Metocean prediction system for BiMEP test site

March 2018

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LIST OF CONTENTS

Contents

List of contents **1**

1. INTRODUCTION **3**

1.1. Disclaimer 3

1.2. Clarifications 3

2. CURRENTS AND SEA LEVEL PREDICTION SYSTEM **5**

2.1. Model description 5

2.1.1. General description 5

2.1.2. Computational domain 5

2.1.3. Temporal resolution 6

2.2. Inputs description 6

2.3. Output description 8

2.4. Validation results 9

3. ATMOSPHERIC PREDICTION SYSTEM **16**

3.1. Numerical model description 16

3.1.1. General description 16

3.1.2. Computational domain 17

3.1.3. Temporal resolution 17

3.2. Data providers 17

3.3. Outputs 18

3.4. Validation results 19

4. WAVES PREDICTION SYSTEM **23**

4.1. Numerical model description 23

4.1.1. General description 23

4.1.2. Computational domain 24

4.1.3. Temporal resolution 24

4.2. Data providers 24

4.3. Outputs 25
4.4. Validation results 26

5. REFERENCES 29

1. INTRODUCTION

The purpose of this document is to describe the metocean prediction system developed for bimep test site in the framework of TRL+ project. The objective of this prediction system is to forecast wind, wave, currents and sea level conditions to be considered in the planning of marine operations at bimep. In addition, the prediction system will feed the decision support system to be developed in TRL+ project. This document provides the description of the metocean prediction system implemented. The contents of the present document are organized in the following sections:

- Currents and sea level prediction system
- Atmospheric prediction system
- Waves prediction system

1.1. Disclaimer

The data provided by the metocean prediction system of TRL+ are in good faith and while every care has been taken in their development, IHCantabria and bimep S. A. give no warranties of whatever nature in respect of these information, including but not limited to the accuracy or completeness of any information provided. IHCantabria and bimep S. A., their directors and employees, cannot be held liable for the use of and reliance of the estimates and forecasts in this system.

The information provided on this document and the prediction system itself may not be used, published or redistributed without including the following reference:

Metocean Prediction System for BiMEP test site, February 2018, Produced by IHCantabria and bimep in the framework of TRL+ project.

1.2. Clarifications

All request for clarifications regarding this document are to be submitted to bimep or IHCantabria:

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2. CURRENTS AND SEA LEVEL PREDICTION SYSTEM

The numerical model implemented for currents and sea level prediction system is called COAWSTbimep OPERATIONAL OCEANOGRAPHIC SYSTEM. The most important characteristics are provided in the following sections.

2.1. Model description

2.1.1. General description

COAWSTbimep oceanographic operational system is based on COAWST modelling system (a Coupled-Ocean-Atmosphere-Wave-Sediment Transport Modelling System) (Warner et al., 2010). COAWST is comprised of the Model Coupling Toolkit to exchange data fields between the ocean model ROMS, the atmosphere model WRF, the wave model SWAN, and the sediment capabilities of the Community Sediment Transport Model.

At this stage, the regional ocean model ROMS is running operationally. ROMS (Shchepetkin and McWilliams, 2005) is a member of a general class of three-dimensional, free-surface, terrain-flowing numerical models that solve the Reynolds-averaged Navier-Stokes equations using the hydrostatic and Boussinesq assumptions as well as the continuity and transport equations.

2.1.2. Computational domain

This operational system provides oceanographic information (currents and sea surface height) of the bimep interest zone: **longitude** between **[-3.18, -2.60]** and **latitude** between **[43.20, 43.62]** (see Figure 1). The computational domain has a **resolution of 325 m** and covers the Gulf Biscay Coast from Asturias Coast to French Coast.

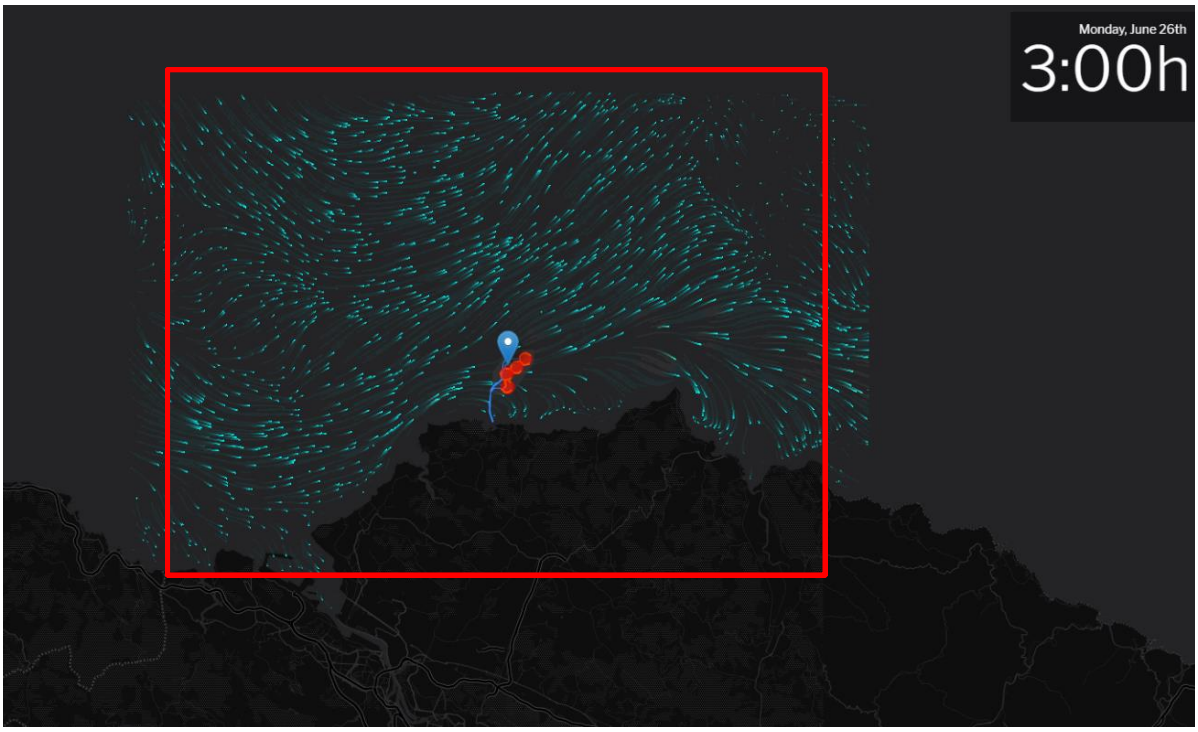


Figure 1. Example of a currents map provided by COAWSTbimep operational oceanographic system.

2.1.3. Temporal resolution

COAWSTbimep operational system provides a **2-day hydrodynamic forecast** (+1 day of hindcast as best estimate) with **hourly resolution**. The system is **daily run**.

2.2. Inputs description

The prediction system uses air pressure and air velocity fields at 10 m over the mean sea level as mesh forcing. Moreover, water level and barotropic velocities are set up as boundary conditions in order to include tides and general pattern velocities from the outside of the numerical domain. In order to obtain these inputs, two different kinds of forecast databases are needed: an oceanographic database and an atmospheric database.

The main characteristics of the numerical databases used to generate the boundary and initial conditions as well as the atmospheric forcing to feed COAWSTbimep operational system are:

1. *Oceanographic conditions:*
   Source: COPERNICUS CMEMS.
   Variables: barotropic velocity (U, V) and sea surface height.
   Spatial resolution: 1/36º.
   Temporal resolution: hourly.
   Time horizon: 5 days.
   Periodicity: daily.

2. *Atmospheric forcings:*
   Source: AEMET HARMONIE.
   Variables: Wind 10 m (U, V) and atmospheric pressure.
   Spatial resolution: 2.5 km.
   Temporal resolution: hourly.
   Time horizon: 48 hours.
   Periodicity: 8 hours.

In addition, in order to offer an extended forecast horizon, the model is also run with the following inputs (not available in the website):

1. *Oceanographic conditions:*
   Source: COPERNICUS CMEMS.
   Variables: barotropic velocity (U, V) and sea surface height.
   Spatial resolution: 1/36º.
   Temporal resolution: hourly.
   Time horizon: 5 days.
   Periodicity: daily.

2. *Atmospheric forcings:*
   Source: IHWRF hib.
   Variables: Wind 10 m (U, V) and atmospheric pressure.
   Spatial resolution: 3 km.
   Temporal resolution: 3-hourly.
   Time horizon: 5 days.
   Periodicity: 6 hours.

2.3. Output description

The outputs of COAWSTbimep operational system are daily available on the web of TRL+ project (http://trlplus.com/metocean_forecast/) through hourly maps of sea surface level and surface currents in the interest zone, with detailed information of each zone of the test site (see Figure 2). Table 1 lists the outputs variables of the currents and sea level prediction system.

