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Hindcast and forecast of the Parsifal storm

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Summary. — On 2 November 1995 a Mistral storm in the Gulf of Lions sank the 16 metre yacht Parsifal claiming six lives out of the nine member crew. We analyse the storm with different meteorological and wave models, verifying the results against the available buoy and satellite measurements. Then we consider the accuracy of the storm forecasts and the information available the days before the accident. The limitations related to the resolution of the meteorological models are explored by hindcasting the storm also with the winds produced by some limited area models. Finally, we discuss the present situation of wind and wave hindcast and forecast in the Mediterranean Sea, and the distribution of these results to the public.

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PACS 92.60.Qx – Storms.
PACS 92.10.Hm – Surface waves, tides, and sea level.

1. – Introduction

On 2 November 1995, around 21 UTC, the Italian 16 metre yacht Parsifal sank between the Balearic Islands and Sardinia, in the Western Mediterranean Sea, during the preliminary phases of a transatlantic sailing race. Six of the nine crew members lost their life in the accident. The event stirred excited comments by the press and also in the specialized magazines. Exceptionally high wind and wave conditions were repeatedly quoted as the main reasons for the accident.

To properly reply to the various questions asked soon after the accident, we have done a detailed analysis of this "Parsifal storm", considering its hindcast with different meteorological and wave models. We have also analysed the forecast of wind and wave conditions available in the previous days, substantiating the results with a comparison against the available observations.

The paper is organized as follows. After describing the overall meteorological situation (sect. **2**), in sect. **3** we report the available measurements. In sect. **4** we list and briefly describe the meteorological and wave models used for this study. Sections **5** and **6** are devoted to the comparison of model results with measured data and to the estimate of the wave conditions at the location and time of the accident. In sect. **7** we discuss the forecast available in the previous days. The limitations related to the resolution of the meteorological models are analysed in sect. **8**. The overall findings, the likely reasons for the discrepancies and the routine distribution of the wave forecast to the public are discussed in the final section **9**.

2. – The meteorological situation

The general meteorological situation at 18 UTC 2 November 1995 is shown in the weather chart of fig. 1. A southward moving cold front is associated to a depression located on the Western Mediterranean Sea, with an intense northerly flow of cold air. Note that the field has been substantially smoothed with respect to the real one, particularly in the region of pronounced orography of the Alps. Note also that the synoptic configuration suggests that the cyclone is the result of a typical orographic lee cyclogenesis over the Western Mediterranean. The situation leads to a typical Mistral storm with strong northerly winds in the Gulf of Lions and in the area between the Balearic Islands and Sardinia. The still warm sea surface water and the cold air lead to highly unstable and turbulent air conditions, with a very active wave generation.

In order to hindcast this storm, we have considered two different meteorological sources, namely the European Centre for Medium-Range Weather Forecasts, Reading, UK (henceforth referred to as ECMWF), and the UK Meteorological Office, Bracknell, UK (referred to as UKMO). Note that for ECMWF we refer here to analysis fields,

