Project - MyWave

Ensemble harbour forecast performance

Reference: MyWave-D3.3

Project N°: FP7-SPACE-2011-284455	**Work programme topic:** SPA.2011.1.5.03 – R&D to enhance future GMES applications in the Marine and Atmosphere areas
Start Date of project : 01.01-2012	**Duration**: 36 Months

WP leader: Luigi Cavalieri	**Issue:** 1.0
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MyWave version scope : All	
Approval Date :	**Approver:**
Dissemination level: PU	

DOCUMENT

VERIFICATION AND DISTRIBUTION LIST

	Name	Work Package	Date
Checked By:			
Distribution			

CHANGE RECORD

Issue	Date	§	Description of Change	Author	Checked By
0.1		all	First draft of document	Cristina Toledano	
1.0		all	Document finalization		

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GLOSSARY AND ABREVIATIONS

AEMET	Spanish Meterological Agency (*Agencia Estatal de Meteorología ,Spain*)
CNMCA	Stato Maggiore Aeronautica – Ufficio Generale Spazio Aereo e Meteorologia
EPS	Ensemble Prediction System
ISMAR	Instituto di Science Marine (*Institute of Marine Science, Italy*)
PDE	Puertos del Estado
SMC	Spherical Multi-Cell grid
UKMO	United Kingdom Met Office

Table 1

APPLICABLE AND REFERENCE DOCUMENTS

Applicable Documents

	Ref	Title	Date / Issue
DA 1	MyWave-A1	MyWave: Annex I – “Description of Work”	September 2011
DA 2	MyWave-D3.1	MyWave: Met Office Wave Model Ensemble Prediction Systems in the ‘Atlantic-Euro Zone’	December 2012
DA 3	MyWave-D4.2a	MyWave: Proposal of metrics for user focused verification of deterministic wave prediction systems	
DA 4	MyWave-D4.2b	MyWave: Proposal of metrics for developer and user focused verification of wave ensemble prediction systems	

Reference Documents

	Ref	Title	Date / Issue
DR 1	Burgers et al. (1998)	Burgers, G., P. J. van Leeuwen and G. Evensen, 1998:Analysis Scheme in the Ensemble Kalman Filter. *Mon. Wea. Rev*., 126, 1719–1724.	
DR 2		Callado, A., Escribà, P., García-Moya, J.A., Montero, J., Santos, C., Santos-Muñoz, D. and Simarro, J. (2013) Ensemble Forecasting, Climate Change and Regional/Local Responses, Dr Pallav Ray (Ed.), ISBN: 978-953-51-1132-0, InTech	
		GARCÍA-MOYA, J.-A., CALLADO, A., ESCRIBÀ, P., SANTOS, C., SANTOS-MUÑOZ, D. and SIMARRO, J. (2011), Predictability of short-range forecasting: a multimodel approach. Tellus A, 63: 550–563. doi: 10.1111/j.1600-0870.2010.00506.x	

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This report documents Task WP3.4, which is a direct application by Aemet-PdE to determinate the advantages of the ensemble approach for the management of commercial harbours. Three locations are to be considered, one on the European Atlantic coast (Gijon), one on the Canarias (Tenerife), and one on the Mediterranean coasts (Barcelona). In order to develop the system, these applications have been adapted to receive boundary conditions and wind fields from the UKMO and CNMCA systems.

Those applications are wave prediction systems on a local scale, developed specifically for harbours and their immediate surroundings. The system is based on the SWAN model and takes into consideration the changes the wave undergoes as it nears the coast.

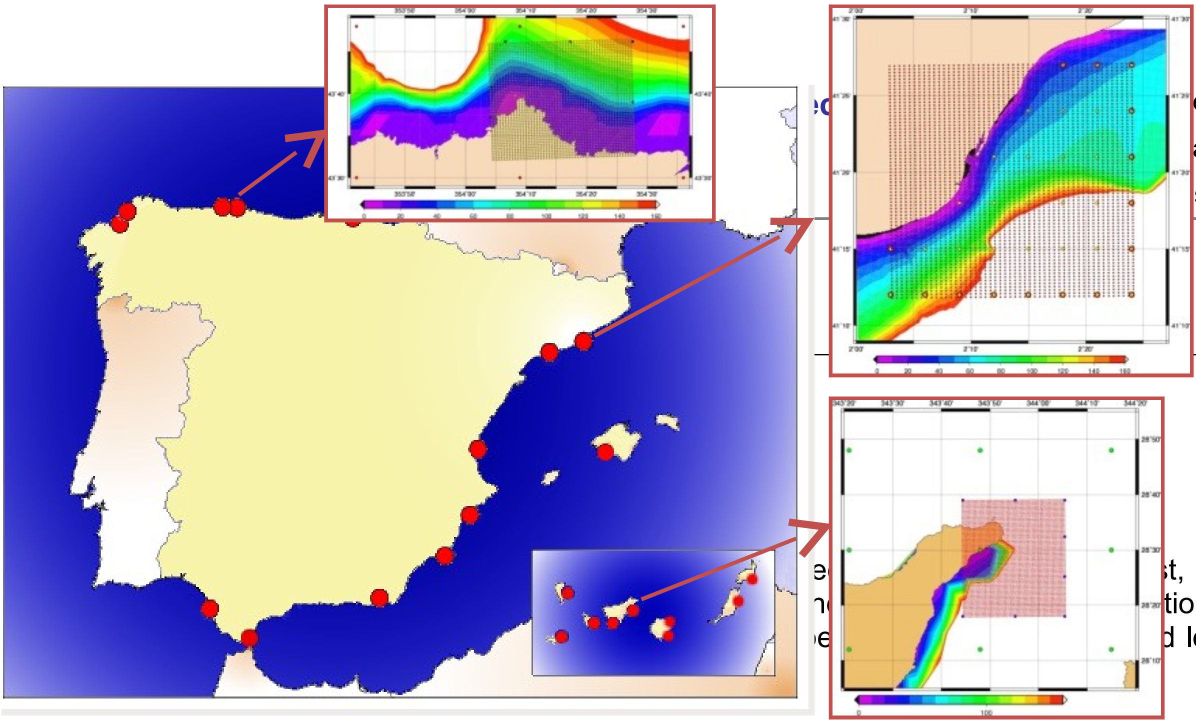


Figure 1 - Local wave forecast system for Spanish harbours operated by PdE (red points). In the boxes, new ensemble applications: Barcelona, Gijon and Tenerife.

II LOCAL WAVE-EPS CONFIGURATION AND RUN CYCLE

II.1 DESCRIPTION OF ATLANTIC LOCAL MODELS.

II.1.1. GIJON APPLICATION

Gijon application has been configured taking the wave boundary conditions and the forcing windfields from MetOffice Model Ensemble Prediction which domain uses a Spherical Multi-Cell grid (SMC) which has variable resolution around the coast.

The local system has been defined on a computational grid of 51x51 points and with resolution of 529x511 meters each cell (WEST -5.93, EAST -5.54, SOUTH 43.54 and NORTH 43.77). The wind fields grid has a resolution of 0.45ºx0.3º. Boundary conditions grid has a variable resolution due to SMC grid.

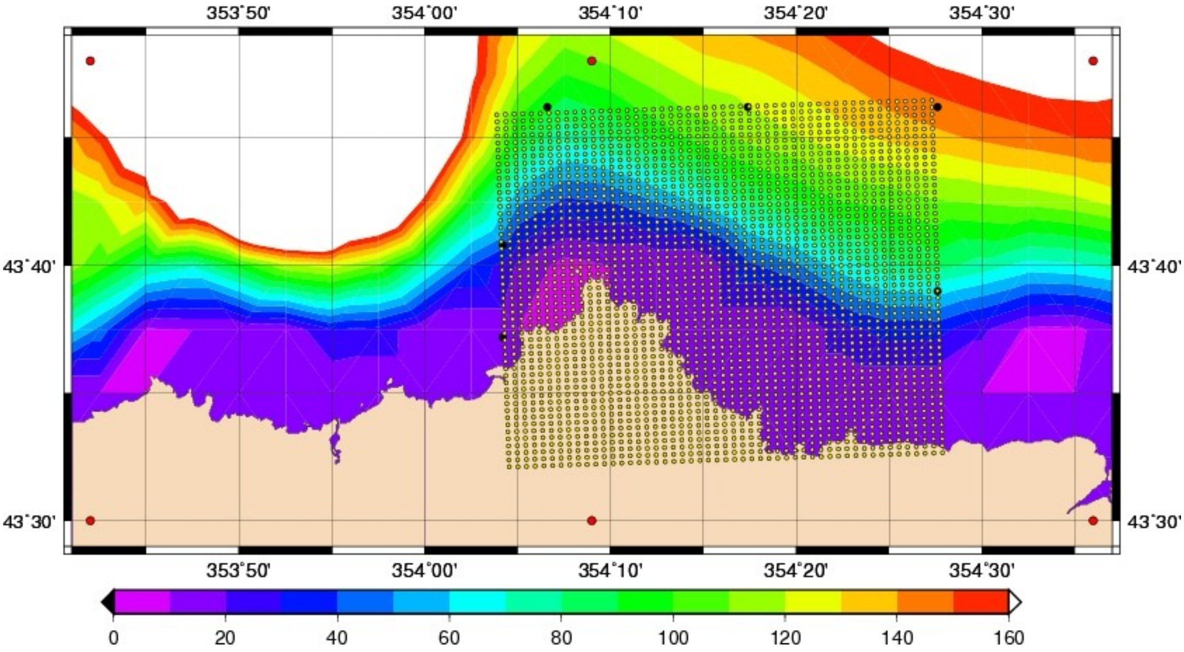


Figure 2 - Configuration of local wave forecast model for Gijon: computational grid (yellow), wind fields (red) and boundary conditions (black).