NetCDF variable name	Variable name	Units
u_current	Eastward sea water velocity at surface layer	m/s
v_current	Northward sea water velocity at surface layer	m/s
ubar_current	vertically integrated u-momentum component at surface layer	m/s
vbar_current	vertically integrated v-momentum component at surface layer	m/s
zeta	free-surface	m

Table 1. Outputs of the currents and sea level prediction model.

Figure 2. Example of a surface level map, the anchoring spots and the detailed information of one of these spots (pop-up menu on the left).

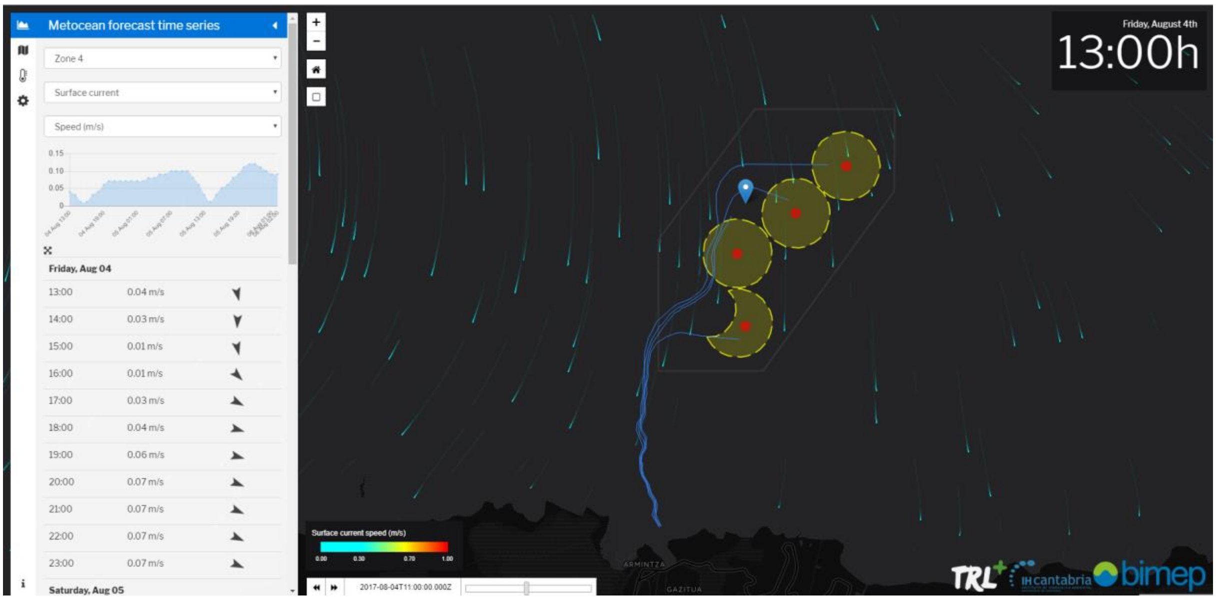


Figure 3. Example of a currents map, the anchoring spots and the detailed information of one of these spots (pop-up menu on the left).

2.4. Validation results

These results are based on a dataset from 14/02/2017 to 08/04/2017. This operational oceanographic system has been calibrated and validated using the measurements provided by the bimep WAVESCAN buoy for a period of 2 months. Figure 4 shows the great agreement obtained between the numerical results and the measurements regarding both components of surface velocity (U,V). Figure 5 shows the corresponding validation in terms of global velocity magnitude and its direction, where the agreement between both databases is also noticeable.

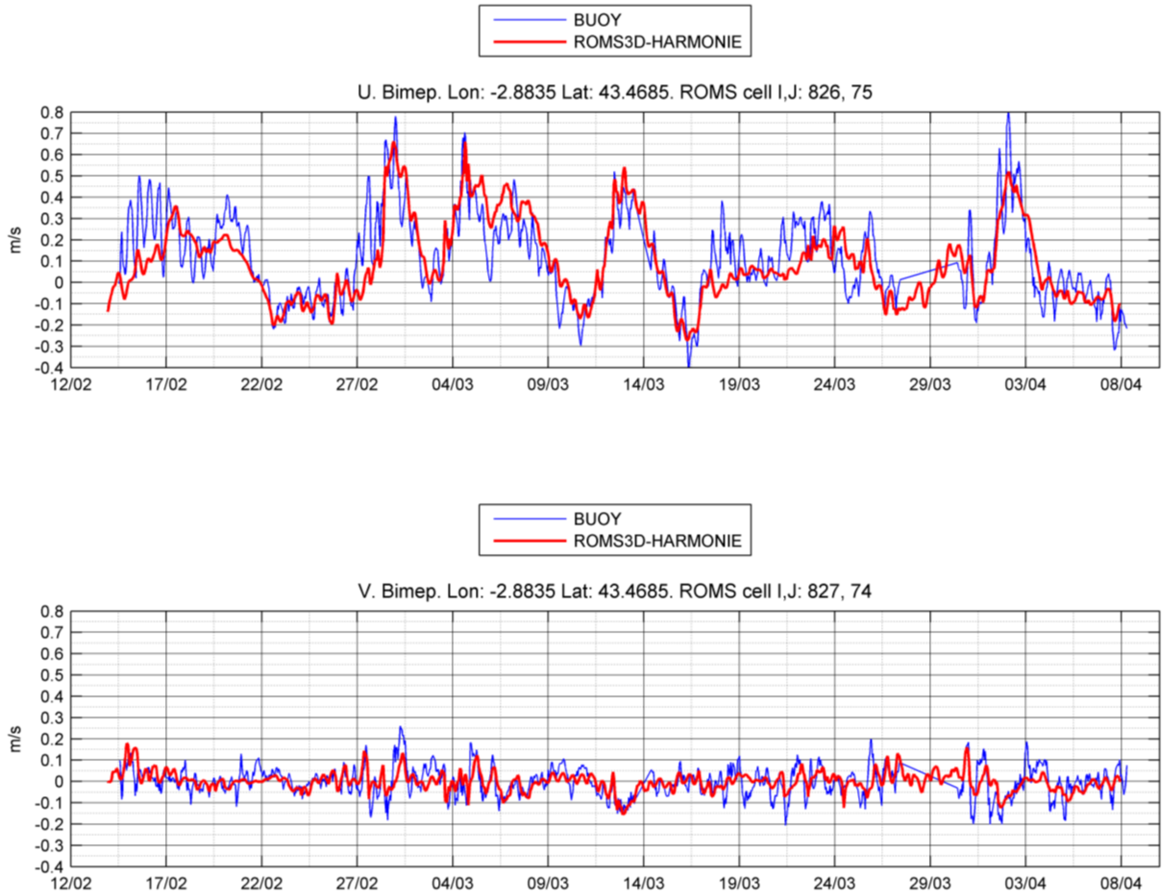
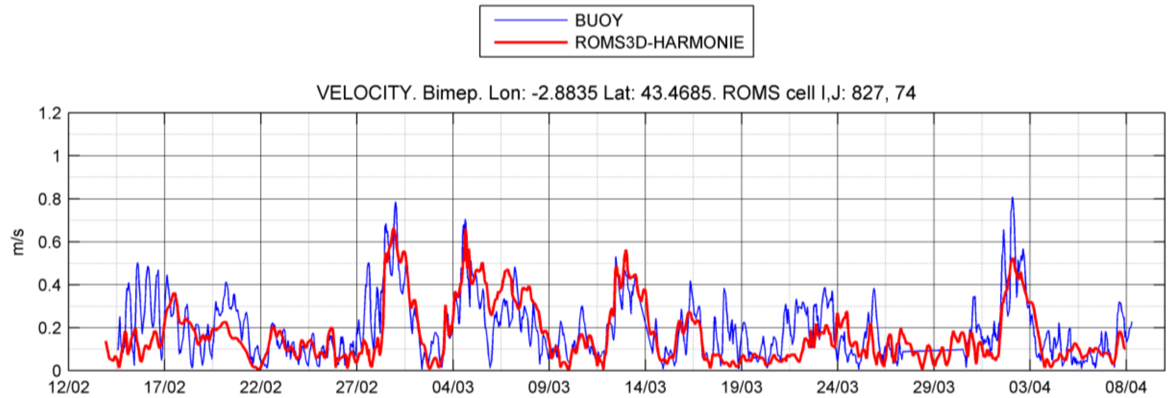


Figure 4. Comparison between numerical results and buoy measurements in terms of surface velocity components U and V.



