P1.1 MODELING UPWELLING WITH A COUPLED ATMOSPHERE-OCEAN MESOSCALE MODEL

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1. INTRODUCTION

Coastal upwelling is an interaction process between the ocean and the atmosphere, with important impacts on the local weather and climate. The western coast of the Iberian Peninsula is a well known upwelling region due to the establishment of a well defined northerly wind regime (the "Nortada"), associated with the joint action of the Azores High and the Thermal Low that typically develops in central Iberian Peninsula during summer (Fig. 1).

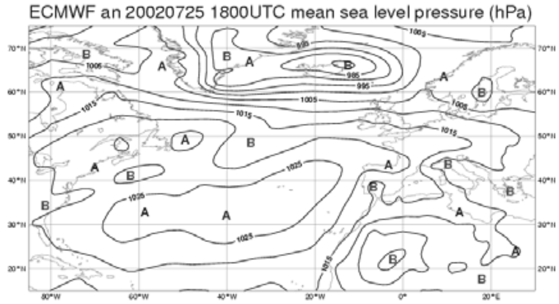

Fig. 1 Typical upwelling situation

The *Nortada* induces, by Ekman effect, a superficial westward ocean current, which, by continuity, leads to upwelling of deep cold waters near the coast. The rising cold waters are rich in nutrients, causing a great impact in the Portuguese economy, due to the renewal of the fishery resource stocks.

The decrease of the sea surface temperature caused by the upwelling tends to locally amplify the sea breeze and to create a positive feedback: the upwelling intensifies the sea breeze which tends to intensify the forcing wind (Clancy et al. 1979, Franshito et al. 1998, Mizzi and Pielke 1984). But, on the other hand, the sea breeze tends to reduce the air temperature in the coastal region, by cold air advection, which can lead to a negative feedback.

In order to study the interactions between the sea breeze and the coastal upwelling, the use of a coupled ocean/atmospheric model is required. This model must have a very good temporal and spatial resolution, to be able to realistically reproduce the upwelling regime and the sea breeze, over a limited area of the Atlantic Ocean, between SW Europe and Africa near the entrance to the Mediterranean Sea. Two mesoscale models were coupled: an atmospheric model (MM5, Anthes and Warner 1978, Dudhia *et al.* 1993) and an ocean model (HYCOM, Bleck 2002). The coupled parameters are: the sea surface temperature, computed by the ocean model, and wind, rainfall, short and long wave radiation, specific humidity and temperature of the air at two meters, computed by the atmospheric model.

Since MM5 is a regional model, it needs not only initial conditions but also boundary conditions that were provided by the six-hourly analyses of the global ECMWF (European Center for Medium-Range Weather Forecast) model. The HYCOM model is a global model, but it can be used as a limited area model, with nesting capabilities. Those characteristics were explored in this study and HYCOM ran in our local computer also as a regional model. So, initial and boundary ocean conditions were also necessary. The ocean analyses were provided by Dr. Alan Wallcraft from Miami Naval Research Laboratory, in which the GLOBAL HYCOM model was forced with ECMWF fields.

Another reason for using MM5 and HYCOM is that both models have versions ready for clusters of personal computer, running Linux. This allows for the computational effort to be divided by several low cost machines, achieving the required spatial resolution.

2. MODEL COUPLING

The MM5 and HYCOM domains are co-located, with a coarse domain resolution of about 27 km, and a nested domain of 9 km on a Mercator projection (Fig. 2). To keep the coupling process between MM5 and HYCOM as simple as possible, and to avoid the need to merge these two rather complex models, the atmosphere and ocean models are run in parallel, HYCOM lagging MM5 by one hour. This approach takes advantage of the much slower evolution of the oceanic variables, and will be justified by the results.

