ASSIMILATION OF ALTIMETRIC AND SEA SURFACE TEMPERATURE OBSERVATIONS IN A COASTAL MODEL: AN EXPLORATORY STUDY WITH AN ENSEMBLE KALMAN FILTER. ANALYSIS OF REPRESENTERS IN FREE SIMULATIONS

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ABSTRACT

As a first step towards the set-up of a data assimilation system based on the Ensemble Kalman Filter (EnKF), we explore the space-time structure of the influence functions of sea surface temperature (SST) observations using stochastic modeling. Our ultimate goal is to constrain our ocean circulation model with high-resolution SST products and altimetric data. We are working in the Bay of Biscay (North-East Atlantic), and use the regional model SYMPHONIE. In this study, the influence functions, or 'representers', are analyzed from an ensemble of simulations. The ensemble is generated by perturbing the wind forcing as we consider that the main source of errors in the simulations are stemming from uncertainties in the wind field.

1. INTRODUCTION

This study presents an analysis of *representers* (influence functions) of sea surface temperature (SST) observations in a coastal model. It is a preliminary and necessary step before the set-up of an assimilation system based on high resolution SST products from the GHRSST (Global High Resolution SST) project. Modeling and assimilation in coastal areas present specific challenges because of (1) the numerous physical processes that need to be taken into account and (2) the wide range of their associated spatial and temporal scales. In particular, the ocean response to high frequency (O(1 day)) atmospheric forcing on the shelf, barotropic and internal tides, coastal waves, mesoscale eddies and instabilities of slope currents are critical mechanisms for the dynamics and hydrology on the shelf and on the slope. In such a context, data assimilation can effectively constrain the model if the method is able to take into account the complexity of the model error subspace. For this reason, we are working with an EnKF method where the full multivariate forecast error covariances are evolved according to nonlinear dynamics and used in the analysis steps. Our interest is on time scales of a few days, with a focus on the surface layers and heat content variability. The area of study is the Bay of Biscay.

For a given observation point, a representer is the influence function of the assimilated variable onto the model state space at the analysis time (see for instance [1]). Here, we analyze SST and, to a lesser extent, SSH representers in temperature, that is the impact of the assimilation of an SST or an SSH measurement at given point and date onto the model temperature field. The zero time lag representers are estimated by the covariance $< \Phi(x_0),T(x,z)>$, where x_0 is the observation point, Φ is the SST or SSH model variable and $T(x,z)$ the model temperature field at point x and level z.

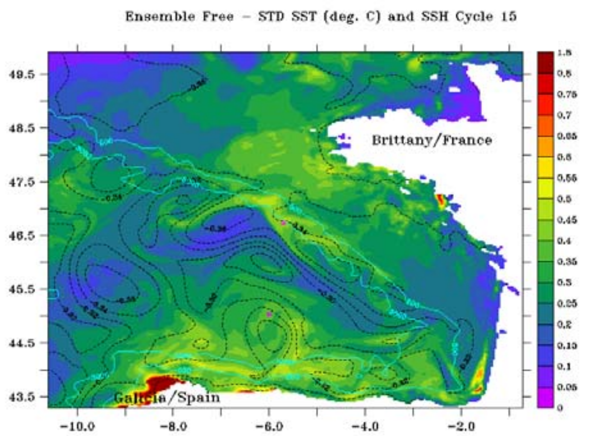

Figure 1: Ensemble spread in SST (colors) for July 17; units are °C. Contours represent the sea surface height for the same date.

2. EXPERIMENTAL SET-UP

We use the SYMPHONIE coastal OGCM ([2], [3]) in a realistic configuration of the Bay of Biscay. The model has 43 generalized sigma levels and 3 km horizontal resolution. It is forced with the Météo-France ALADIN 3 hourly atmospheric fields and with MERCATOR products at the open boundaries.
We generate an ensemble of simulations by perturbing the wind stress forcing, in an attempt to represent one major source of errors for numerical models in that area. The perturbations are built as described in [4], [5]: first, we estimate the main 10 bivariate EOFs of the wind

