Mediterranean Storms
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OCEANOGRAPHIC AND ATMOSPHERIC ANALYSIS OF THE 10-16 NOVEMBER 2001 STORM IN THE WESTERN MEDITERRANEAN

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ABSTRACT

Along several days of November 2001 the Western Mediterranean coast was lashed by one of the most extreme storms of the last years. Between the 10th and the 16th, high winds and waves in coincidence with an extreme storm surge were registered, which produced remarkable damage in the coast, not only for their intensity but also for their persistence. The present communication describes this event, using the information provided by the networks and forecast systems of Puertos del Estado, analysing, not only the storm, but also the response of these systems.

1 INTRODUCTION

Puertos del Estado (PE) is the official institution in charge of the co-ordination of the state-ruled Spanish Ports System (SPS) constituted by twenty-seven Port Authorities, which are responsible of forty-five Ports. Between the responsibilities assigned by law to PE are those related with the technological development of the SPS including within this topic the activities related with the Aids to Navigation and Marine Climate Monitoring Systems.

Puertos del Estado maintains real time marine measurement networks deployed along the Spanish waters which measure, among others, waves, sea level and atmospheric parameters. In addition, a wave and a sea level forecast system is run operationally, on a twice a day cycle. All the information provided by the networks and the forecast system is updated on real time at the web site of PE, http://www.puertos.es, and is available without any restriction.

Puertos del Estado, as a part of its technological responsibilities within the SPS, issues the official ROM design guides or Maritime Works Recommendations that settle best practice design criteria and environmental parameters for such kind of works. ROM design guides are developed by a Commission of well-known experts in the different fields leaded by PE.

2 STORM DESCRIPTION

A high pressure system blocking the zonal circulation, centred over the Atlantic Ocean was the origin of two, windward and leeward, low pressure systems. The system centred over North Africa moved to the North and North Northeast along days 11th to 14th, and finally on the 15th to the South Southwest, centred over the Balearic Islands. Along the 16th, the high pressure system moved gradually inside the continent, finishing this way one of the biggest and more persistent storm registered the last years in the area.

The evolution of this situation produced high waves and surges accompanied by torrential rains in the coast of the Iberian Peninsula, Balearic Islands and North African Coast, with peaks on the 11th and 15th which damaged harbours and beaches, with lost of human lives. On the first peak, high waves propagating to the South were generated, and on the second one, waves propagating to the East damaged the coast of Cataluña and Levante. High surges in coincidence with waves contributed to the worsening of the conditions in the coast.

3 MONITORING AND FORECASTING SYSTEMS OF PUERTOS DEL ESTADO

3.1 Monitoring networks

The Puertos del Estado marine networks are deployed to obtain real time information on the physical characteristics (waves, currents, tides, temperatures, etc...) of the Spanish waters. There are different networks, with different and complementary objectives: the deep sea, the coastal, and the tide gauges networks. See figure 1.

The Deep Sea Network is based on 9 Seawatch and 3 Wavescan buoy stations. The instruments are located at points with depths between 200 and 800 m and measure atmospheric and oceanographic parameters.

The coastal buoy network is providing real time data in some specific points located at shallow waters. The main objective of the measurements is to complement those of the Deep Sea Network at those locations of special interest for the port operations or wave modelling validation. The buoys employed are scalar Waverider (REMRO network, being its maintenance carried out by CEDEX), and directional (smart and triaxys buoys).

The REDMAR tide gauge network is in operation since 1992. The goal is the real time monitoring of sea level and the generation of historical series for their further study. At this moment the network is composed of 15 SONAR acoustic sensors and 4 Aanderaa pressure sensors.

Measurements of all these networks are transmitted in real-time to Puertos del Estado, posted to the web and used for validation and assimilation in the forecasting systems.

