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Discussions

Towards a regional ocean forecasting system for the IBI (Iberia-Biscay-Ireland area): developments and improvements within the ECOOP project framework

S. Cailleau[1], J. Chanut[1], J.-M. Lellouche[1], B. Levier[1], C. Maraldi[2], G. Reffray[1], and M. Garcia Sotillo[3]

[1]Mercator Océan, Toulouse, France
[2]Service Hydrographique et Océanographique de la Marine, SHOM, Toulouse, France
[3]Puertos del Estado, PdE, Madrid, Spain

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Correspondence to: S. Cailleau (sylvain.cailleau@mercator-ocean.fr)

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Abstract

ECOOP project allowed the improvement of the regional and coastal operational forecasting systems for the different European Seas. In the Iberia-Biscay-Ireland area (IBI) a regional system has been developed and improved for the project in order to provide IBI partners the best initial and boundary conditions to their embedded coastal systems. End users could also get access to the regional hindcasts and forecasts through the ECOOP website. This system has been upgraded as follow: a first existing version V0, a second base-line version V1 ready for the ECOOP Target Operational Period and a third one V2 which consists in a new generation regional system. This paper especially pays attention to the improvements from the V1 system, whose physics are close to a large scale basin system, to the V2 one which physics are more adapted to shelf and coastal issues. Strong developments which allow further regional physics resolution in the NEMO OGCM such as tide, non linear free surface and adapted vertical mixing scheme among other have been carried out from V1 to V2 versions for the project. Thus, regional thermal fronts due to tidal mixing appear in V2 solution and are quite well placed. Moreover, simulation of the stratification in shelf areas is also improved in V2.

1 Introduction

The aim of ECOOP Project (www.ecoop.eu) consists in building a Pan-European ocean operational system of observation and forecasting. Five areas are considered: the Baltic Sea (BOOS = Baltic sea Ocean Operational System), the North-west shelf (NOOS = North-west shelf Ocean Operational System), the Iberia-Biscay-Ireland area (IBIROOS = Iberia-Irish-Ireland Regional Ocean Operational System) the Med Sea (MOON = Mediterranean Ocean Operational system) and the Black Sea (BS-GOOS = Black Sea Global Ocean Operational System). Each area is composed by regional systems and embedded coastal ones.

In the beginning of the project, a first general inventory of existing European ocean systems were carried out, but at that time there were not neither any common standard (in terms of outputs data, validation diagnostics, etc.), nor very much connections between systems. Furthermore, there were not so much documentation about users' data available from these systems, as well as the way to download them. At this first step, systems are considered to be the version V0 in the ECOOP Project.

In a second step of ECOOP, for each area, systems are upgraded and integrated by improving downscalling from regional to coastal systems to reach the V1 version of systems. These V1 version systems run all together for a 6-month operational experiment (TOP: Target Operational Period). For the TOP users can get data and corresponding informations through the central ECOOP portal EuroMISS. Users can also directly display data in the ECOOP website via the DQV tool (Dynamic Quick View, a google earth application), and can quickly assess them thanks to the validation page of the ECOOP website too.

In a final step of ECOOP, a next V2 version of each system is improved in order to reduce V1 uncertainties. Moreover, Mercator Ocean team is still upgrading this V2 system version in the framework of the EU FP7 project MyOcean (www.myocean.eu.org).

In this paper, we focus on the evolution of the regional Mercator Ocean IBI forecasting system from V0 to V2, with particular attention to the final V2 version. The first part is dedicated to the description of each regional IBI system versions, whereas the second one pays attention to the comparison between V1 and V2 system solutions.

2 Description of regional Mercator Ocean System V0: PSY2V2

Five partners have been involved in the IBIROOS integrated system: Mercator Ocean (France), PdE (Puertos del Estado, Spain), IST (Instituto Superior Técnico, Portugal), PREVIMER (France) and IMI (Irish Marine Istitute, Ireland). The integrated IBIROOS

V0 system consists in an inventory of existing European regional and coastal systems in the IBI area. It is composed by 5 different elements (see Fig. 1): a basin system for the North Atlantic ocean: PSY2V2 (Mercator Ocean), a Regional System, covering the entire Iberian area: ESEOAT (PdE, Sotillo et al., 2007) and three Sub-regional Systems covering respectively the Irish shelf system IMI-NE-Atlantic (IMI), the bay of Biscay and the Western channel system: GDGE (PREVIMER), and the Iberian coasts system: MOHID (IST). PSY2V2 provides boundary conditions to the IMI and IST systems, whereas the PdE and PREVIMER forecast systems are independent, not having any link with the rest of components of the ECOOP IBIROOS system. The downscaling scheme is not complete and this first global IBIROOS V0 system is not integrated. The improvement of connections between regional and coastal systems (e.g. here in the IBI area) is one of the main task to get an integrated IBIROOS V1 ready for the TOP experiment.

PSY2V2 model configuration is based on the OPA8.1 Ocean General Circulation Model (Madec et al., 1998), a general circulation model developed at LOCEAN (Paris). The rigid lid hypothesis is applied at the surface in order to filter fast external gravity waves this model can not resolve.

The model configuration covers the North Atlantic ocean (between 9° N and 70° N) embedding the IBI area. The primitive equations are discretized on a 1/15° (~5 km in IBI) irregular rotated grid of Mercator and on 43 z-levels in the vertical, with a resolution decreasing from ~6 m near the surface to more than 300 m in the abyssal plain. A simple full cell representation of the bathymetry is used. The bathymetry is derived from the ETOPO2 data set. Initial conditions for temperature and salinity are derived from Reynaud climatology in Atlantic and MEDATLAS in Mediterranean Sea.

Regarding forcings, Meteorological fluxes from the European Centre for Medium-Range Weather Forecasts (ECMWF) with a daily and 0.25° × 0.25° resolution are used to force the model. Surface fresh water and heat fluxes are directly applied to the model surface. The short wave radiation penetrates the surface layer according to a simple extension law (2 extension lengths), without any dependence with ocean colour.

The model also includes river fresh inputs from a monthly runoff climatology built by averaging data from the Global Runoff Data Center (http://grdc.bafg.de). Buffer zones are used at the closed boundaries with a damping toward the T-S Reynaud climatology.

Regarding data assimilation, a multivariate multi data optimal method is applied. The statistical representation of the forecast error is established analytically in 2 dimensions (horizontal) and from EOFs in 1 dimension (vertical). Altimetric SLA (Jason-1, Envisat, GFO), SST Reynolds and in situ T/S vertical profiles are assimilated in a fully multivariate way.

Finally, about the operational protocol, each Wednesday (day (D) of run), PSY2V2 provides one week of hindcast (best estimates: with assimilation of full observation data sets) from D-14 to D-7, one week of nowcast from D-7 to D (with assimilation of available observation data sets) and two weeks of forecasts from D to D+14. This V0 description is summarized in Table 1.

3 Description of regional Mercator Ocean System V1: PSY2V3

The integrated IBIROOS V1 system is composed by 4 different elements (see Fig. 2): a basin system of the North Atlantic ocean: PSY2V3 (Mercator Ocean), and three Subregional Systems covering respectively: the Irish shelf: IMI-NE-Atlantic (IMI), the bay of Biscay and the Western channel: MANGA (PREVIMER), and the Iberian coasts: MOHID (IST). At this step, the IBIROOS V1 is fully integrated: PSY2V3 provides boundary conditions to the three other subregional systems in real time via Mercator Ocean OpenDAP. It can be remarked that in V1 there is just one regional system which provides boundary conditions and initial conditions to the 3 other coastal systems. The PdE system ESEOAT is no more present in this integrated IBIROOS V1. For ECOOP, PdE and Mercator Ocean worked together on validation tools and on the development of the next version of the regional IBIROOS-V2. This collaboration is still on-going and strengthens within the MyOcean EU Project.

The PSY2V3 model configuration is based on the NEMO1.09 Ocean General Circulation Model (Madec et al., 1998; Madec, 2008). The linear free surface hypothesis is applied at the surface and just filter fast external gravity waves this model cannot resolve.

The model configuration covers the North Atlantic ocean between 20° N and 80° N, embedding the IBI area. The primitive equations are discretized on a 1/12° (~6 km in IBI) irregular ORCA grid of NEMO and on 50 z-levels in the vertical, with a resolution decreasing from ~1 m near the surface to more than 400 m in the abyssal plain. Partial step representation of the bathymetry is used, which improves the model solution in the North Atlantic Ocean (Barnier et al., 2006). The bathymetry is derived from the ETOPO2 data set. Initial conditions for temperature and salinity are derived from the Levitus climatology. Forcings and operational protocols are the same than for the previous system version.

