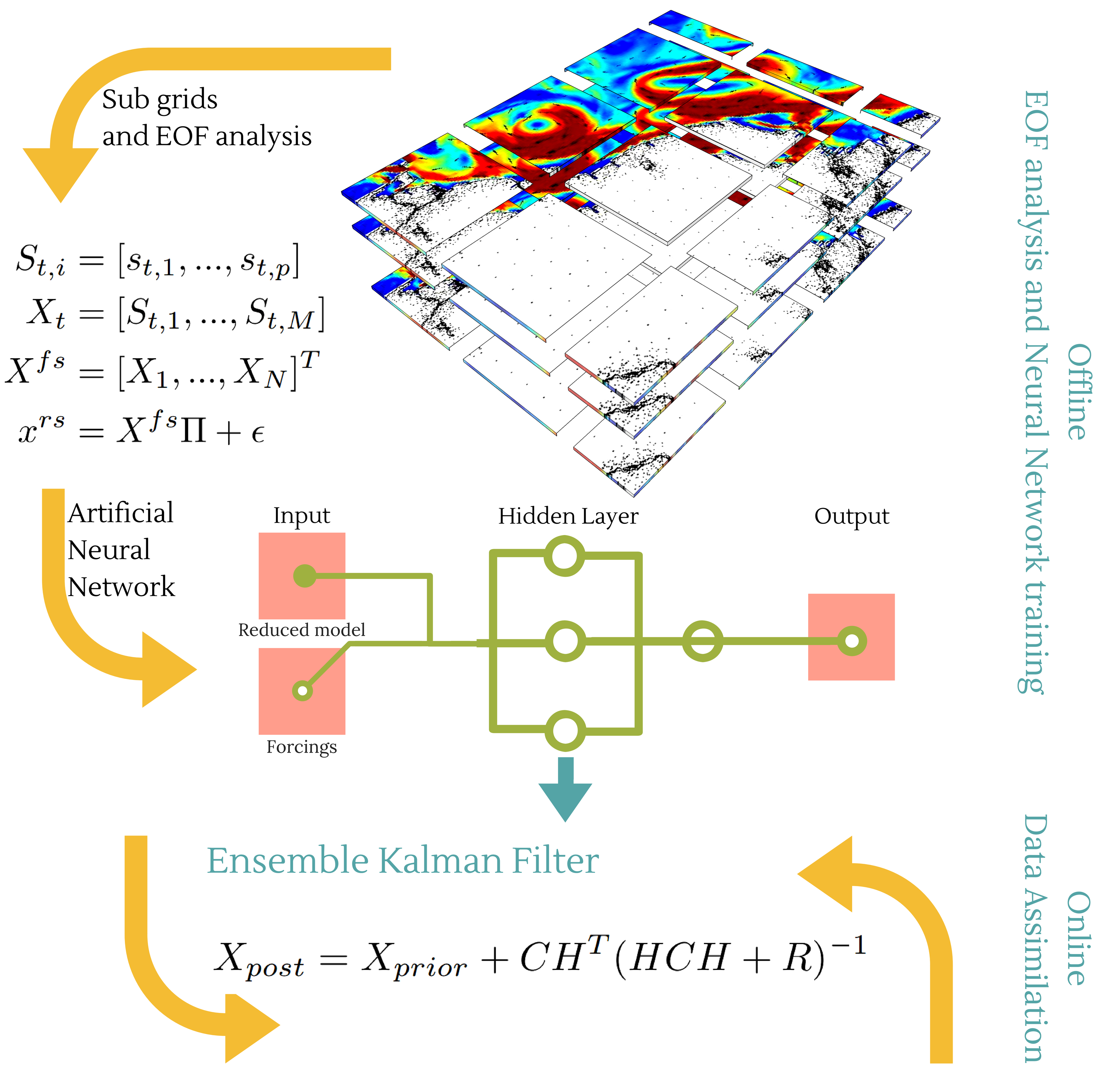

Fig. 2 Schematic diagram of the utilised framework. The first stage includes a division in subgrids (S) and a subsequently EOF analysis on each one of them. The compound of these creates the reduced dimension dataset (x), which then is trained using an ANN. This replicates the full physical model needed for the EnKF. Here, C and R are the covariance matrices of the model and the observations, respectively, and H is the interpolation function. The process is iterative and creates a posterior from a rectified prior state.