II.1.2. TENERIFE APPLICATION

Tenerife application has also been configured taking the wave boundary conditions and the forcing windfields from UKMO Model Ensemble Prediction.

The local system has been defined on a computational grid of 61x71 points and with resolution of 571x554 meters each cell (WEST -16.26, EAST -15.91, SOUTH 28.3 and NORTH 28.65). The wind fields grid has a resolution of 0.45ºx0.3º. Boundary conditions grid has a variable resolution due to SMC grid.

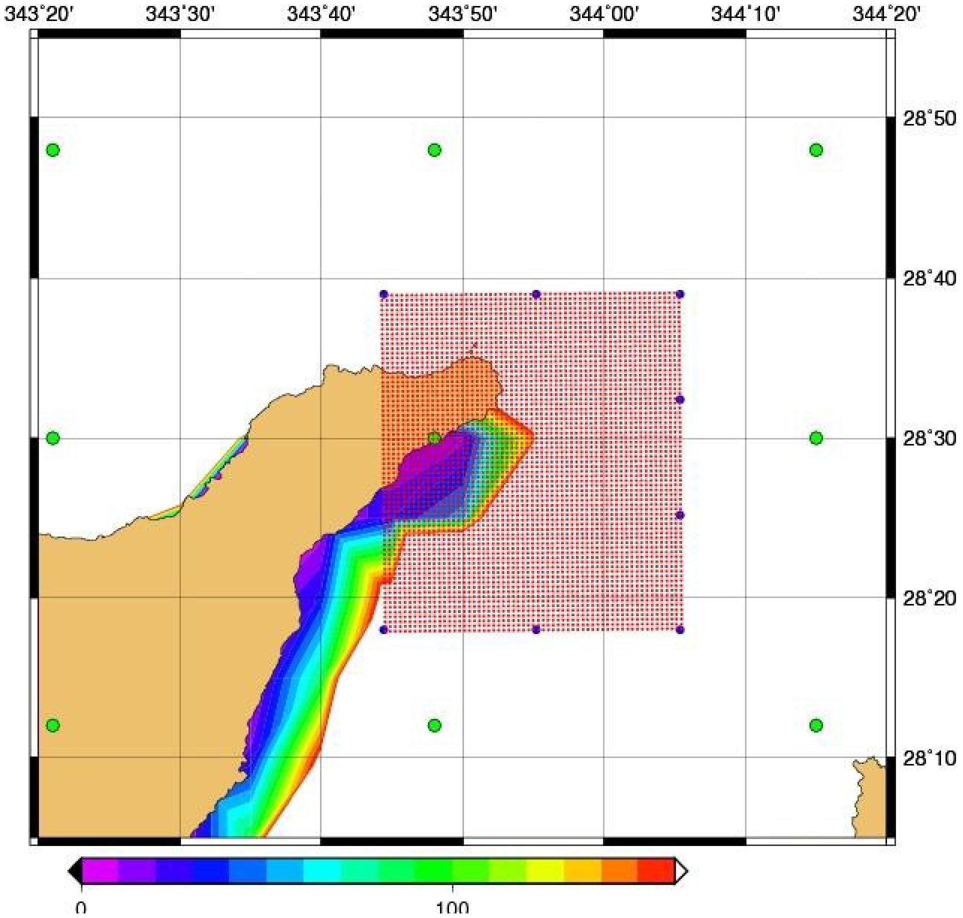


Figure 3 - Configuration of local wave forecast model for Tenerife: computational grid (red), wind fields (green) and boundary conditions (blue).

II.1.3. UKMO wave-EPS Local models

Tenerife and Gijon Harbour applications are generated by applying forcing files from UKMO, so they run with the same time resolution as UKMO wave-EPS is defined:

- 4 runs: 0z/6z/12z/18z
- Control member and 22 members :
    - 0z/12z: Members 1-11 run out to full 72h forecast, 12-22 perform short update cycle.

- 6z/18z: Members 2-22 run out to full 72h forecast, 1-11 perform short update cycle.
- Restart dumps produced at T+6

Therefore, only the control and half of 22 forecast members run out to full forecast horizon at any one forecast cycle, the remaining members run in a short cycle step of 7 hours in order to maintain continuity. During the next cycle, the members that ran a short-step previously are now run to full forecast and vice-versa. The full 22 member ensemble product can then be generated using overlapping full forecast members from the last two runs.

From August the local systems are operationally running in a four day cycle. Each application starts connecting with the FTP server hosted at UKMO were daily wind and spectral forcing data are transferred.

Once PdE has the forcing file, after separate the archives of the 23 members, it creates a directory for each one where the model individually runs.

II.2 DESCRIPTION OF MEDITERRANEAN LOCAL WAVE MODEL.

II.2.1. BARCELONA APPLICATION.

Barcelona application has been configured taking the forcing windfields from CNMCA and the boundary conditions from NETTUNO ensemble model. Those forcing files are defined in a grid with a resolution at 0.05 degrees (WEST 2.05, EAST 2.4, SOUTH 41.2 and NORTH 41.45).

The local system has been defined on a computational grid of 50x71 points and with resolution of 600x500 meters each cell. The grids of wind fields and boundary conditions have a resolution of 3’.

At Madrid meeting (April 2013) it was decided to develop another Barcelona application taking forcing files from Met Office ensemble model to compare the results. Met Office has interpolated the wind to the CNMCA locations and waves to the NETTUNO locations for Barcelona domain so that application has the same spatial resolution.

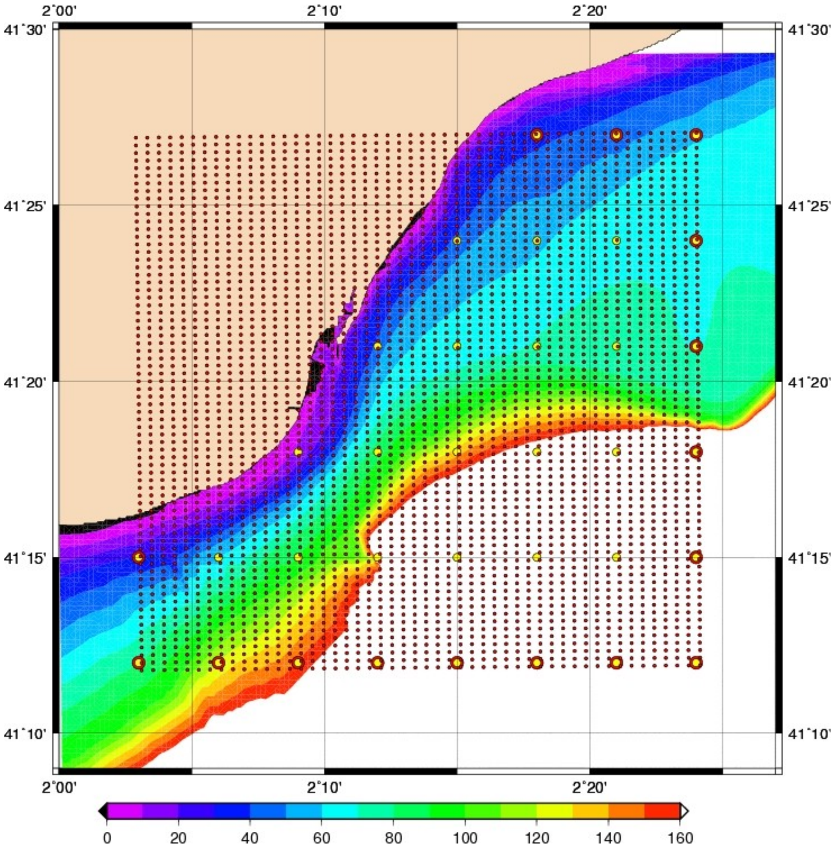


Figure 4 - Configuration of local wave forecast model for Barcelona: computational grid (black), wind fields (yellow) and boundary conditions (red).

The NETTUNO-EPS consists of 40+1 members, integrated at 00 UTC up to 48 hours forecast in the Mediterranean basin. The ensemble is run once a day at 00 UTC.

