Modeling the circulation off Iberian Peninsula

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Introduction

The major task of IST in OMEX is the implementation and validation of a 3D ocean model for the study area, in order to determine relevant water fluxes. To achieve this objective IST uses the 3D ocean model, MOHID3D (Santos, 1995), previously implemented during OMEX I and OMEX II.1. The model was upgraded to a finite volume spatial discretization method that uses a generic vertical coordinate (Martins *et al., in press*). The model was used in several contexts and in particular was used during OMEX I and in the investigation of a possible mechanism driving the slope current along Iberian slope (Coelho *et al., in press*). Coupled to MOHID3D there is an eulerian transport module of able to compute advective and diffusive fluxes of any property. There is also a lagrangian transport module capable to simulate the dispersion of particles/water masses containing a large number of properties such as volume, phytoplankton concentration, nutrient concentration, etc. The turbulent diffusion coefficient depends on the vertical shear and density stratification. In general the horizontal grid is not fine enough to resolve explicitly those eddies and the vertical eddy viscosity becomes independent of the grid step. This model includes a independent module for turbulence allowing determination of vertical diffusion coefficients with different closures based on empirical formulae, the Prandtl mixing length formulation and a one-equation model (Coelho, 1996; Huthnance *et al*, *submitted to Deep Sea Research*).

Circulation in the Atlantic Iberian continental margin is markedly seasonal being dominated by a southward surface current driven by the wind during the upwelling season and by a poleward density driven current during the winter. The poleward current extends from about the depth of Mediterranean Water to 200 m during the upwelling season and reaches the surface when the upwelling favorable wind relax. In this context the major task for physicists is to determine the volume transport across OMEX boundary boxes. The determination of volume transport requires that flow field is known. There are to ways to compute the water fluxes – to measure directly the currents or to simulate the currents using models. The second hypothesis is adequate only if it is possible to have some confidence in model results. For that we need to understand physical processes independently to make possible a good description and understanding of model results (we must keep in mind the volume of information produced by an oceanic model). On the other hand accurate data is needed to initialize, force and validate the model. As first year is essentially to collect data, we have decided to put some effort on process oriented studies that will help us in the future: a) to better understand physical processes controlling exchanges in OMEX II.2 area; b) To better know our needs about data. According to that we investigate: a) processes related to slope current generation and structure; b) Filament structure and dependence on windstress spatial and temporal variability; c) Parameterization of turbulence in 3D model; d) Implementation of a 3D nested model; e) Tidal induced circulation; f) Coupling between hydrodynamics and biochemical models.

To achieve this last objective a biochemical module was implemented. The model uses a trophic structure approach where energy flows from the autotrophic to the heterotrophic producers was used. The state variables are nitrogen (three inorganic forms, ammonia, nitrate, nitrite and three organic forms, refractory and non- refractory dissolved organic nitrogen and particulate organic nitrogen), primary and secondary production. Equations of the model are described in Miranda (1998)

The environmental variables controlling the rates of production of these properties are the light and the temperature. The light is assumed to have an exponential decay and the temperature is calculated by the temperature module also used by the hydrodynamic model to calculate the baroclinic terms. For stability reasons the system of equations is solved using an implicit algorithm. For each calculation point, a set of 8 equations is solved using a Gauss algorithm.

Results of process oriented studies

IST is involved in several tasks both in WPI and WPII. However all the work already done and to be done by IST in OMEX is based in the 3D Ocean Circulation model, MOHID3D. For that reason it is appropriate do firstly describe model results obtained during the first year of the project and then link it to each task.

Slope Current

As it was described in the introduction the circulation around Iberia is very complex thus it needs some previous understanding of some isolated processes. Slope current is one of the major features occurring along the outer continental shelf and upper slope. As it was noted by Mazé *et al*. (1997) the volume transport by the slope current largely exceeds the eastward volume transport by oceanic large-scale circulation. It is of crucial importance both for model qualitative validation and for interpretation of the results that generation and structure of the slope current is well understood.