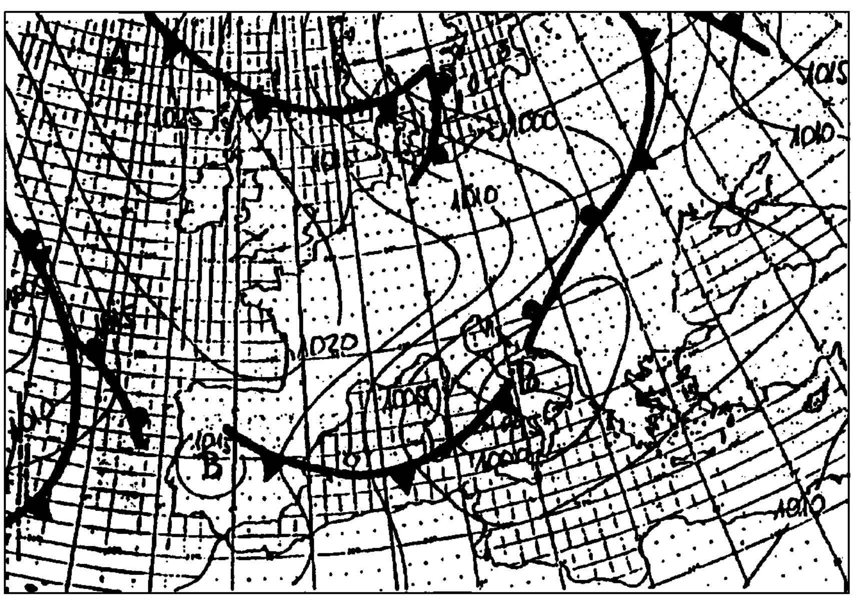

Fig. 1. – The meteorological situation at 18 UTC 2 November 1995. Isobars at 5 mbar intervals.

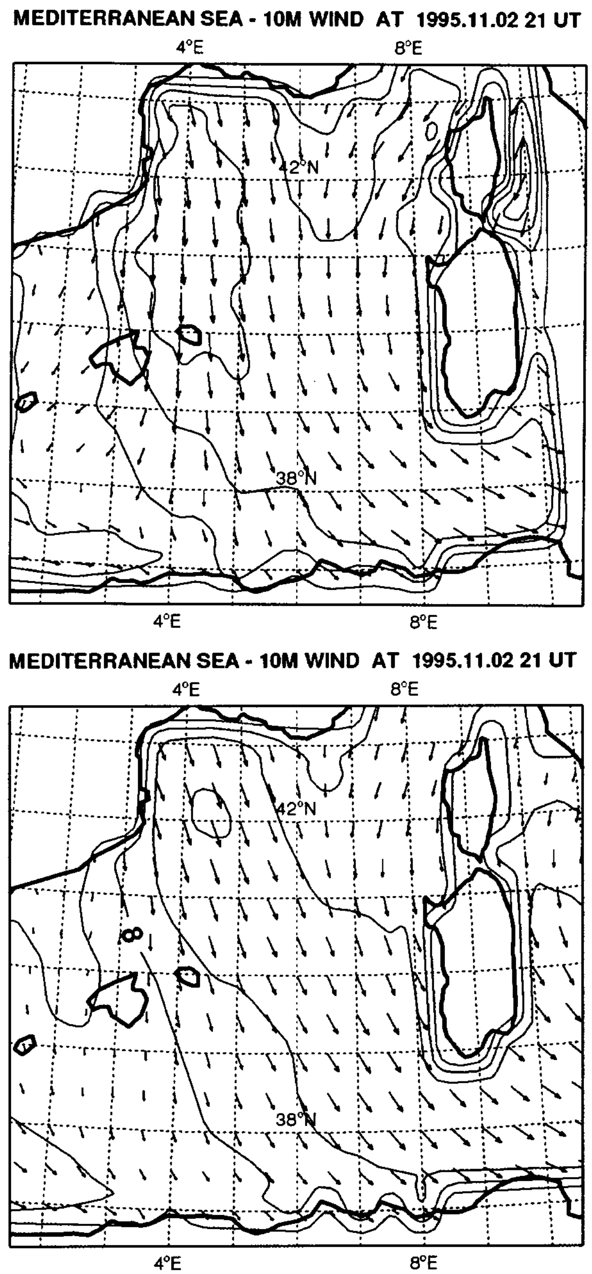

Fig. 2. – The wind field over the Western Mediterranean Sea at 21 UTC 2 November 1995, according to the UKMO-LAM (top) and ECMWF (bottom) analysis. Isolines at 4 m/s intervals.

available at six hour interval (00, 06, 12, 18 UTC), while for UKMO we have made use of short term (1 to 12 hours) LAM forecasts, available at one hour interval, starting from the global analysis of 00 and 12 UTC. As such, the different analyses, particularly over the sea where very few or no observations are available, are largely model dependent via the assimilation cycle.

The two wind fields, corresponding to 21 UTC 2 November 1995, are shown in fig. 2. The ECMWF field has been obtained as linear time interpolation between the previous (18 UTC 2 Nov.) and the following (00 UTC 3 Nov.) available fields. With respect to the standard northwesterly Mistral storms we find here a more intense North-South component, aiming directly at the Balearic Islands.