Barcelona-CNMA application runs with the same time resolution as NETTUNO-EPS is defined. The system is operationally running once a day and starts at 8:30 UTC connecting with a SFTP server hosted at ISMAR to collect the forcing files. If forcing files are not yet on the server, the application will try again 15 minutes later. The application is programmed to do 5 tries.

Once PdE has the forcing file, after separate the archives of the 41 members, it creates a directory for each one where the model individually runs.

Barcelona–UKMO application runs in a four day cycle with the same time resolution as UKMO wave-EPS Local models.

III DETERMINISTIC WAVE MODEL VALIDATION

III.1 Introduction

Deterministic models are operational since August 2013. The validation study presented in this document has been done with the results from January to October 2014.

The operational model is provided with a routine that generates the time series in a specific point of the application. The wave parameters of those time series are significant wave height, mean direction, mean period, peak period, wind speed and wind direction. The point of the time series is the location of the buoy that has been used to compare the model with the observed data

In September 2013 Gijon Buoy stopped working so the validation study has been done only for the other 3 applications: Tenerife, Barcelona-CNMCA and Barcelona-UKMO. These results give an idea of the behaviour of the member 0 (deterministic model) prior to development the ensemble forecasting framework.

Buoy	Lat	Lon	Depth
Barcelona Buoy	41,32º N	2,20ºE	68 m
Santa Cruz Tenerife Buoy	28,46º N	16,23ºW	56 m

Table 1 - Depth and location of the buoys used for validation.

Statistics presented in this section are based on the analysis of the significant wave height and mean direction parameters to evaluate how the system works. The scatterplots comprise the behaviour of the models for the period before next cycle, and at lead time 24, 48 and 72 hours. The metrics of the validation table are parameter root mean square error (RMSE) value, error mean (bias), slope regression coefficient and spread.

III.2 Barcelona-CNMCA Application

Significant wave height data and mean direction from Barcelona-CNMCA application are compared with Barcelona Buoy data with 3 groups of samples: one with the model values that covers the first 24 hours (up to next cycle), other with the values at forecast range +24 and the last one at forecast range +48.

In Figure 5, the left panel is the scatterplot of the first group is the scatterplot with the values +24 and the right panel is the scatterplot with the values at lead time +48. It is observed a good correlation between the model and observed data and the root mean square error increases with the time horizon.

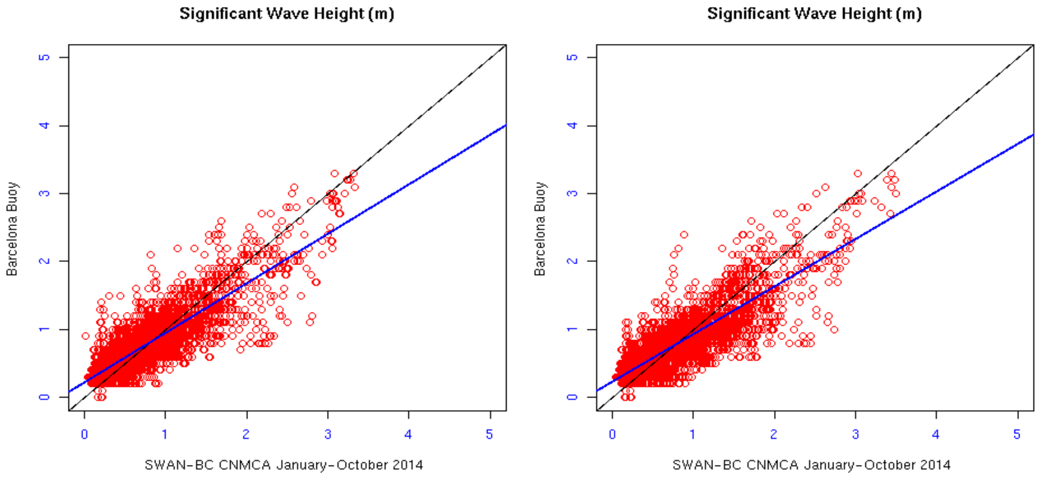


Figure 5 – Barcelona-CNMCA: Scatterplots significant wave height of deterministic model against buoy data.

Significant Wave Height	Num data	Corr.	Slope	RMSE	Bias	Spread
SWAN - Barcelona Buoy	4831	0.86	0.73	0.26	0.03	0.37
SWAN 48 -Barcelona Buoy	4808	0.84	0.70	0.28	0.01	0.39

Table 2 – Statistical results of significant wave height for Barcelona-CNMCA model

Mean Direction	Num. data	Corr.	Slope	RMSE	Bias	Spread
SWAN - Barcelona Buoy	591	0.61	0.55	128	-34.5	0.61
SWAN 24 -Barcelona Buoy	583	0.63	0.57	126	-45,24	0.59
SWAN 48 -Barcelona Buoy	577	0.63	0.57	126.5	-45.2	0.59

Table 3 – Statistical results of mean direction for Barcelona-CNMCA model

III.3 Barcelona – UKMO Application

Significant wave height data and mean direction from Barcelona-UKMO application are compared with Barcelona Buoy data with 4 groups of samples: one with the model values that covers the first 6 hours (up to next cycle),and the others with the values at forecast range +24 , +48 and +72 hours.

In Figure 6, the top left panel is the scatterplot of the first group; the top right panel is the scatterplot with the values +24, the bottom left panel is the scatterplot with values at lead time +48 and the bottom right panel is the scatterplot with the values at lead time +72.

The results are worse than in CNMCA model, being underestimated the significant wave height parameters by the model. It is observed high values of root mean square error parameter.

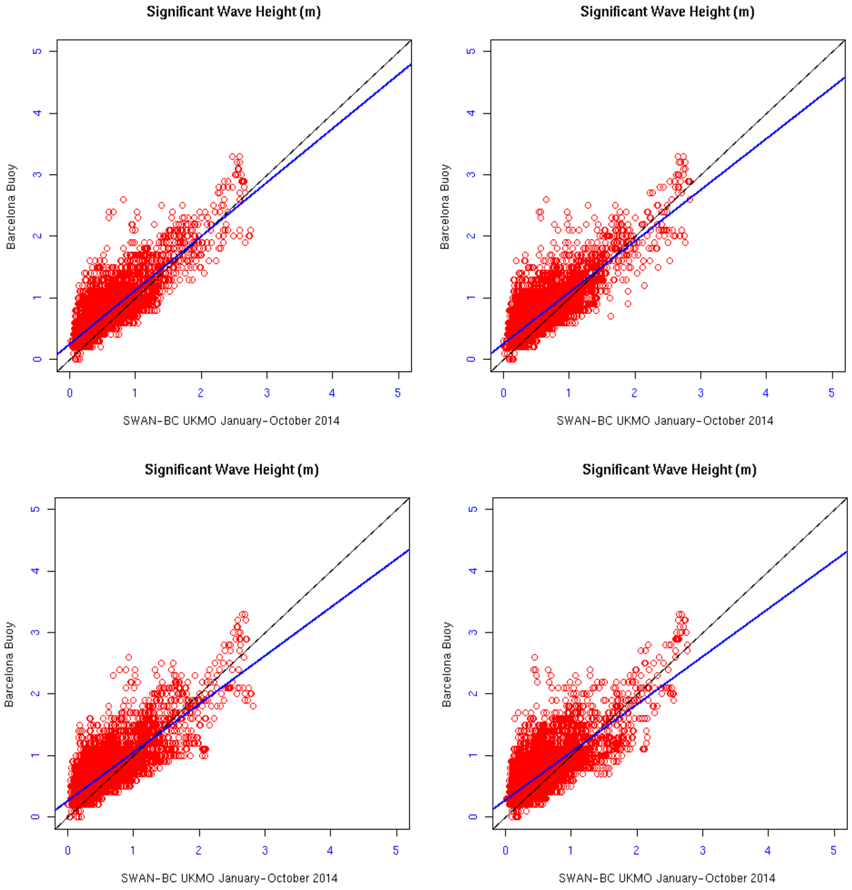


Figure 6 – Barcelona-UKMO: Scatterplots significant wave height of deterministic model against buoy data

Significant Wave Height	Num. data	Corr	Regre	RMSE	Bias	Spread
SWAN - Barcelona Buoy	7022	0.84	0.87	0.30	0.19	0.58
SWAN 24 - Barcelona Buoy	7005	0.82	0.83	0.30	0.18	0.57
SWAN 48 - Barcelona Buoy	6980	0.80	0.79	0.30	0.15	0.54
SWAN 72 – Barcelona Buoy	6956	0.76	0.78	0.32	0.16	0.59

Table 4 – Statistical results of significant wave height for Barcelona-UKMO model

Mean direction	Num. data	Corr	Regres	RMSE	Bias	Spread
SWAN - Barcelona Buoy	2402	0.78	0.81	35.5	26.1	0.24
SWAN 24 - Barcelona Buoy	2672	0.97	0.96	34.3	-0.77	0.25
SWAN 48 - Barcelona Buoy	2612	0.93	0.94	46.5	3.4	0.35
SWAN 72 – Barcelona Buoy	2506	0.87	0.86	37.4	7.7	0.54

Table 5 – Statistical results of mean direction for Barcelona-UKMO model

III.4 Tenerife – UKMO Application

Significant wave height data and mean direction from Tenerife-UKMO application are compared with Barcelona Buoy data with 4 groups of samples: one with the model values that covers the first 6 hours (up to next cycle),and the others with the values at forecast range +24 , +48 and +72 hours.