One of the major problems in ocean modelling is the initial condition. Assuming that JEBAR is the major driving mechanism for the slope current (and there is some evidence of that, e.g., Huthnance; 1984, Pingree and Le Cann, 19901) the density distribution assumes a very important role for the task of simulating the slope current. On the other hand during the entire year slope current is one of the major sources bringing water into the OMEX box. The correct prediction of how much water is carried into the OMEX box is absolutely need to close the volume budget across box boundaries. There is some evidence for an intensification of poleward current north of Cabo da Roca (Lisbon) but the reason for that is not clear. One of the possible causes is the deflection to the left of the current in front of Cabo da Roca. Similar feature was observed in the California Current system. Other possibility is the existence of a density front at the latitude of Lisbon (Vitorino, personal communication) leading to a rapid increase of meridional density gradient enhancing the JEBAR forcing. Climatological density fields are often used to initialize ocean models. However resolution of these density fields is very poor (order of 100 km) filtering phenomena like oceanic fronts with spatial scales of the same order. According to measurements made by IH the extension of the meridional front latitude of Lisbon is about 100 km, thus Levitus (1982) data does not contain it. It is then clear that we need to know more about temperature and salinity distribution not only in OMEX II area but also along the entire Iberian Margin. IH will treat available data from previous cruises to provide an initial density field suitable for model initialization that takes into account small-scale spatial variability like the mentioned front.

During this first year of the project, IST, concerning the slope current, carried out some process-oriented studies. Several experiments were made but here we present only the more relevant ones. Experiments 1 and 2 were carried in order to establish a slope current driven by JEBAR forcing and to determine the magnitude of volume transport by the slope current at different latitudes. The results are then compared with observations made in the past by Fouin *et al.*, (1991) and Mazé et al, (1997). The basic difference between experiment 1 and 2 is that in the former we impose a linear increase of density with latitude in ocean thermal layer (say the first 1000 m) while in the second we consider the existence of a front extending for 100 km centered at 39.6ºN. In both cases model domain has an extension of 500 km by 600 km in the zonal and meridional directions respectively. The horizontal spatial step is 12 km and the vertical resolution is 50 m in the upper 200 m, 75 m between 200 m and 3000 m and 250 m below. The topography is very schematic considering a continental shelf varying from 25 depth near the coast to 200 m at the shelf break. The slope is infinite and the ocean depth is constant (4000 m). The offshore extent of continental shelf is 60 km.

In third experiment presented here MOHID3D was implemented in the Northeast Atlantic (30ºN to 60ºN and 5ºE to 25ºW) with a local high resolution in the slope and shelf regions. To investigate the north-south density gradient as the driving mechanism for the poleward current, model was forced by Levitus (1994) climatological data. The spatial step of the model varies from 40 km near the boundaries to 8 km near continental shelf and slope. The model has 14 layers in the vertical. The upper sigma domain (first 200 m) has 8 equal layers and the lower domain the remaining 6. Each of the first 5 layers of the lower domain represents 10 percent of the depth below 200m. Results of this third experiment can be found in Coelho *et al.* (*in press*)

Model results from all the experiments lead us to identify a current aligned with shelf break/upper slope whose characteristics are very similar with the observed poleward current (Ambar *et al.*, 1986; Haynes and Barton, 1991; Frouin *et al.*, 1991). The current is narrow and decays both shelfward and oceanward (see figure 1). The vertical extension of the current is about 1000 m (approximately the depth of the thermal layer).

Volume transports were computed. For experiment 2, at 41.7ºN we obtained 4.0 Sv between the surface and 1060 m depth in a section across the slope current between 9.8ºW and the coast. The average transport per grid cell is 0.09 Sv. Further south, at 40.1ºN, in a similar cross section we obtained 2.7 Sv. These results are in the range of observed values (see Mazé *et al.*, 1997) and agree with JEBAR hypothesis that predicts an increase in slope current with latitude.

Upwelling and filaments

During spring and summer upwelling is usually present along the Iberian margin. Associated with upwelling events there are eddies, jets and filaments along the coastal transition zone. Specially important are the filaments that allow exchange between coastal region and open ocean. Filaments are cold tongues of upwelled nutrient rich water that moves offshore with velocities that can exceed 50 cm/s. The width of filaments is typically 30-50 km and offshore extension is about 200 km. The vertical signature of a filament extends to 200/300 m.

The origin of filaments is not clear. Some authors argued that barotropic and/or baroclinic instability is responsible for filament generation. Another possibility is that filaments are associated with bottom irregularities (e. g. canyons) and coastal morphology. Supporting former thesis is the fact that in different regions such as Iberia, North Africa and California the alongshore distance between filaments is approximately the same (150-200 km) which indicates no special dependence of topography. On the other hand is true that filaments are generally observed near capes indicating that coastal morphology may play an important role at least in the location of the filaments. Probably both hypothesis are valid and topographic irregularities are important on generating instabilities. However this subject needs further investigation. IST plans to do some work on this topic during OMEX II although this is not a major task in the project.