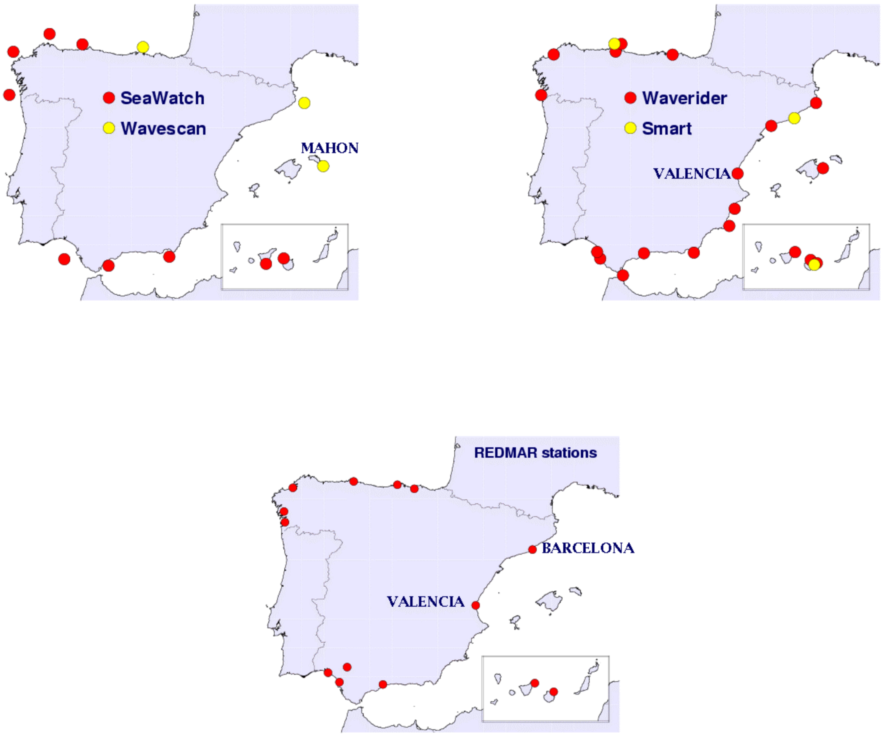

Figure 1. Location of the deep sea buoy, the coastal buoy and tide gauge networks. The names shown, Mahón, Valencia and Barcelona, are those of the buoys and tide gauges used in the paper.

3.2 Forecasting systems

Since 1995, a wave forecast for the Spanish Atlantic and Mediterranean Coast is computed and freely distributed by PE every 12 hours with a forecast horizon of 48 hours. The system is based on a number of applications of the WAM cycle 4, modified by PE to introduce a variable grid spacing scheme, and on the WAVEWATCH III model. Forcing is provided by the Spanish Meteorological Institute (INM) from their operational HIRLAM model, nested to the ECMWF global model. The system is verified in real time with data provided by PE's buoy network.

The Nivmar sea level forecasting system is based on the ocean circulation HAMSOM model and on the harmonical prediction of tides computed from data measured by the tide gauge network REDMAR, managed by Puertos del Estado. At this moment, HAMSOM is running barotropic and vertically integrated within Nivmar. The system is executed twice a day using the output from the INM application of HIRLAM atmospheric model. Data from REDMAR tide gauges are used, allowing the system to correct systematic errors in the mean sea level due to physicals processes that are not included in the ocean model (i.e. steric height). The forecast horizon is 48 hours.

4 STORM MEASURED AND MODELLED DATA

The monitoring and forecasting systems worked with normality from the 10th to the 16th of November, and the forecast was issued daily. There were continuous measurements from the buoy network in the area except for two buoys in the Gulf of Lyon which were out of service for different reasons. Figures 3 and 4 (dots) show the measurements at Mahón and Valencia (see Figure 1), where two maximums at the 11th and 15th were registered. These peaks are not extraordinary in the area but the peak period (13 seconds) is remarkable. The tidal gauges worked correctly recording the maximum residuals ever registered in the area since the beginning of the REDMAR operation (1992). Figure 5 shows a meteorological residual of about 55 cm in Valencia and Barcelona. As an indication of the magnitude of the surge, the maximum total level registered in Barcelona since 1992 to 1999 was 1.72 m above the harbour datum; during this storm the total level was above 1.70 m for 20 hours.