In Figure 7, the top left panel is the scatterplot of the first group; the top right panel is the scatterplot with the values +24, the bottom left panel is the scatterplot with values at lead time +48 and the bottom right panel is the scatterplot with the values at lead time +72.

It is observed a good correlation between the model and observed data and the model has a reasonably low overall bias (between 0.1 and 0.01).

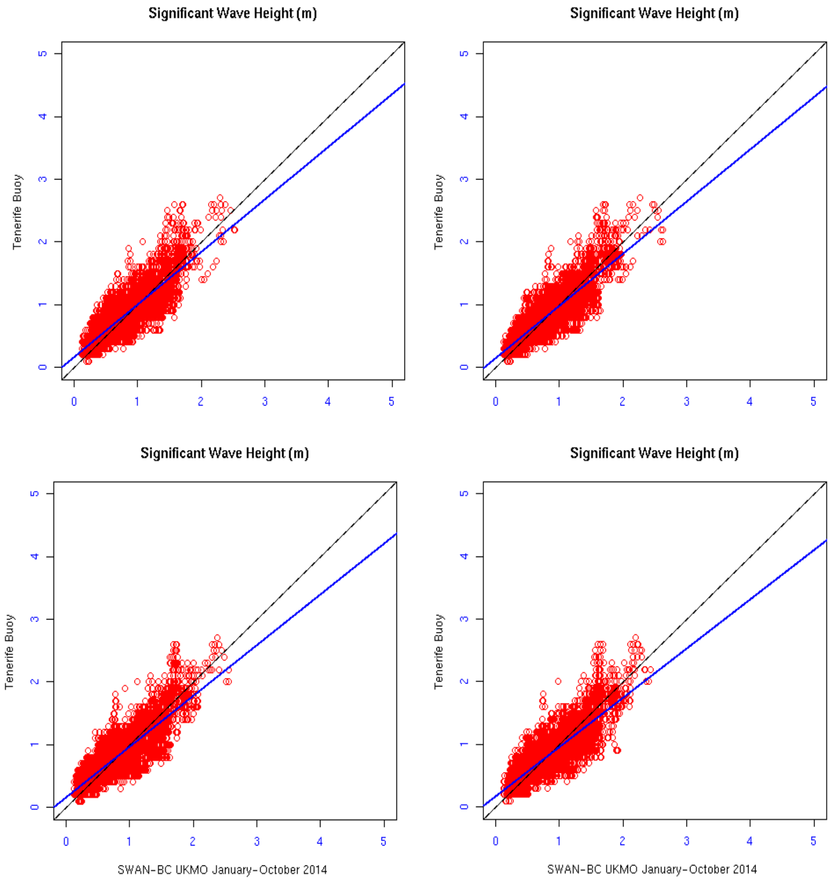


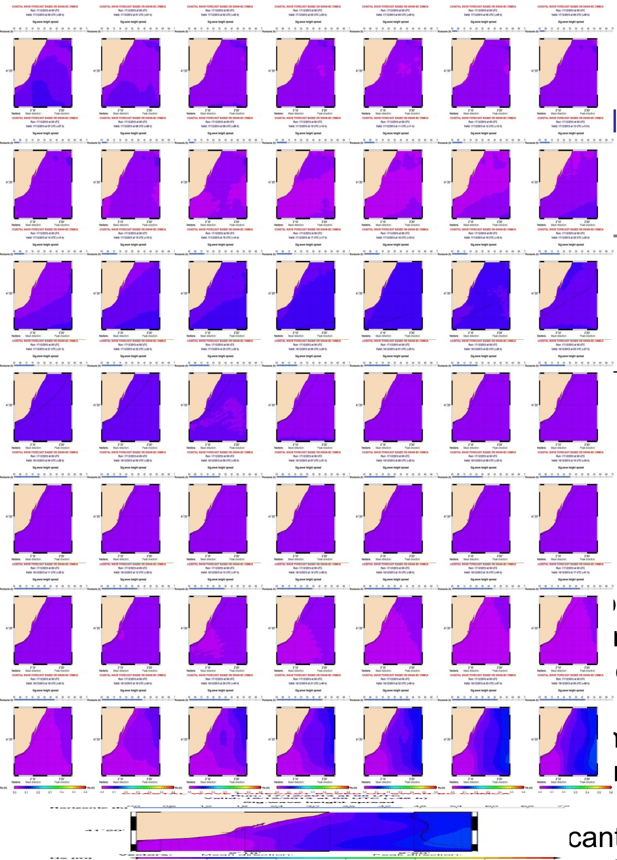
Figure 7 – Tenerife - UKMO: Scatterplots significant wave height of deterministic model against buoy data.

Significant Wave Height	Num.data	Corr	Regres	RMSE	Bias	Spread
SWAN - Tenerife Buoy	6822	0.85	0.83	0.22	0.05	0.29
SWAN 24 - Tenerife Buoy	6803	0.86	0.83	0.21	0.02	0.27
SWAN 48 - Tenerife Buoy	6783	0.86	0.81	0.22	0.01	0.27
SWAN 72 – Tenerife Buoy	6753	0.84	0.79	0.22	0.01	0.28

Table 6 – Statistical results of significant wave height for Tenerife-UKMO model

Mean direction	**Num. data**	**Corr**	**Regres**	**RMSE**	**Bias**	**Spread**
SWAN - Tenerife Buoy	2665	0.69	0.62	32.6	-19	0.12
SWAN 24 - Tenerife Buoy	2646	0.69	0.64	32.1	-17.6	0.12
SWAN 48 - Tenerife Buoy	2642	0.75	0.72	30.3	-17.4	0.12
SWAN 72 – Tenerife Buoy	2632	0.72	0.74	30.0	-16.3	0.11

Table 7 – Statistical results of mean direction for Tenerife-UKMO model



ɔperational since September 2013. The first validation study rom October to December 2013. To estimate reliability to a ensemble of 20 members a sample size of approximately this basis a recommended sample period for wave-EPS ıs. In this document the validation for wave-EPS has been ry to May 2014 (4 months).

cant wave height spread maps with the contour line of the ensemble mean value has been implemented.

For applications with the forcing files from MetOffice, which have only half of their members running in a full forecast, spread has been calculated taking into account lagged members (instead of using members in short cycle, takes those members of the cycle before). With this system, lead time prediction is H+66.

Figure 8 – Sig. wave height (m) ensemble mean (contour) and spread (shaded).