Because of the main reason for this study, we have focused our attention mainly on the situation of 2 and 3 November. However, only two days later a similar, but more intense storm hit the area. The associated front is visible in fig. 1, located on the Northeastern Atlantic Ocean and the North Sea.

3. – Available measured data

The locations where measurements are available are indicated in fig. 3. Three wave-measuring buoys are located at Alghero (A), Mahon (M) and Cap de Pera (C). The buoy at A is part of the Italian network ("RON") managed by the Servizio Idrografico e Mareografico Nazionale (SIMN). The buoys at M and C are run by Clima Marítimo, Puertos del Estado of Spain. Table I provides the geographical coordinates of each location and the local depth.

The buoys are of the directional type, providing an estimate of the 2D and 1D spectra, and, among others, the integral parameters significant wave height H_s, peak and mean period T_p, T_m and mean direction θ_m. Because in the area of interest the conditions were purely generative, with no relevant coastal effects, as is evident from the data, the spectral shape is similar to a classical JONSWAP (Hasselmann *et al.*, 1973). We have focused our attention on the quantification of the event, namely on H_s, and, at a lower level, on T_p or T_m and θ_m. These data are available at three hour intervals, at synoptic times (00, 03, 06, ... UTC).

The buoy at M would have been the most interesting one, being located along the main line of the storm and being the closest one to the location of sinking. Besides, it is equipped also with an anemometer. Unluckily, it stopped functioning in the early phase of the storm. However, its data show well the rapid growth of the wind speed U up to 18 m/s and of the significant wave height up to 4.76 m.

A second source of data is provided by the Topex altimeter of the T/P satellite. Its ground track, where measurements are available, at 4.55 UTC 3 November 1995 during

TABLE I. – *Geographical coordinates and depth of the locations shown in fig.* 3.

Location	Symbol	Lat. N	Long. E	Depth (m)
Parsifal	P	40.39	5.20	∼2500
Alghero	A	40.32	8.06	∼100
Mahon	M	39.43	4.26	∼300
Cap de Pera	C	39.39	3.28	48

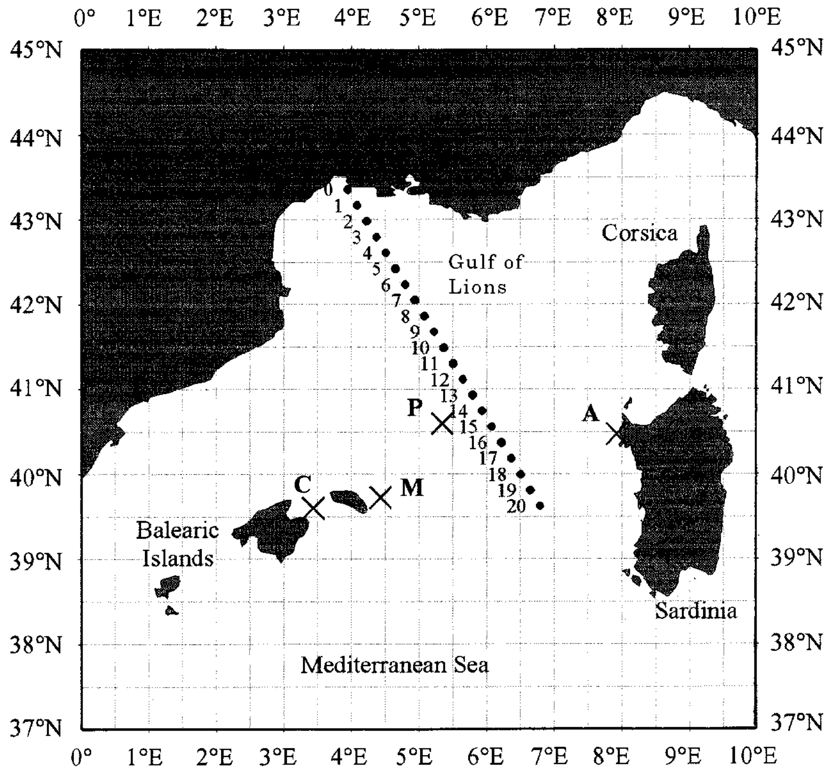

Fig. 3. – Location of available data. Wave measuring buoys at Alghero (A), Mahon (M) and Cap de Pera (C). The T/P satellite, providing estimates of wind speed and wave height, passed along the marked surface track at 4.55 UTC 3 November 1995. P marks the position where the Parsifal yacht sank.