To study filament characteristics (not their generation) a schematized bathymetry was implemented. Meridional and zonal extensions are 800 km and 600 km, respectively – correspondent horizontal spatial steps are 8 and 12 km. Vertical resolution is the same described before for the slope current. Initial density distribution is horizontally uniform to isolate the role of windstress. The wind field imposed corresponds to a climatological pattern for summer months (Bakun and Nelson, 1991) but has superimposed a large anticyclonic windstress curl near the coast as it is suggested by McClain *et al.*, (1986). The wind field is constant with latitude inside the domain but is set to zero in the 50 km near the northern and southern boundaries. The use of band wind forcing in the interior of the domain although somewhat artificial, allows for the propagation of coastal Kelvin waves, which can establish the alongshore pressure gradient field, resulting in a surface trapped coastal jet and an approximately realistic undercurrent (Bateen *et al.*, 1989).

Model results show the formation of filaments along the coast. Filaments start to form a few time after the beginning of the run (2-3 days) and are clearly identified after 1 week. Figure 2 shows the SST distribution after 20 days where 3 filaments are well developed and a fourth in the southern area is forming. The distance between filaments their width and offshore extension are well predicted. The speed inside the northernmost filament reaches 70 cm/s. Figure 3 is a cross section along the filament axis revealing that vertical extension of filament signature reaches 300 m depth. Figure 3 also enhances the presence of a strong front at the head of the filament.

Tidal modeling

Initialisation

The water level is initialised at the open boundaries using 6 harmonic components (M2, S2, K2, 01, P1, Q1) obtained from the CSR1.6 output model. The CSR1.6 model is a long-wavelength adjustment of the FES94.1 pure hydrodynamic model (Le Provost *et al.*, 1994) for the M2 and S2 constituents using the first two years of T/P crossover data (70 repeat cycles) and JGM-3 orbits. The resolution is 0.5 x 0.5 degrees within the latitude range 65 S to 65 N.

Validation

To calibrate the model for the OMEX area, the flow is simulated in barotropic mode using a 183 x 191 points grid with variable step from 20km near the boundaries to 10km near the coast. For the vertical discretization a sigma co-ordinate with 1 layer is used.

The models results are compared with elevation data time series made using Schwiderski tidal components field (Schwiderski, E.W. 1980).

Figure 6 shows that simulated water level agree with the sea level generated using Schwiderski data. Away from the boundaries the error slightly increases (Figure 7).

Figures 4 show a main tidal amplification in the English Channel. As it was expected after a phase lag of 12h25mn corresponding to M2 time period, we have the ebb tide turning into the flow tide (and vice-versa) (Pedlosky, 1987).
Amphidromic points with a cyclonic circulation can also been seen in the North Sea and in the South of England.

Specific results for tasks

Task I.6

A nested model module was implemented in MOHID3D. The utility of this module is the ability to simulate small specific areas without diminishing spatial step in the all modeled area. The kind of model implemented for now is a 1 way, meaning that information is passed only from the large-scale model to the small scale model. In this implementation it is allowed that a run for the nested model is done separately from the regional model. This represents a considerable reduction in CPU and makes possible that another different team use the results of the regional model to run the nested model for is own purposes. In particular the nested model is available for SINTEF to run it coupled with biochemical model (see also Task I.7).

Technically, when nested model option is chose, the regional model code recognizes the specific area to be simulated with a fine resolution and creates itself all the files needed to do the run. The files are the exported and available for a nested model run. When running the nested model the boundary conditions previously created are linearly interpolated.

Preliminary results are presented in this report. It is a very simple test in a small basin where tidal harmonics are imposed at the boundaries. The nested model has a dimension of 10x10 grid cells in the large model. The reduction of grid cells in the nested model is 1/3 so that it has 30x30 grid cells. Figure 8a) show both domains (large model and nested model). On figures 8b) and c) one can see the sea level computed in the same area by the large model and the nested model. Finally, figure 8d) shows a comparison of time series of sea level in the same point.

Task I.7

Biochemical and circulation modeling have been two weakly coupled scientific areas. Ecological models should couple circulation and biochemical models, resolving equations of the form:

$$\frac{\partial P}{\partial t}+v_j\frac{\partial P}{\partial x_j}=\frac{\partial}{\partial x_j}\left(K_{jj}\frac{\partial P}{\partial x_j}\right)+S_P\,,$$

Where P is a generic non-conservative property, x_j the spatial coordinate, V_j is the velocity, K is the diffusion coefficient (provided by the turbulence model) and S_P represents the *source - sink* terms solved by the biochemical module.