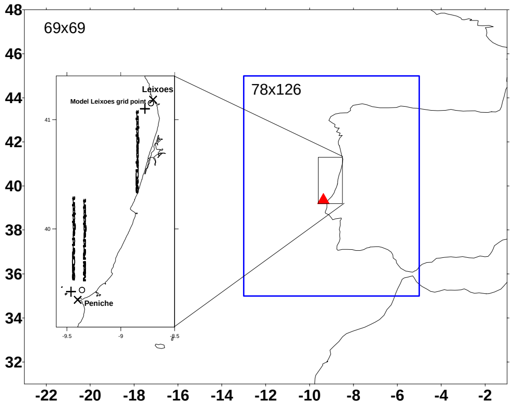

Fig.2 - Model domains: coarse and fine grids. Also shown a zoom of the Peniche coastal region where results are compared against observations.

At t=0, MM5 is initialized with ECMWF analysis, including SST. Until t=4, MM5 runs with ECMWF boundary conditions and SST. This is the spin-up period of the simulation. At this time, HYCOM is initialized with the global HYCOM fields corresponding to t=2 and runs for 1 hour (until t=3) with MM5 fields, which are already known. The SST field from HYCOM at this time replaces the SST at t=4 in MM5, for another hour of integration.

The procedure is repeated for each successive hour. So, the SST values in MM5 are kept constant for each hour of integration, corresponding to values obtained by HYCOM one hour earlier.

In spite of this one hour lag between HYCOM and MM5, results indicate that the SST response is very good, in comparison with satellite data, and that there are also significant improvements in the dynamical fields associated with upwelling.

3. COMPARISON WITH IN SITU OBSERVATIONS

A period of sixty summer days, starting on 30 June 2000 at 22 UTC, was chosen for the simulations with the coupled MM5/HYCOM model. This period was characterized by the occurrence of 3 strong upwelling episodes, easily spotted in observations shown in Fig. 3, taken at the fishing town of Peniche (9.37ºW, 39.35ºN) at 9 UTC. The observations include 10m wind measurements in the coastal synoptic weather station and sea temperatures obtained by an immersed thermometer at a depth of 1 meter.

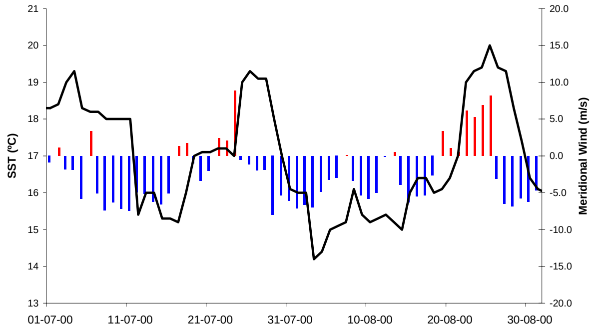

Fig. 3 – Observed SST (black line) and meridional wind (northerly – blue bars, southerly – red bars) in Peniche at 9 UTC.

In clear sky conditions, another evaluation of SST may be obtained from satellite data, giving, in those cases, spatial fields directly comparable with model results. The satellite data from NOAA/AVHRR was used to retrieve spatial SST, with an algorithm (M-F/CMS, 2004), developed by the "Ocean and Sea Ice SAF" (SAFO), with 2 km resolution in cloud free regions. A comparison between these satellite data, in-situ observations and modeling results is shown in Fig. 4. For this comparison, two nearby grid points (one in the model grid, the other from satellite data) were chosen (see insert in Fig. 2). The model grid point is the closest to the station, whereas the satellite pixel is slightly displaced in order to maximize the number of available (cloud free) observations.

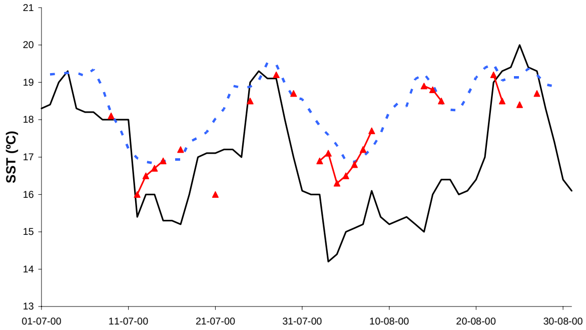

Fig. 4 - Observed (solid black), satellite retrieval (red triangles) and modeled SST (dashed blue) near Peniche at 9 UTC.

