Downscalling CMEMS IBI 3D hourly solution

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Abstract: The IBI 3D hourly solution was tested as an alternative initial and open boundary condition to the present methodology used by Hidromod based in the CMEMS global forecast. The tests were done for an implementation of the MOHID model to the Algarve coast with a ~400 m horizontal resolution. Models results were compared with several observation data sources: Lagos tidal gauge, Faro buoy temperature, Algarve-Huelva HF radar for December 2017. The tests lead to the follow conclusions: (1) downscaling of IBI solution for domains restricted to the continental shelf area do not present any numerical limitations; (2) for domains where a significant percentage of the model domain is located outside of the continental shelf, there is the need of follow the same downscaling methodology used in the IBI solution. In this methodology extra salinity and temperature (spectral nudging) sinks/sources terms are added to force the density field to converge outside of the shelf to the CMEMS global solution.

Key words: Downscalling, hydrodynamic model, spin-up, nudging, CMEMS, MOHID, Algarve

1. INTRODUCTION

The operational IBI (Iberian Biscay Irish) Ocean Analysis and Forecasting system, daily run by Puertos del Estado, provides a 5-day hydrodynamic forecast including high frequency processes of paramount importance to characterize regional scale marine processes (e.g. tidal forcing, surges and high frequency atmospheric forcing, fresh water river discharge). This product covers a large area that goes from North of Ireland to the Canary Islands (Sotillo *et al*., 2017).

IBI 3D hourly solution (foreseen to be publish in the CMEMS online in 2018) was tested as an alternative open boundary condition to the present methodology used by Hidromod based in the CMEMS global hydrodynamic forecast. The tests were done for the Algarve coast.

Two spin up technics were tested: one where the initial condition of the high resolution model is assumed equal to the IBI 3D hourly product and no restriction is imposed to the forcing terms; a second one where a slow connection of the forcing terms was used. The tests were done for December 2017. Models results were compared with several observation data sources: Lagos tidal gauge, Faro buoy (temperature) and Algarve-Huelva HF radar (surface currents).

Presently Hidromod downscales the CMEMS global solution via MOHID model implementations for different coastal areas of interest. In the IBI area Hidromod manages two models running daily covering the follow areas: West Iberia and Madeira archipelagos. In a second step these models are used to feed very high resolution models which supports a number of stakeholders\activities in areas such as ports, utilities, emergence response, aquaculture, etc.

Hidromod also supported the implementation of several systems running in forecast mode for the IBI area. The most notable ones are managed by:

• IST – PCOMS twin model of the one run by Hidromod for West Iberia (Mateus et al., 2012);

• MeteoGalicia - covers the Galicia coast (Huhn *et al.*, 2012);

• Suez environment - French Bask country (Delpey *et al*., 2014);

• Algarve University – Algarve coast (Janeiro *et al.,* 2017).

The main goal of this modelling exercise is to propose to MOHID users a methodology to use the CMEMS IBI 3D hourly product as reference solution to define initial and open boundary conditions of coastal/local scale implementations.

The Algarve coast was chosen as the testing area because:

• It is an area of great interest for developing downstream services (e.g. aquaculture is a fast growing activity);

• High frequency observations: buoys and HF radar data;

• It is an area with complex hydrodynamics (e.g. upwelling jet, Mediterranean outflow).

2. METHODOLOGY

The standard downscale methodology proposed by Hidromod to MOHID users is the following:

• **Reference solution**: Hidromod proposes a reference solution that results from adding linearly the CMEMS global solution, the astronomic tide global solution FES2012 and the inverted barometer approximation. This reference solution used to define the initial and open boundary conditions.

• **Open boundary conditions** (Leitão *et al*., 2005):

1. Sea level and barotropic flow – Flather radiation condition;
2. 3D velocity, temperature and salinity - boundary relaxation scheme with a time scale equal to the period between two instants of the temperature/salinity reference solution (e.g. CMEMS global solution – 1 day) in the boundary cells. An exponential evolution of relaxation time scales from the border to the model domain interior along 10 cells;

• **Spin up/ Method 1**:

1. Initial condition: sea level, velocity, salinity and temperature interpolated directly from the reference solution;
2. Forcing: no restrictions;
3. Limitations: Experience shows that can only be used is shallow depths (< 300 m depth);

• **Spin up/ Method 2** (for a detailed description see Leitão *et al*., 2005):

1. Initial condition: salinity/temperature equal to the reference solution, null velocity field and null seal level gradients;
2. Forcing: Slow connection of all forcing terms: wind, atmospheric pressure, baroclinic force, etc;
3. Limitations: long spin up periods (~3 days for domains with few hundreds of kilometers).