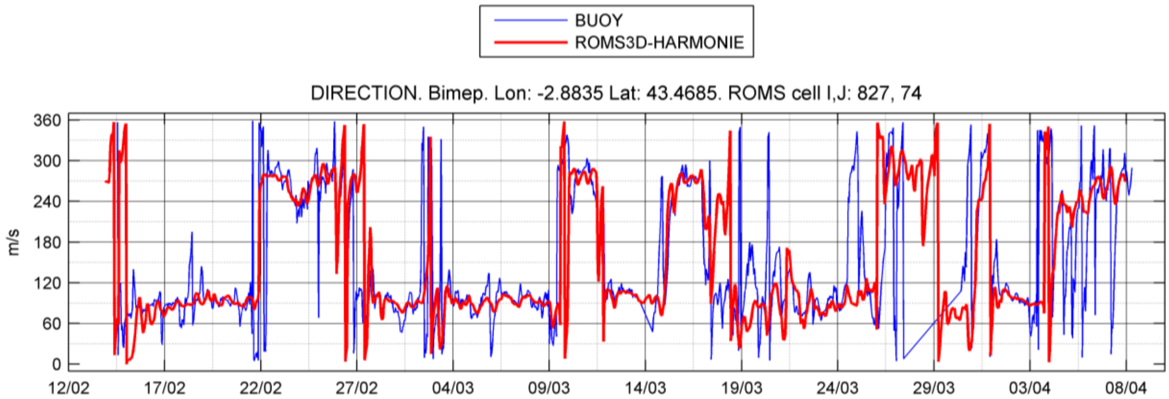


Figure 5. Comparison between numerical results and buoy measurements in terms of global velocity magnitude and its direction.

In addition, Figure 6 reveals the scatter plots of the velocity components (U and V), and its corresponding global magnitude (right hand side). The values of the main statistical parameters are also presented in these graphs, showing skill indexes of 0.893, 0.714 y 0.830 for the U component, V component and global velocity magnitude, respectively.

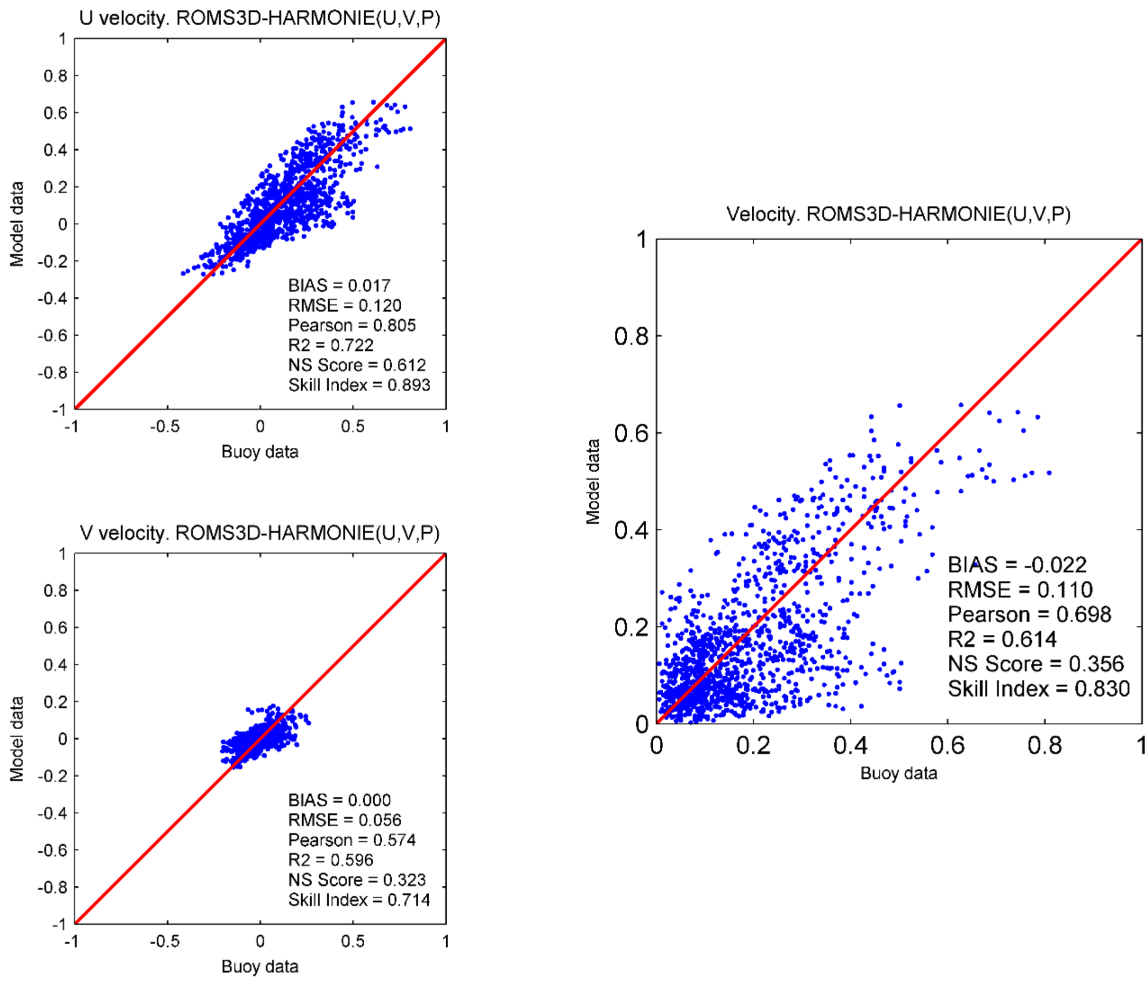


Figure 6. Scatter plots and main statistical parameters obtained from the validation analysis of surface velocity (U and V components and global velocity magnitude).

Furthermore, the extended horizon forecast system has been analysed through another complete validation versus the data provided by the bimep WAVESCAN buoy at the same validation period. The results of this validation are showed in figures 6, 7 and 8.

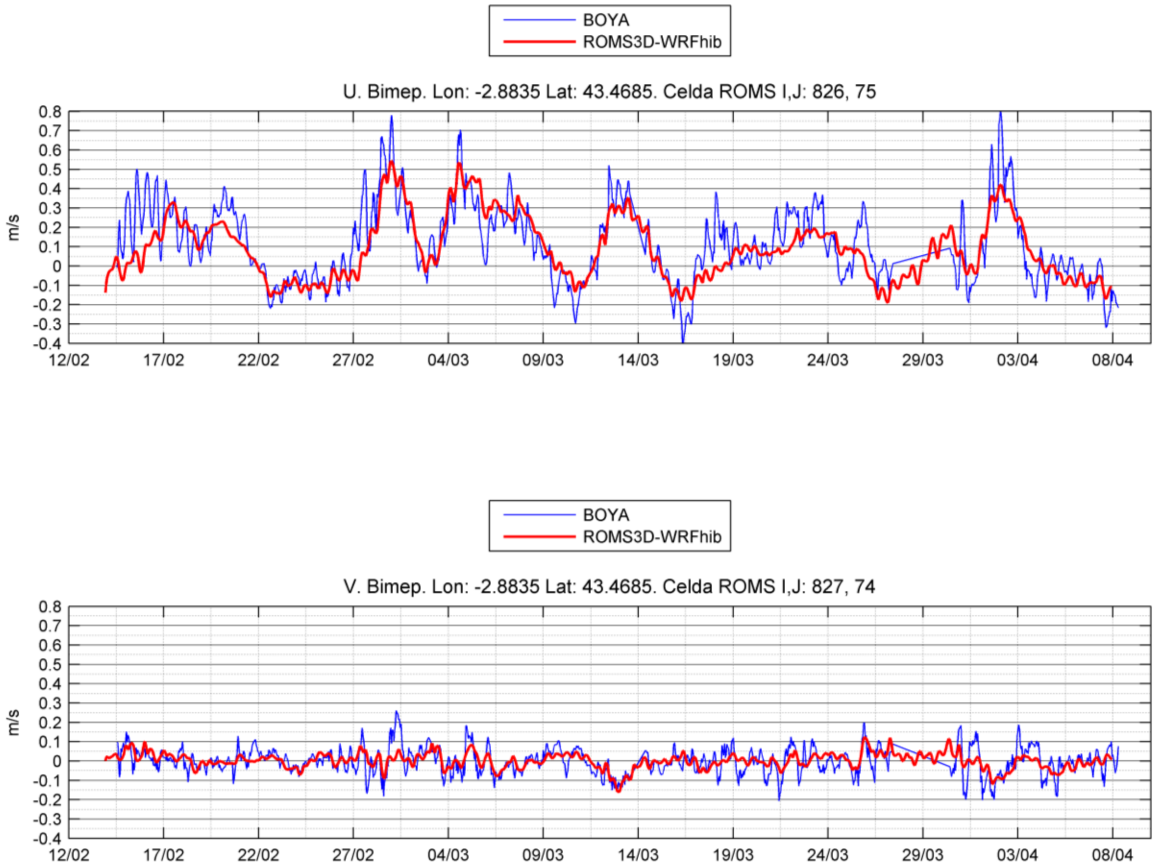
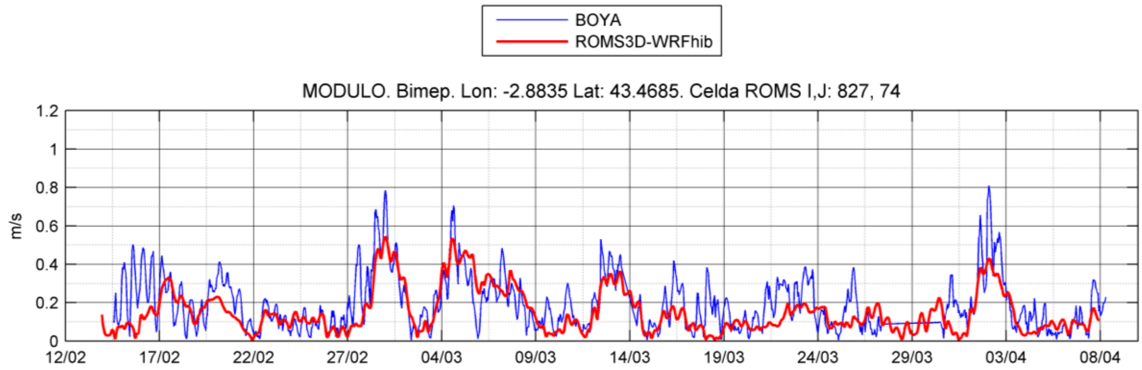


Figure 7. Comparison between numerical results and buoy measurements in terms of surface velocity components U and V (extended horizon forecast system).



