HIGH RESOLUTION WIND-WAVE MODELING IN NW MEDITERRANEAN

Jordi Cateura, Agustín Sánchez-Arcilla, Rodolfo Bolaños

Abstract: Wind-wave generation modeling has received increasing interest in many areas, specially the bounding and propagation of errors. The important effect of spatial and temporal resolution on the corresponding wind and wave models has also received attention. The Mediterranean Sea presents many small scale features produced by its heterogeneous shape and orography/bathymetry. This paper presents a high resolution modeling test at the NW Mediterranean. The wind fields come from the ARPEGE-ALADIN, SKYRON and MASS atmospheric models. The ALADIN data consist of wind fields every 1 hour with a spatial resolution of 0.1°. Additional data from the SKYRON wind model is used with the same resolution as ARPEGE-ALADIN. The same applying to the MASS model which is currently running in an operational way at the Meteorological Service of Catalunya with a spatial resolution of 0.16° and with one wind field every 6 hours. All wind field sources will be applied to the wave model WAM. The study period is January 2003; chosen within the MFSTEP project. This allows for the evaluation of wind and wave models under various situations considering high by detailed spatial and temporal features. The results obtained show that high resolution codes do not provide much better results than a lower resolution model.

Keywords: wind-wave modelling, WAM, errors, ALADIN, SKYRON, MASS

1. INTRODUCTION

Wind waves in the NW Mediterranean have proved to be an important physical factor for human activities, and biological and physical processes (Bolaños et al., 2003; Grémare et al.,...
2003). As a result, wind-wave generation modeling has received increasing interest in such areas. Cavaleri and Bertotti (2004) and Bolaños et al. (2004) have studied the error of this modeling demonstrating the important effect of spatial and temporal resolution on wind and wave models.

The European project MFSTEP (Mediterranean Forecasting Systems Towards Environmental Predictions) whose objective is to obtain an oceanographic system for operational predictions in the Mediterranean Sea has allowed a comprehensive intercomparison, based on real time observations and numerical modelling. Within this framework the validation of different meteorological numerical models for a scientific validation period (SVP) has been carried out.

The main aim of this paper is thus to assess the resulting limitations in accuracy for operational wave predictions in the NW Mediterranean considering high time and spatial resolution for the wind fields. This is achieved by using three state of the art atmospheric models, and one state of the art wave model. This is supplemented by field data from coastal buoys from the XIOM (oceanographic and meteorological instrumental network from the Catalan Government) and Puertos del Estado (Spanish Harbours Authorities, Ministry if Publish Works).

In the paper a comparison between the different meteorological models (within the MFSTEP project) applied to a wave model is made using physical knowledge and statistical analysis. The characteristics of the used models as well as the statistical methodology, are explained in section 2 of the paper. The characteristics of the events are analyzed in section 2.1. We have specially focused our attention on the Catalan sea and its coastal zone. This is a region of sharp gradients in topography and very complex bathymetry (Figure 1). The results are explained in section 3 while some discussion and conclusions are presented in section 4. Moreover, all three modeled wind fields have been used as input for the wave model WAM (WAMDI group, 1988). This has allowed a comparison between three wave outputs and coastal buoy data. This allows evaluating sensitivities and implications for an operational wave forecasting system during wind-wave storms.

2. METHODS
2.1 Scientific Validation Period (SVP)

The paper focuses on the NW Mediterranean, particulary the catalan coast wind fields during the SVP, January 2003. This geographical area has very complex topography and bathymetry. We have used data from four coastal buoys belonging to the XIOM network (Figure 1). This has allowed to identify three storm wave events (defined in wave terms) along the catalan coast. Data come every 1 hour from the XIOM buoys and every 3 hours time from a deep-water wave buoy (1200m depth) and a shallow water buoy (35m depth) both belongs to Puertos del Estado. Only values of significant wave height have been analysed.
These events were not extremely energetic, although all of them were over the 1.50m Hs threshold in most of the buoys and happened in a very short period of time. Only eleven days of calm happened during this month.