Barcelona-CNMCA application. Run: 17/12/2013 at 00 UTC. Lead time +48H

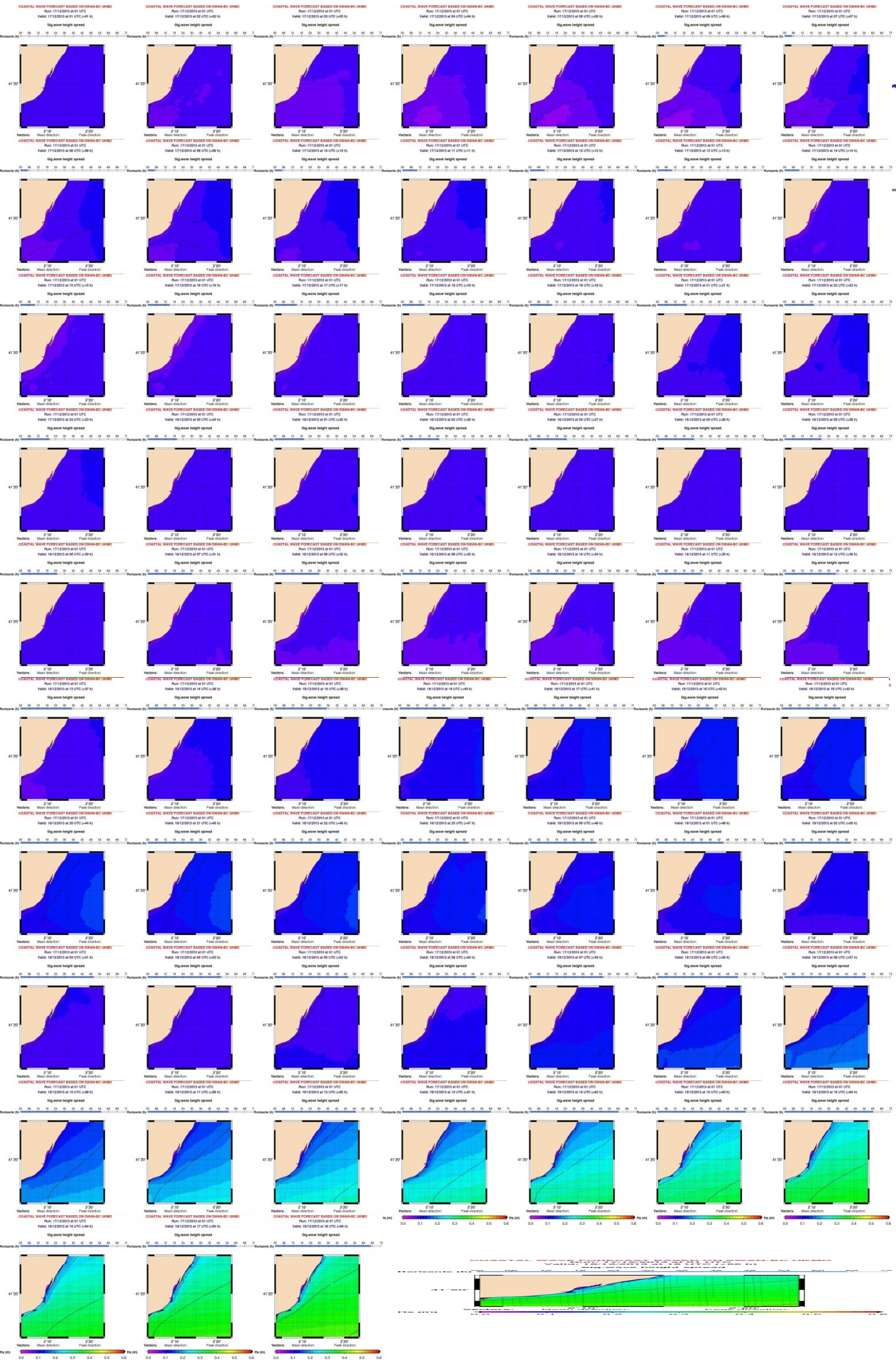


Figure 9 – Sig. wave height (m) ensemble mean (contour) and spread (shaded).

Barcelona-UKMO application. Run: 17/12/2013 at 00 UTC. Lead time +66H

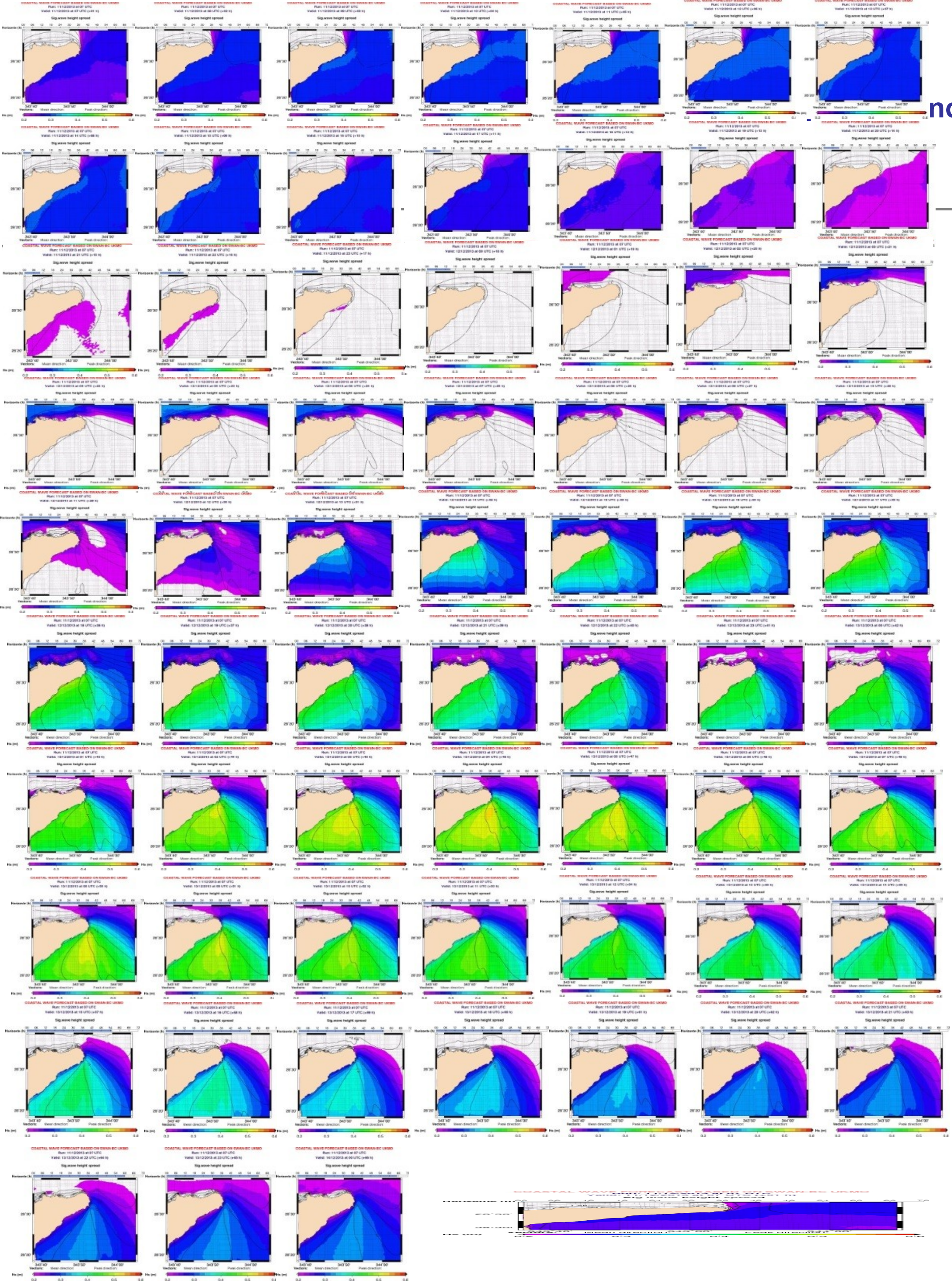


Figure 10 – Sig. wave height (m) ensemble mean (contour) and spread (shaded).

Tenerife-UKMO application. Run: 11/12/2013 at 06 UTC. Lead time +66H

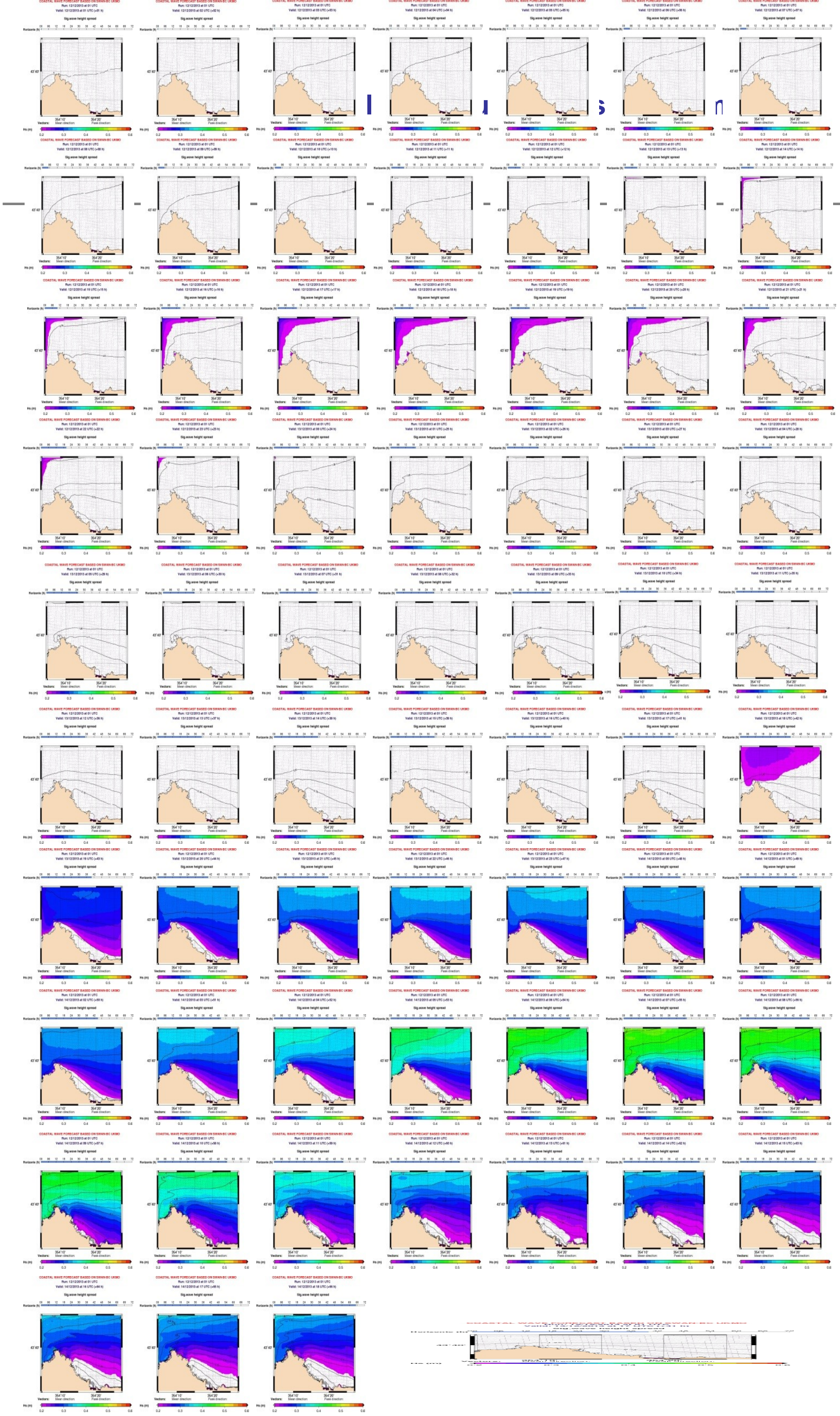


Figure 11 – Sig. wave height (m) ensemble mean (contour) and spread (shaded).