stress zonal and meridional components variability over the period of study; the perturbations on each component consist then in a random linear combination of the EOFs. Both the EOFs spatial structure and time series are taken into account in the perturbations. An ensemble of 19 members is generated on our local cluster. The ensemble size is limited in this preliminary step because of computational cost. It is likely too small for derived statistics to be used when starting the EnKF. However, we believe that these exploratory results are providing useful information on the main signals in the representers structure and on issues that need to be addressed before starting data assimilation. All the 19 simulations start from the same initial conditions; the period of integration is July-August 2004. This study is a first step towards the set-up of data assimilation experiments where high-frequency (at least daily) SST products are assimilated: in this presentation, we therefore focus on short-time scales. The representers analysis is carried out for three dates: July 17, 21 and 30. Between July 17 and July 30, the SST increases south of 47°N, with a maximum in the southeast. Eddy signatures are detected in the abyssal plain and along the Armorican slope. An intense cyclone is observed off the slope at ~ 7°W throughout the entire period of study. At its periphery, it induces a filament-shaped cold SST structure stemming from the shelf towards the plain, then on to the southeast. Upwellings take place south of Brittany and on the Galician coast (around 8°W). M. Le Hénaff [6] notes that the Galician upwelling occurs during two distinct events (12-18 July and 24-30 July) characterized by favorable wind conditions.

3. RESULTS AND DISCUSSION

The ensemble spread (*i.e.* standard deviation across the ensemble) in SST varies between 0.05°C and 1.8°C (e.g. Fig. 1 for July 17). Large spatial gradients as well as significant time variability are observed. Maximum spreads are reached in the Galician upwelling on July 17 and 30; as this structure is generated by wind forcing, its sensitivity to wind perturbations is high. The SST spread is increasing with time south of 47.5°N, except in the south-eastern corner. We suggest that, as the surface layers get warmer and the mixed-layer shallower, the SST sensitivity to changes in vertical mixing induced by wind perturbations becomes larger. In the abyssal plain, the spread seems to be correlated to the mesoscale fields with larger values at the eddies periphery: this is clear on Fig. 1, where a patch of large spread coincides with the cold SST around the cyclone at 7°W mentioned earlier.

SST representers have been estimated at different points. Fig. 2 shows for example the representers in SST (covariance <SST(x_0), SST(x)>) for points 14 and 7 in the abyssal plain at 45°N, and on the slope at 46.7°N respectively. The structure of the representers shows complex patterns that differ significantly according to the point and dates where they are estimated: these patterns result from the particular combination of error subspace processes at that location and time.