After selecting the mentioned storm events we have analysed the underlying meteorological patterns. We have studied mean sea level pressure maps and 500hPa charts for all the SVP month. The synoptic meteorological evolution can be summarized by:

- **Storm 1 (N-NW storm):** From 5th to 8th Jan ‘03. An Atlantic low deepens over the Lion Gulf and travels fast up to the Adriatic sea which generates N-NW winds in the NW Mediterranean. The passage of a new front generates a mesoscale low in the W Mediterranean.

- **Storm 2 (N storm):** From 9th to 15th Jan ‘03. The low moves to Genoa Gulf and another low is generated in the Cadiz Gulf. This generates a strong pressure gradient with the high pressure area over the British Islands, which induces strong N winds over the NW Mediterranean. The low travels towards N Africa and the high pressure area gets down to the Iberian peninsula.

- **Storm 3 (N, NE, N-NE storm):** From 23rd to 31st Jan ‘03 (and going on during the first days of February). The high pressure area over the Atlantic becomes stronger and a deep low over the North Sea induces cold N fluxes over the west Mediterranean. Cold air feeds a Mediterranean low and it becomes deeper, generating strong NE winds in the Catalan coast. It is a very persistent situation. The low moves towards the E, the Atlantic high pressure area gains a more central position in the middle of the ocean and a deep low appears over Scandinavia. This situation allows progressively increasing velocity of N-NW winds over the W Mediterranean. At last, cold air develops a low in Genoa Gulf.
2.2 Meteorological models

Within the framework of the MFSTEP project the models to be used in the validation period are the ALADIN (Air Limitée Adaptation Dynamique developement InterNational) and the SKIRON model.

ALADIN is a limited area model that is nested within the greater scale ARPEGE model (Action de Recherche Petite Echelle Echelle). This corresponds to a numerical forecasting model of planetary scale developed by Météo-France since 1987 (Courtier et al., 1991), being operational since 1992. ALADIN project was started by Météo-France in 1990. It consisted in a collaboration with National Meteorological Services of Central and Eastern Europe concerning numerical weather prediction at high resolution with a Limited Area Model (LAM). ALADIN-LAM fields supplied by the MFSTEP project have been implemented as a collaboration between Météo-France and CHMI (Czech Hydro-meteorological Institute). The main characteristics of the model are a space resolution of 0.1° (9km) that covers all the Mediterranean Sea and a temporal resolution of 1 hour with a horizon of prediction of 120 hours, with 37 vertical levels.

The SKIRON model was developed at the University of Athens (Kallos et al., 1997). This model is used operationally in meteorological sciences, research institutes and private companies. The central component of the SKIRON system is the *Eta* limited-area weather forecasting model. The model's input data (geopotential, wind components, humidity, sea surface temperature, terrain topography, soil temperature and humidity) are acquired and prepared from data sets obtained by satellites, airports, meteorological stations, ship vessels and similar sources. The SKIRON system incorporates an advanced version of the Eta model, which can be executed with the finest horizontal resolution of about 1-20 km. 120 hour weather forecasting is provided daily from the Atmospheric Modelling group for educational and general use purposes. The SKIRON forecasting system is running daily. The model is initialised once per week with the boundary conditions from ARPEGE. It has a space resolution of 0.1° (9km) covering all the Mediterranean Sea, with 1hr time resolution, a horizon of prediction of up to 120 hours and 38 atmospheric levels. The model is initialised every 24 hours, but it does not give any analysed field.