Biochemical modelers have been the major developers of ecological models, assuming usually simple approaches both for advective and diffusive transport. In coastal areas where advective transport plays a major role the so-called water quality models were developed mainly by circulation modeling teams using, in this case, simple biochemical models.

Two main reasons have contributed for this situation: (1) the lack of knowledge in both disciplines and (2) the reduced computing power available. Both limitations have been slowly eliminated and both groups have, nowadays, conditions to develop their models in a coupled way. A major task of the coupling procedure is the definition of the interface between both models. This interface must allow separated development of the codes and the distribution of the calculation among several CPU's or even computers.

During last months of OMEX I and this first OMEX II year a prototype of that interface have been developed. The biochemical model is a "zero-dimensional" model. Each property knows only the values of the state variables determining its activity. A specific module performs the calculation of the state variable values. This module uses the hydrodynamics information provided by the circulation model, the internal transformations calculated by the biochemical model and the fluxes across the boundaries (free-surface, bottom and lateral boundaries). Fluxes across the bottom interface are calculated using a benthic

diagenetic module developed using a similar philosophy. In the benthic module lateral transport is negligible and the calculation becomes one-dimensional.
A clear splitting of the biochemical and transport processes allows the use of the most adequate numerical algorithm for transport in each situation and a simple exchange of biochemical modules among different teams. Simulations in the Goban Spur were carried out using both Eulerian and Lagrangian approaches for transport. Results show that both approaches can produce similar results (Miranda, 1998).

Task II.1

Historical currents processed by UCG will be compared with virtual time series of currents produced by the model in the same locations and for the same period. Locations and periods to do the comparisons were choose having in mind available atmospheric data to force 3D ocean circulation model. Virtual time series will be analyzed as if they are real (computation of mean, standard deviation, etc.) and comparison is made in that way.

Task II.3

The one-dimensional vertical model used by IST during OMEX I is a kind of laboratory both for testing turbulence closures and coupling with biochemical models. During OMEX I the model was used (Huthnance *et al.*, 1998) to reproduce the vertical variability of temperature, phytoplankton and nutrients in the Goban Spur region using atmospheric forcing and sea surface temperature (SST) measured at K1 buoy made available by BODC. In that work it was noted that SST tends to diverge from observed SST after the end of August with the higher temperatures being obtained in the model. A similar run was made for the OMEX II-II region using climatological data from Esbensen and Kushnir (1981) and SST form Levitus (1982). The results showed a very similar problem. Further investigation revealed an error heat fluxes in both cases leading to a consistent warming in the upper ocean. A technique for correction of heat fluxes was developed using observed SST producing more accurate results for temperatures and for turbulence parameters such as turbulent kinetic energy, turbulent viscosity and turbulent diffusivities.

UCW-b will made available profiles of temperature, kinetic energy and turbulent viscosity as well as atmospheric forcing for comparison with 1D and 3D correspondent profiles in order to validate more accurately the turbulence closure used in MOHID3D.

Future work

For the second year of the project IST has the following plan.

1 – Validation of the model using historical current meter statistics (in collaboration with UCG). For this task ECMWF atmospheric data for 1994 will be used since there are a reasonable number of observations for that period (Tasks II.1.5 and II.4.3)

2 – To use IH meridional sections of density to force the model in order to obtain a more accurate slope current.

3 – Once the model is calibrated net fluxes across box boundaries will be computed.(Task II.4.3)

4 – To compare turbulence parameters already obtained with 1D vertical model and that will be obtained with 3D model with data measured by FLY. (Task II.3.3).

5 – In cooperation with SINTEF the interface between the large-scale model and nested model will be implemented as well as the interface between hydrodinamic model and ecological model (Tasks I.6 and I.7).