The wave forecast over predicted the storm in the Gulf of Lyon, and this over prediction was partially corrected as the forecast horizon decreased. The over prediction was found in the forcing wind fields. Figure 2 shows the HIRLAM wind field (analysis) for the 11th and the corresponding WAM wave field. Figures 3 and 4 show a comparison of the model (continuos line) with buoy data at Mahon and Valencia (see Figure 1), where the correct performance of the model can be seen.

The sea level forecast predicted the high surge correctly both in elevation and time, although some underestimation in the peaks was found. Figure 6 shows a sea level map produced by the system and a comparison of a surge time series produced by the model (continuos black line) with the measured residuals (blue dots) at Barcelona (see Figure 1).There was an underestimation of about 15 cm at the peaks. A poor resolution of the wind fields (0.5 degrees) or the absence in the model of the energy contribution produced by the dissipation of wave can be the origin of this underestimation.

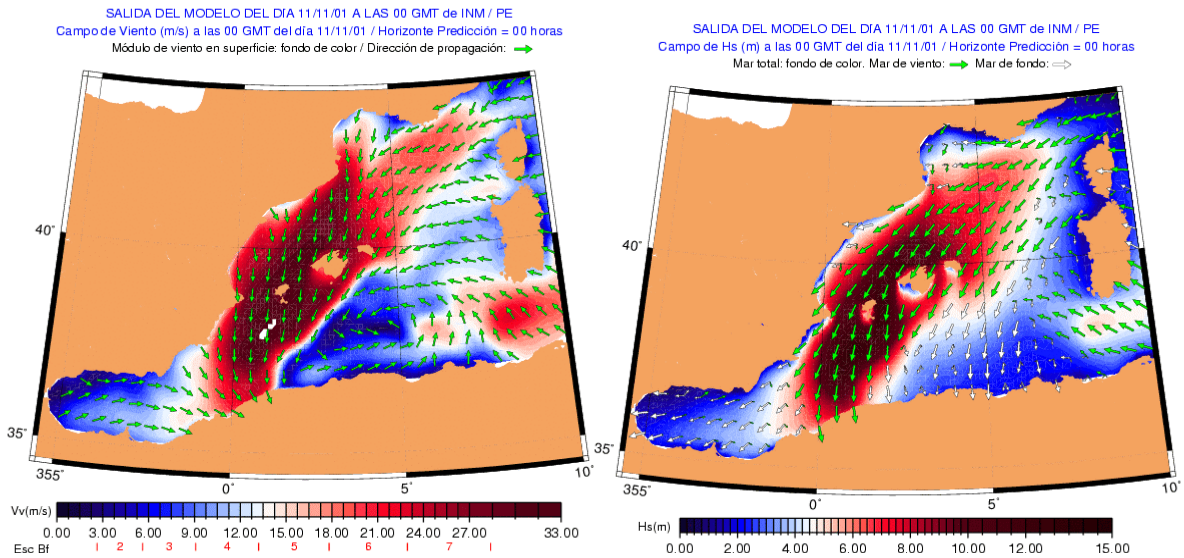

Figure 2. HIRLAM 10m-windfields and WAM significant wave height for November the 11th