Regarding data assimilation, a multivariate multidata SEEK filter is used. The forecast error covariances are represented by 3-D modes from a set of anomalies (statistical approach). Altimetric SLA (Jason-1, Envisat, GFO), Reynolds SST (RTG) and in situ T/S vertical profiles are assimilated in a fully multivariate way. This description of V1 version is summarized in Table 2.

This V1 system version constitutes the baseline IBI regional system for the 6-month ECOOP TOP experiment. For this TOP exercise, PSY2V3 hindcasts and forecasts were available through the ECOOP central portal EuroMISS in real time to be used as boundary conditions and initial conditions by the coastal systems embedded in PSY2V3 following the downscaling scheme Fig. 2. As it is shown in Fig. 3, on the ECOOP website, users could display PSY2V3 outputs thanks to the Dynamics Quick View (a Google Earth application developed in the framework of ECOOP). Finally, users could also assess the quality of PSY2V3 hindcasts and forecasts through the ECOOP validation web page, where modelled SST was compared to the satellite SST ODYSSEA (see Fig. 4).

4 Description of regional Mercator Ocean System V2: IBI36

The integrated IBIROOS V2 system comprises 4 different components together with an extra basin system used to provide OBCs to the IMI-NE-Atlantic system and to the new IBI36 system (see Fig. 5). Apart of this PSY2V3 basin system for the North Atlantic ocean, the former regional IBIROOS V1 previously described, the V2 system incorporates a Regional System, covering the entire IBI area (IBI36; Mercator Ocean regional system V2), and three Sub-regional Systems covering respectively: the Irish shelf system IMI-NE-Atlantic (IMI Irish Marine Institute), the bay of Biscay and Western channel system MANGA (PREVIMER), and the Iberian coasts system MOHID (IST). It should be noted that this V2 integrated system is not still ready since IBI36 would not be fully operational untill spring 2011 (within the MyOcean Project framework).

The integrated IBIROOS V2 version incorporates not only improvements of the already existing V1 base-line regional and coastal systems, but also the generation of new forecast systems. IBIROOS V2 must be more accurate of course, must include more physical and ecosystem processes and must add best assimilation scheme. Like in previous sections, we give here, a description of Mercator Ocean Regional IBI system V2, which will soon provide boundaries and/or initial conditions for the subsystems. A summary of the characteristics of the system is given in Table 3.

IBI36 is based on the NEMO/OPA9 Ocean General Circulation Model (Madec et al., 1998; Madec, 2008). In order to allow fast external gravity waves, a “filtered” free surface formulation has been replaced by a time-splitting scheme of Griffies and Pacanowski (2001): the barotropic part of the dynamical equations is integrated explicitly with a short time step whereas depth varying prognostic variables (baroclinic velocities and tracers) that evolve more slow are solved with a larger time step (Chanut et al., 2008). The linear free surface formulation has also been replaced by the non-linear free surface to allow a good representation of tidal waves in coastal regions where their amplitudes are large compared to the local depth (Levier et al., 2007). The vertical turbulent mixing exchanges are estimated from the Generic Length Scale (GLS) model

(Umlauf and Burchard, 2003). This model resolves a prognostic equation for turbulent kinetic energy and another for a generic length scale (mixing length, dissipation rate, etc.). Thus, commonly used closure scheme can be considered: Mellor-Yamada (1982), k-ε (Rodi, 1987) or k-ω (Wilcox, 1988). The turbulent viscosities and diffusivities are calculated by means of these two prognostic quantities but also thanks to stability functions (Canuto, 2001). This turbulent closure scheme is able to control instable cases as convection because of the capacity of these stability functions to take very high values in such situations. For our applications, we used the k-ε model. The surface and bottom values are calculated thanks to a Neumann condition. At the surface, the wave effect is considered (Craig-Banner, 1994).

The model domain covers part of the North East Atlantic ocean, going from the Canary Islands to Iceland. It encompasses also part of the Western Mediterranean Sea and the North Sea, reaching the Skagerrak Strait that connects the Baltic Sea to the North Sea. The primitive equations are discretized on a 1/36° (~2 km) curvilinear grid and on 50 z-levels in the vertical. Vertical resolution decreases from ~1 m near the surface to more than 400 m in the abyssal plain. A partial step representation of the bathymetry is used. The bathymetry is derived from the 30 arc-second resolution GEBCO 08 data set (Becker et al., 2009) merged with regional bathymetry provided by IFREMER, the French Navy (SHOM, Service Hydrographique et Océanographique de la Marine) and NOOS community (North West Shelf Operational Oceanographic System, http://www.noos.cc).

Regarding atmospheric forcings, meteorological fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) with a 3-h and $0.25^{\circ} \times 0.25^{\circ}$ resolution are used to force the model. According to Bernie et al. (2005), this temporal resolution is enough to solve diurnal variations of SST. Fresh water and heat surface fluxes are computed from CORE bulk formulae (Large and Yeager, 2004) using a set of atmospheric variables such as 2-m air temperature, precipitation, relative humidity and radiative surface heat fluxes. Atmospheric pressure and wind stress fields are also used to force the momentum equations. Note that solar heating flux is not evenly distributed within the depth of the top model layers. Instead, the short wave radiation penetrates the surface layer according to an extension law whose extinction coefficient is dependent of the ocean colour. This factor is need to be considered in order to correctly simulate diurnal cycle in the surface oceans (Dai and Trenberth, 2004). In this specific model set-up, a monthly ocean colour climatology based on SeaWiFS data was used to this purpose. Astronomical tidal forcing is also included. It also includes river fresh inputs from a monthly runoff climatology built by averaging data from the Global Runoff Data Center (http://grdc.bafg.de) and the French hydrographic database "Banque Hydro" (http://hydro.eaufrance.fr). Finally, 35 major rivers were taken into account and applied at lateral open boundaries over the model area.

Temperature, salinity and sea surface heights from PSY2V3 daily fields are specified at lateral open boundaries. As PSY2V3 does not include tidal forcing and atmospheric pressure forcing, these signals are added at the open boundaries. Tidal elevations and currents of 11 tidal constituent (M2, S2, K2, N2, K1, O1, P1, Q1, M4, Mf, Mm) are provided from the TPXO7.1 global tide model (Egbert et al., 1994) and applied using Dirichlet boundary conditions. Elevations due to atmospheric pressure static effects, also known as inverse barometer effects (Wunsch and Stammer, 1997), are computed from the ECMWF pressure fields.

Regarding the operational protocol, the system does not include any data assimilation, and the downscalling methodology used here and depicted in Fig. 6 is inherited from the strategy developed and tested in the area for the ESEOAT system (Sotillo et al., 2007). Every week, the regional system is initialized in the past from analysed outputs (3-D temperature, salinity velocities and sea-level) taken from the PSY2 system and bilinearly interpolated on the refined grid. The model is then integrated until D0 to allow the spin up of small scales and the convergence of physical processes that are not resolved by the parent system. The analysed output at D0 is then used to provide one week forecasts until the next analysis stage. Note that in the future operational context, the scenario will be somehow different: to account for the best available atmospheric forcing, a 5 days forecast will be performed every day from D0 to D0+5.

In order to study the impact of the duration of the spin-up phase on the forecasts results, some tests were performed using 1, 2, 3 and 4 week spin-up durations. This test helps to determine the best choice for the spin-up time period.

Figure 8a and b shows the RMS of the Sea Surface Temperature difference between high resolution satellite-based observations (L3 multi-sensor product from Météo France CMS center in Lannion, France) and the model, for (a) one week spin-up simulation and (b) four weeks spin-up simulation, for the period May–June 2009, for the Bay of Biscay and Channel region. In the one week spin-up simulation case, the largest errors occur in the Channel and along the shelf break, linked with the tides dynamics, and north of the Galicia coast probably due to the initialization temperature field. The four week spin up simulation exhibits substantial error decrease in the Channel. The RMS error pattern north of Galicia has disappeared. The RMS error is also reduced over the French shelf. On the other hand, the RMS error is slightly increased along the shelf break probably due to a lack of internal tides mixing; it also increases close to the Landes coast. So, in some specific areas where the tides are important or in frontal zones, a longer spin-up time would be necessary to reduce the RMS error.