An inspection of Fig. 4 indicates that there are important discrepancies between the three datasets. The comparison between satellite data and *in situ* observations shows a +1.0ºC bias, a rmse of 1.68ºC and a 0.41 correlation. Considering the conditions of the comparison this is not too bad. On the other hand, the comparison between observations and model results are comparable (bias 1.36ºC, rmse 1.82, correlation 0.56), which is a remarkable result. Indeed, the model results are much closer to satellite retrievals than to *in situ* data, as one would expect from a scale analysis point of view.

The amplitude of SST oscillations is clearly greater in the *in situ* measurements than in either satellite or model data. These data seems to underestimate the intensity of upwelling. Small scale effects may be responsible for this discrepancy.

The results obtained with the coupled model are very satisfactory, with a performance that is comparable with the satellite derived SST, showing better correlation and similar rmse and bias. Attending that the satellite only gives SST in days without clouds, the use of the model can represent an effective improvement in SST studies.

4. SPATIAL ANALYSIS

In this section one will analyze the spatial distributions of temperature and low level wind. In order to get a comparison between satellite and modeled temperature retrievals it will be necessary to interpolate satellite data to the model grid. It should be emphasized that the number and location of available satellite pixels varies from day to day, depending on the cloud cover and so many of the satellite grid points used. The comparisons have been produced by interpolation (kriging) of nearby retrievals.

