Developments of a dynamically consistent targeting and assimilation method

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The ability of a data assimilation system to control the instabilities, present in the forecast error and responsible for error growth, can be improved by the combination of targeting strategies and dynamically consistent assimilation. The benefit of adaptively located observations is greatly enhanced if their positions and their assimilation are designed in order to target the instabilities, estimated by Breeding on the Data Assimilation System (**BDAS**). The analysis update has locally the same structure as the unstable structure whose maximum is in the location chosen for the adaptive observation. In this way, advantage can also be taken of an existing, fixed observational network, as long as this is is adequate to detect the migrating instabilities. These concepts are demonstrated by means of observing system simulation experiments with a quasi-geostrophic atmospheric model and with a primitive equation oceanic model.

A presentation of the method with a small nonlinear model can be found in: Trevisan, A. and F. Uboldi, 2004. Assimilation of Standard and Targeted Observations within the Unstable Subspace of the Observation-Analysis-Forecast Cycle System. *J. of Atmos. Sci.*, **61**, 103-113.

QG ATMOSPHERE MODEL

The model is a 64x32 grid, 7 levels periodic channel; the *land* area (longitudinal grid points 1-20) is completely covered by observations, always assimilated by a 3DVAR scheme. 1 adaptive observation is located over the *ocean* (longitudinal grid points 21-64) and is assimilated either with the proposed scheme, or, for comparison, with the same 3DVAR scheme used on land.

The unstable subspace of the data-forced system is estimated by means of BDAS, a modified breeding technique where all perturbed states undergo the same assimilation processes as the control state. A "regionalization" procedure is used to isolate maximum/minimum structures present in the forced bred vectors, and the analysis increment is confined in the subspace spanned by these structures. In this application only one unstable structure is used at each analysis time, and the adaptive observation is located in the maximum of the current structure, **e**. This vector is then used to assimilate the observations. For a scalar observation y^o:

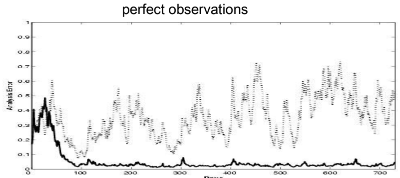
$$\mathbf{x}^a = \mathbf{x}^f + \mathbf{e}\,\frac{y^o - \mathbf{Hx}^f}{\mathbf{He}}\,\frac{\gamma^2(\mathbf{He})^2}{\gamma^2(\mathbf{He})^2 + \sigma^2}$$

where **H** is the linear observation operator. The last factor on the right-end side, used for a noisy observation, is estimated from the average over an appropriate time interval of the innovation, and it is equal to 1 when the observation is perfect. For further details and results, see :

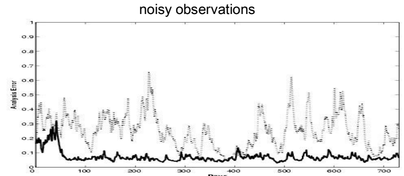
Carrassi, A., A. Trevisan and F. Uboldi, 2005. Deterministic Data Assimilation and Targeting by Breeding on the Data Assimilation System. *J. of Atmos. Sci.*, under review.

The two panels below show the global analysis error as a function of time. The error is expressed as total potential enstrophy and is normalized by natural variability. The two panels refer to the cases of perfect observations (left) and noisy observations (right). In both panels two experiments are compared: 1) Dotted line: the adaptive observation consists of a complete T, U, V vertical profile and is assimilated with 3DVAR; 2) Continuous Line: the adaptive observation consists of a single scalar temperature and is assimilated with the proposed method. In both cases the adaptive observation is placed in the location where the current bred vector attains its maximum amplitude.

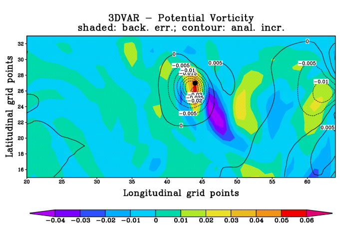
perfect observations

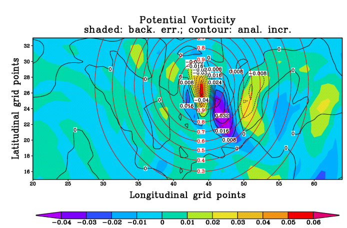


noisy observations



The two panels below show how , with the same background field, an observation in the same horizontal position is assimilated by 3DVAR (left) and by the proposed method (right). The "shaded" field is the forecast (background) error, and the contoured field is the analysis increment. In the case of 3DVAR a complete T,U,V vertical profile is assimilated, while in the case of the proposed method just a single scalar temperature observation, located at the highest level, is assimilated.