Figure 8c shows the RMS error evolution for different regions (GLOB, IBER, NSEA, BOBI and MEDI domains depicted in Fig. 7) and for each IBI36 simulations (from 0 to 4 weeks spin-up). As expected, the RMS decreases strongly with the one week spinup simulation (except in the Mediterranean Sea) thanks to the improved physics of the model compared to the parent model. Then, the model drifts and the RMS error tends to slightly increase (except in the Bay of Biscay region). Finally, it was considered that a two weeks spin-up time is quite sufficient for the system to stabilize, with less technical operational constraints.

5 Validation and V2 Vs V1 comparisons

First, it is qualitatively study and validate the representation of different regional physical processes in the IBI area. Then, a more quantitative study is performed. Most of the shown diagnostics corresponds to the operational simulation IBI36-OPER, which follows the operational protocol previously described. Nevertheless, some diagnostics from a 2-years continuous free simulation IBI36-CONT (from June 2007 to July 2009) are also used . By default, when IBI36-CONT is not specified in the text, IBI36 refers to the IBI36-OPER set-up.

5.1 Qualitative validation

5.1.1 Thermal fronts

From Sea Surface Temperature (SST) gradients it can be simply estimated the thermal fronts locations. In order to make a direct comparison of model results with observations, it was interpolated in space and time model SST onto the observational grid. We then calculate the temperature gradient along the x and y-axis and sum their norms. Finally, we map the maximum gradients for the model and the observations, as seen in Fig. 9 in the English Channel and Celtic Sea region. These fronts are located at the boundaries between stratified areas and mixed areas, where tides interact with bathymetry. On 24 June 2009, the IBI-V2 simulation and satellite-based observations (L3 multi-sensor from Météo France CMS) show a very good agreement (Fig. 9). Almost all the main fronts are reproduced at the right position by the model, along the Brittany coast, across the English Channel, or along the Cornwall coast. The main discrepancy comes from the front crossing from Ireland to Wales: this front goes deep into the Irish Sea in the IBI-V2 simulation. This is not the case with a test simulation of 4 weeks of spinup instead of 2 (not shown), which indicates that for this area a longer spin-up period is necessary to correctly reproduce the tidal dynamics. The PSY2V3 simulation, which does not include any tidal processes, can not reproduce the fronts.

The Ushant front, off French Britain coast, is carried out from the interaction between bathymetry and tidal currents. In summer, close to this coast, the tide is weak and water column is well stratified. Further, tidal currents are strong and bottom is not so deep: so the bottom friction mixes the whole water column. And further, the bottom is deep and the water stays stratified. Thus the colder homogeneous water area between both well stratified water areas brings about a strong front in the surface layer. Fig. 10 shows a comparison of measured SST (L3 multi-sensor from Météo France CMS), V2 and V1 system SSTs on June 2009: two cold cores of water around the Sein and Ushant islands can be identified in the observations and in the V2 system. The Ushant front can not be represented by the V1 system which does not include the tidal dynamics.

5.1.2 Water masses and stratification

The salty Mediterranean waters flow through the Gibraltar straight, deepen between 1000–1200 m levels to spread in the North eastern Atlantic. Figure 11 shows the yearly mean profile of salinity: the Mediterranean water layer is at about 800–1000 m of depth for V2 system (IBI36-CONT simulation) against 600–800 m for V1 one. So these waters are better deepened for V2 but they are too salty compared with climatology.

In order to validate stratification over the Bay of Biscay shelf, we use the in situ profile measurements from the PELGAS 2009 oceanographic cruise (IFREMER; the data have been extracted from data holdings at the SISMER data centre) accomplished in the Bay of Biscay in May 2009 for comparisons with IBI36 and PSY2V3 systems. The data are irregularly distributed in space and time and we used a collocalisation tool (adapted from Juza 2008) to build modeled profiles at the same location and same day than observed profiles. Observed and modeled profiles are then interpolated on a 3-D grid for visualization. Figures 12 and 13 present the interpolated temperature and salinity fields for the observations, the IBI36 and the PSY2V3 systems. Each profile's date is different so the fields are not snapshots of a particular day but for the whole period of May 2009. The ship track goes from the South to the North. At the end of May, more measurements were made again in the South of the shelf (the results of this part of the cruise are presented in a separated little window). The observed thermal stratification shows two minima (Fig. 12). One along the Aquitaine coast: the measurements were made in this area at the beginning of May when the thermal stratification is not yet established; surface waters in this area can also be influenced by the Gironde plume. The other minimum is observed west of the Brittany coast, in the Ushant front; in this area, the thermal stratification can not set up due to the strong tidal mixing. A maximum of thermal stratification is observed near 47° N, 2.5° W. At the end of May (small window on Fig. 12) the thermal stratification is set up and difference between surface and bottom can reach 5 °C over the shelf. The IBI simulation is close to the observations, being the minimum and maximum are well reproduced. The thermal stratification is slightly over-estimated offshore the 200 m isobath. The PSY2V3 simulation, which does not use tidal forcing, is not able to reproduce the minimum of stratification in the Ushant front. The thermal stratification is too weak for these two simulations. The observed haline stratification (Fig. 13) shows an along-shore gradient over the shelf with a maximum in the Gironde estuary, a secondary maximum near the Loire estuary, and a minimum near Brittany. The difference between surface and bottom salinity is negative all over the shelf up to Brittany. This is due to the rivers plumes which spread over the shelf. In the southern part of the shelf, the IBI simulation reproduces the haline stratification pattern, but the Gironde estuary maximum is under-estimated. The positive difference near Brittany and offshore the 200 m isobath is not reproduced. However, the IBI36 simulation slightly improves the results compared to the PSY2v3 one by which it was initialized. As a conclusion, the IBI36 system ability to reproduce haline stratification is reduced by its initial conditions. The thermal stratification is well reproduced, despite problem in the Gironde plume near field due to a too strong mixing.

The Navidad current is an advection of warm water mass triggered on December. It flows northward along the shelf break in the Bay of Biscay during the winter. Figure 14 shows a comparison of measured SST (AVHRR), V2 and V1 system SSTs on January

2008: the spreading of Navidad along the shelf break as well as its intensity is far better reproduced for V2 system than V1.

5.2 Quantitative validation

Figure 15 shows a map of SST bias between satellite-based observations (Météo France CMS L3 multi-sensor SST) and model outputs for the May–June 2009 period. Compared to PSY2V3, the new IBI36 system reduces the errors almost everywhere, except along the shelf slope, around the Cape St Vincent, between the Capo Verde islands and the Moroccan coast, and between Iceland and the Feroe Islands. The enhancement is net on the Armorican shelf and in the north Sea. Table 4 gathers statistics calculated for both models for different areas of the IBI region; the IBI36 model has most of the best scores.

Regarding residual currents, we compare model currents with observed current measurement time series from the Puertos del Estado deep sea water Network (Alvarez Fanjul et al., 2002; http://www.puertos.es). The buoys considered hereafter are located around the north-west Spanish coasts: Cabo Silleiro (9.39° W, 42.13° N), Villano-Sisargas (9.21° W, 43.5° N), Estaca de Bares (7.62° W, 44.06° N), Cabo de Peñas (6.17° W, 43.74° N). In order to remove the tidal signal from the current time series, we perform a harmonic analysis of the IBI36 outputs, but not on the PSY2V3 data which does not include the tidal forcing and which outputs are daily averaged. Figure 16 represents the zonal and meridional components of the near surface residual current (hourly measurements, one-day filtered and smoothed) at the Cabo Silleiro buoys. This buoy is located on the west Spanish coast (north of Portugal boundary) above the continental slope (above the 600 m isobath) which is oriented north-south, so the meridional component is equivalent to the along-shore component, and the zonal component is equivalent to the cross-shore component. During the May 2009 period, IBI36 system is well correlated with observed measurements, especially for the cross-shore component. The along-shore component is under-estimated by IBI36. Table 5 presents the RMS error as well as detrended correlation for the zonal and meridional components of the current at different locations. The RMS error is calculated with IBI36 hourly currents and PSY2V3 daily currents. RMS error is reduced in IBI36. About correlation, it is more difficult to conclude: correlations are generally weak, and IBI36 does not seem to perform better than PSY2V3. In the Cabo Peñas mooring, the simulated meridian component of current at 3m is even non correlated with data for IBI36 (8 %) whereas it is even uncorrelated for PSY2V3 (–31 %).