2.1 Algarve Test case

Two model domains were tested (Fig. 1): one restricted to the shelf area (Option 1) and another with the open boundaries located more off-shore (Option 2). In both domains to minimize the vertical interpolation errors a z-level vertical discretization similar to the IBI new product was assumed. Also for both domains a horizontal spatial resolution of 0.004º was used. The model bathymetry was defined using the bathymetric data available via EMODNET bathymetry portal. The atmospheric boundary condition was based in a WRF with 5 km horizontal resolution provided by the University of Aveiro. The initial and open boundary conditions, as described above, was based in the new IBI 3D hourly product. No river discharges were imposed.

For “Option 1” implementation the spin up “Method 1” described above was used. The “Method 2” was considered in the “Option 2” implementation. The modelling results analysis was limited to the period from 9 to 22 of December of 2017. To maintain consistency in both implementations a 5 day spin up period was assumed. All simulations started at December 4th of 2017.

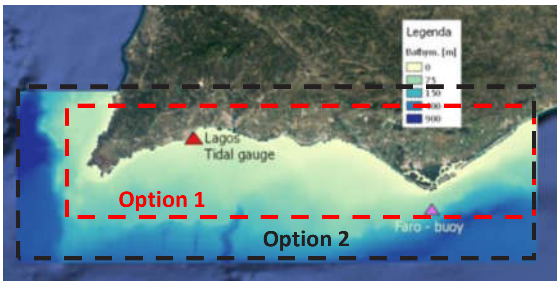

Fig. 1. MOHID Option 1 and 2 model domains and bathymetry. Option 2 domain volume ~5 times greater than Option 1.

2.2 Validation data

The main strategy to validate the MOHID model implementations was to compare the model results with publicly available high frequency (3 h or less) observations for the area of interest. Additionally, the IBI solution was compared with the MOHID model results and observations. The follow observation data sources were used:

• HF radar – surface velocities (hourly);

• Faro buoy – sea surface temperature (every 10 minute);

• Lagos tidal gauge – sea level (every 5 seconds).

3. RESULTS

3.1 Potential and Kinetic Energy Evolution

One way to check the consistence of a downscaling procedure is to compare the evolution in time of the kinetic (KE) and potential (PE) energy average in space of the high resolution (MOHID) and reference (IBI 3D hourly) solutions. In the case of the MOHID Option 1 the evolution of KE and PE is quite similar to the reference solution (Fig. 2). However, this is not the case for the MOHID Option 2 where the PE after December 15 diverges clearly from the IBI solution (Fig. 3). KE diverge only significantly in the last few days.

In April 2016 the IBI downscale methodology was upgrade. The periodic weekly re-initialization was replaced by a spectral nudging technique (Katavouta and Thompson, 2016). This method permits to “nudge” the low frequency IBI system solution towards the large scale GLOBAL analysis in those areas where this global solution is expected to be more accurate (mainly off the shelf and in deep waters) due to the assimilation of lower frequency signals. This upgrade explains the perfect match of PE evolution of the IBI and Global CMEMS solutions after filtering out the semi-diurnal variability for Option 2 domain (Fig. 2).

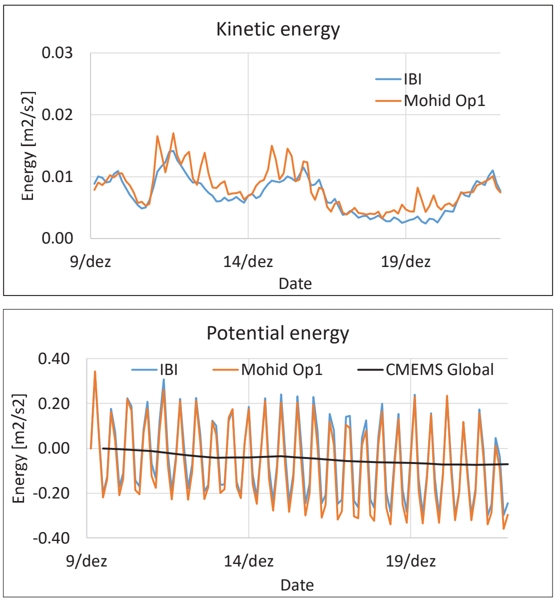

Fig. 2. Evolution in time of KE (upper panel) and PE (lower panel) average in space: MOHID Option 1 (orange line), IBI (blue line) and CMEMS global (black line).

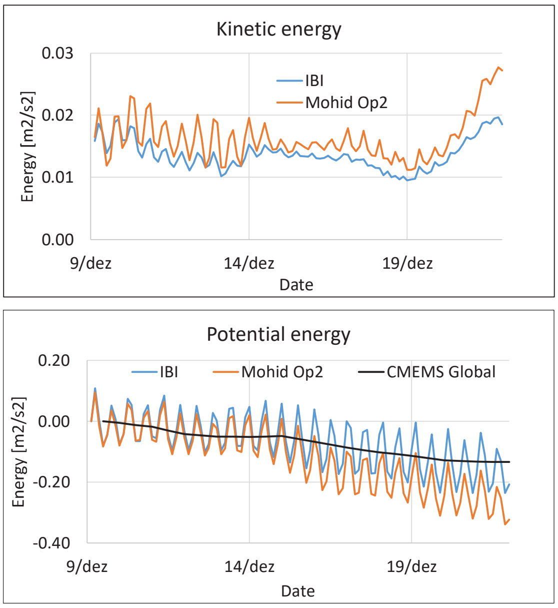

Fig. 3. Evolution in time of KE (upper panel) and PE (lower panel) average in space: MOHID Option 2 (orange line), IBI (blue line) and CMEMS global (black line).