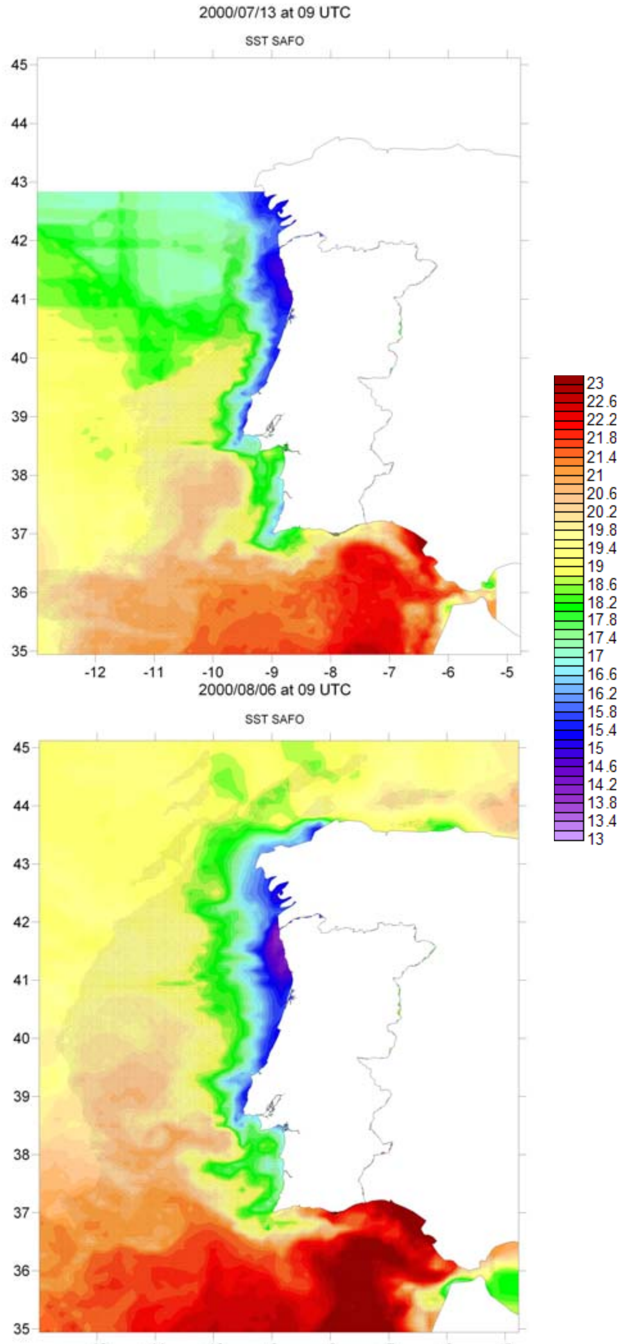

Fig. 5 – Interpolated satellite SST (NOAA AVHRR) at 9 UTC on 13 July 2000 and 6 August 2000.

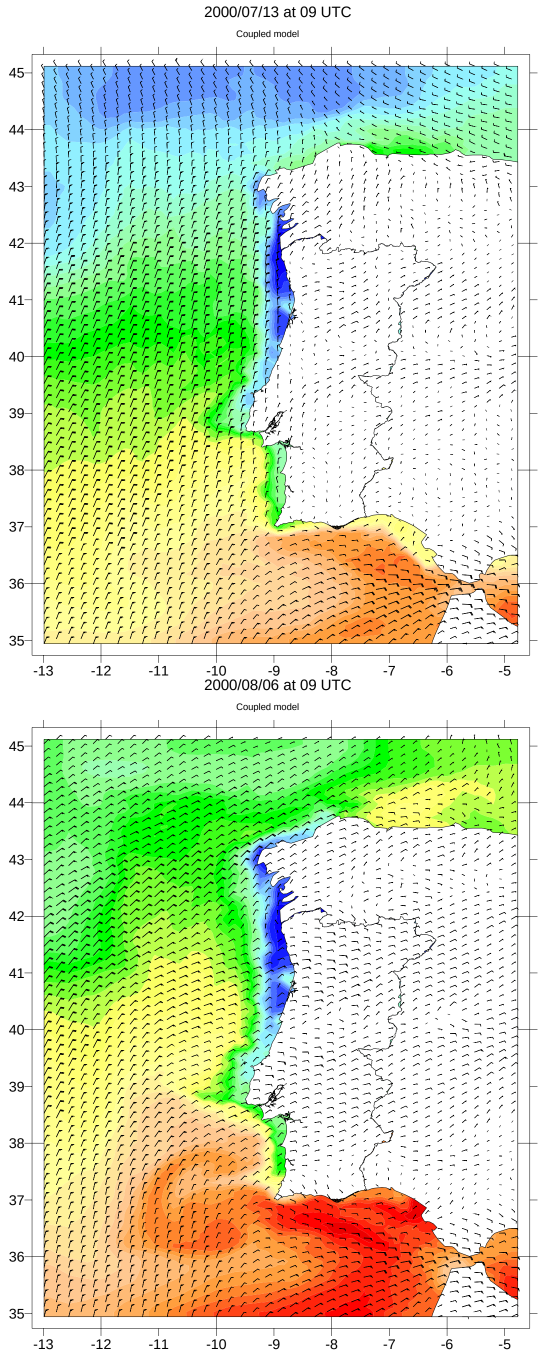

Fig. 6 – As Fig 5, for the coupled model. Shown SST and low level wind.

Considering the availability of good quality satellite data, one will concentrate on 2 upwelling episodes, peaking on 13 July 2000 and 6 August 2000. Fig 5 shows interpolated satellite SST, whereas, the coupled model simulation in the finer grid is shown in Fig. 6.

The importance of using a coupled model to study upwelling can be clearly seen when one repeats the experiment without the ocean model. Fig. 7 shows the results obtained, when MM5 is forced by ECMWF analysis all along, including SST. During the full simulation there is no upwelling and the spatial structure of all fields is much smoother, unlike observations.