Results Here, the first 50 EOFs hold ~85% of the variability when sea surface temperature (SST), sea surface height (SSH), and U and V current components are considered. The retained variability (Fig. 3) ranges from 79% to 99.8% when using different combinations of these four variables. Observational data is obtained from GHRSST, AVISO, and OSCAR to assimilate and validate SST, SSH and currents, respectively.

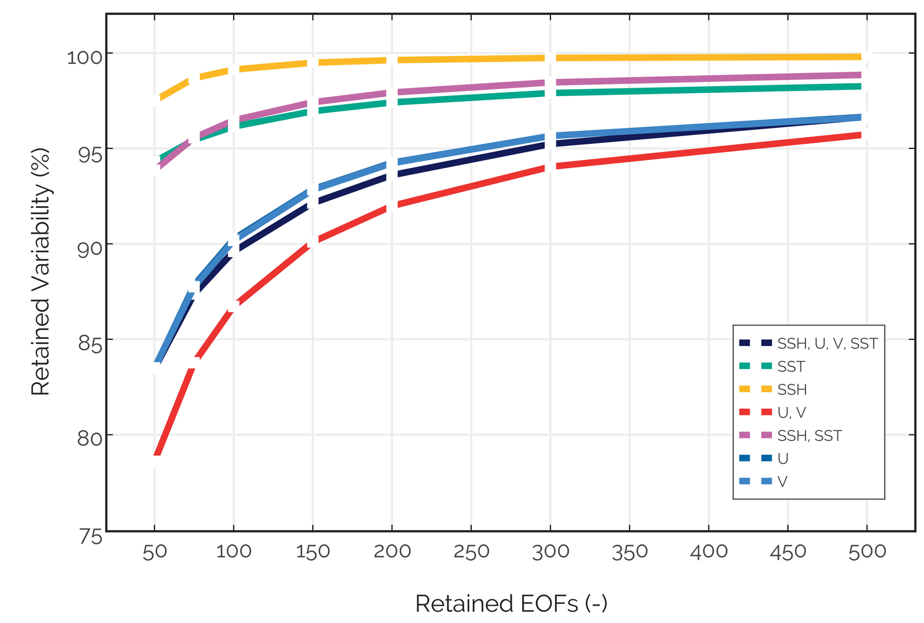

Fig. 3 Comparison of retained variability respect to number of EOFs kept. Ocean currents present high variability and need more EOFs to represent this.

The DA was performed outside the training period (2011) using 50 ensemble members. Only SST has been assimilated so far. The influence of assimilated SST on other variables can be seen in fig. 4. In average, it is possible to assimilate 30 days in less than 30 minutes, without the use of a "supercomputer". This creates improved initial conditions in order to create better forecasts. The results are highly dependent on the setup parameters of the ANN and the EnKF.