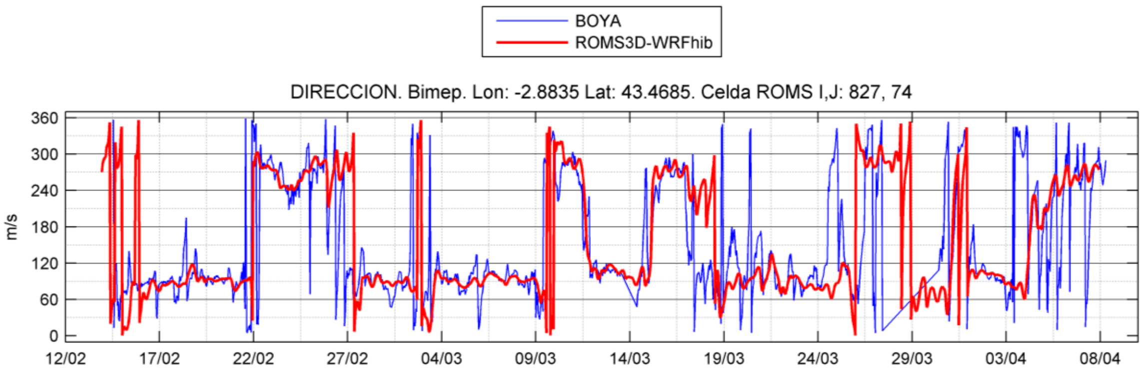


Figure 8. Comparison between numerical results and buoy measurements in terms of global velocity magnitude and its direction (extended horizon forecast system).

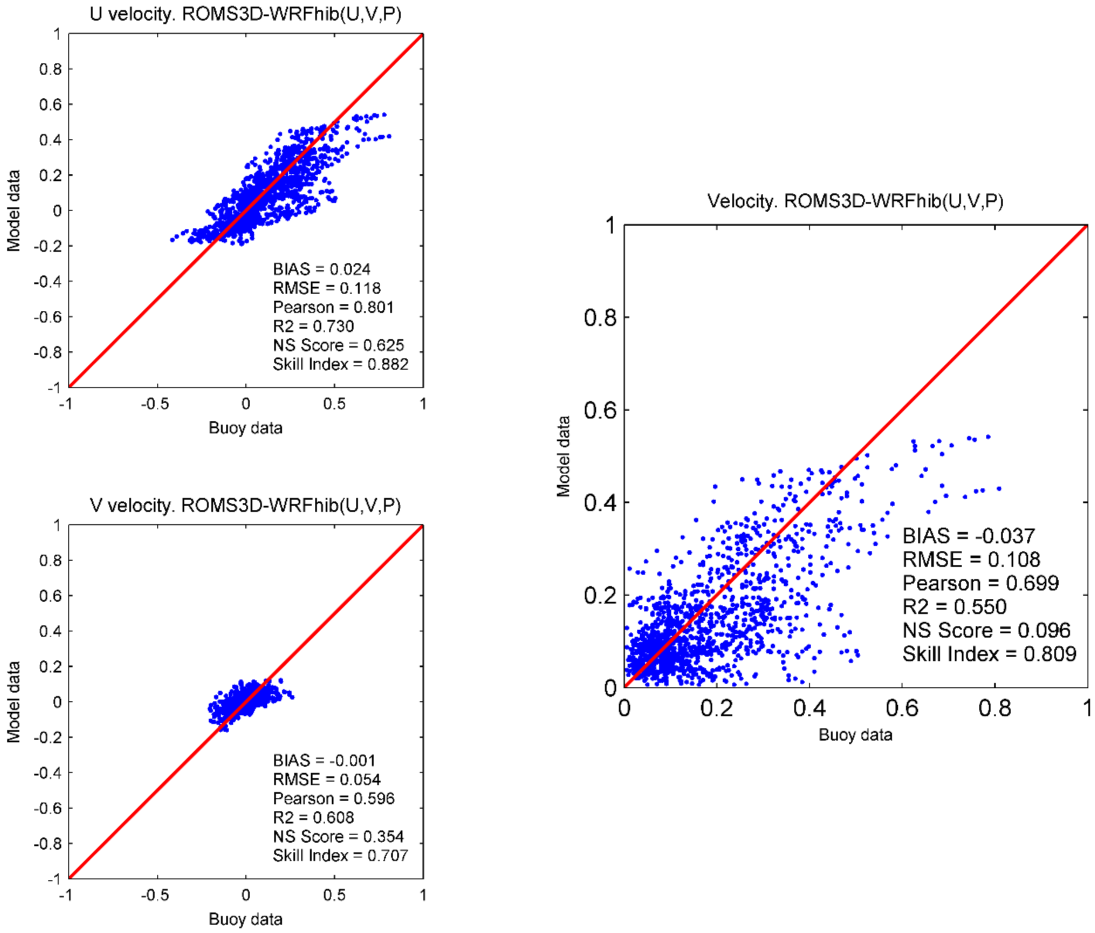


Figure 9. Scatter plots and main statistical parameters obtained from the validation analysis of surface velocity (U and V components and global velocity magnitude, of the extended horizon forecast system).

This system is able to reproduce the ocean currents measured by the buoy obtaining skill indexes of 0.882, 0.707 y 0.809 for the U component, V component and global velocity magnitude, respectively. These results show a suitable agreement between predicted and measured data. As expected, the accuracy achieved is slightly lower than in Figure 4 to Figure 6, due to the extended temporal horizon, especially for highest current velocities.

3. ATMOSPHERIC PREDICTION SYSTEM

This section describes the prediction system designed to provide coastal atmospheric conditions data in bimep test site, in order to generate useful information to manage the test site and plan operations.

3.1. Numerical model description

3.1.1. General description

The aim of the atmospheric prediction system is to generate a forecast of winds and other atmospheric variables in the BiMEP test site with a temporal horizon of several days, with a low computational cost and a high temporal and spatial resolution. The suitable methodology to apply is a hybrid downscaling method that requires a low computational effort and offers a high spatial resolution. The hybrid downscaling method combines the numerical modelling (dynamical downscaling) with mathematical tools (statistical downscaling).

The Figure 10 shows the flow chart of the hybrid downscaling methodology applied to obtain the forecast data at high resolution.

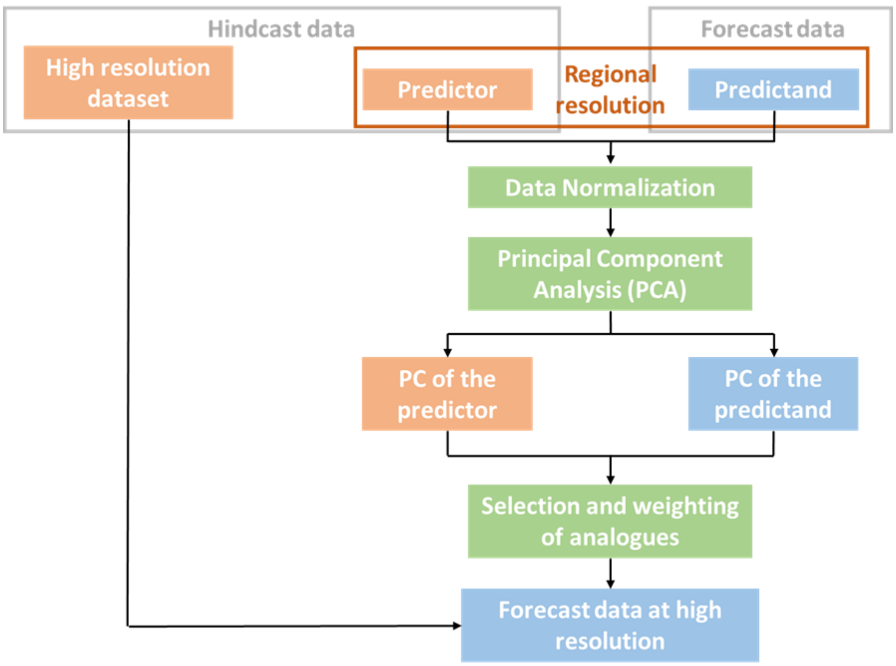


Figure 10. Flow chart of the applied methodology (PC: Principal components).