6 Conclusion and prospects

This paper has presented the evolution of the regional IBI system of Mercator Ocean from the beginning of the ECOOP project up to now (from early 2007 untill 2011). Since the ECOOP launch, the regional system has been updated into 3 versions (IBIROOS-V0 to IBIROOS-V2) described here. The first existing version V0 (PSY2V2) has been updated to a base-line V1 one (PSY2V3) which has been used for the 6-month ECOOP Target Operational Period (TOP), the central objective for all forecasting systems belonging to ECOOP. Contrary to V2, both V0 and V1 versions covered the whole North Atlantic Ocean, so for ECOOP, an extraction over the IBI area were considered. For the TOP, IBIROOS-V1 (PSY2V3) successfully provided data as boundary and initial conditions of embedded coastal systems of the other IBI partners, in real time. Besides, for this period, users could display hindcasts and forecasts of IBIROOS-V1 through the ECOOP website (thanks to a display tool and a validation web page developed during the project). In parallel, an upgraded IBIROOS-V2 (IBI36) has been developed. Strong efforts were made in order to include further coastal physics in the NEMO code, which was usually used to simulate larger scales processes. Now 11 tidal components can be taken into account thanks to a new non-linear free surface, the time splitting which permits to separate high frequency barotropic signals from baroclinic ones, and new formulations of open boundary conditions. The K-epsilon turbulent scheme has improved the vertical mixing too. High frequency 3-hourly atmospheric fluxes have been used to force surface model. And a merged bathymetry has been generated from different regional data basis. The 1/36° horizontal resolution has allowed the model to resolve mesoscale and sub-mesoscale structures and specially improve the representation of local front areas. For the operational scenario, the system is initialized by PSY2V3 (and soon PSY2V4, its upgrade). All these developments have allowed the model to adapt itself to coastal dynamics.

In a second part, this paper has shown the validation of the last version IBIROOS-V2 system against data and the previous version IBIROOS-V1. We have distinguished on the one hand a qualitative validation which has directly compared simulation outputs to some known physical characteristics in IBI area, and on the other hand a quantitative validation where current time series and statistical scores have been compared.

A better representation of frontal zones in the IBIROOS-V2 system vs V1 is showing the impact of tide in the model. The Ushant thermal front is particularly well represented in the IBIROOS-V2.

IBIROOS-V2 deepens the Mediterranean water in right depth (between 800 and 1000 m) against IBIROOS-V1 but they are too salty vs the climatology.

A use of in situ data (PELGAS 2009) has allowed the validation of the stratification on the Biscay shelf. The thermal stratification of the IBI system corresponds to data, whereas the haline stratification is further away from observations probably because the IBIROOS-V2 system is too influenced by initialization of PSY2V3. The use of climatological monthly runoffs could also play a role.

The Navidad, this warm water advection along the shelf break which occurs on December seems to be far better simulated by IBIROOS-V2 in term of spreading and intensity.

About SST statistics (bias, and RMS and correlations by subregions), the IBIROOS-V2 system has shown globally the best results against IBIROOS-V1. Regarding dynamics, the IBIROOS-V2 system currents are better than in IBIROOS-V1.

So to conclude, further regional physics taken into account in the new version V2 have proved a real improvement of results against the previous version V1.

This new system which has been developed within the ECOOP project, is now almost ready to become the V1 version for the latest EU project MyOcean and should better answer the need of coastal modellers (in term of initial and boundary conditions). Following the first conclusions from the validation and in order to improve the system for the V2 version for My Ocean next year, several upgrades have been planned:

- MetNO (Norway) can provide to Mercator Ocean new wind stress which takes into account more wave components than the stress from ECMWF presently used. As a result a more realistic vertical mixing should be reached.
- New daily runoffs from a data base used by PREVIMER and real time runoffs modelled by HYPE (from SMHI, Sweden) and/or ISBA (from MétéoFrance) hydrological models should improve the haline stratification on shelves.
- Another operational scenario with a decreasing influence of PSY2 initial condition on shelves should improve the solution in these areas since IBI system physics is more adapted.
- A part of the large scale SST bias seems to be triggered by large scale radiation fluxes bias. So a correction of ECMWF fluxes with CMS satellite fluxes should reduce this bias.
- Each week the operational system IBI36 will be restarted with initial conditions from the new PSY2V4 system. The PSY2V4 system will replace the PSY2V3 system and benefits of many enhancements: use of IAU (Incremental Analysis Update) in the data assimilation algorithm, use of a large bias correction method, ECMWF 3-hourly forcings, ... In particular the incremental analysis update is an efficient way to distribute the correction in time and allows us to restart from an equilibrate state, which was not the case with the PSY2V3 system. This new basin system will provide boundary conditions too.

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Thank you to the LEGOS (Laboratoire d'Etude Geophysique et Océanographie Spatiale, Toulouse, France) for the fruitful discussions.

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Table 1. Description of regional IBIROOS-V0: PSY2V2.

REGIONAL IBIROOS-V0: PSY2V2	
Domain	North Atlantic: 9° N to 70° N (20°W/0° and 30° N/52° N)
PHYSICS	
Calculation Code	OPA 8.1 (Primitive Equations) Madec et al. (1998)
Output frequency	Daily
Horizontal grid	Rotated Mercator 1/15° grid in Atlantic, 1/16° in Mediterranean sea
Vertical grid	– 43 vertical levels (6 m to 300 m) – Rigid lid surface – Full cells at the bottom
Bathymetry	ETOPO2
Surface Forcings	– Direct atmospheric flux forcings – Daily mean ECMWF analysis & forecasts – Monthly run off – Short wave radiation penetration with 2 band scheme
Boundary Conditions	– Buffer zone (closed boundary with T-S damping) – T-S damping towards Reynaud climatology
Lateral Friction	Partial slip lateral boundary friction condition
Bottom Friction	Non linear bottom friction
Horizontal Diffusion for the Dynamics	Biharmonic diffusion
Horizontal Diffusion for the Tracers	Isopycnal laplacian diffusion
Vertical Mixing	TKE vertical mixing model (Gaspar, 90)
Tide	No tide
BIOLOGY	
	No Biology
ASSIMILATION	
Method	Multivariate Multidata Optimal Interpolation
Statistical Representation of the Forecast Error	2-D analytical (horizontal) + EOFs 1-D (vertical)
Assimilated Data	Altimetric SLA (Jason-1, Envisat, GFO), SST Reynolds and in situ T/S vertical profiles

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Table 2. Description of regional IBIROOS-V1: PSY2V3. Differences between V1 and V0 versions are written in bold characters.

REGIONAL IBIROOS-V1: PSY2V3	
Domain	North Atlantic: **20° S to 80° N**
PHYSICS	
Calculation Code	**NEMO 1.09 (Primitive Equations) Madec et al. (2008)**
Output frequency	Daily
Horizontal grid	**Tripolar ORCA grid 1/12°**
Vertical grid	– **50 vertical levels (1 m to 480 m)** – **Free linearized filtered surface** – **Partial steps at the bottom**
Bathymetry	ETOPO2
Surface Forcings	– **Bulk formula: CLIO Oberhuber (1988)** – Daily mean ECMWF analysis & forecasts – Monthly run off – Short wave radiation penetration with 2 band scheme
Boundary Conditions	– Buffer zone (closed boundary with T-S damping) – T-S damping towards Reynaud climatology
Lateral Friction	Partial slip lateral boundary friction condition
Bottom Friction	Non linear bottom friction
Horizontal Diffusion for the Dynamics	Biharmonic diffusion
Horizontal Diffusion for the Tracers	Isopycnal laplacian diffusion
Vertical Mixing	TKE vertical mixing model (Gaspar, 90)
Tide	No tide
BIOLOGY	
	No Biology
ASSIMILATION	
Method	**Multivariate multidata SEEK filter**
Statistical Representation of the Forecast Error	**EOFs 3-D from a set of anomalies**
Assimilated Data	Altimetric SLA (Jason-1, Envisat, GFO), SST Reynolds and in situ T/S vertical profiles.

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Table 3. Description of regional IBIROOS-V2: IBI36. Differences between V2 and V1 versions are written in bold characters.