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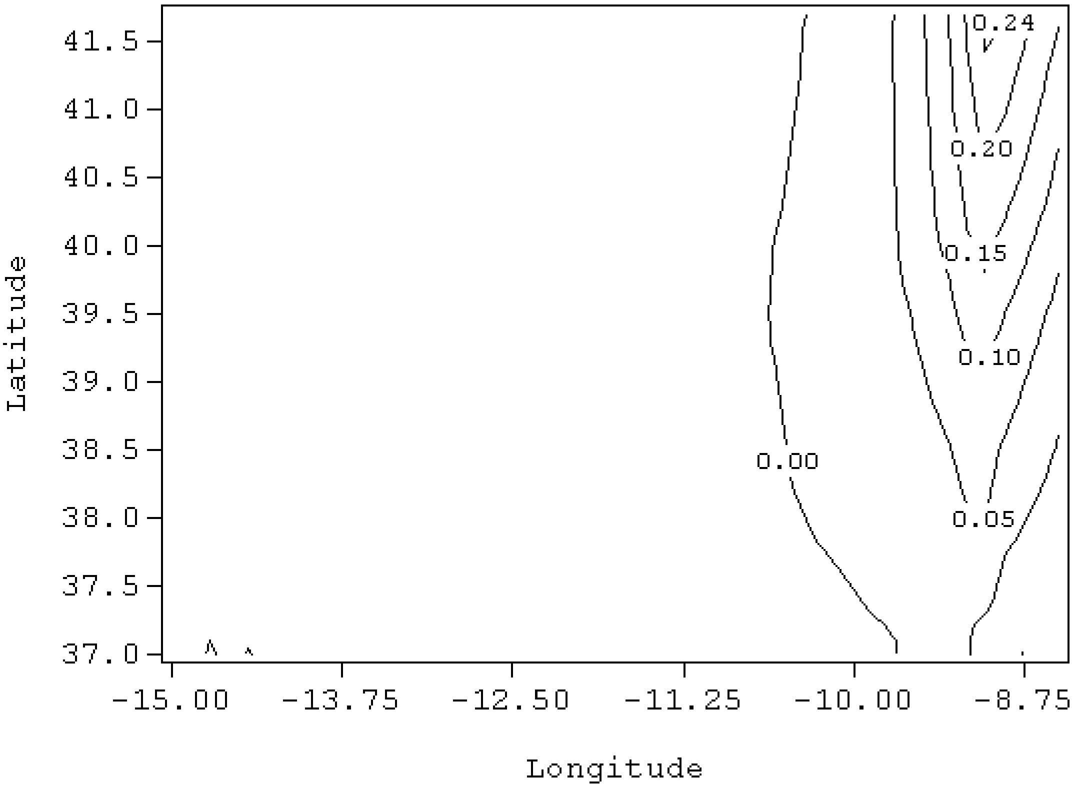

Figure 1 – Meriodional velocity (in m/s) obtained in experiment 2.

