Control of a free-surface barotropic model of the Bay of Biscay by assimilation of sea-level dynamic forcing errors

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Abstract

The purpose of this study is to assess various altimetry and tide-gauge data in the barotropic, free-surface, finite element model MOG2D, covering the Bay of Biscay and nested in a North East Atlantic domain. In a first step, we explore the errors subspace of the model in presence of forcing uncertainties, and especially in presence of high frequency atmospheric forcing errors. This is done by an ensemble modelling approach (Monte-Carlo) in which the atmospheric fields are perturbed in a multi-scale fashion while the oceanic forcing is unaltered. Then, the forecast covariance matrix is computed from the ensemble forecast error Ensemble EOFs. These statistics, in form of 2D-EOFs (Sea Level Anomaly, barotropic velocities, surface pressure and wind stress components), are used in a reduced-order sequential scheme, SDEA, used on an Optimal Interpolation configuration with the MANTA kernel developed at LEGOS/POC (De Mey, 2005), to constrain the model forecast in the framework of twin experiments. In a reference experiment, the data assimilation system is calibrated and validated on the assimilation of high frequency forcing and low frequency forcing. These results are compared with background field data and with fields from ensemble analysis. The system permits to constrain atmospheric forcing fields to achieve an efficient control of the model error. Finally, the capability of realistic observing networks to reduce the model errors is compared. Frequent and regularly spaced observations, such as tide-gauges (SLA) or HF radars and buoys (velocity), are used to be adapted to the present data assimilation configuration once altimetry data are available.

1 - Model configuration

MOG2D model (Lynch and Gray, 1979, adapted by Greenberg and Lyard)

- Non-linear
- Finite Element method for spatial resolution (refine study in coastal and steep barrier area)
- Zone of Bay of Biscay: English Channel (EC) = Celtic Sea (CS), nested in European shelf area (Fig.1)
- Sea Level Anomaly, barotropic velocities

configuration

- Atmospheric forcing: surface pressure and 10-meters wind velocity fields derived from atmospheric models
- Tide forcing
- European shelf solution as open boundary
- Time period: 16/11/1999, 00:00 to 03/12/1999, 00:00

2 - Barotropic dynamics in response to atmospheric forcing

- The non-linear is dynamic is predominant in EC, with Kelvin wave propagation onto both the Bay of Biscay and French and English coasts and stationary processes it’s much elsewhere:

- Perturbation strategy and ensemble simulation: Figure 5 outlines the perturbation strategy/ensemble modelling approach we implemented in the study:

3 - Impact of atmospheric model differences on oceanic model results

- In EC (A): oceanic errors are mainly wind-driven
- In NB (B): SLA errors controlled by wind-stress uncertainties

4 - Ensemble modelling approach

As a prior requirement (and a research subject) for data assimilation, the specification of an atmospheric forcing is generating a prior ensemble of perturbed atmospheric fields (10-meters wind and surface pressure from ARPEGE metemological model) and computing the corresponding a posterior ensemble of model states, one can approximate the forecast errors of the model by ensemble spread statistics. These statistics are shown to be neither homogeneous over the domain, nor stationary, since they are very dependent on the meteorological forcing. Then, the forecast covariance matrix of the model error is approximated by ensemble forecast error Ensemble EOFs. These statistics, either in form of 2D-EOFs (Sea Level Anomaly, barotropic velocities, surface pressure and wind stress components), are used in a reduced-order sequential scheme, SDEA, used on an Optimal Interpolation configuration with the MANTA kernel developed at LEGOS/POC (De Mey, 2005), to constrain the model forecast in the framework of twin experiments. In a reference experiment, the data assimilation system is calibrated and validated on the assimilation of high frequency forcing and low frequency forcing. These results are compared with background field data and with fields from ensemble analysis. The system permits to constrain atmospheric forcing fields to achieve an efficient control of the model error. Finally, the capability of realistic observing networks to reduce the model errors is compared. Frequent and regularly spaced observations, such as tide-gauges (SLA) or HF radars and buoys (velocity), are used to be adapted to the present data assimilation configuration once altimetry data are available.

5 - Characterization of model errors via ensemble statistics

- Oceanic errors are non-stationary (Fig.7)
- 24h error growth
- Closer following atmospheric error development
- In EC (A): oceanic errors are mainly wind-driven
- In NB (B): SLA errors controlled by wind-stress uncertainties

6 - Data assimilation methodology

We implemented the extended ensemble-observation assimilation system SDEA, used on an Optimal Interpolation configuration with the MANTA kernel (De Mey, 2005).

- Analysis step: \( x_t = x^a_t + K_t H_t x_t \)

- Order reduction:

- Sensitivity tests:

- Reference configuration tests network

- Results

- Significant differences: storm surge structures on French Atlantic coasts, differences patterns in EC

7 - Control of model errors via data assimilation

The control of model errors due to atmospheric forcing uncertainties is achieved in the framework of twin experiment: a particular member of the perturbed oceanic trajectories ensemble is taken as a “control” simulation, from which simulated oceanic trajectories are extracted and randomly noise added to 10 tide-gauges locations (see Fig.10), and then assimilated in another member of the ensemble, a so-called “free” simulation.

8 - Observation network performances

- Total Error Reduction

- λ1...λ5: characteristic eigenvalues of the reduced-order data assimilation system

- Covariance error structures in form of oceanic error multivariate EOFs (Fig.8)

- 100 EOFs are calculated using ensemble members as samples at 5 various dates in order to take non-stationarities of errors into account

- Red spectrum - good representability of error structures

- In mode: error "regime" in EC

- In model: error "regime" in NB

9 - Conclusion

- Oceanic errors are non-stationary
- Oceanic and non-stationary / field evolution of errors (24h) are linked to atm. error evolution
- Significant error reduction for all variables
- Significant removal at the end of the period / main representability of error EOFs
- Correction zone located in the analysis step

- Perspectives

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