a descending phase orbit, is shown in fig. 3. Starting at a few tens of kilometers off the coast, wind speed and H_s estimates are provided at about 7 km (*i.e.* 1 s) intervals.

4. – Meteorological and wave modelling

Overall wind fields in the Mediterranean area are available from global meteorological models, among these ECMWF and UKMO. ECMWF (see Simmons, 1991) runs a spectral model with a practical resolution of 90 km. UKMO (see Cullen, 1991) runs a grid model with a resolution of about 90 km at 40 degree latitude. In addition, UKMO runs a limited area model (LAM), covering also the whole Mediterranean Sea, with about 45 km resolution. The two fields in fig. 2 represent the results of UKMO-LAM and ECMWF, respectively.

These wind fields are used as input to the wave models. These are typically characterized as 1st, 2nd and 3rd generation models, according to the level of sophistication with which they describe the processes involved in the evolution of the wave field, in particular the nonlinear wave-wave interactions. We have considered the results of three different wave models, with different meteo-wave combinations. UKMO uses a 2nd generation wave model, EWM, described by Golding (1983). WAM is amply described in the liter-

TABLE II. – *Combination between meteorological and wave models considered for this study.*

Wave model	Meteorological model	
	ECMWF	UKMO-LAM
EWM		⋆
WAM	⋆	⋆
HYDRUS		⋆

ature (see the two classical references WAMDI, 1988 and Komen *et al.*, 1994, the latter henceforth referred to as K), and it is in regular use at most major meteorological and oceanographic centres. It is a 3rd generation model. HYDRUS is a recent 2nd generation model described by Magnaldi and Ferrauto (1996).

All these models are spectral, *i.e.* they analyse the evolution in time and space of each single component (frequency and direction) of the wave spectrum. All the relevant physical processes of wave generation-dissipation-advection are considered, the differences depending mainly on the sophistication with which the nonlinear terms are dealt with in