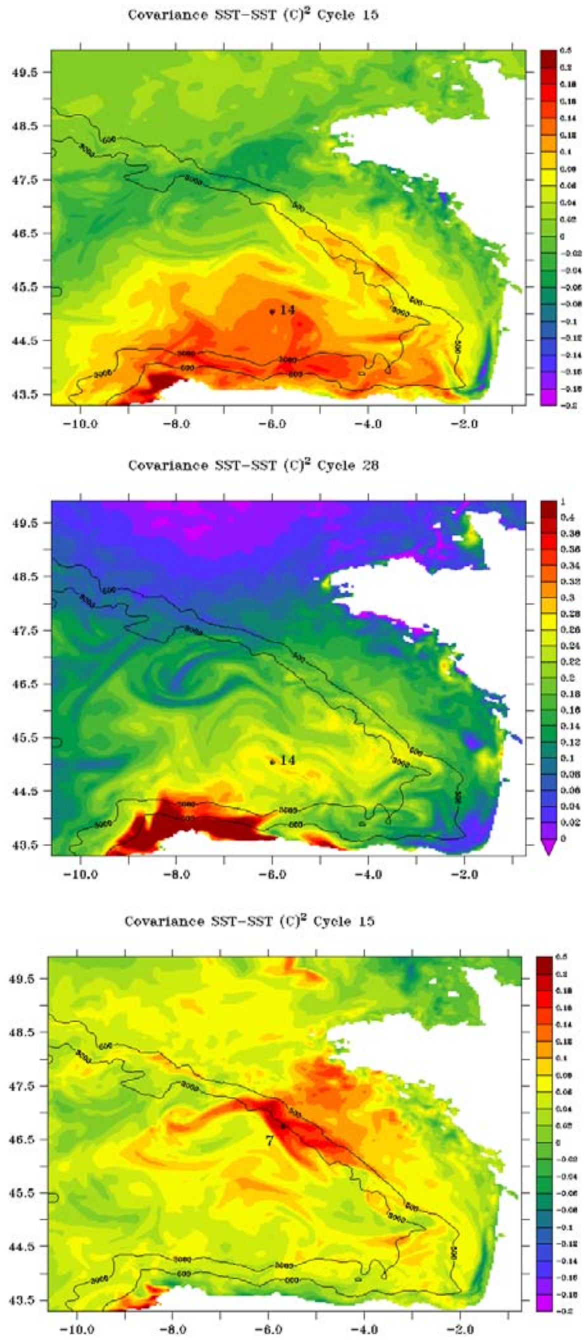

Figure 2: Influence functions (in °C.°C) on the model SST field of individual observations of SST at points 14 and 7: representer at point 14 for July 17 (top) and July 30 (middle), at point 7 for July 17 (bottom). Note that the color scale is different for the middle map.

Large scales of positive covariances are linked to the summer SST warming in the southern part of the basin; some redundancy of information is therefore expected when assimilating close observation points. Representer structures are linked to the main circulation patterns, for instance slope currents, and are therefore strongly constrained by the bathymetry. However, the influence functions cannot be modeled as function of topography only, because these circulation signals are highly variable in time (with change in amplitude, direction, location with respect to the slope). For instance, on Fig. 2 (top), the patterns of weak covariance in the plain are associated with eastward and southward currents that originate at the western boundary whereas large negative covariances near the French coast south of 44°N correspond to an area of west-northward current from the coast. On July 30 (Fig. 2, middle), the covariances increase south of 47.5°N, as a result of change in surface circulation and of warming over the whole area. Finally, small scales in the influence functions are associated with mesoscale circulation patterns, such as coastal upwellings or filament-shaped structures associated to the eddy field in the abyssal plain. SST representers also contain cross-slope information (e.g. Fig. 2, bottom); this suggests that observations in the plain can constrain the model state on the shelf and vice-versa.

The influence functions of SST data on the subsurface temperature field are mainly linked to the seasonal thermocline depth: this is expected since the ensemble is generated by perturbing the wind stress that has a direct impact on vertical mixing. At point 14 (resp. 7), the vertical profiles of the SST representers at 45°N (resp. at 6°W) show positive covariances above the seasonal thermocline and negative ones below (not shown). Moreover, the significant change of the representers vertical profiles between July 17 and July 30 could indicate that these latter depend on the SST 'regime', that is on situation where the main driving SST process is horizontal advection or vertical mixing. At last, does the vertical structure with positive/negative covariances just above/below the thermocline suggest that SST information could constrain the thermocline depth?

First comparisons between the influence functions of individual SST and altimetric SSH observations at a given point in the abyssal plain (near point 14) suggest that partly redundant information is brought by both data types on the surface and subsurface temperature fields. Indeed, similarities are found in the influence functions. Unexpectedly, the SSH observation brings a weak constraint on local T(z) with respect to the SST observation. However, the ensemble spread in SSH is weak except very close to the coast and we suspect that the model errors in SSH due to uncertainties in the wind forcing is underestimated in this ensemble.

4. PERSPECTIVES

The next step of this work will be dedicated to the generation of a new ensemble of wind perturbations; one possibility is to estimate the perturbations from the comparison between two atmospheric products. Perturbations on other atmospheric variables such as air temperature near the surface will be introduced to represent uncertainties on the air-sea heat flux, that are expected to impact the model's SST. Then, we will consider an additional source of errors (such as uncertainties in the open-boundary conditions) to represent the model error subspace in SSH.

The study will be carried on with the set-up of the assimilation system. One issue that we will address concerns the relevance of the existing satellite datasets (for altimetry and SST) coverage to constrain our model. Indeed, the availability of high spatial resolution observations at daily or at a few days time scale is a challenging issue in coastal areas. For instance, the nadir altimetric data coverage may be insufficient to constrain the mesoscale features in the SSH field. In winter, the data assimilation system performance is likely to be reduced because of the lack of SST satellite data due to cloudy conditions.

5. ACKNOWLEDGMENTS

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