A Storm Surge Operational System for the Mediterranean Sea based on a dynamical model and a 4D-PSAS assimilation system

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The model

The model is a simplified version of the SHYFEM (Shallow Water Hydrodynamic Finite Element Model) model, in a 2-dimensional formulation allowing only the barotropic transports. The dynamical equations are the following:

$$\frac{\partial U}{\partial t} - fV = -H\left[g\frac{\partial \zeta}{\partial x} + \frac{1}{\rho_0}\frac{\partial p_a}{\partial x}\right] + A_H \Delta U + \frac{1}{\rho_0}(\tau_{wx} - \tau_{bx})$$

$$\frac{\partial V}{\partial t} + fU = -H\left[g\frac{\partial \zeta}{\partial y} + \frac{1}{\rho_0}\frac{\partial p_a}{\partial y}\right] + A_H \Delta V \frac{1}{\rho_0}(\tau_{wy} - \tau_{by})$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0$$

Where *U, V are* the transports, *f* the Coriolis parameter, H the total water depth, *g* the gravity acceleration, ζ the sea level anomaly, ρ_0 the undisturbed water density, p_a the mean sea level pressure, τ_b the stress at the bottom, τ_ω the wind stress on the sea surface, A_H is a horizontal diffusion parameter. SHYFEM uses finite elements for spatial integration and a semi-implicit algorithm for the integration in time.
The model is forced with wind and pressure forecast fields provided by ECMWF. Their resolution is of 0.5 degrees, every 6 hours.

Computational grids

Two computational grids where created, with 13,180 and 50,409 elements respectively (see Fig. 1). The resolution of the elements is increased in the area of interest (i.e., the Adriatic Sea) and with the square root of the bathymetry, in order to well reproduce gravity waves.