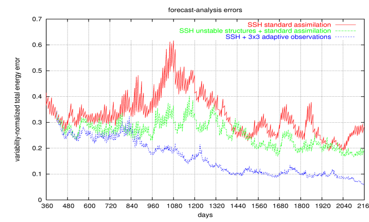




PRIMITIVE EQUATION ISOPYCNAL OCEAN MODEL "MICOM"

The configuration is a rectangular box with 180x140, 20km grid and 4 isopycnal layers (0-5000m). Perfect model, perfect observations. BDAS is implemented here with 36 perturbed trajectories, and the unstable structures are extracted from sets of 6 bred vectors at a time. A description of how the unstable structures are estimated and how they are used with the "standard observation" SSH field can be found in:

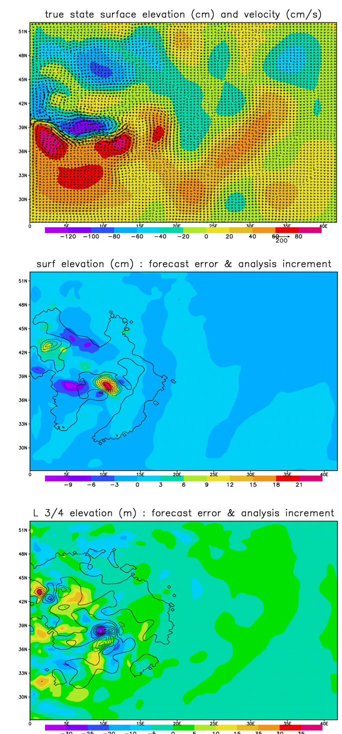
Uboldi, F., Trevisan, A. and A. Carrassi, 2005: Developing a Dynamically Based Assimilation Method for Targeted and Standard Observations. *Nonl. Pr. Geo.*, **12**, 149-156.



The panel on the right shows the sequence of forecast and analysis total energy errors, normalized with natural variability. RED: standard Cooper-Haines assimilation of "satellite" Sea Surface Height every 10 days. GREEN: the observed SSH field is used for eliminating the forecast error component on the estimated unstable subspace at standard analysis times. BLUE: 3 adaptive observations are added on days +2.5, +5.0, +7.5 after each SSH analysis, and assimilated with the proposed method.

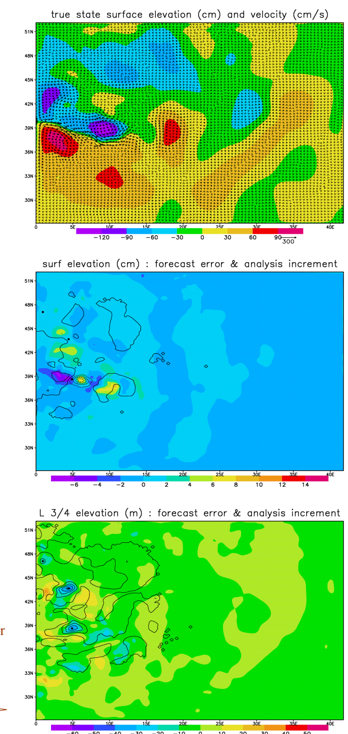
Complete results with standard and adaptive observations with this ocean system will be included in a manuscript in preparation.

day 1940 - assimilation of SSH only:



Day 1940 (of the blue curve above). The observed SSH field is assimilated first with proposed method for eliminating the selected unstable structures.
A standard assimilation is performed afterwards, using the previous analysis as a background field.
Here the corresponding forecast error (colour) and analysis increment (black contour) are shown at the surface and at the interface between layers 3 and 4.
Note the complex vertical structure of the signals, and how the correlation between forecast error and analysis increment is conserved in the deeper layers.

day 1935 - assimilation of 3 adaptive observations:



Day 1935 (of the blue curve above). The horizontal locations of the 3 adaptive observations are shown as black dots. The observed variable is the elevation of the interface between isopycnal layers 3 and 4: this quantity can be obtained by measuring a vertical profile of temperature and salinity.
Note the vertical tilt of the structure at 6E,38N and how the forecast error (colour) and analysis increment (black contour) are correlated at the surface, too.