REGIONAL IBIROOS-V2: IBI36	
Domain	**North East Atlantic:** **20° W–17° E/26° N–64° N**
PHYSICS	
Calculation Code	**NEMO 2.3** (Primitive Equations) Madec et al. (2008)
Output frequency	Daily 3-D variables **+ hourly 2-D surface variables (SST, SSH and surface current)**
Horizontal grid	Tripolar ORCA grid **at 1/36° horizontal resolution (approx. 2 km)**
Vertical grid	– 50 geopotential levels (1 m to 480 m) – **Explicit non-linear free surface (Level, Levier et al., 2007; Griffies and Pacanowski, 2001)** – Partial bottom cells
Bathymetry	**Mixed local bathymetries: GEBCO 0.8, IFREMER (Esturies and Med Sea (MEDIMAP)), SHOM (Biscay), BODC (Irish and Celtic Seas), IOW (Baltic), SHOM-Portugal (Portugese coasts)**
Surface Forcings	– **Bulk formula: CORE Oberhuber (1988)** – **3-hourly ECMWF analysis & forecasts** – **Surface pressure (surge component) included** – **35 climatological, monthly river inflows (GRDC + French Hydrobase datasets)** – Short wave radiation penetration with 2 band scheme **and variable climatological PAR absorption depth**
Boundary Conditions	**Daily open boundary data (u, v, T, S, SSH) from Mercator PSY2V3 North Atlantic system:** – **Barotropic variables: characteristic method Blayo et al. (2005),** – **Baroclinic velocities and tracers: 30-pts relaxation (1-day timescale)**
Lateral Friction	Partial slip lateral boundary condition
Bottom Friction	Logarithmic bottom friction
Horizontal Diffusion for the Dynamics	Biharmonic horizontal mixing
Horizontal Diffusion for the Tracers	None
Vertical Mixing	**K-epsilon Jones and Launde (1972); Burchard et al. (1988)**
Advection	**QUICKEST + ULTIMATE Leonard (1979, 1991)**
Tide	**11 harmonical constituents initially adjusted from TPXO7.1 and FES2004 at open boundaries, tidal potential**
BIOLOGY	
	No Biology
ASSIMILATION	
Method	**None for the moment**

Table 4. Spatial average (observation minus model) Sea Surface Temperature difference (˚C) (left), correlation (middle) and RMS (observation minus model) SST error (˚C) (right) for the period May–June 2009 in the different regions presented in Fig. 7. Best scores are in bold. We subtracted the linear trend of the time series before calculating the correlations.

	Difference (˚C)		Correlation		RMS error (˚C)	
	IBI3	PSY2v3	IBI	PSY2v3	IBI	PSY2v3
BOBI	**−0.03**	0.30	**0.52**	0.43	**0.63**	0.73
CANA	−0.08	**0.05**	**0.64**	0.52	0.59	**0.55**
ESEO	**−0.07**	0.25	**0.55**	0.49	**0.61**	0.65
IBER	**−0.08**	0.19	**0.53**	0.47	**0.65**	0.67
ISHF	−0.19	**0.03**	**0.48**	0.44	0.89	**0.84**
MEDI	−0.11	**−0.04**	0.65	0.65	0.69	**0.66**
NSEA	**−0.11**	0.23	**0.70**	0.64	**0.60**	0.73
GLOB	**−0.07**	0.16	**0.59**	0.53	**0.58**	0.62

Table 5. RMS difference and correlation observation-model for zonal/meridional component of currents at 3 m depth for the period May–June 2009 at different buoys (presented in Fig. 7). Statistics for IBI36 is calculated with 1 day filtered residual currents. Statistics for PSY2v3 is calculated with daily averaged currents. Best scores are in bold.

	RMS ($\mathrm{cm\,s^{-1}}$)		Correlation	
	IBI36	PSY2v3	IBI36	PSY2v3
Cabo Penas	**7/7**	18/9	**73/8**	54/–31
Cabo Silleiro	**5/9**	8/10	**67**/39	56/**67**
Estaca bares	**9/5**	22/10	52/**72**	**69**/24
Villano Sisargas	**11**/9	14/9	40/**40**	**49**/25

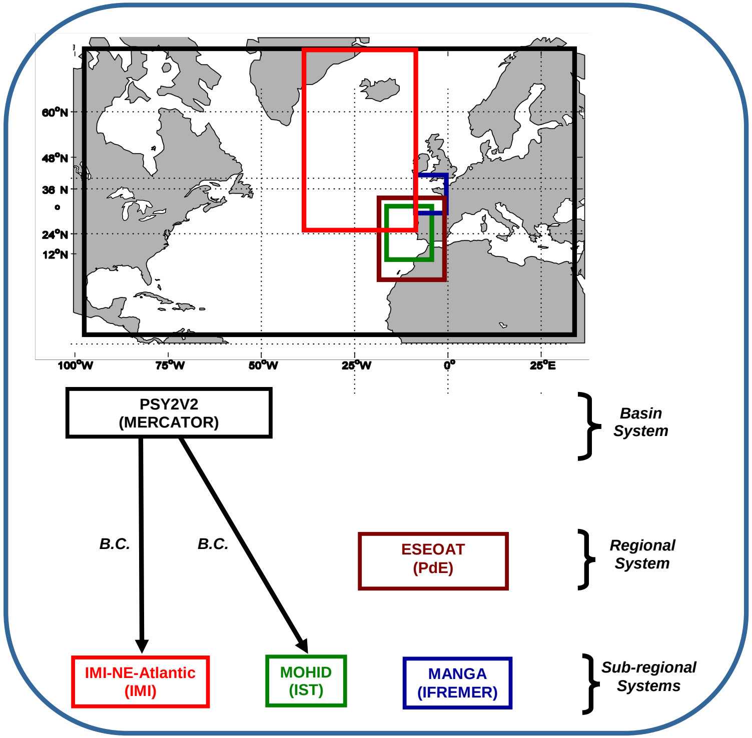

Fig. 1. Downscalling scheme of integrated IBIROOS V0 (B.C. = Boundary Conditions).

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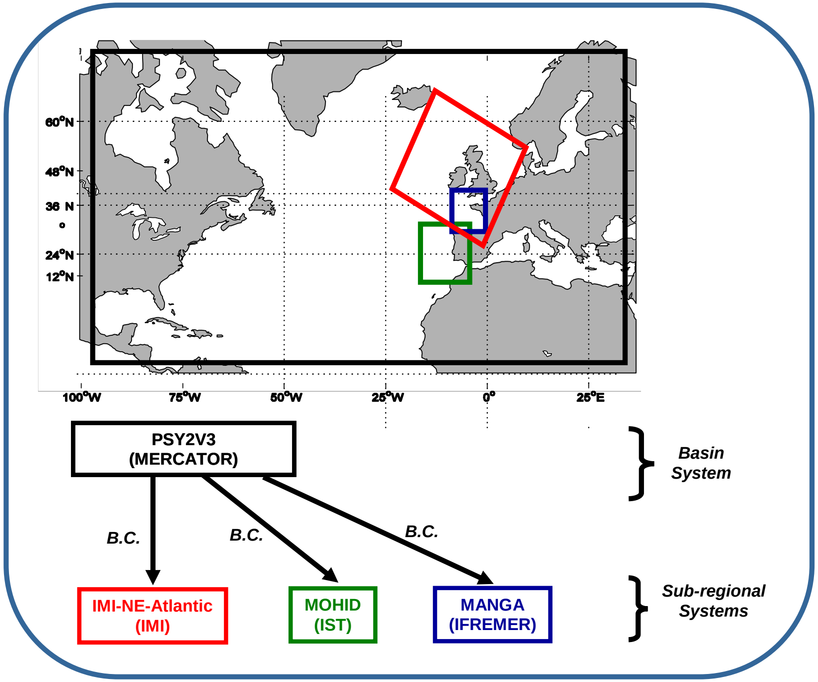
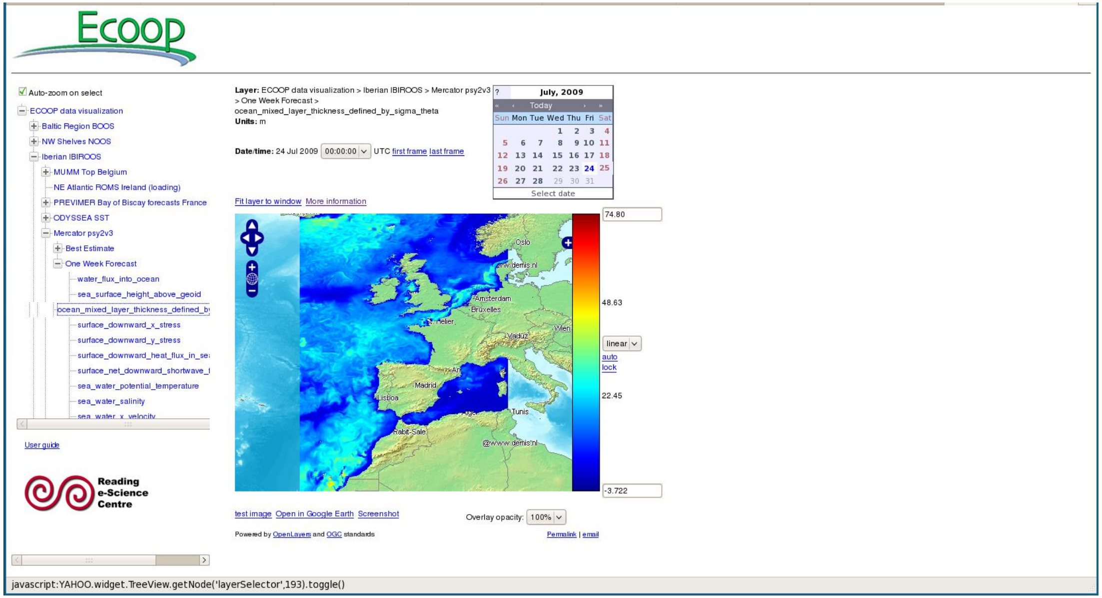


Fig. 2. Downscalling scheme of integrated IBIROOS V1(B.C. = Boundary Conditions).