In addition to these two models and in order to get a more comprehensive intercomparison we decided to use another meteorological model for the same scientific validation period. This is the MASS model (Kaplan et al., 1982) which is the one used routinely for operational predictions by the Meteorologic Service of Catalonia. The MASS (Mesoscale Atmospheric Simulation System) model was developed by NASA during the 80’s. Version MASS5 was adapted during the 90’s for western Europe, specially over the Iberian Peninsula by Barcelona University (UB) and the Meteorologic Service of Catalonia (SMC) (Codina et al., 1997). MASS is initialised twice every day, at 00h and 12h UTC using data from a Global Model (Schrodin and Link, 2001) from the German Meteorological Institute (Deutscher Wetterdienst) as boundary conditions. MASS has 6h time resolution. In this nesting part measured data are interpolated in order to generate the desired mesh. The resulting grid is combined with the output fields from global models in order to generate initial analysed fields. Then a simulation is
produced with a 55km grid centred over SW Europe, using 20 atmospheric levels and running until 36 hours. A nesting strategy is applied for the NW Mediterranean with a resolution of 30km. Input wind data for wave models have been interpolated into an 18km grid.

The basic characteristics of all models are summarized in Table 1.

<table>
<thead>
<tr>
<th>Model</th>
<th>Spatial Resolution</th>
<th>Time Resolution</th>
<th>Prediction Horizon</th>
<th>Analysed fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALADIN</td>
<td>0.1º</td>
<td>1h</td>
<td>120 h</td>
<td>+6 h / +24h</td>
</tr>
<tr>
<td>SKIRON</td>
<td>0.1º</td>
<td>1h</td>
<td>120 h</td>
<td>+24 h</td>
</tr>
<tr>
<td>MASS</td>
<td>30km (18km)</td>
<td>6 h</td>
<td>36 h</td>
<td>+12 h</td>
</tr>
</tbody>
</table>

2.5 Wave model

In order to analyse the effect of wind fields from different atmospheric codes when modelling wind waves we have used one wave generation model. It is the WAve Model (WAM-P, Monbailu et al., 2000), henceforth denoted WAM. This model is a widely known spectral wave models that solve the transport equation (WAMDI group, 1988; Komen et al., 1994) without any limitation on the wave energy spectral form. The main processes considered in this type of model are wind input, dissipation and non-linear wave interactions. The settings used are the standard ones, 25 frequencies and 12 directions. The lowest frequency was set to 0.041. Janssen (1991) formulation was used for the wind input term and JONSWAP spectra for initial conditions. However, the runs started sufficiently in advance of the storms to reach non parametric conditions before the events.

We have applied these models using the same geographical grid and covering latitudes 34ºN to 45º N and longitudes 5ºW to 18ºE and with the same spatial and time resolution for each input wind velocity (U10m) field. The WAM model is currently operational at the SMC (Servei Meteorologic de Catalunya – Meteorological Service of Catalonia) running twice daily with a forecasting horizon of 36 hours.

2.6 Buoy data

The buoys belong to the XIOM and Puertos del Estado and are used for operational wave measurements along the Catalan coast. They are moored at depths ranging from 45 to 74 m, except the Begur buoy that is moored in a depth about 1200m. Tortosa and Begur buoys are directional waveriders.

2.7 Methodology for wave model assessment

We have limited our study to the comparison of WAM results using the different wind fields. Furthermore, this comparison has been made in the points where we have buoy data. Sensitivity of WAM to wind fields has been obtained using two common statistic parameters BIAS and RMSE for each storm event and considering only the significant wave height as working variable.
3. RESULTS
3.2. Wave fields

Figure 2 shows the errors (BIAS and RMSE) for significant wave height at each buoy position.

As it is explained in previous references (Cavaleri, L. and Bertotti, L., 2004) in most positions during storm 1 there is an understimation of the model versus data buoy, shown by the BIAS. On the other hand, it is amazing to find that for storms 2 and 3 for most of the models and positions there is an overestimation, specially using ALADIN. During these two storms, only in Begur and Tortosa, there is a clear understimation. The largest BIAS are obtained using SKIRON and ALADIN in Begur during the storm 1, SKIRON in Begur and Tortosa during storm 3. The smallest ones are for the three models in Tarragona during Storm 2, for ALADIN and SKIRON in Blanes during Storm 2, ALADIN in Begur during Storm 2 and SKIRON in Blanes during Storm 3.