3.2 Model vs Observations

The Algarve-Huelva HF Radar observations average velocity field show in the area of interest a persistent eastward/south-eastward direction (Fig. 3). The same can be observe in the IBI solution but there is a tendency for the velocities to present a southwest direction in the south border vicinity.

The average intensity of the IBI solution is approximately half of the observations. MOHID implementations present the same velocities direction of IBI solution but the average intensity is higher and more similar to the derived from observations. In the case of Option 1 the velocities directions look to be quite similar to the observe ones.

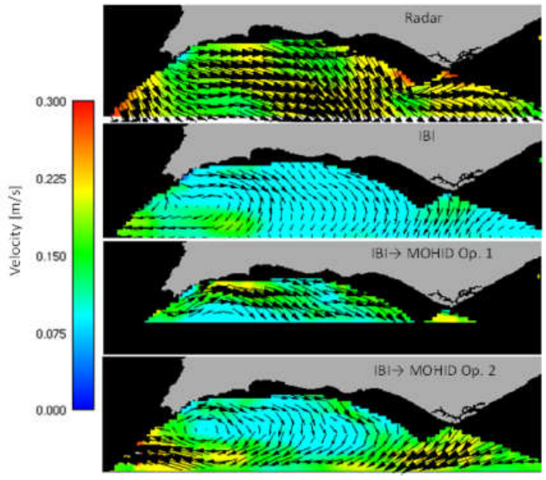

Fig. 4. Surface velocity field Average in time from the top: Radar HF, IBI, MOHID Option 1 and MOHID Option 2.

Option 1 present lower values of RMSE in time that IBI and Option 2 solutions. The zonal and meridional velocities correlation are quite similar to the IBI solution. The statistical metrics average in space shows the MOHID Option 1 present better agreement with observations (Table I).

Table I. Statistical metrics for the surface velocities components: RMSE and correlation in time average in space.

	RMSE U [m/s]	RMSE V [m/s]	Corr. U	Corr. V
IBI	0.17	0.13	0.34	0.33
MOHID Op.1	0.12	0.10	0.39	0.43
MOHID Op.2	0.21	0.11	0.42	0.40

The statistical metrics derived from this comparison are similar to the ones presented in the quality information document of the CMEMS product CMEMS-IBI-QUID-005-001 for the Algarve-Huelva HF radar (Sotillo *et al*. 2017).

The IBI and MOHID solutions present lower temperature values relatively to the data collect by the Faro buoy. In Table II the statistical metrics that summarizes the comparison of temperature between all analysed solutions are presented. The MOHID solutions present an average temperature slightly lower and more intense currents than the IBI solution. The more intense currents will induce stronger vertical mixing decreasing the surface temperature values. However, the average differences can be considered small (~0.5 ºC).

Table II. Statistical metrics for the surface temperature for the Faro buoy location.

	IBI	MOHID Op.1	MOHID Op.2
Bias [ºC]	-0.3	-1.0	-1.1
RMSE [ºC]	0.5	1.1	1.2
Correlation	0.76	0.76	0.7

The MOHID solutions for the Lagos tidal gauge for the period of interest present an unbiased RMSE of 9.3 cm (Option 1) and 10.4 cm (Option 2). These values are similar to the ones of the IBI solution (8.4 cm see Table III). Again Option 1 presents a better agreement than Option 2 with observations.

Table III. Statistical metrics derived from the comparison of the Lagos tidal gauge sea level with the follow model solutions: IBI, MOHID Op. 1 and MOHID Op. 2.

	IBI	MOHID Op.1	MOHID Op.2
Unbiased [cm]	8.4	9.3	10.4
Correlation [-]	0.99	0.99	0.99

This result reinforce the overall better agreement of Option 1 downscalling methodology with observations for the area and period of interest.

4. CONCLUSIONS

• For the analysed spatial/temporal windows the IBI 3D hourly solution is a good option for defining the open boundary conditions of MOHID model high resolution implementations;

• The downscaling of IBI solution for the model domain restricted to the continental shelf (Option 1) present a good agreement with observations and with the reference solution;

• For Option 2 (model domain where a significant percentage of the model domain is located outside of the continental shelf) there is tendency for the model results diverge in a significant way from the reference solution (IBI / Global CMEMS). A way of overcoming this problem is to implement a spectral nudging option in the MOHID source code similar to the one used in the IBI solution (Katavouta and Thompson, 2016).

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