3.1.2. Computational domain

The prediction system covers the whole test site and the route from the coast to the test site with a spatial resolution of 600 m.

3.1.3. Temporal resolution

The atmospheric prediction system provides a 2 days atmospheric forecast with hourly resolution using the data from AEMET HARMONIE and a 10 days atmospheric forecast with three hourly resolution with the data from GFS. The system is running four times daily.

3.2. Data providers

Different databases are necessary to apply the hybrid downscaling method. The high-resolution dataset and the predictor are hindcast data and the predictand is forecast data, being all the inputs files in NetCDF format. Two different configurations of predictor and predictand have been selected to predict the wind speed, in order to cover different temporal horizons and to get different forecasts in the area.

In the first configuration, the predictor is the wind from the Global atmospheric reanalysis CFSR (Climate Forecast System Reanalysis, Saha et al. 2010) and the predictand is the wind from the Global Forecast System (GFS, NCEP Office Note 442, 2003), which is the operational data provider. CFSR has a spatial resolution of 0.312° x ~0.312° that covers the period from 1979 to 2010 (for the first version) and of 0.205° x ~0.204° that covers the period from 2011 until present (for the second version), being the temporal resolution hourly. The predictand are the winds from GFS, which is made up of the Global Assimilation System (GDAS), the own GFS and the Ensemble forecast (ENS). The GFS results used are distributed in an equispaced regular mesh of 0.25° with 47 vertical levels. GFS is running four times daily (at 0000, 0600, 1200, 1800 UTC) and the temporal horizon of the forecast data is of 16 days. However, a horizon of 10 days is used for the present prediction system, with a temporal resolution of three hours.

In the second configuration, the predictors are the winds from SeaWind BiMEP (Metocean Analysis of BiMEP for Offshore Design, www.trlplus.com/metocean-information), with a spatial resolution of 3 km, which is the pattern domain of the SeaWind BiMEP of 600 m. The predictands are the winds from the model HARMONIE (HIRLAM-ALADIN Research on Meso-scale Operational NWP In Europe. Simarro and Hortal, 2012; Sánchez, 2013), which is the model of high resolution of AEMET (http://www.aemet.es), with a spatial resolution of 2.5 km, 65 vertical levels and hourly temporal resolution. The model HARMONIE is running four times daily (at 0000, 0600, 1200, 1800 UTC) and the temporal horizon of the forecast data is of 2 days.

The left-hand side of Figure 11 shows the selected points of the predictor CFSR. The predictands were obtained in these points using linear interpolation with the data of GFS. In the right-hand side of Figure 11 the selected points of the predictor SeaWind BiMEP of 3 km are shown. The predictand in the nearest node of HARMONIE have been obtained in these points.

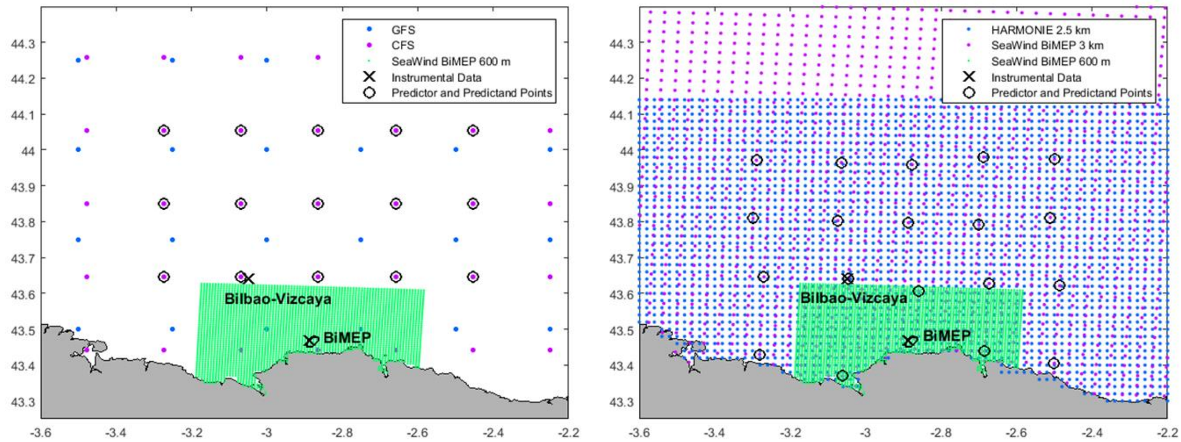


Figure 11. Numerical domain of the predictor, predictand and high-resolution datasets for each configuration in the BiMEP area.

In order to get high resolution forecast with the hybrid downscaling method, a subset of cases that provide the most representative atmospheric conditions is necessary. The subset of cases for this prediction system is the hindcast SeaWind BiMEP of 600 m that covers all the atmospheric conditions since 1985 until 2015 with hourly temporal resolution.

3.3. Outputs

The output of the hybrid model are the high resolution coastal winds and other atmospheric variables over the bimep area. The prediction system generates one output file for each simulation and configuration. These output files are in NetCDF format and the height of the winds provided is of 10 meters above the surface (Table 2).

NetCDF variable name	Variable name	Units	Height
grid_eastward_wind	Eastward wind	m/s	10 m above the surface
grid_northward_wind	Northward wind	m/s	10 m above the surface
Pressure_surface	Reduced sea level pressure	Pa	sea level height
air_temperature_2m	Air temperature	K	2 m above the surface

Table 2. Outputs of the wind prediction model.

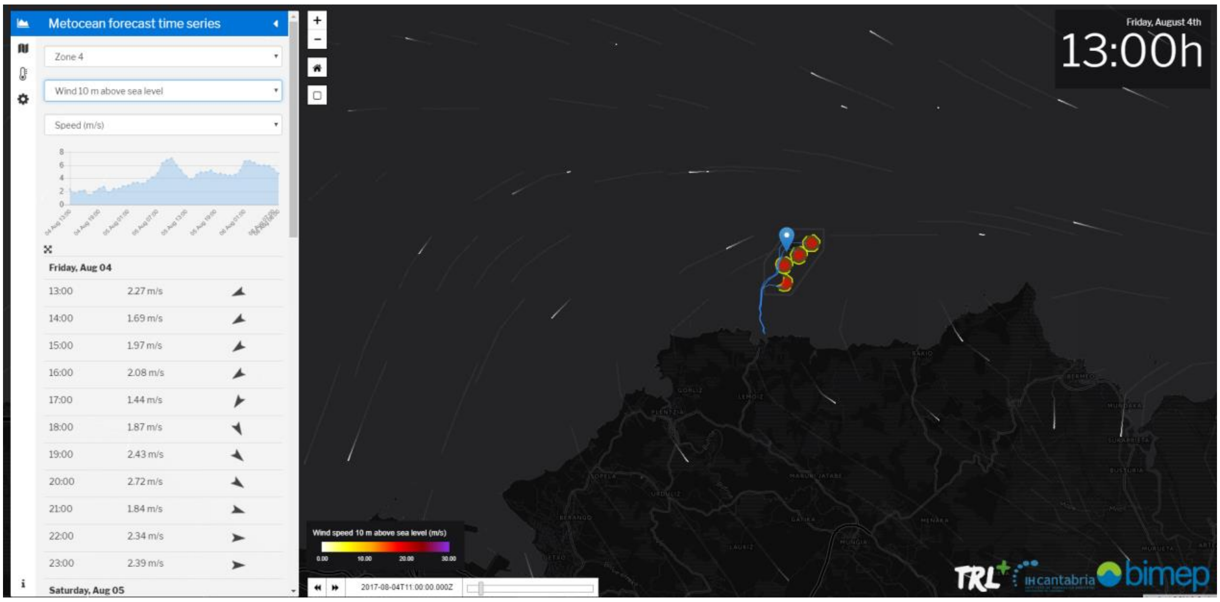


Figure 12. Example of a wind speed map, the anchoring spots and the detailed information of one of these spots (pop-up menu on the left).

3.4. Validation results

These validation results correspond to a prediction dataset forced by GFS data (from 14/02/2017 to 30/06/2017) and a prediction dataset forced by HARMONIE (from 14/02/2017 to 08/04/2017). This operational atmospheric prediction system has been calibrated and validated using the field measurements provided by the BiMEP WAVESCAN buoy for a period of 4 months for GFS inputs and 2 months for HARMONIE inputs. Figure 13 shows the temporal series of the buoy records and the outputs of the atmospheric prediction system forced by GFS (wind speed, direction, mean sea level pressure). The agreement between both databases is noticeable.