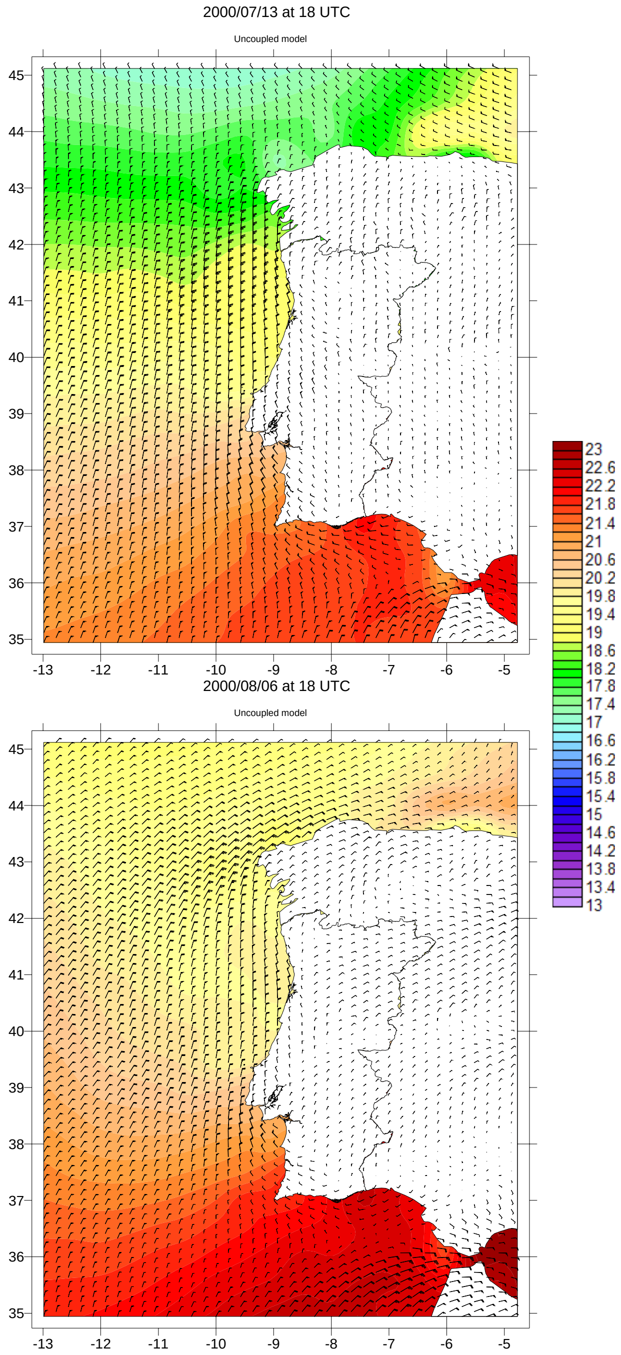

Fig. 7. As Fig 6 for the uncoupled (MM5) model.

5. CONCLUSIONS AND FUTURE WORK

Coupled atmospheric-ocean models with mesoscale resolution are clearly needed for studying upwelling and its interaction with the regional climate. The approach here presented represents a first step with that objective. The remarkable agreement between model results and available satellite retrieved SST, and also with some *in situ* measurements, indicates that a simple methodology may be sufficient for that purpose.

While SST satellite data are only available in days and regions without clouds, a coupled model can produce consistent fields in any conditions, which may be used for a better representation of upwelling processes. On the other hand, the model may be used for climate change assessments, dealing with the important feedbacks between upwelling, the sea breeze and local climate.

Future developments of this study include higher resolution simulations, in a finer 3×3 km nested grid, currently under way, that may explain important coastal details of the ocean circulation while improving the representation of the sea-breeze. Detailed analysis of the boundary layer evolution over land (as in Teixeira et al 2004) and over the sea may contribute for a better understanding of the atmosphere-ocean interactions involved in the upwelling feedbacks.

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