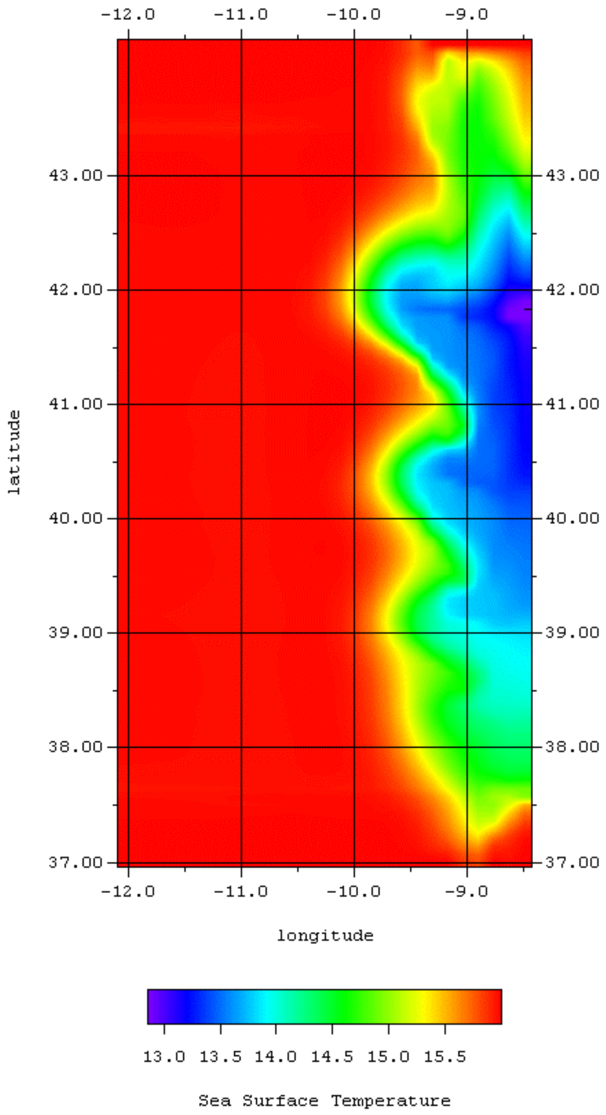

Figure 2 – SST distribution after 15 days

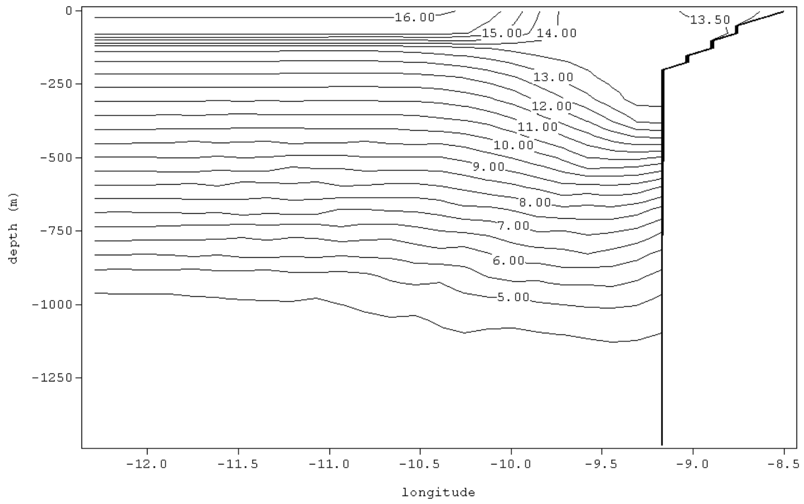

Figure 3 - Cross section of temperature along the northernmost filament axis.

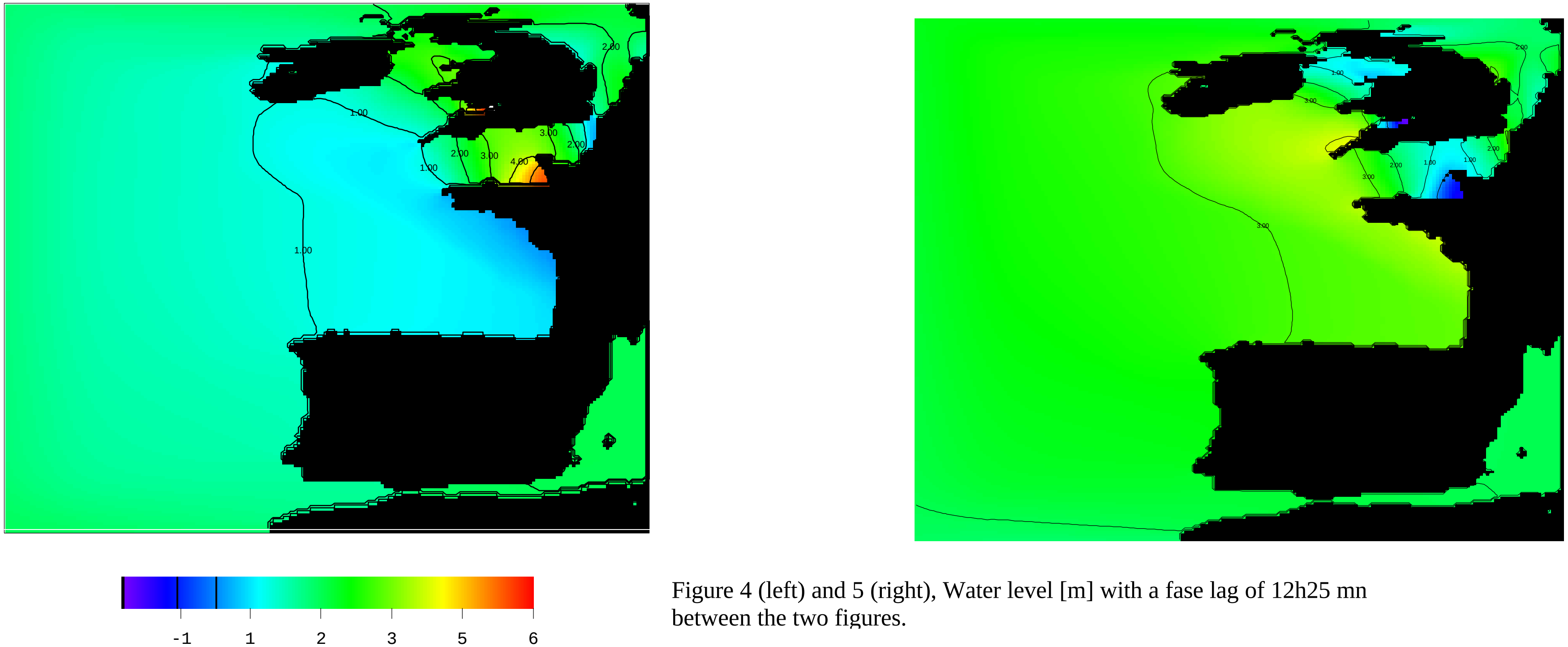

Figure 4 (left) and 5 (right), Water level [m] with a fase lag of 12h25 mn between the two figures.