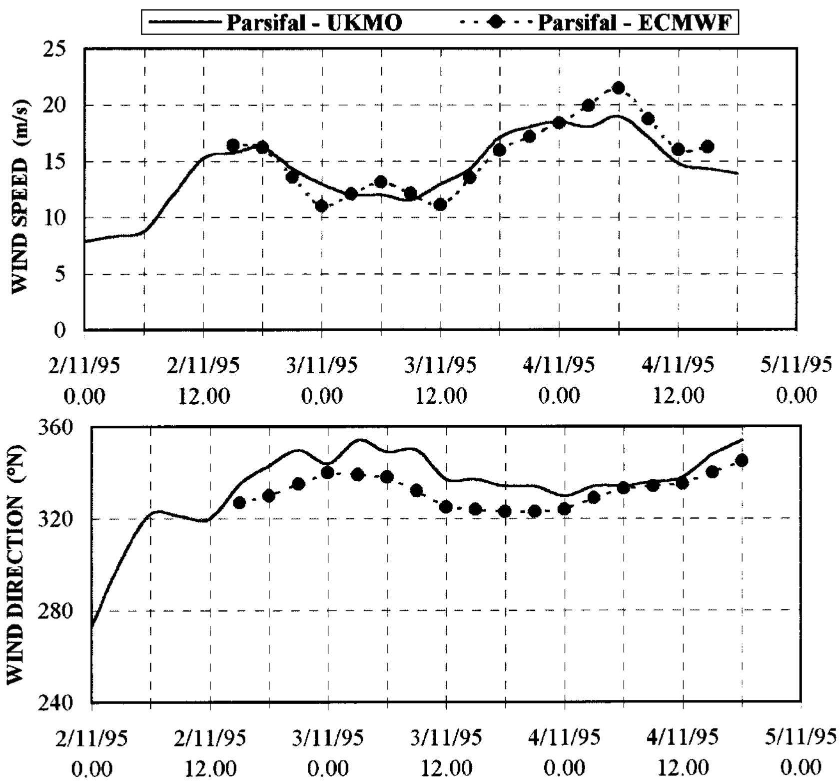

Fig. 4. – Time series of wind speed and direction at Parsifal location (see fig. 3) according to the UKMO-LAM and ECMWF analysis.

the numerical solution of the basic energy equation. For the interested reader, the basic reference is K, which provides exhaustive discussion of all the aspects of wave modelling and related results.

In practice, the average quality is good enough for all the three models, substantial differences appearing mainly in complicated situations. More in general, as discussed extensively in K, advanced 3rd generation wave models are presently more accurate than meteorological models. The quality of the wave results depends basically on that of the input wind fields. This is particularly true in simple situations, such as the Parsifal storm, with a well defined wind field blowing off the coast. In this simple classical case all the wave models are expected to reach similar results, their quality depending essentially on that of the wind.

Table II provides the different combinations of meteo-wave models used during the tests. Besides, using the ECMWF wind, WAM was run with both 0.5 and 0.25 degree resolution. However, because of the simplicity of the case and the geometry of the storm, no substantial difference was found. This argument will not be further discussed.

The wind field at 21 UTC 2 November 1995 is shown in fig. 2, for UKMO-LAM and ECMWF, respectively. As expected, the two overall structures are similar, with a mentioned incoming northerly flow of cold air. However, differences are visible. The ECMWF field has an easterly flow component, while the UKMO-LAM one is fully directed North to South. So (see fig. 3) ECMWF places Parsifal at the heart of the flow, while the boat position is slightly aside in the other case. This more or less compensates for the higher wind speeds in the UKMO-LAM field, where the area with $U > 16$ m/s is much larger than for ECMWF. As a result, the two models indicate a similar evolution of the wind

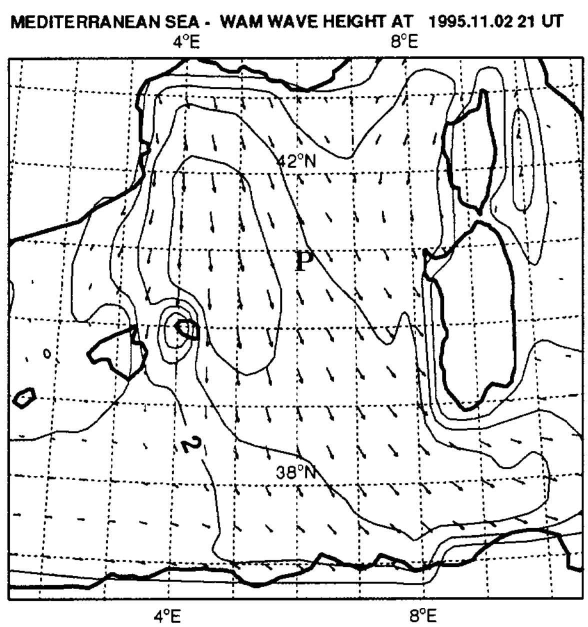

Fig. 5. – Wave field at 21 UTC 2 November 1995. UKMO-LAM/WAM combination. The vectors, with length proportional to the local wave height, indicate the mean wave direction. Isolines of wave height at 1 m intervals. P indicates the position where the Parsifal sank.