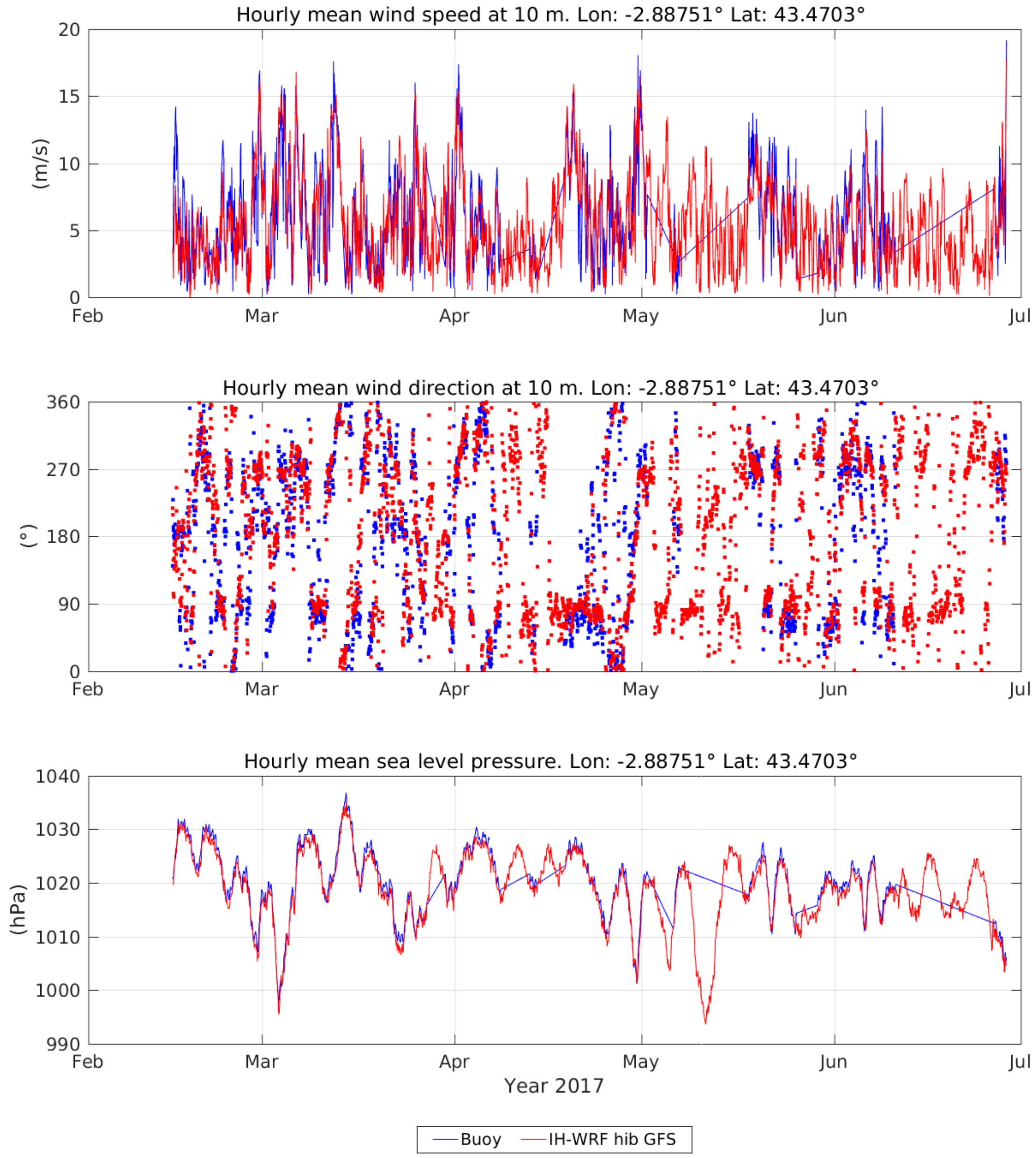


Figure 13. Comparison between numerical results of the model forced by GFS and buoy measurements in terms of wind speed, wind direction and mean sea level pressure.

Figure 14 shows the temporal series of the buoy records and the outputs of the atmospheric prediction system forced by HARMONIE (wind speed, direction, mean sea level pressure). The agreement between both series is successful and the agreement between the maximum values of wind speed is noticeable.

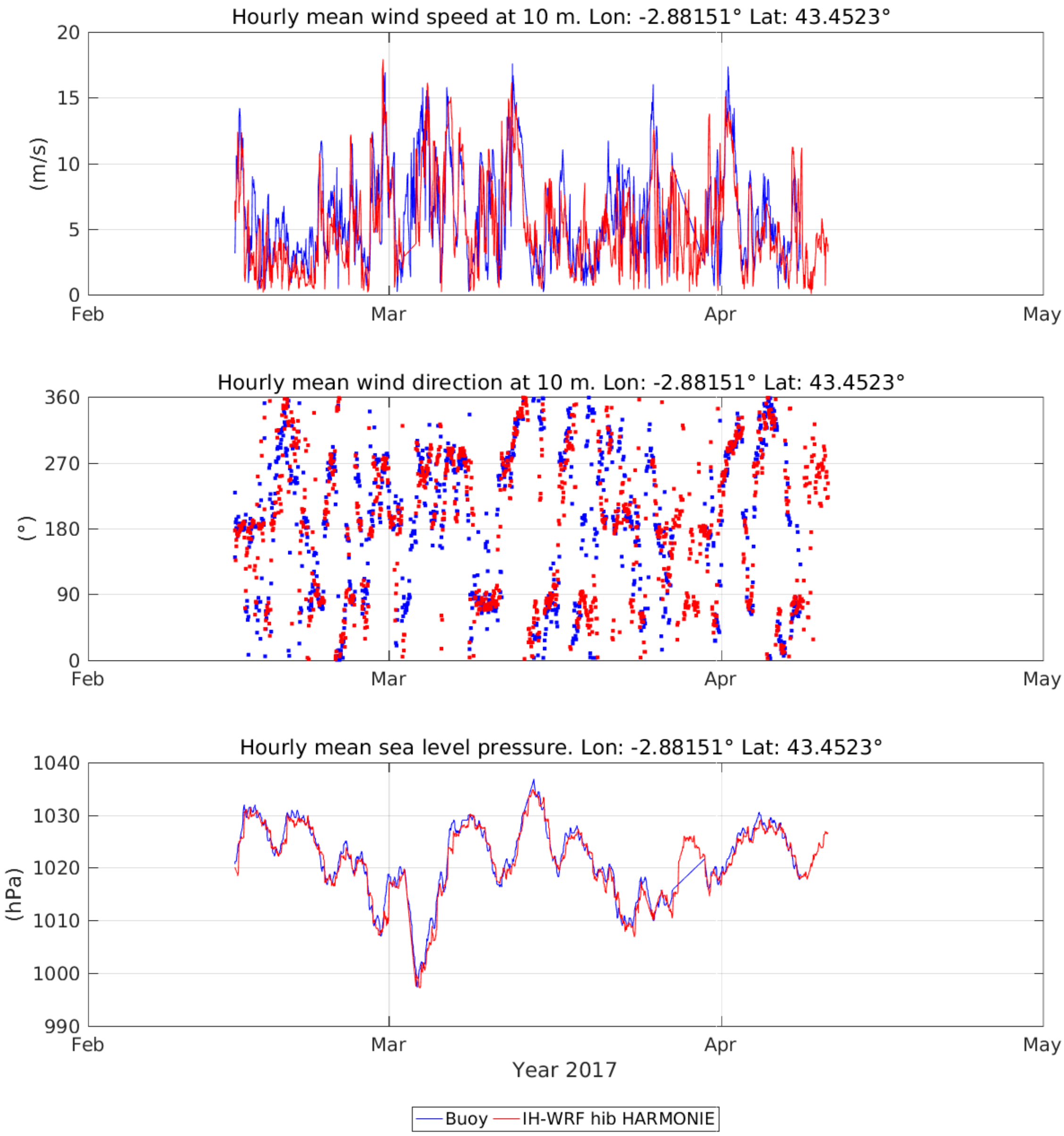


Figure 14. Comparison between numerical results of the model forced by HARMONIE and buoy measurements in terms of wind speed, wind direction and mean sea level pressure.

For a better knowledge of the goodness of the atmospheric prediction system, the scatter plots as well as statistical parameters have been obtained for each forcing (GFS and HARMONIE). Figure 15 shows the scatter plots between measured and prediction data for the hourly mean wind speed at 10 m (up) and hourly mean sea level pressure (down). Regarding wind speed, the model forced by GFS shows a BIAS error of 0.215 m/s and a Pearson correlation index of 0.71, which are slightly better than the results obtained for the model forced by HARMONIE (with a BIAS error of -0.656 m/s and Pearson correlation index of 0.70). Regarding mean sea level pressure, both models show a good agreement with low BIAS error values (lower than 1 hPa) and high Pearson correlation index values (higher than 0.98).