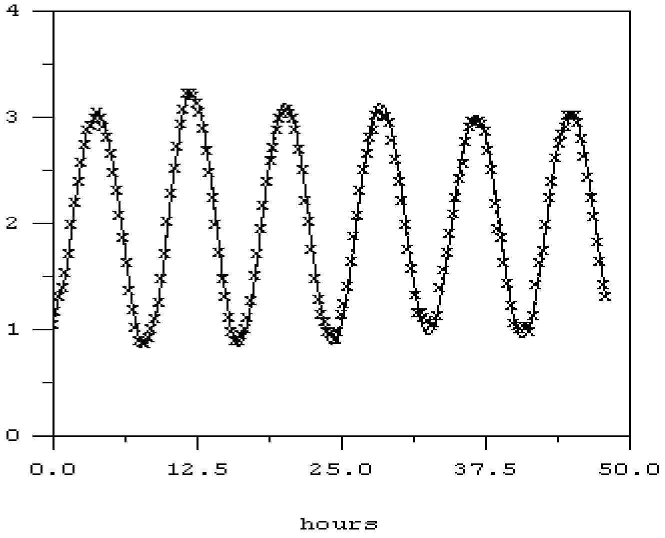

Figure 6: Water level [m] at (34ºN, 16W)

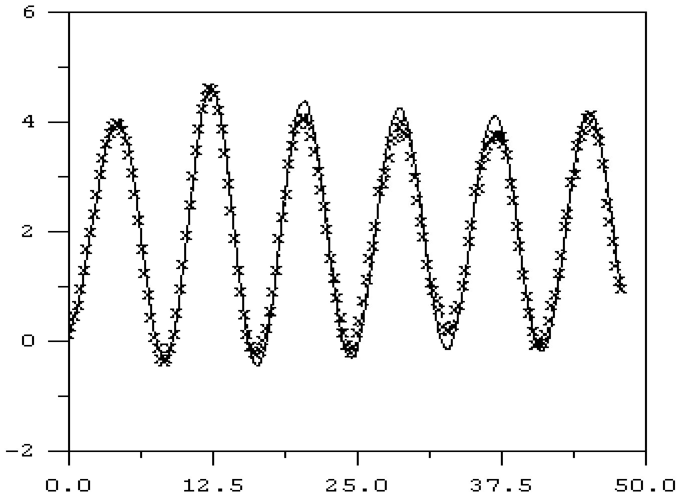

Figure 7: Water level [m] off Vigo (41ºN, 9W)