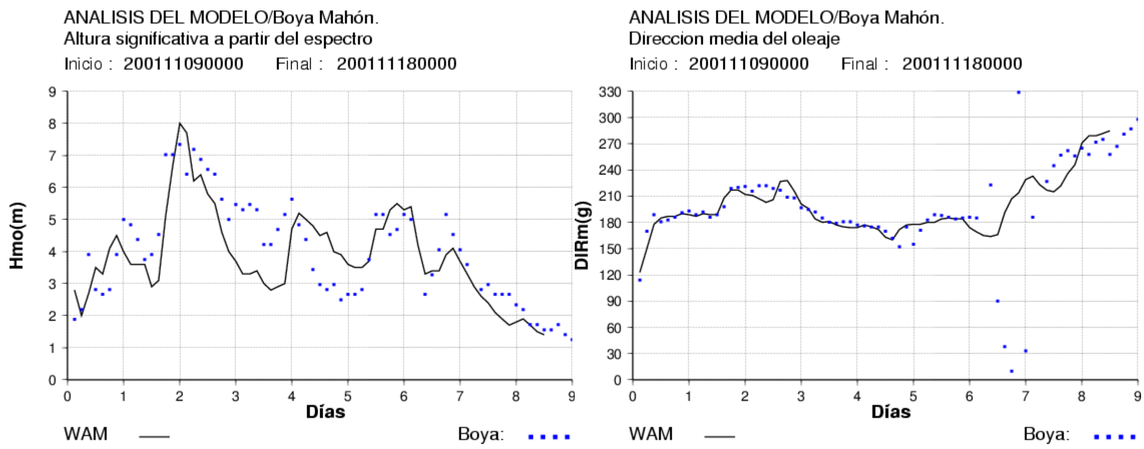

Figure 3. Verification of the WAM model at Mahón buoy. Significant wave height (right) and mean wave direction (left).

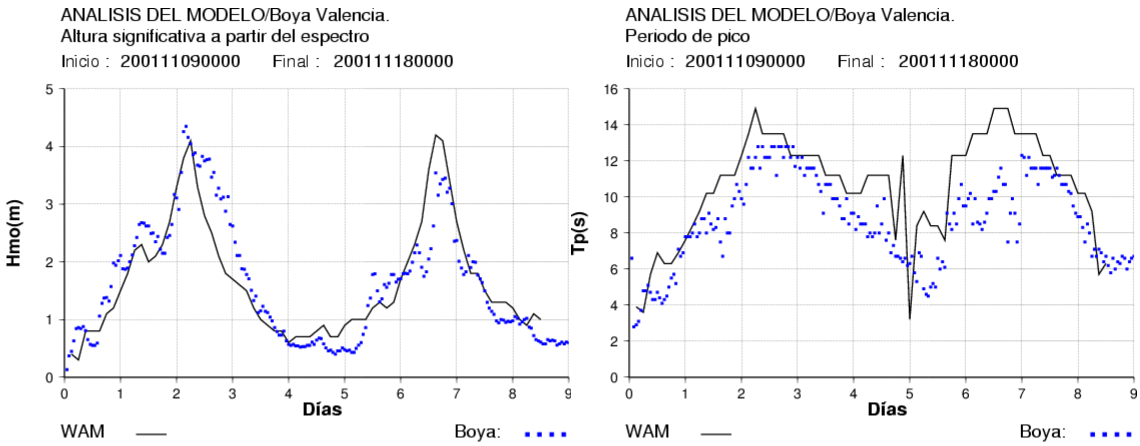

Figure 4. Verification of the WAM model at Valencia buoy. Significant wave height (right) and peak period (left).