Gijon-UKMO application. Run: 12/12/2013 at 00 UTC. Lead time +66H

IV.2 Ensemble consistency.

Taking into consideration the sample period for was only 2 months in December 2013 and a recommended sample period for wave-EPS verification is at least 3-6 months, this validation study has been repeated for the period January-April 2014 to have an idea how ensemble local models are working.

The first step in the validation of an EPS, as a probabilistic prediction system, is to check its statistical consistency with observations. The rank histogram can be used to check if verifying observation is statistically indistinguishable from the set of forecast values (or if any ensemble member, as well as the verifying observation, can be considered equally likely to be the truth). Such a system must show an approximately flat-shaped rank histogram.

In Fig. 11 rank histograms corresponding to Barcelona-CNMCA at lead time T+06, T+24 and T+48 show how the model starts with low spread and as the forecast horizon increases, spreads increases too, with a rank histogram under-dispersive at lead time +6 and consistent at lead time +24, +48.

In Fig. 12 rank histograms corresponding to Barcelona-UKMO at lead time T+06, T+24, T+48 and T+66 show spread does not increase with the forecast horizon and most of the days the wave-EPS system subpredict (negative bias). This histogram is done using the lagged members for the short cycle.

In Fig. 13 rank histograms corresponding to Tenerife-UKMO at lead time T+06, T+24, T+48 and T+66 show the ensemble is statistically consistent (calibrated) with a flat-shaped rank histogram. This histogram is done using the lagged members for the short cycle.

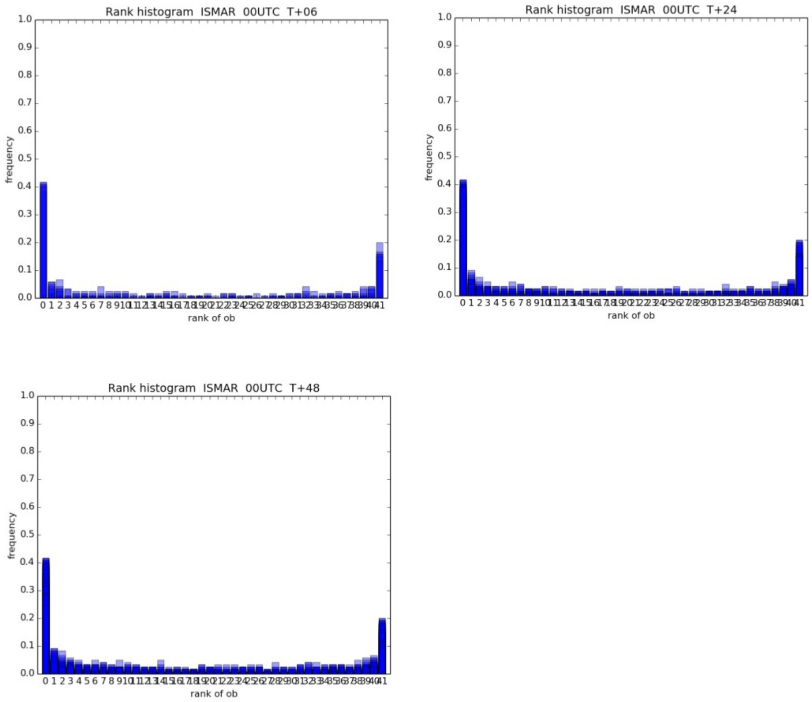


Figure 12 - Rank histogram of sig.wave height Barcelona-CNMCA at lead time T +06, T+24, T+48.

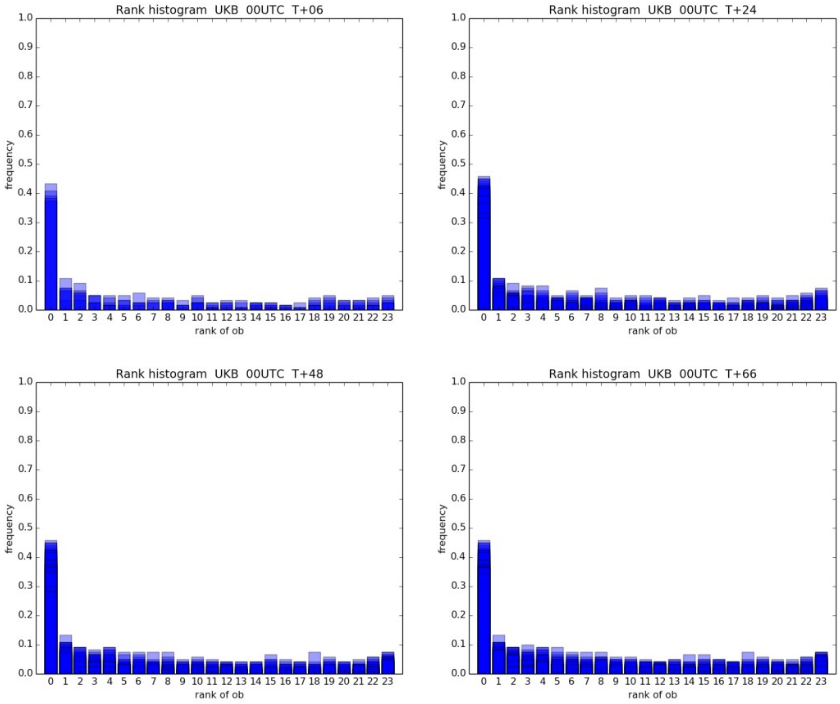


Figure 13 - Rank histogram of sig.wave height Barcelona-UKMO at lead time T +06, T+24, T+48, T+66.

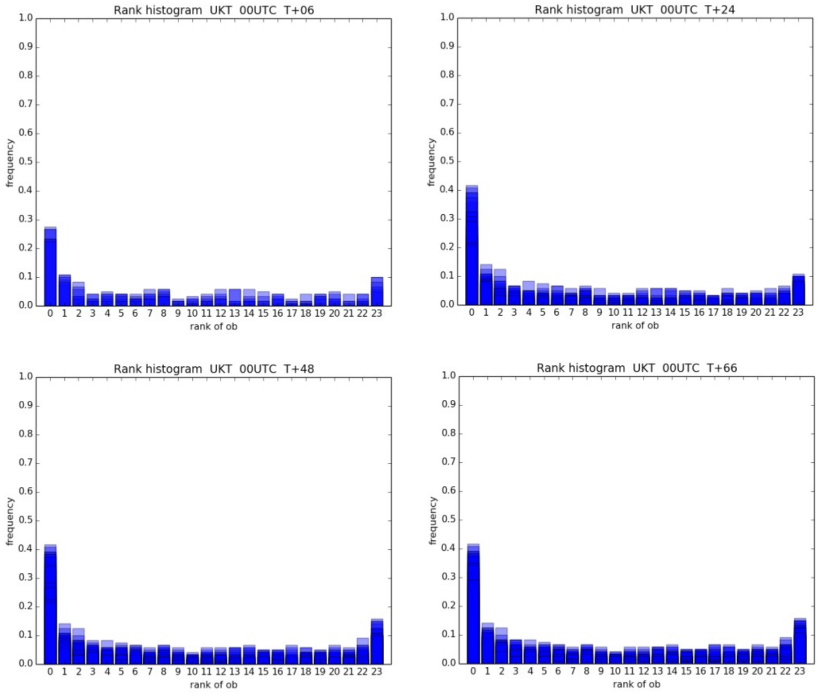


Figure 14 - Rank histogram of sig.wave height Tenerife-UKMO at lead time T +06, T+24, T+48, T+66