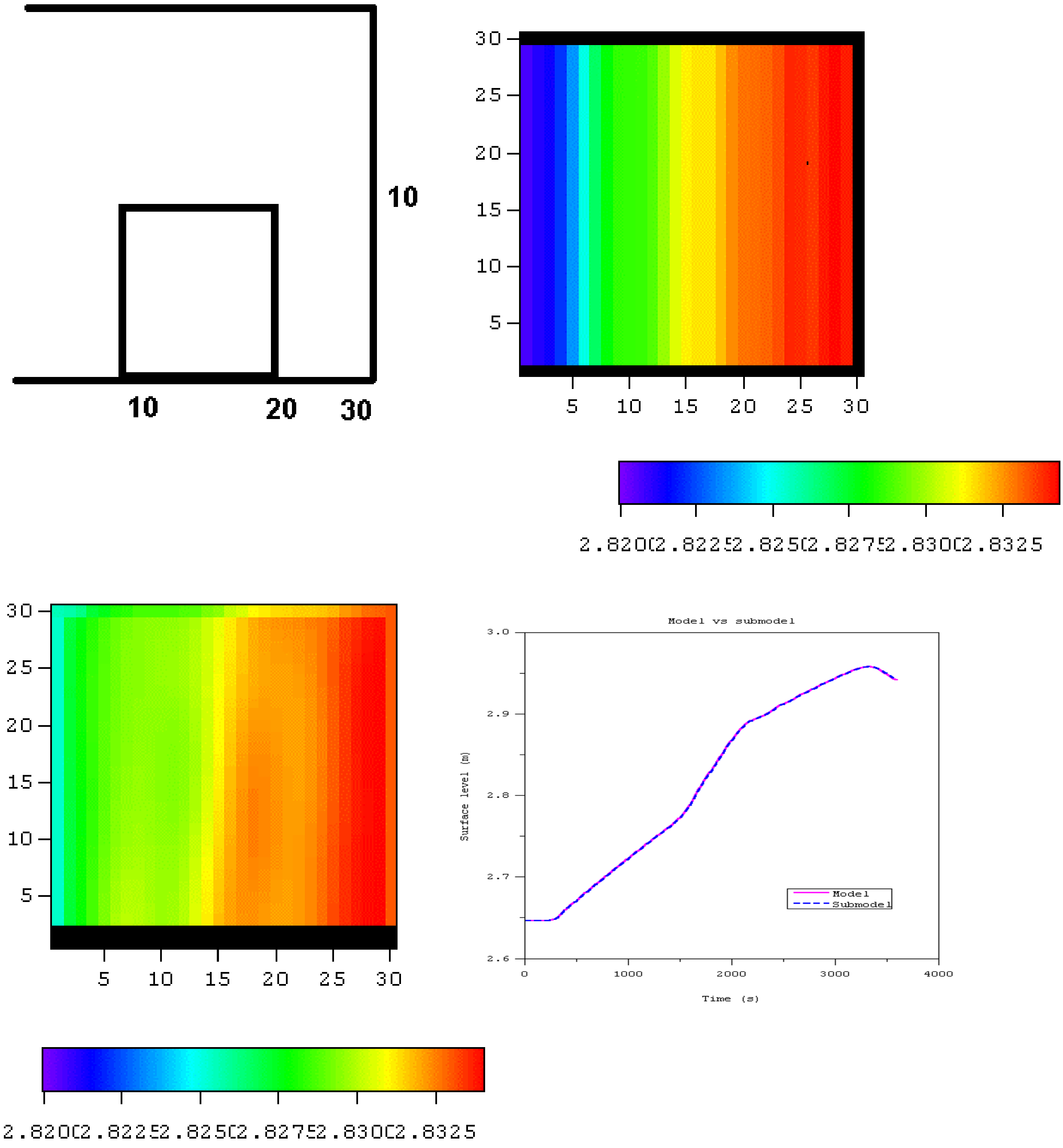

Figure 8 – A) Representation of the domains of the model and nested model. B) Sea level (in m) obtained in the model. C) Sea level obtained in the nested model. D) Comparison of sea level in the same point.

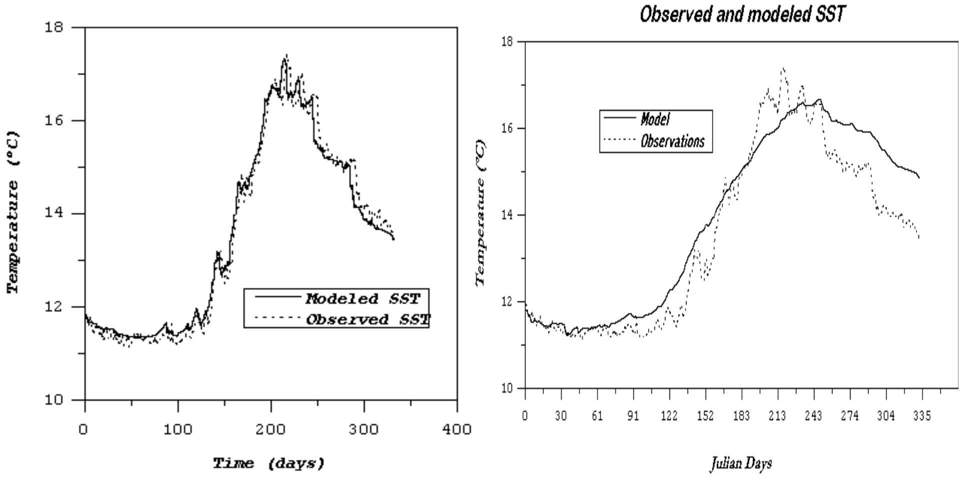

Figure 9 – Comparison of modeled SST with observed SST at K1 buoy for 1994. On the left results obtained with a technique for correction of heat fluxes. On the right results obtained without correction (Huthnance et al., *submitted to Deep Sea Research*)