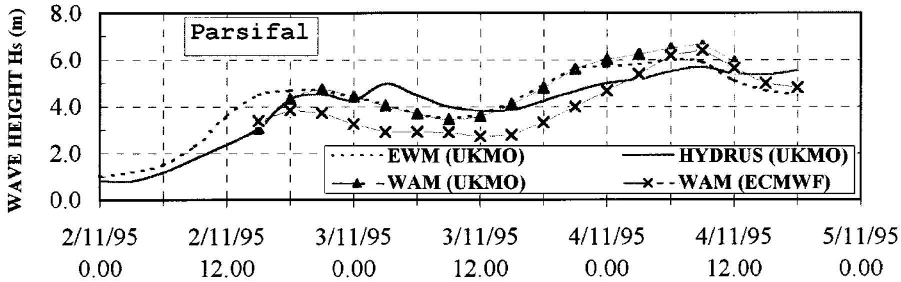

Fig. 6. – Time series of the significant wave height H_s at position P (see fig. 5), according to the different combinations of meteo-wave models.

conditions at the Parsifal location, as shown in fig. 4. However, since waves are an integrated effect, in space and time, of the driving wind fields, differences do appear in the estimated wave conditions.

The wave field at 21 UTC 2 November 1995, for the UKMO-LAM/WAM combination, is shown in fig. 5. The structure reflects that of the wind field in fig. 2 (top). The isolines, at 1 m intervals, show a progressive increase of wave height moving off the French/Spanish coast. Significant wave heights around 4 m are shown at the Parsifal position P.

The differences between the output of the various meteorological and wave models are given in fig. 6, showing the time series of H_s at P. We consider first the two runs of WAM with UKMO-LAM and ECMWF wind. There is a steady underestimate of ECMWF with respect to UKMO-LAM, except at the end of the period (when the second storm peak occurred), corresponding to lower wind speeds of the former with respect to the latter. This is a classical point. As amply discussed in K, a better spatial resolution of the meteorological models leads generally, particularly in enclosed basins, to an enhancement of the surface wind fields, more evident in the area of strong gradients, *i.e.* higher wind speeds, and, consequently, higher waves.

As regards the use of different wave models with the same UKMO-LAM wind, the three models show basically the same evolution, with a satisfactory performance also of the 2nd generation models. In particular, they show the same peak value in the night between 2 and 3 November. The limited differences reflect the different formulations of the physics and numerics in the models. While this is itself an interesting point, it is out of the scope of the paper, and will not be further pursued here.

5. – Comparison with measured data

The comparison of the model wind data with the few available measurements confirms the general considerations done in the previous section. The high wind speeds recorded at Mahon (up to 18.5 m/s at the time of the accident, see fig. 3 for its location and table III for the data) are well reproduced by UKMO (16.5 m/s), but largely underestimated by ECMWF (12.0 m/s), which converges the main flow towards the centre of the basin. Similarly to the data at the Parsifal position shown in fig. 4, both the meteorological models show more or less the same speed (12-14 m/s) along the ground track of T/P (at 04.55 UTC of 3 November, see fig. 3), with only a minor underestimate with respect to the altimeter measurements (13-16 m/s). About direction, the differences between model and measured data are limited to about 20 degrees at most. However, the proximity of Minorca Island,

TABLE III. – *Comparison between measured and model wind data at Mahon (see fig. 3 for its position).*

Time	Wind speed (m/s)			Wind direction (degrees)		
2/11/95	Mahon	UKMO	ECMWF	Mahon	UKMO	ECMWF
15 UTC	13.0	12.0	9.0	329	347	336
18 UTC	14.5	14.0	10.5	330	353	338
21 UTC	18.5	16.5	12.0	331	352	340

not well represented in the meteorological models, impedes any conclusive consideration.

As regards the wave height, we consider first the buoy data, in particular those at A and C (in fig. 3). Again, the time series available at M, however informative, is too short for any substantial consideration about the evolution of the sea storm.

The time series of modelled and measured H_s are shown in fig. 7. As expected, the differences consequent upon the use of different meteorological or wave models are similar to those already shown for the Parsifal location, with a more pronounced underestimate of ECMWF at Cap de Pera, as a consequence of the geometry of the wind field (see fig. 2).