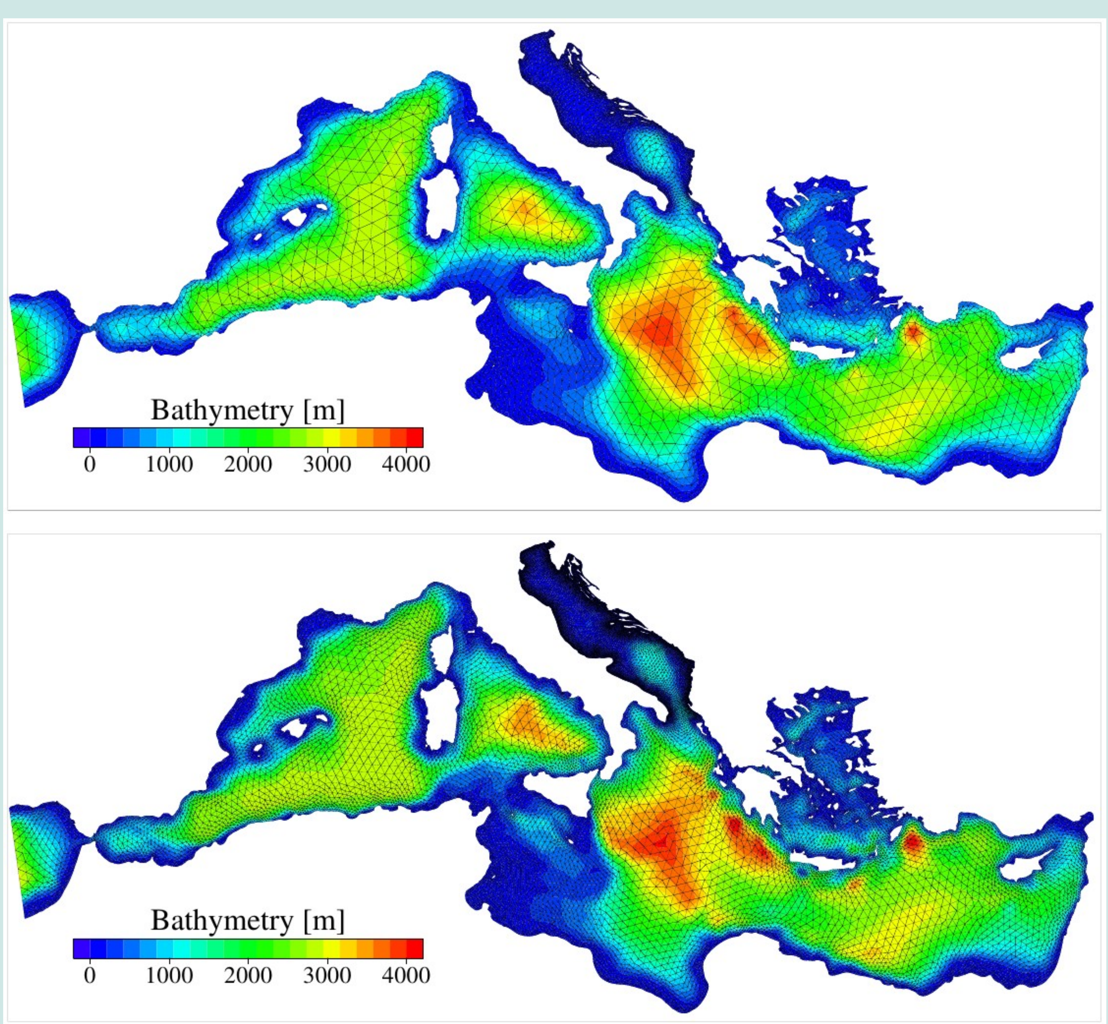

FIG. 1 : Low and high definition computational grids used by the model.

The first grid was used mainly to test the assimilation system, as it is quite faster. However results with this grid are similar to those obtained with the high resolution grid.

In Fig. 2 the model is tested with analysis meteo fields to reproduce a storm surge event in Venice, happened on December 1st, 2008.

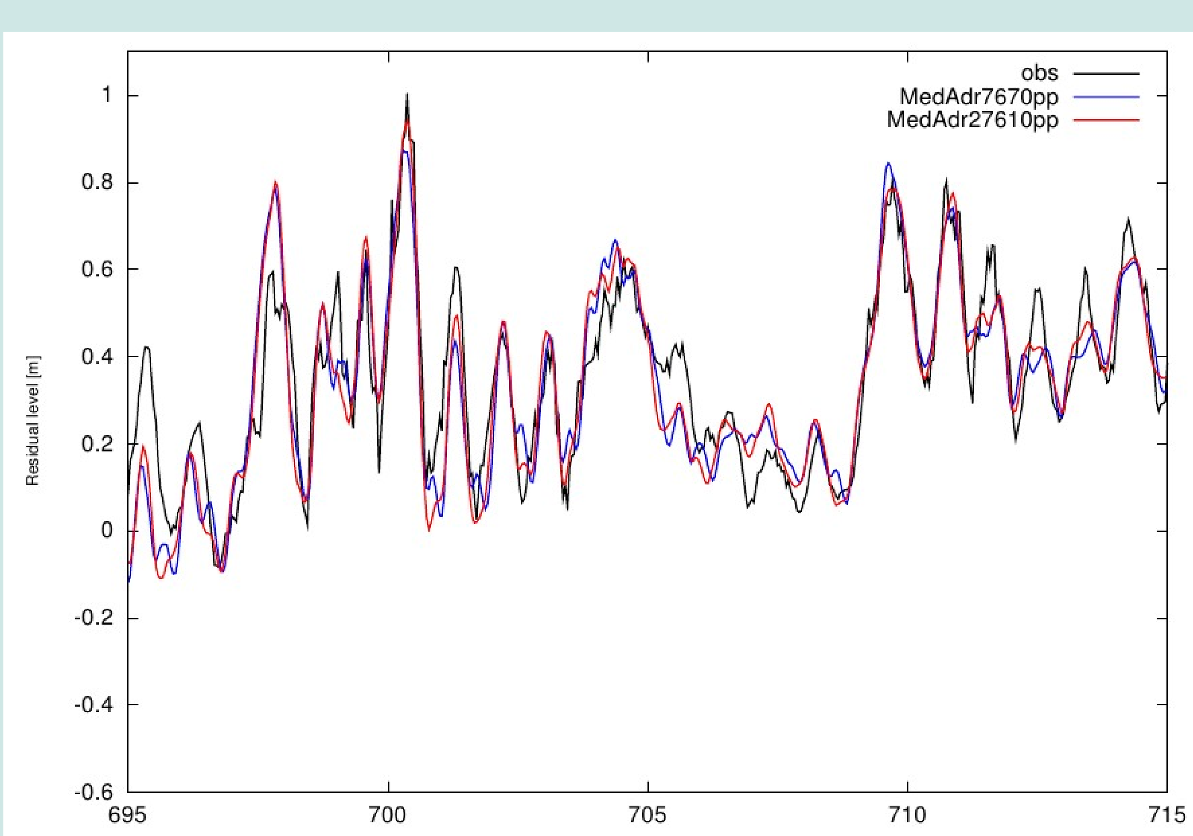

FIG. 2 : Storm surge signal, from observations (obs) and modelled with the two grids. Peaks are better reproduced by the high resolution grid.