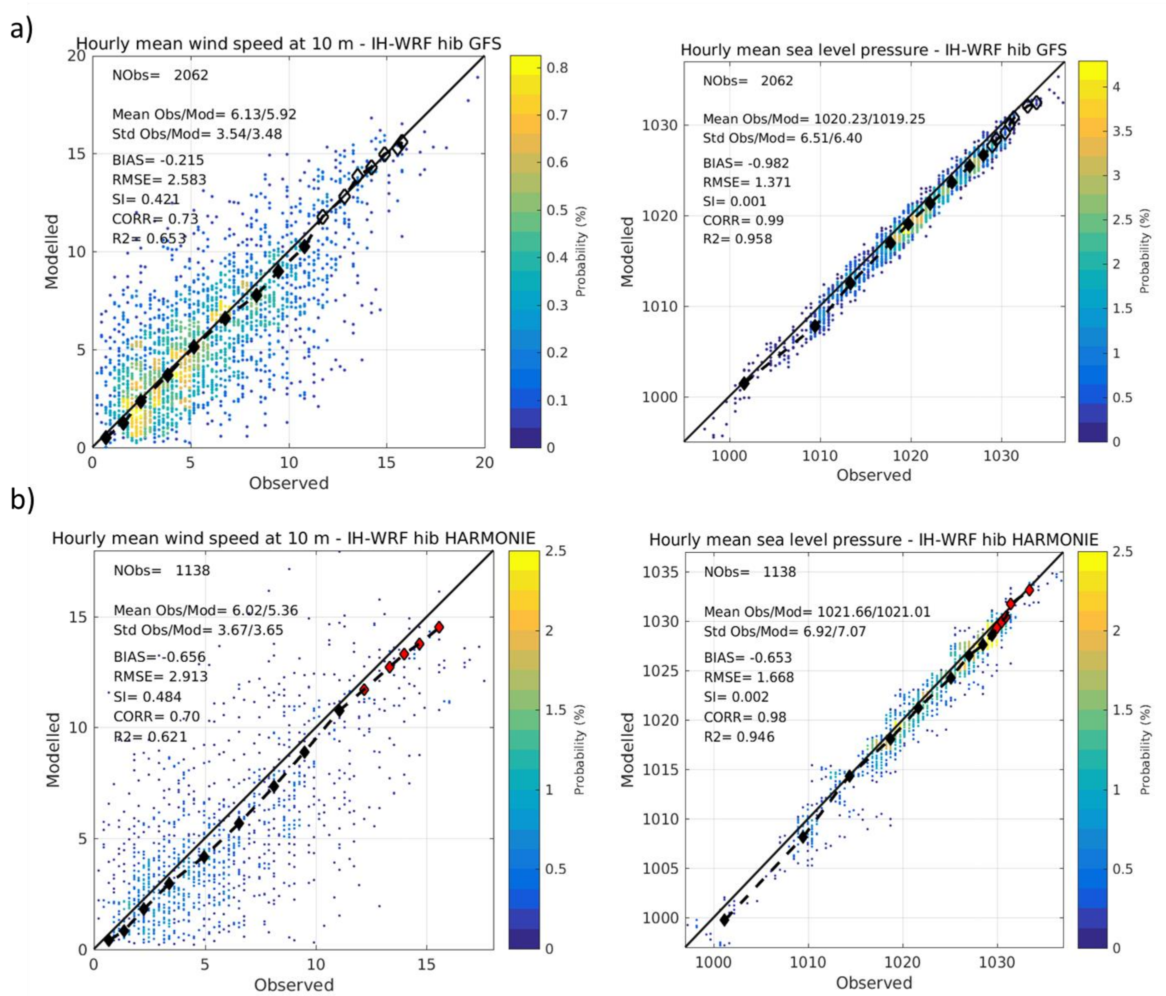


Figure 15. Scatter plots and main statistical parameters obtained from the validation analysis of the hourly mean wind speed at 10 m and hourly mean sea level pressure for the model forced by CFS (a) and HARMONIE (b).

4. WAVES PREDICTION SYSTEM

This section describes the prediction system designed to provide the data that define the wave climate conditions in bimep test site.

4.1. Numerical model description

4.1.1. General description

The aim of the wave conditions prediction system is to generate a forecast of the variables that characterize the wave conditions in bimep test site with a temporal horizon of several days, with a low computational cost and with a high temporal and spatial resolution.

The numerical model SWAN (Simulation Waves Nearshore; N Booij, RC Ris, E Cecchi 1999), version 41.01, is used in the wave prediction system. The computational cost of SWAN model is acceptable to get the wave conditions of several days. The Figure 16 shows the flow chart of the methodology used for the simulations with SWAN model with different inputs.

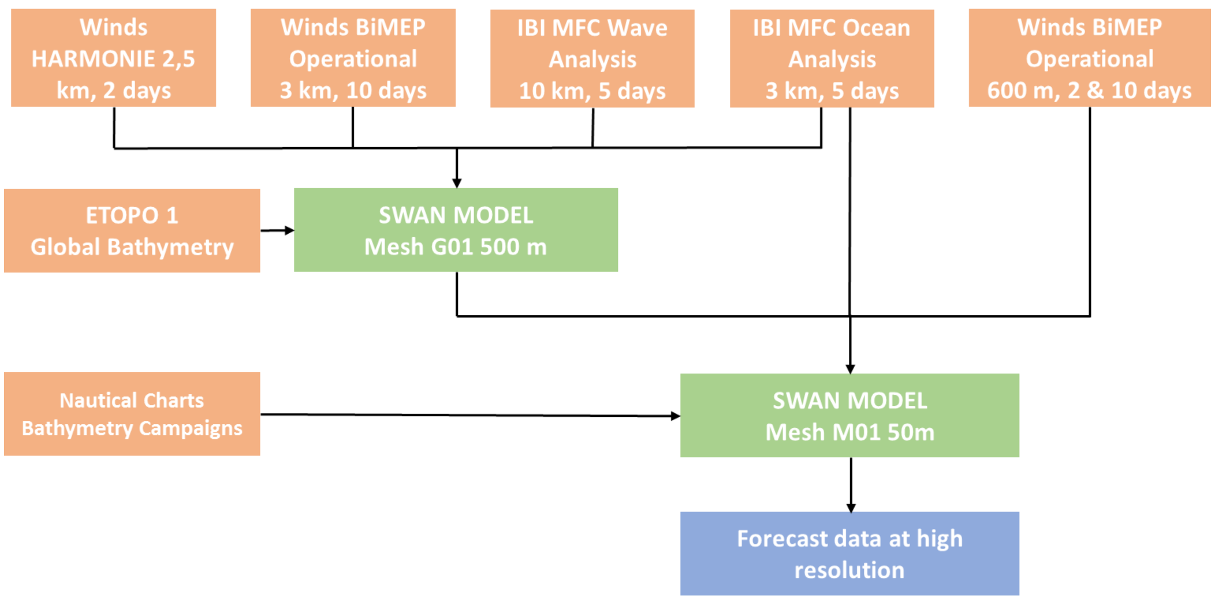


Figure 16. Flowchart of the numerical model.

4.1.2. Computational domain

Two nested numerical mesh have been used to get the wave conditions with a spatial resolution of 50 m.

4.1.3. Temporal resolution

The wave prediction system provides a **4-day wave conditions forecast** (the first 2 days is forcing with HARMONIE winds, the next 2 days with Winds BiMEP Operational) with **hourly resolution**. The system is **daily run**.

4.2. Data providers

Different data providers are used to run the SWAN model. The model is running with inputs of wave spectra, wind speed, current speed and sea level. To provide all the variables three data providers are used:

1. The waves spectra are reconstructed with the statistical wave parameters from the **IBI MFC wave System** that provides a short term (5-days) high-resolution wave forecast product for the IBI (Iberian Bis-cay Irish) area. The IBI MFC wave model system is daily run by Puertos del Estado and it is based on the MFWAM model. It is run on a grid of 10 km of horizontal resolution, forced with the ECMWF wind data and it uses boundary conditions (wave spectra) from the global CMEMS wave system.
2. The **IBI MFC Ocean Analysis and Forecast System** provides the sea level and current speed. It is daily run by Puertos del Estado in the CESGA Supercomputing facilities. Its objective is to produce a near-real-time short-term (5-days) forecast of currents and other oceanographic variables such as temperature, salinity, and sea level, as well as to obtain a better understanding of the ocean dynamic in the IBI Atlantic waters (Sotillo et al., 2015). The system is based on a (eddy-resolving) NEMO model application run at 1/36° horizontal resolution.
3. The winds are provided in two different ways.
    a. For the first two days, winds are provided by the model HARMONIE (2.5 km spatial resolution, hourly temporal resolution) in the general mesh and by the Atmospheric prediction system foced by HARMONIE in the detailed mesh (600 m, hourly resolution).

b. For the next days, winds are provided by the Atmospheric prediction system foced by GFS in the general mesh (3 km spatial resolution, three hourly temporal resolution) and the detailed mesh (600 m spatial resolution, three hourly temporal resolution).

4.3. Outputs

The output of wave model are the statistical wave parameters over the bimep area. The numerical model generates two output files for each simulation. The output files are in NetCDF format (Table 3).