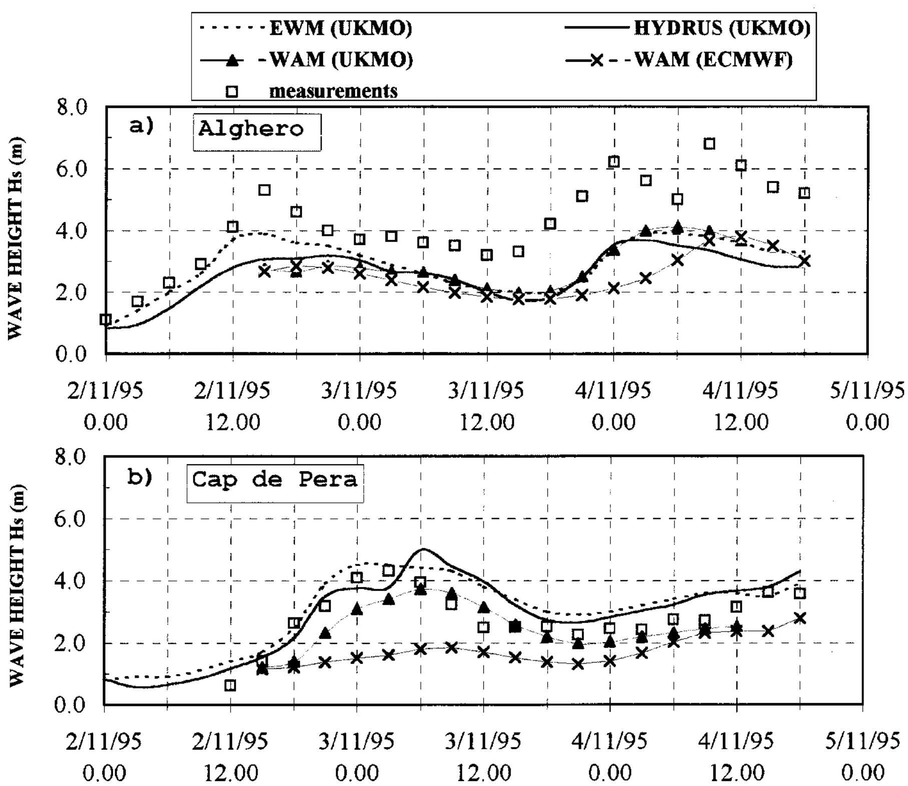

Fig. 7. – Comparison of modelled and measured wave height at a) Alghero and b) Cap de Pera.

The obvious fact of interest is the drastic underestimate of H_s at Alghero, where the model results are consistently lower than the measurements by a percentage between 20 and 40% for the whole period. Note that the eventual poor resolution of the coastline in the models does not affect the results at this location, because the waves move towards the coast and the measurements are done well off the coast, where also the reflection of energy is kept to a minimum. Following the simple geometry of the storm (an offshore blowing wind) and the basic rules of wave generation by wind (Hasselmann *et al.*, 1973), a lower, but similar, underestimate is found also for the wave period. The direction in the wave model results reflects plainly that of the input wind fields.

These results are not surprising. Pontes *et al.* (1996), during an extensive study of the wave conditions along the European coasts, have analysed extensive data sets of modelled and measured wave data. In particular, the analysis of three years of data at Alghero has shown an average underestimate of H_s by the models of about 30%. A more extensive discussion is given in the final section, but the key point is the lack of strength of the wind fields. What is particularly disappointing is the poor performance also of the high resolution UKMO-LAM meteorological model, that does not show here any substantial advantage with respect to the coarser ECMWF model. A possible explanation is again the geometry of the wind field that in the case of UKMO-LAM (see fig. 2) shows a well defined North to South structure, with limited wind speeds and fetch at the Alghero position. This hypothesis is supported by the locally measured wave direction, about 30 degrees counterclockwise with respect to the wind. Because in purely generative conditions, as this is the case, waves move on the average in the wind direction, this is a strong indication of the error in the wind model results.

The comparison is more positive at Cap de Pera, where the use of the UKMO wind leads to good results with all three wave models. Note how, following the previous description of the ECMWF wind in sect. **4**, we find here a drastic underestimate on the most westerly side of the storm. The underestimate is more pronounced for H_s than for the wave period (not shown), because of the energy radiating out of the main line of action of the storm.