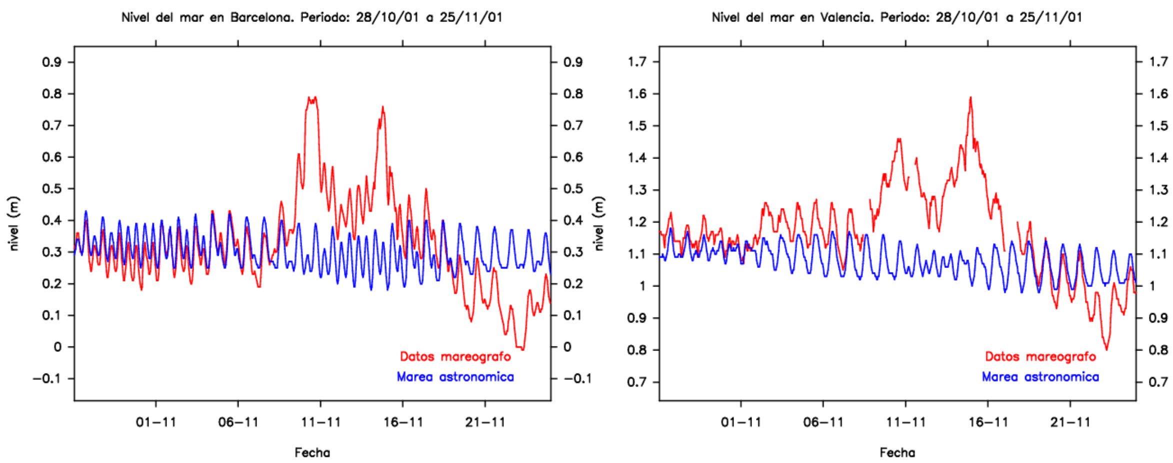

Figure 5. Sea level data at Barcelona and Valencia tide gauges for November. Red line: measured, blue line astronomical tide.

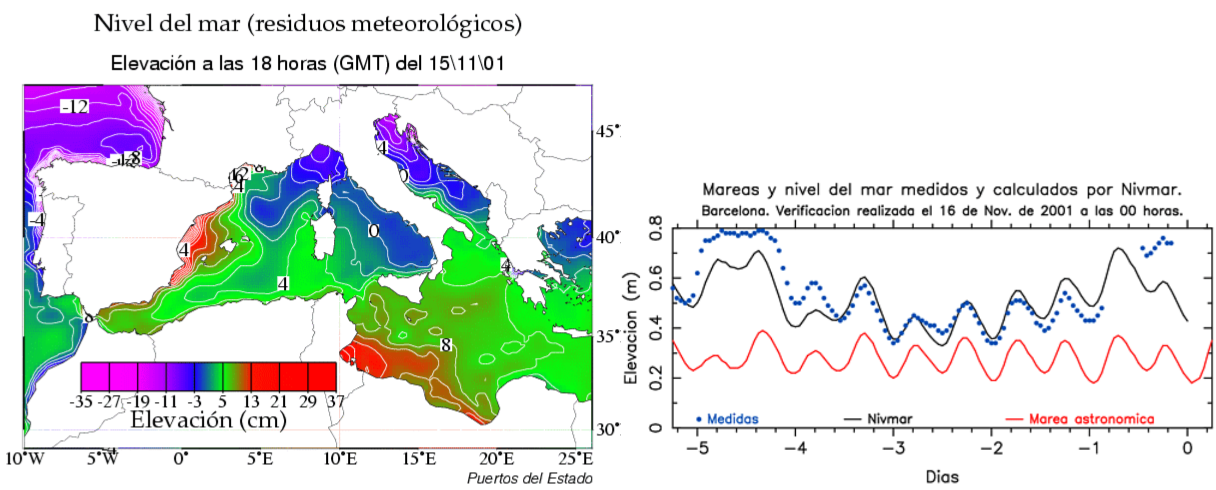

Figure 6. Sea level forecast system output for November the15th (left) and verification at Barcelona: black line model output, blue dots measures, red line astronomical tide (right).

5 CONCLUSIONS

Waves by themselves are not the origin of the extensive damages caused by this storm, but the coincidence of extreme surges, waves and the persistence of these parameters. Also the enhance of the wave steepness by return currents near the coast have possible worsened the damage on harbours. These facts leads to the conclusion that the effort carried out in the preparation of the Maritime Works Recommendations (ROM) should be continued introducing a global conception of the action of waves, persistence and sea level. The effort carried out by PE in the development and maintenance of measuring networks is a key point for the development of better ROM Recommendations and should be continued.

Waves and sea level were properly forecasted, contributing in this way to reduce the risk and the damage produced by the storm, although it seems desirable to couple both systems in the future to produce a combined sea level and wave forecast. In addition, a better resolution, both in time and space, is deemed necessary to model the area.

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