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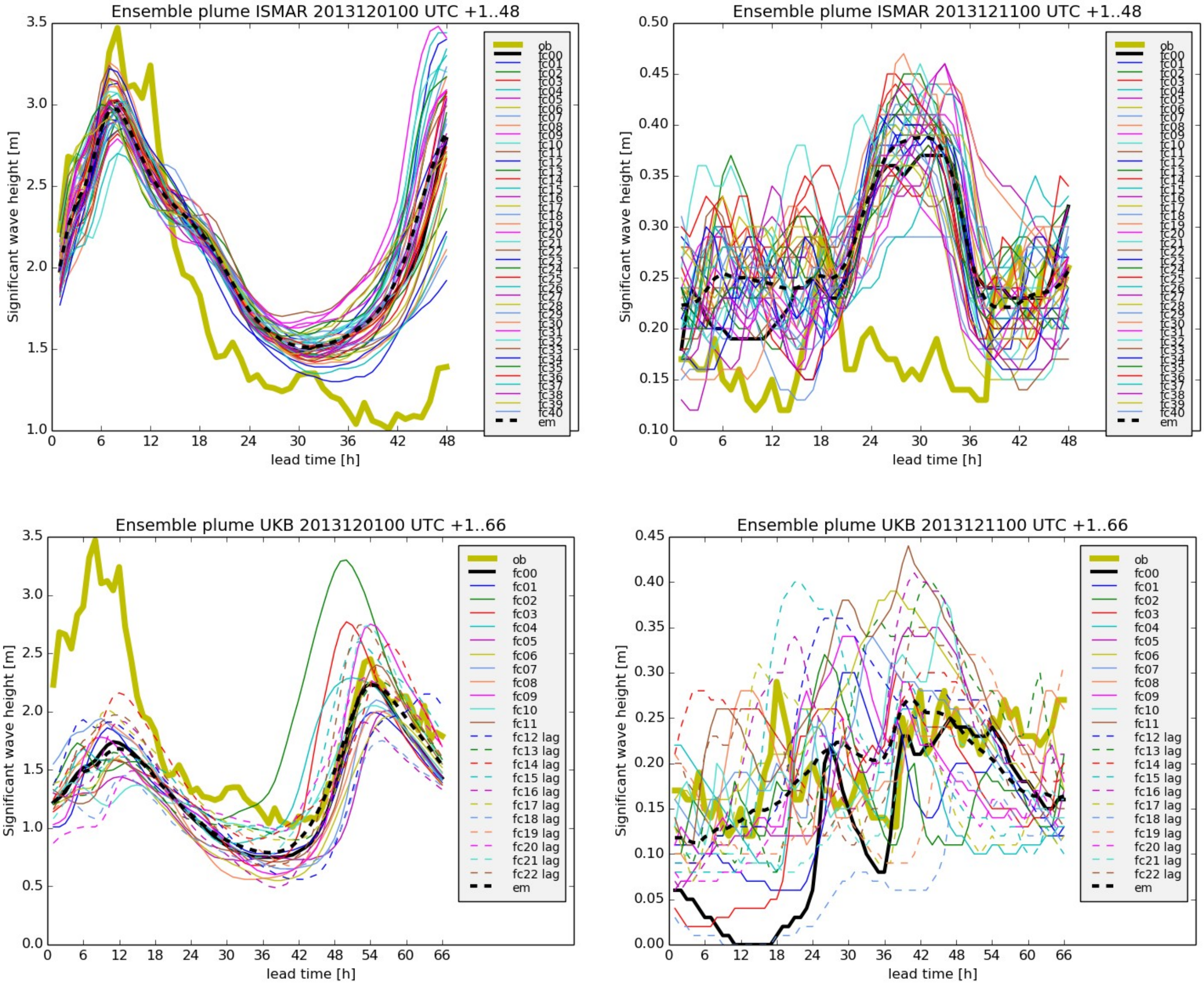

Figure 15 – Barcelona-CNMCA (top) and Barcelona-UKMO (bottom) sig. wave height time series.

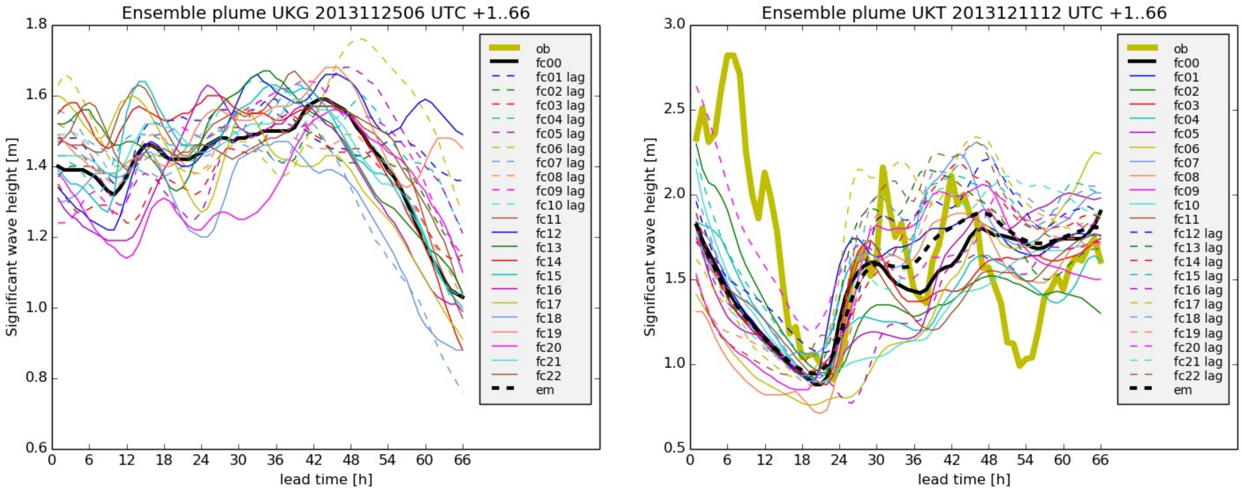

Figure 16 – Atlantic harbour sig. wave height time series. Gijon-UKMO wave EPS (left) and Tenerife-UKMO wave EPS.

V RESULTS

The two main new products obtained with the ensemble wave forecast are the EPS gram and the probability maps. Examples of both for the three harbours, Gijón, Tenerife and Barcelona are shown in figures 17, 18, 19, 20, 21 and 22.

The EPS gram, figures 17, 19 and 21, gives the ensemble information at an individual grid – point location, which indicates the time evolution of the given parameter. In the case of harbour applications, the represented parameters are the significant wave height and the mean direction.

The spread is indicated by the range of forecast values. 50% of the members are distributed evenly around the median to define a vertical rectangle. The remaining members define the extreme 25 % spikes. The box-epsgram thus provides a discrete probability information in the intervals 0-25%, 25-50% and 75-100%. The deterministic member (control member) is included as a reference. The continue-epsgram gives hourly information that is the time resolution of the model.

The probability maps show the probability that a certain parameter exceeds a given threshold. Figure 18 shows the probability that Hs exceed 4.5 meters at Gijón harbour, and figures 20 and 22 show the probability that Hs exceed 1.8 meters at Tenerife and Barcelona harbours.

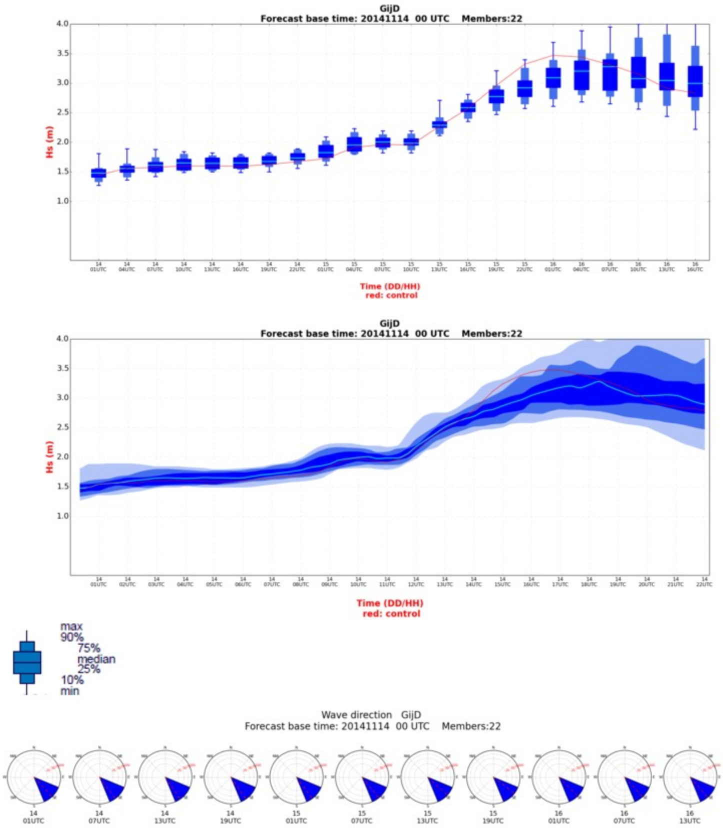

Fig 17 – Example of Gijon EPSgram for the significant wave height, above, and wave direction, below. Run: 2014111400