Fig. 2. BIAS and RMSE obtained by all models at the buoy positions
RMSE shows that the maximum error is around 1m, obtained for SKIRON and ALADIN during Storm 1 in Begur and MASS also in Begur during Storm 3. On the other hand, the minimum error is similar for all three models and its value is about 0.1m. However, in general the RMSE for each model relative to each position is around 0.5m.

In most of the storms the lowest error (RMSE) values for all the models used correspond to Blanes, Llobregat and Tarragona. Buoys are all located at central positions in the Catalan Coast. They are, thus, more removed from the Pyrenees shadow and from the Ebre river valley channelling. This means that wind fields at the central Catalan coast should be more homogenous and with less sharp gradients. This could explain the lower RMSE that is obtained.

The performance of WAM using the different meteorological models can be also inferred from figures 3 and 4. All a long Storm 1 the model underestimates buoy data using all three wind models in all the buoy positions. It is surprising how ALADIN and SKIRON have almost the same evolution. During the other two storms there is an alternance of underestimation and overestimation periods. SKIRON always seems to have lower values in comparison to other models. On the other hand, the highest values change from MASS to ALADIN depending on the bouy and storm, even with time within the same storm. However, it is possible to say that MASS shows larger differences with buoy data. It is noticiable the performance of ALADIN winds in the Begur buoy during Storm 3.

![Fig. 3. Values obtained in the Begur buoy during the stormy events.](image-url)
4. DISCUSSION

Two high resolution wind model (ALADIN and SKIRON) have been run with WAM to generate the corresponding wave fields. However they do not produce very closely the observed results, excepting one storm for which they are identical. The third code (MASS), which has a lower resolution, has a different performance from the other two, as it was expected. However, its behaviour is not clearly worst in spite of its limited resolution. Thus the combination of the three meteorological models with the WAM wave model produces in overall terms similar results.

When different wind fields are applied in the same wave model we obtain very close results for all three models using common statistic errors. However, studying their evolution in comparison to buoy data during these storms it is possible to say that the “best” combination is obtained using ALADIN+WAM. It is this combination that has the lowest RMSE and BIAS for the whole SVP. As it has been said, the other two models show also a good performance but at a slightly lower level. However, SKIRON+WAM gives the lowest results almost always. And MASS+WAM presents an overall irregular performance. That means that it has large overstimations and understimations and good agreement depending on space/time intervals and position.

The obtained statistical values do not differ significantly from the ones obtained for MASS in operational predictions in comparison to XIOM buoys. These values are obtained daily for all buoy positions since year 2000. Their values are RMSE of about 0.4 – 0.5m and BIAS around -0.5m in mean conditions and about 1m in stormy conditions.
5. SUMMARY AND CONCLUSIONS

The three meteorological models used in spite of their spatial/time resolution have produced very close results when they are applied to feed the WAM wave model. Of course, the highest resolution codes show a better performance following the buoy data tendencies. On the other hand, a more objective analysis using statistical values shows that errors with comparable magnitude are produced by all three codes.

However, it is possible to say that ALADIN produces the “best” results. This is due to its high spatial resolution and its capability to reproduce more accurately high velocity areas. In the same way, SKIRON that shows lower wind speeds also gives in combination with WAM the lower significant wave heights. Moreover, these two high resolution models follow better than MASS the buoy data tendencies.

It is important to emphasize that all combinations tend to underestimate the significant wave height for different buoys. However, ALADIN tends to be an overestimator. It has been thus seen that high resolution models do not necessarily have a better performance than a lower resolution one.

On going work includes applying a more comprehensive statistical methodology to a larger data set. This could include an index of performance, like BSS, all over the domain that will also allow the intercomparison with satellite images. It will produce directly a ranking of performance between the models used in respect to a baseline prediction or a reanalysis field.

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