Layer: ECOOP data visualization > Iberian IBIROOS > Mercator psy2v3 > One Week Forecast > ocean_mixed_layer_thickness_defined_by_sigma_theta

Units: m

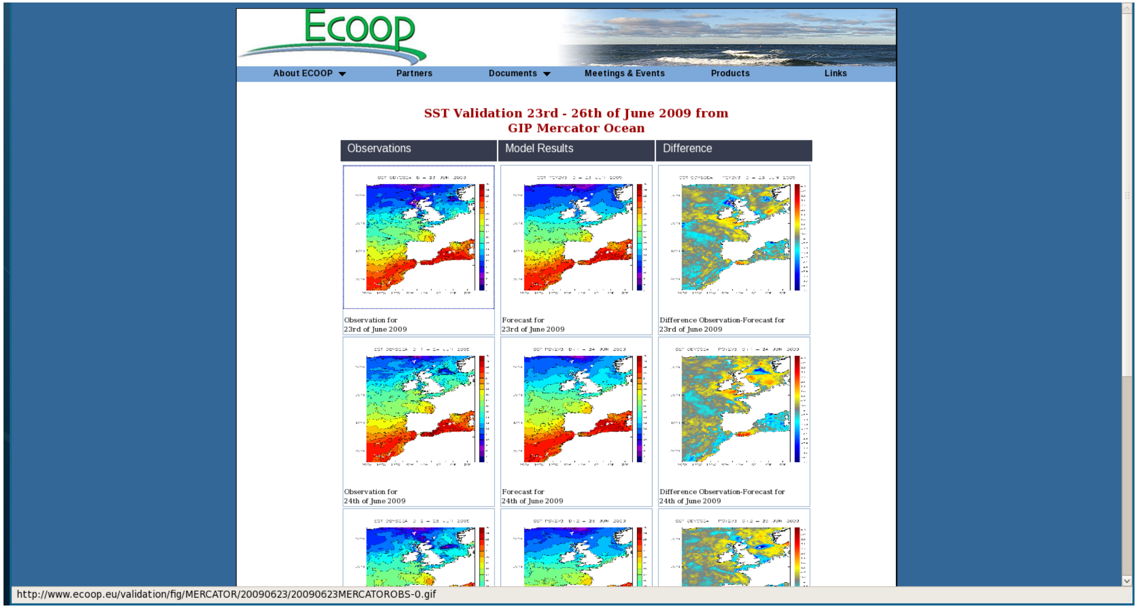
Date/time: 24 Jul 2009 00:00:00 UTC first frame last frame

Overlay opacity: 100%

Powered by OpenLayers and OGC standards

javascript:YAHOO.widget.TreeView.getNode('layerSelector',193).toggle()

Fig. 3. Dynamic Quick Viewer to display the forecasts of the ECOOP operational systems: e.g. for IBI regional system.



SST Validation 23rd - 26th of June 2009 from
GIP Mercator Ocean

Observations	Model Results	Difference
Observation for 23rd of June 2009	Forecast for 23rd of June 2009	Difference Observation-Forecast for 23rd of June 2009
Observation for 24th of June 2009	Forecast for 24th of June 2009	Difference Observation-Forecast for 24th of June 2009

http://www.ecoop.eu/validation/fig/MERCATOR/20090623/20090623MERCATOROBS-0.gif

Fig. 4. ECOOP Validation webpage: e.g. for IBI regional system.

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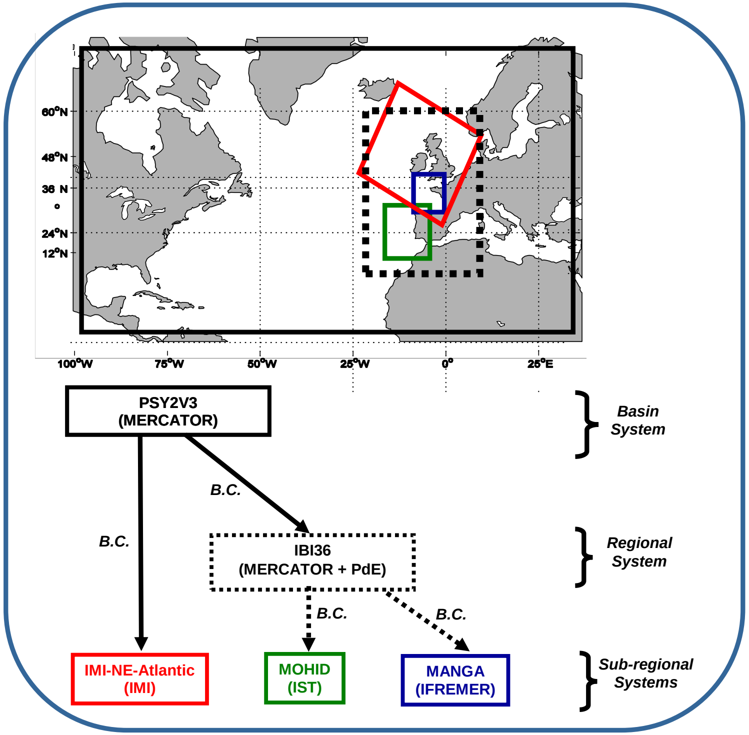

Fig. 5. Downscalling scheme planned for integrated IBIROOS V2 but still not operational for ECOOP (B.C. = Boundary Conditions).

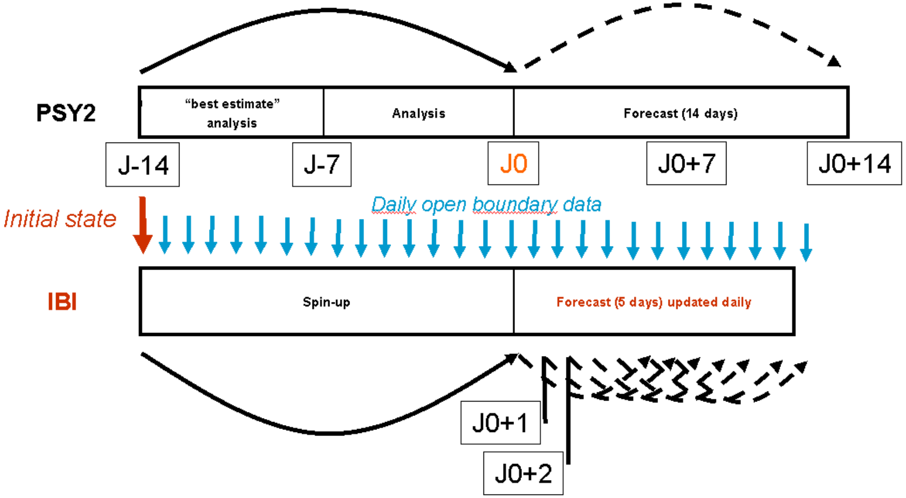

Fig. 6. Operational protocol scheme for V2 system.