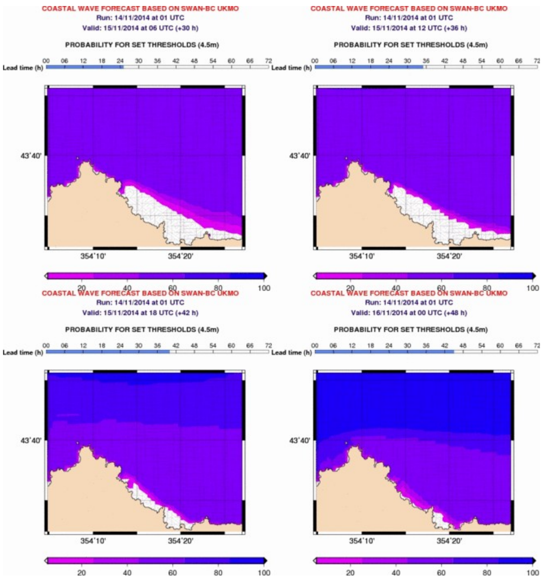

Fig 18 – Gijon probability maps. Hs thereshold: 4.5 meters

Lead time +30h, +36h, +42h and +48h. Run:2014111400

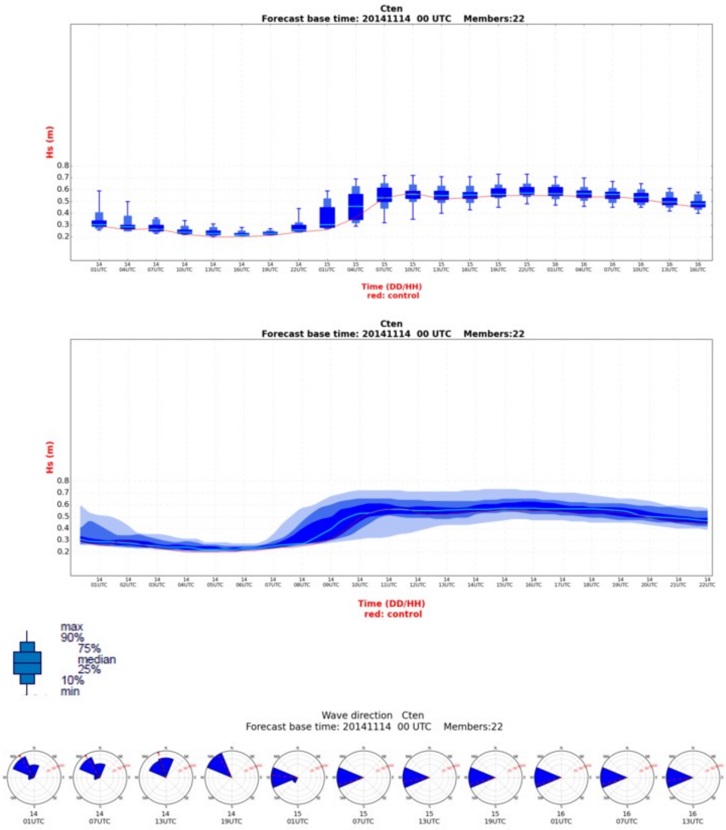

Fig 19 – Example of Tenerife EPSgram . for the significant wave height, above, and wave direction, below Run: 2014111400

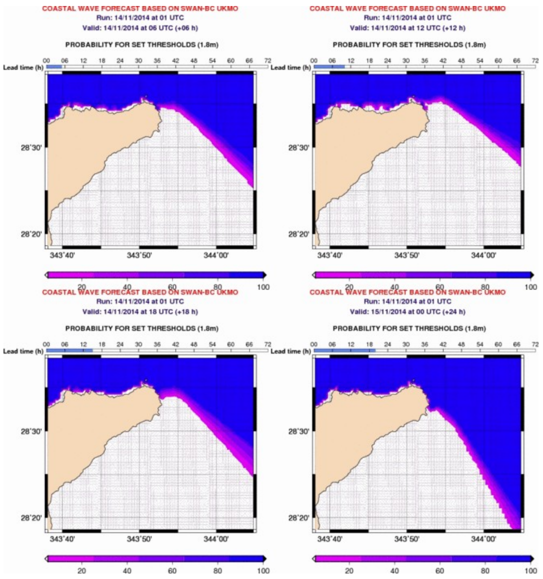

Fig 20 – Tenerife probability maps. Hs thereshold: 1.8m

Lead time +6h, +12h, +18h and +24h. Run:2014111400

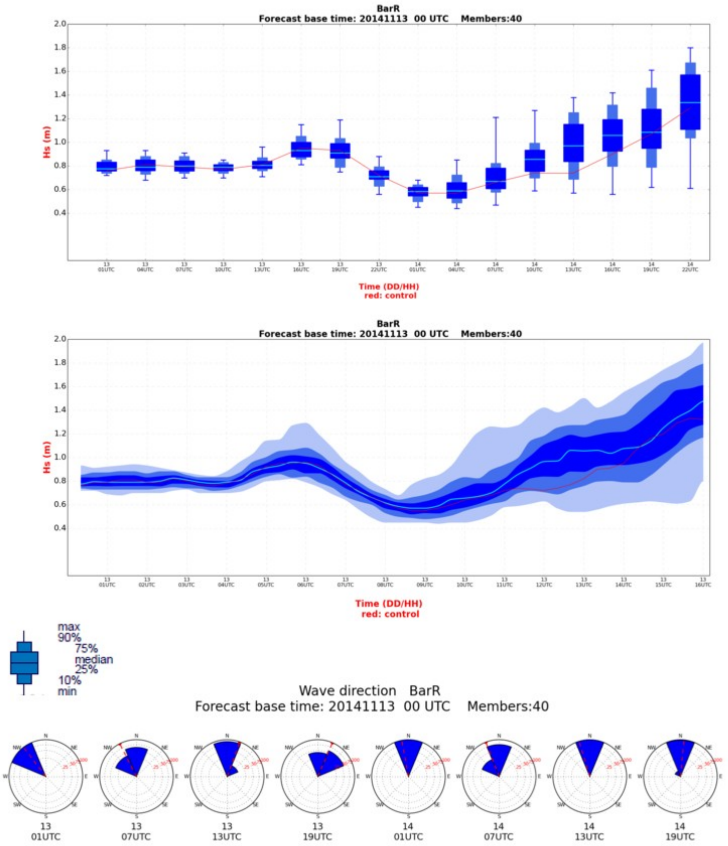

Fig 21 – Example of Barcelona-CNMCA EPSgram for the significant wave height, above, and wave direction, below. Run: 2014111300

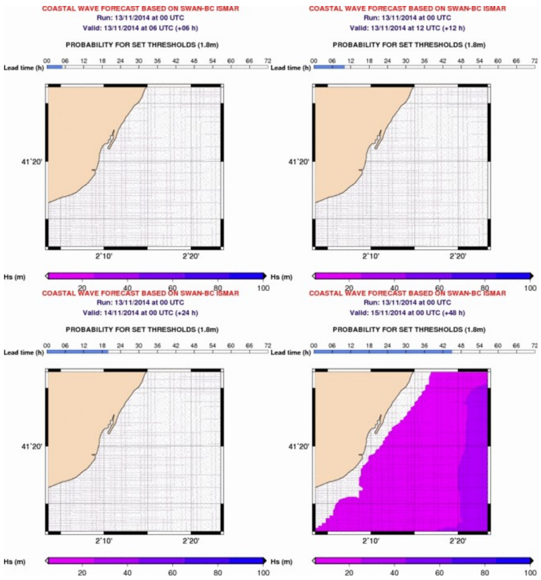

Fig 22 – Barcelona CNMCA probability maps. Hs thereshold: 1.8 m.

Lead time +6h, +12h, +24h and +48h. Run:2014111300

VI CONCLUSIONS

Generating an ensemble wave forecast has provided a number of options for new products and visualization. The probabilistic information instead of deterministic one, provided to Barcelona, Gijon and Tenerife harbours has been adapted to their necessities.

Wave-EPs local models are operational from September 2013 with the mainly purpose of providing categorical forecast with the highest possible accuracy and a quantitative basis for reliable and useful probability forecast.

Routines that generate EPS grams, probability and spread maps have been added to the operational models.

If the purpose of the EPS was just to produce accurate categorical forecasts, there would be needed less members to define sufficient accurate ensemble mean. The reason why the EPS has so many members is the need to obtain accurate probabilistic estimates of the risk of extreme and rare events.

The probability maps developed for the 3 harbour authorities are an important tool to add to the system alert that the harbours already have with their deterministic forecast.

Although Wave-EPS local models could produce more outputs for the commercial ports, the epsgrams with the wave direction or the significant wave height and the probability maps are the most useful tools to start to introduce the predictability to the users, adding a categorical forecast to the deterministic information.