The 4D-PSAS assimilation

Theory

The 4D-PSAS method is a dual formulation of the 4D-VAR system (Courtier, P., 1997), allowing the specification of model errors.
Though the system corrects the initial dynamical state, the cost function and its gradient are expressed as functions of control variables in the observational space, rather than in the model space (as 4D-VAR). This allows a speed up of the minimisation process if the observational space has a lower dimension than the model space.
Moreover there is no need to compute the inverse of the background covariance matrix, B, and the model errors can be specified in an easier way.

The practical implementation

As 4D-VAR, 4D-PSAS needs to run the tangent and adjoint codes several times to minimise the cost function. The codes were obtained partly using Tapenade, an automatic differentiation tool, partly by hand.
The minimisation routine uses the L-BFGS-B code developed by Zhu, C, et al. (1994), based on the gradient projection method.

Observation errors
The observations assimilated are hourly sea levels coming from **9 coastal stations** along the Italian coast of the Adriatic Sea. Observations are independent each other and their correlation is set to 0.

Model errors
Model errors are included with constant values. Variables are not correlated to each other.

Background errors
The background covariance matrix is specified through the specification of the standard deviations and the correlations. The standard deviations are updated every 20 days using the differences between background and analysis states, as described in Parrish and Derber (1991).

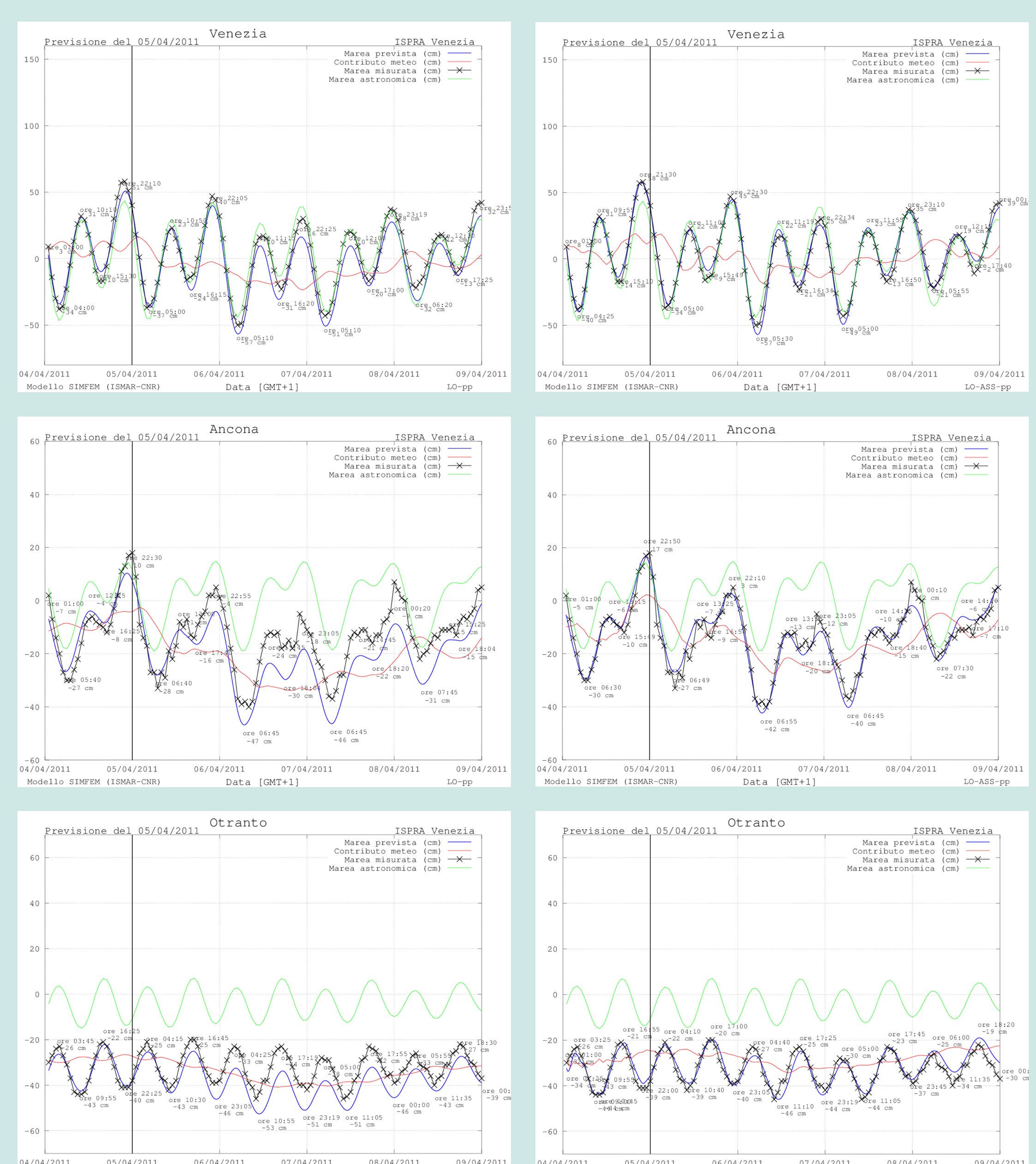

FIG. 3 : Forecast without (left plots) and with (right plots) data assimilation.

Results

Since the implementation is very recent, only preliminary results are shown. In Fig.3 we have re-run the forecasts of April 5 and results are extracted in three stations along the Italian coast on the Adriatic Sea. On the left plots there are the modelled forecasts without data assimilation, while on the right, results after the data assimilation are shown.
Observations have been assimilated on April 4.
For the same simulation Fig. 4 shows the initial state before (left) and after (right) the data assimilation.

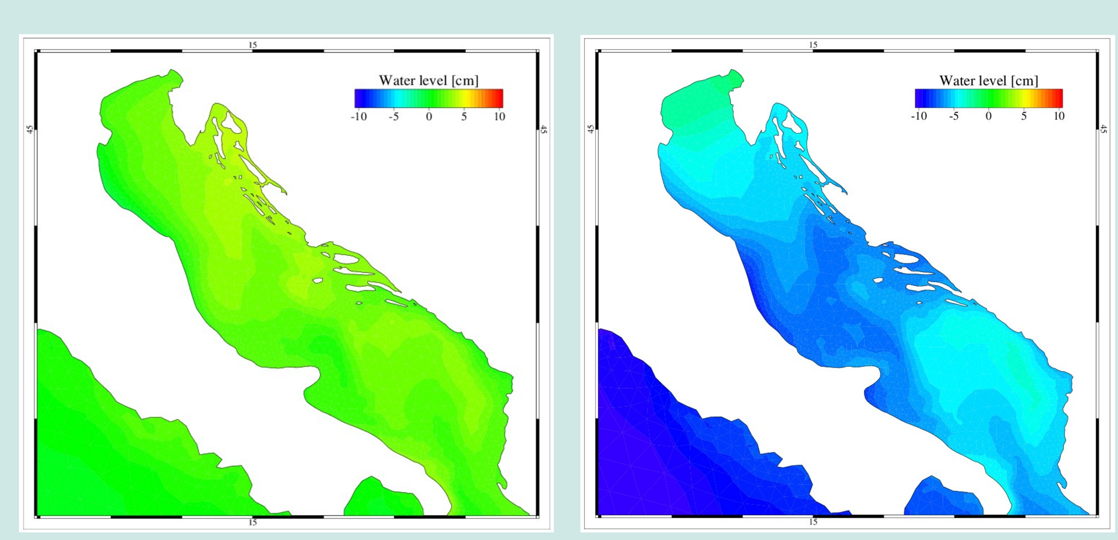

FIG. 4 : Initial state of the water level without assimilation (left plot) and with (right plot).

Conclusions

As shown in the results, data assimilation can give a big improvement to the initial forecast, not only for short lead times but also for longer periods.
However the system still needs to be calibrated properly and further work has to be done also in the formulation of the background covariance matrix.

Bibliography
Coutier, P., Dual formulation of four-dimensional variational assimilation, *Q.J.R.Meteorol. Soc., 1997;*
Parrish, D., F. and Derber, J., C., The national Meteorological Center's Spectral Statistical-Interpolation Analysis System, *Monthly Weather Review, 1992.*

Acknowledgements: We would like to thank the ISPRA Institute for the financial support to carry out this project.

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