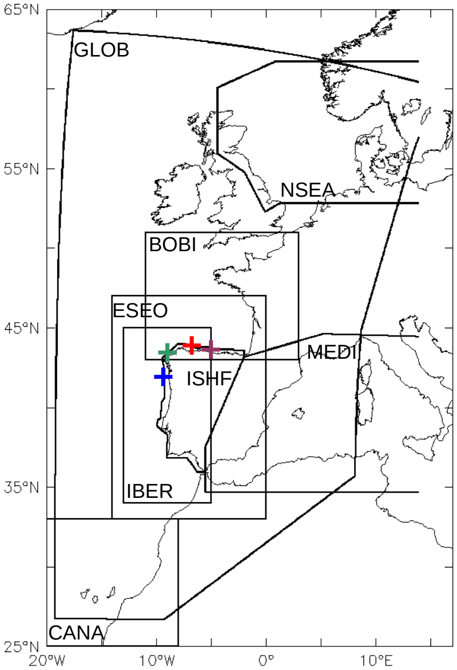

Fig. 7. Map of IBI area with boxes where statistics have been calculated: Bay of Biscay region (BOBI: 11° W–3° E, 43° N–51° N), the Canary Islands region (CANA: 21° W–8° W, 25° N–33° N), the ESEOAT region (ESEO: 14° W–0° E, 33° N–47° N), the Iberic Peninsula region (IBER: 13° W–5° W, 34° N–45° N), the Iberic Peninsula shelf region (ISHF: IBER region over the shelf), the Mediterranean Sea region (MEDI: from Gibraltar strait to 9° E), the North Sea region (NSEA: 12° W–14° E, 48° N–62° N) and the IBI domain region (GLOB). The colored crosses corresponds to the moorings: Cabo Silleiro in blue (9.39° W, 42.13° N), Villano-Sisargas in green (9.21° W, 43.5° N), Estaca de Bares in red (7.62° W, 44.06° N), Cabo de Penas in brown (6.17° W, 43.74° N).

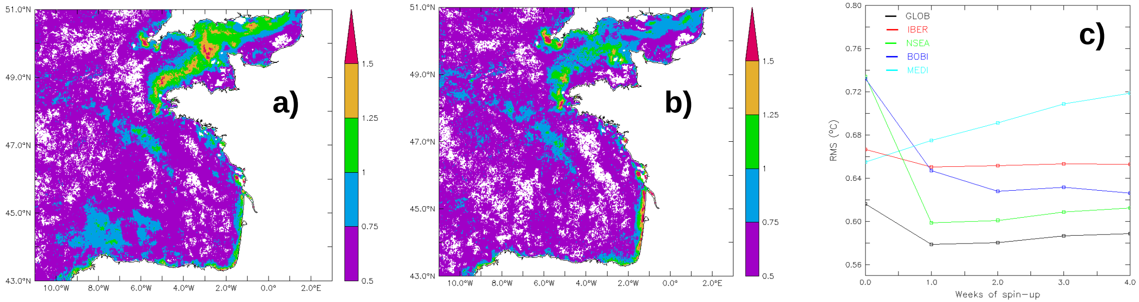

Fig. 8. **(a), (b)**: RMS (observation minus model) Sea Surface Temperature (SST) difference (°C) for the period May–June 2009 for **(a)** the 1 week spin-up IBI simulation and **(b)** the 4 weeks spin-up IBI simulation, for the Bay of Biscay and Channel region. **(c)** Spatial average RMS (observation (CMS) minus model) SST difference (°C) for the period May–June 2009 for the 0 to 4 weeks spin-up IBI36 simulations, for the regions GLOB, IBER, NSEA, BOBI and MEDI presented in Fig. 7.

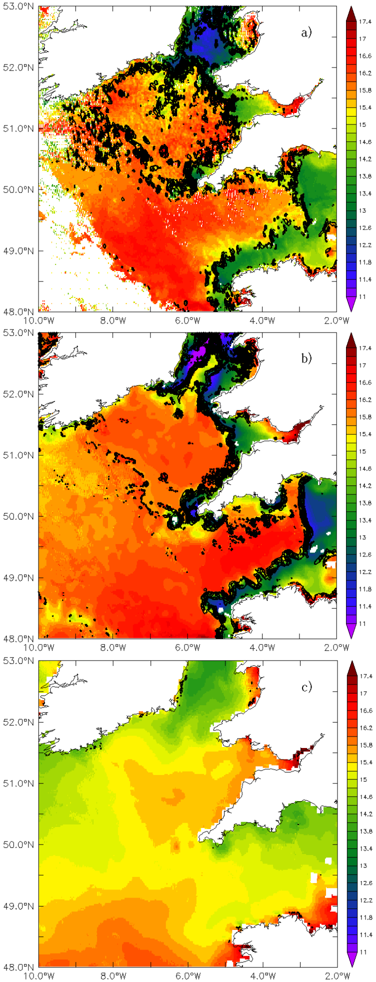

Fig. 9. Sea Surface Temperature (˚C) on 24 June with maximum horizontal gradients of SST overlaid for observation **(a)**, V2 system **(b)** and V1 system **(c)**.

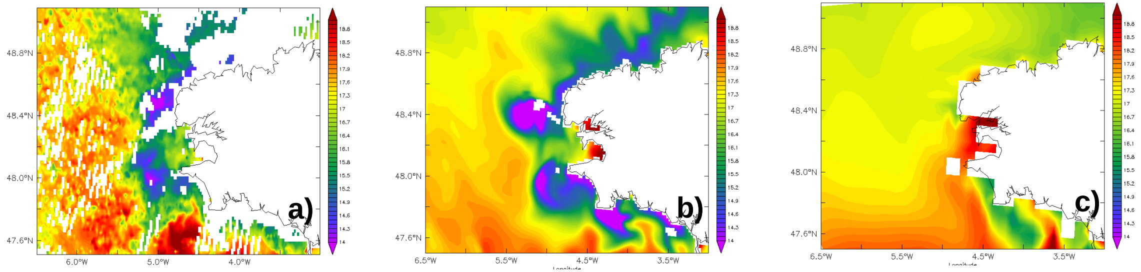

Fig. 10. Ushant front off French Britain coasts on June 2009 **(a)** MF CMS SST; **(b)** V2 system SST; **(c)** V1 system SST.

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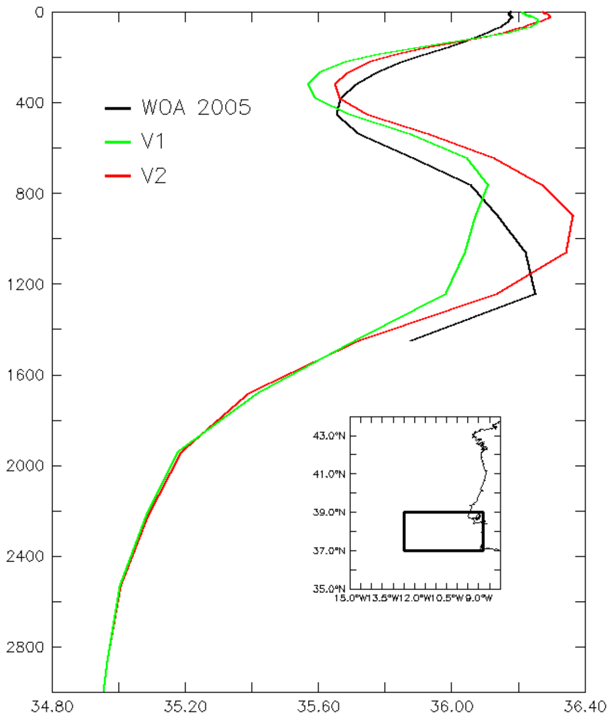

Fig. 11. 2009 annual mean salinity profile off Spanish coast: black line for WOA 2005 climatology, green line for V1 system (IBI36-CONT) and red line for V2 system.

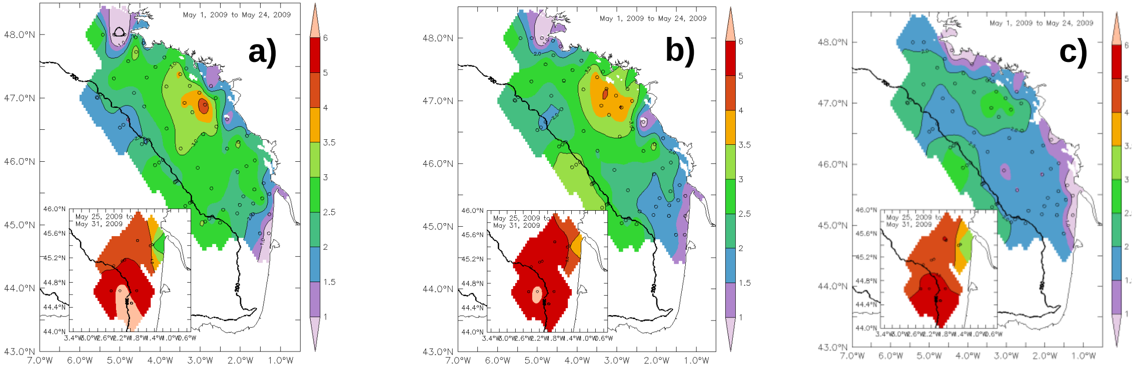

Fig. 12. Surface minus near bed temperature difference (°C) for observation (panel **a**), V2 system (panel **b**) and V1 system (panel **c**).