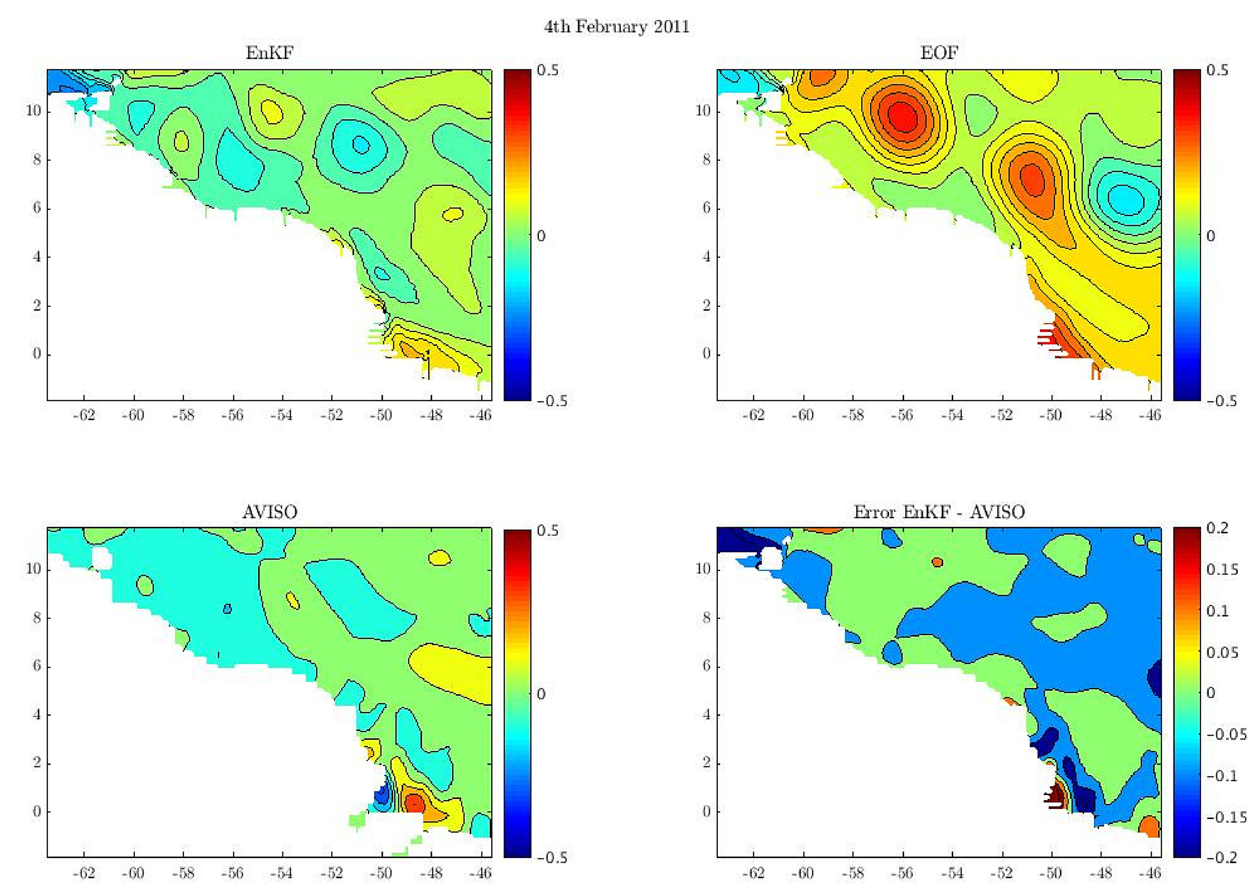

Fig. 4 Snapshot of change in SSH (m), when SST and SSH are being assimilated. Top Left: SSH after the assimilation; Bottom left: Observations from AVISO data; Top right: EOF Reconstruction from ROMS model; Bottom right: Differences between before and after the assimilation when compared to AVISO data during the same day. The assimilation changes the pattern and reduces the RMSE between the model and the observations by 0.1 m.

Conclusions This framework proves to be faster than other DA methods, nevertheless EOFs do not represent the whole variability of the model. In the future, more variables will be assimilated and their influence over ocean currents will be assessed. Other reanalysis datasets and novel data driven methods might be tested also. By using this methodology, ocean weather forecasting remains a work in progress, but is becoming increasingly more accurate.

References
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Dengler, Marcus, et al. "Break-up of the Atlantic deep western boundary current into eddies at 8 S." Nature 432.7020 (2004): 1018-1020.

Contact: cesar.quilodran-casas13@imperial.ac.uk