NetCDF variable name	Variable long name	Units
hs	Significant wave height	m
hswell	Significant wave height associated with the low frequency part of spectrum	m
dir	Mean wave direction	degree
pdir	Peak wave direction	degree
tm02	Mean absolute zero-crossing period	s
tm01	Mean absolute wave period	s
tm10	Mean absolute wave period	s
tp	Peak period	s
dspr	Directional spreading of the waves	degree
fspr	Normalized width of the frequency spectrum	
Transp_x	Transport of energy X	m^3/s
Transp_y	Transport of energy Y	m^3/s
WForce_x	Wave-induced force per unit surface area X	N/ m^2
WForce_y	Wave-induced force per unit surface area Y	N/ m^2

Table 3. Definition of the waves prediction model outputs.

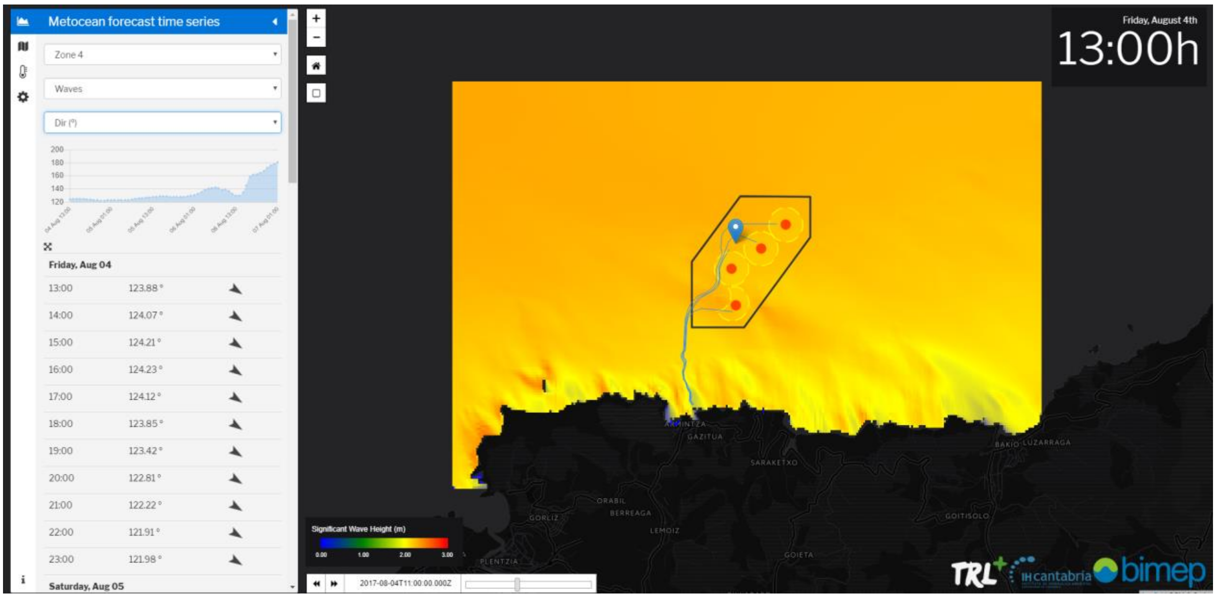


Figure 17. Example of a wave forecast map, the anchoring spots and the detailed information of one of these spots (pop-up menu on the left).

4.4. Validation results

These results are based on a dataset from 14/02/2017 to 05/05/2017. This wave prediction system has been calibrated and validated using the measurements provided by the BiMEP WAVESCAN buoy for a period of 3 months. Figure 18 shows the comparison between the numerical prediction results and the field measurements in terms of significant wave height and mean wave direction, where a successful agreement is observed.

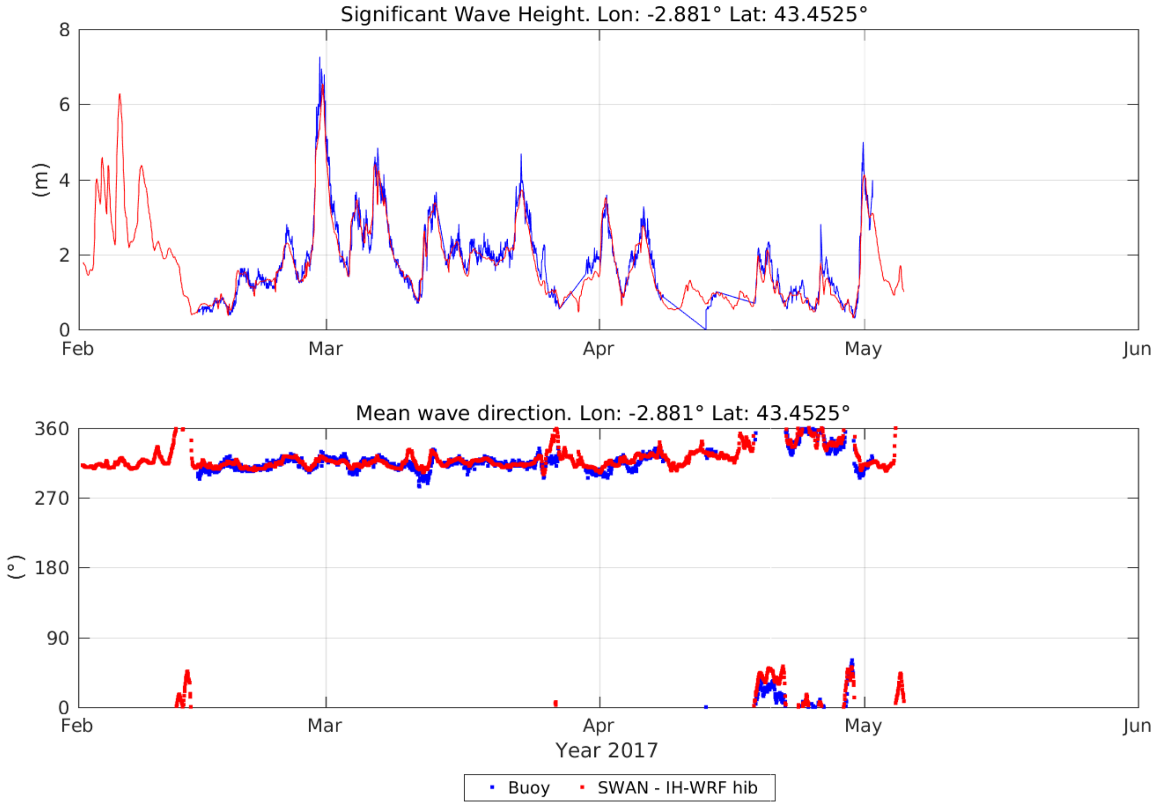


Figure 18. Comparison between numerical results and buoy measurements in terms of significant wave height (up) and mean wave direction (down).

For a better knowledge of the goodness of the waves prediction system, Figure 19 shows the scatter plot of the significant wave height. The values of the main statistical parameters are also presented in this graph, showing a BIAS error of 0.089 m, a Pearson correlation index of 0.97, a Root mean square error of 0.283 and a Scatter inter lower than 0.2.

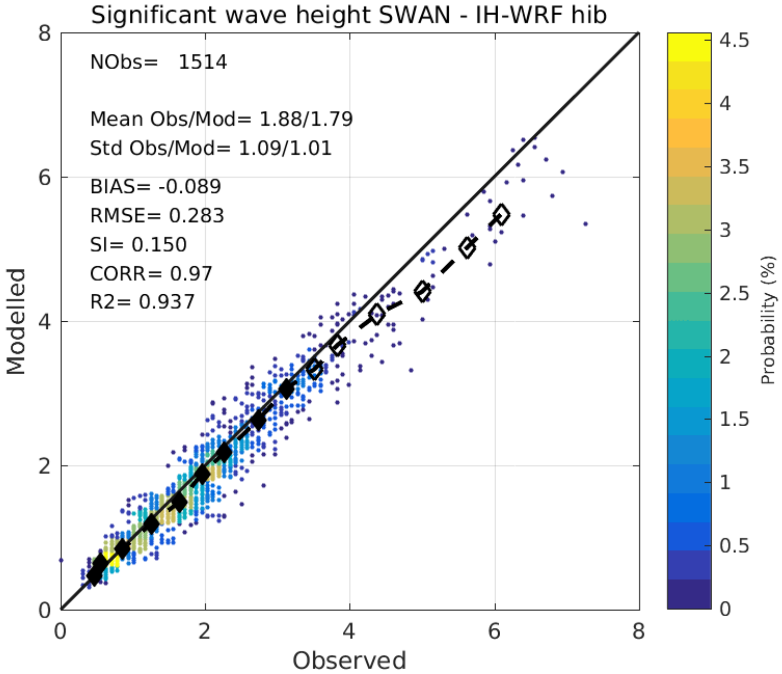


Figure 19. Scatter plot and main statistical parameters obtained from the validation analysis of the significant wave height.

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