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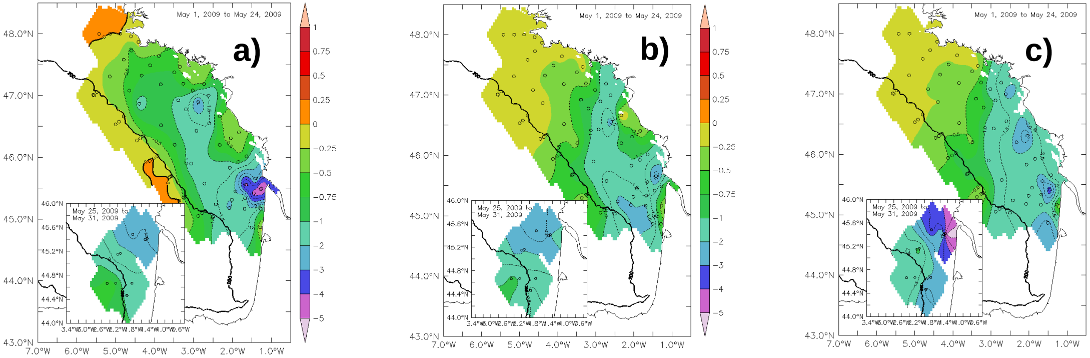

Fig. 13. Same as previous figure but for salinity (psu).

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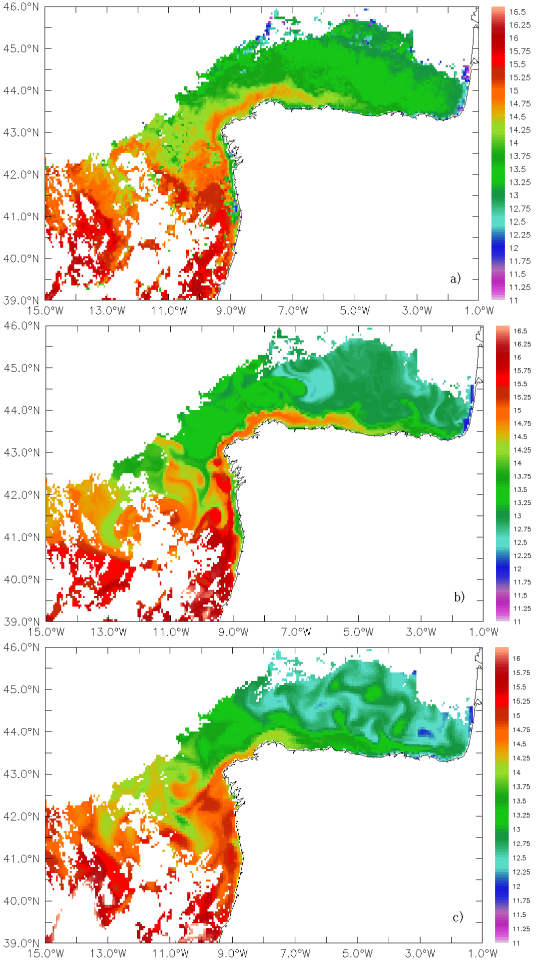

Fig. 14. Navidad: surface warm current along Spanish and french coasts. SST on January 2008 **(a)** AVHRR; **(b)** V2 system (IBI36-CONT); **(c)** V1 system.

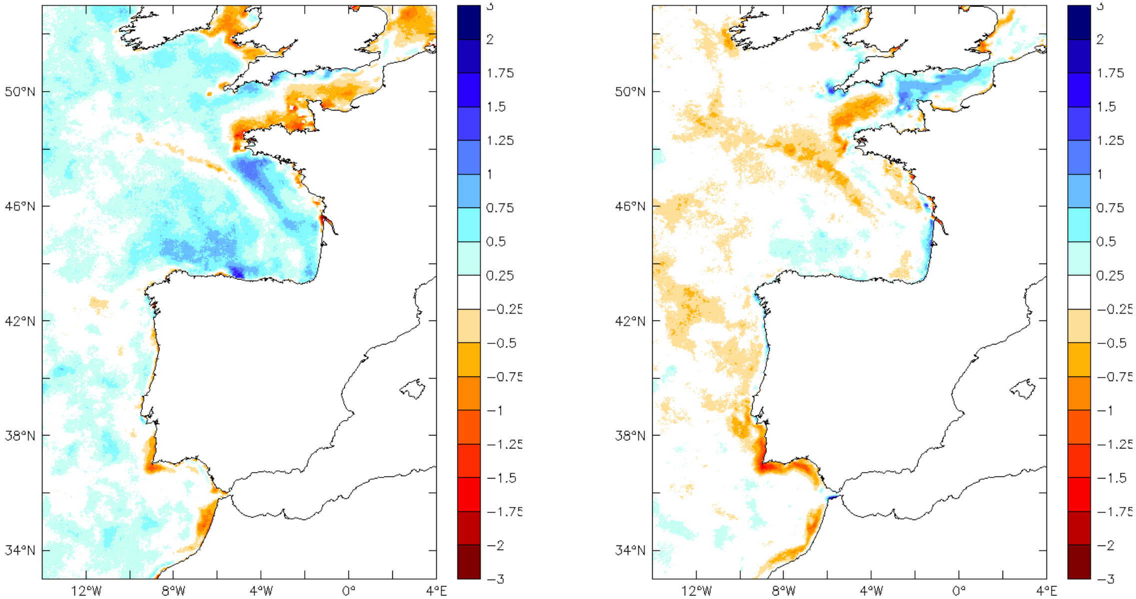

Fig. 15. (observation minus model) Sea Surface Temperature difference (°C) for the period May–June 2009 (left) for V1 system, (right) V2 system. Observations come from CMS L3S SST. The Mediterranean Sea is masked.

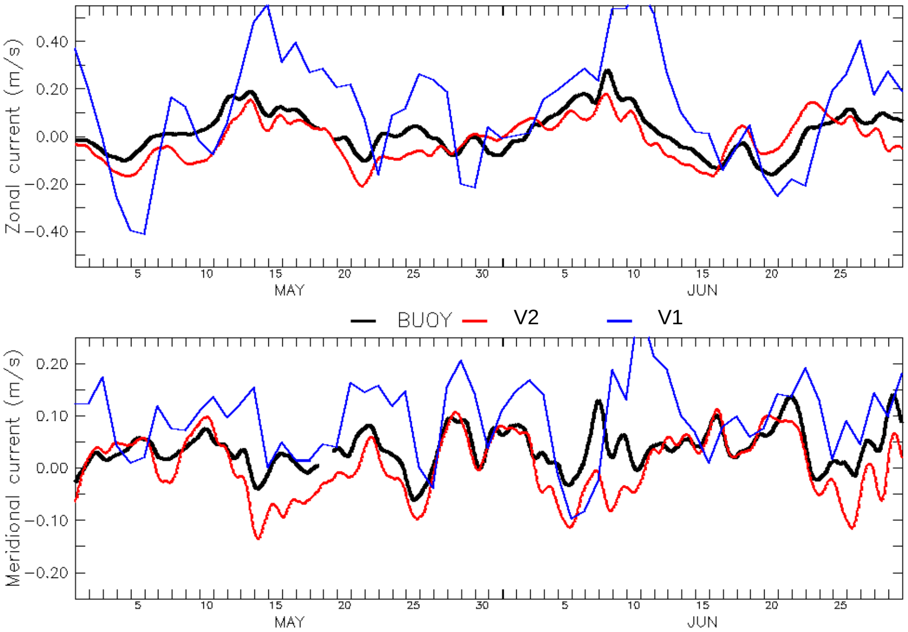

Fig. 16. Time series of zonal (top) and meridional (bottom) components of the current (m s^{-1}) at 3 m depth for the period May–June 2009 at Estaca de Bares buoy (North-West Spanish coast near Capo Finisterra: see Fig. 7). Observation is in black, V2 system in red and V1 system in blue. Residual current on May–June 2009 at the mooring Estaca de Bares (North-West Spanish coast near Capo Finisterra: see Fig. 7).

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