A convincing argument about the underestimate of wind speed by the meteorological models is given in fig. 8, where we compare the output from the HYDRUS wave model

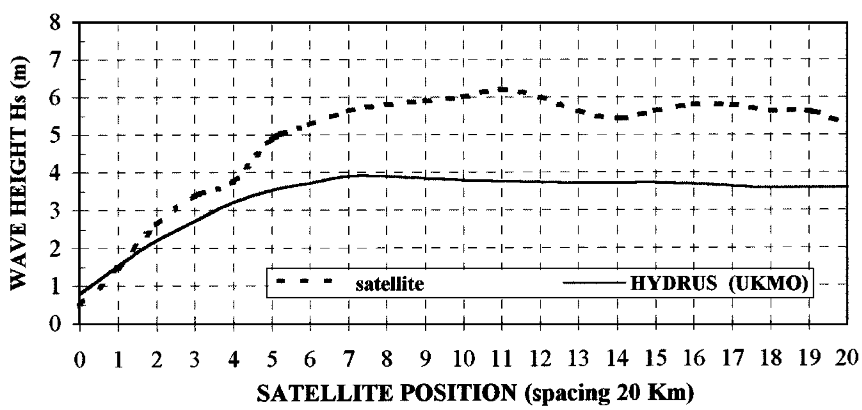

Fig. 8. – Comparison between the significant wave height from the HYDRUS model and the measurements by the Topex altimeter, along the line shown in fig. 3.

vs. the Topex measurements of H_s along the line shown in fig. 3. As mentioned in the previous section, a properly formulated wave model, as is the case for the three ones here considered, can hardly be wrong in such a simple situation. The drastic average underestimate of H_s by about 30% (4 instead of 6 m) must be basically attributed to a low wind input, *i.e.* to low wind speeds. The accuracy of the altimeter measurements, believed to underestimate the wave height by a few percents (Cotton, personal communication) is not essential for the present arguments. An evaluation of the wind underestimate is achieved considering that H_s depends linearly on U on fetch limited conditions, just off the coast. It approaches a square dependence with mature sea (after about point 10 in fig. 3). The overall suggests an underestimate of the wind speed between 15 and 20%.

6. – Situation at Parsifal position

The model results have been shown in fig. 6. Using the wind by UKMO-LAM, basically all the wave models agree on a value between 4.6 and 4.8 m for H_s at the time of the accident. However, the data from the buoys and the satellite suggest that the actual conditions were more severe. This conclusion is consistent with the previous extensive statistics (Pontes *et al.*, 1996). Considering a 30% underestimate of the significant wave height, a value coherent with all the available information, we estimate that H_s between 6.5 and 7 m were present in the area of Parsifal in the late evening of 2 November 1995.

To judge if these are exceptional values, it is worthwhile to remember that on 4 November, only two days later, during the following storm mentioned in sect. **2**, the wave heights were measured and estimated at values more than 20% higher than during the "Parsifal storm".

7. – Forecast

Of course, it is of interest to check also the forecast available in the days before the accident.

ECMWF produces daily the meteorological, hence also surface wind, forecast for the next ten days. All the results shown till now have been obtained using analysis fields, *i.e.* with the estimate obtained *a posteriori*, on the basis of all the available model and measured data. The UKMO-LAM results represent short term (11 hours at most) forecasts starting from the global analysis. This gives in principle the best possible estimate, but it does not say anything about the forecast for that time. To check this, we have considered the sequence of wind fields produced, for each day, the day before. In practice, we use the so-called 1-d forecast wind fields to drive the WAM model. This provides evidence of the expectation of the various events regularly produced 24 hours in advance (this is not strictly correct, but it provides a simple description of the procedure). A similar exercise with the UKMO-LAM was not possible as UKMO does not archive the LAM forecast.

The results are given in fig. 9, where we compare the results from the analysis and the 1-d forecast. We have repeated the procedure for the 2-d and 3-d forecasts, *i.e.* for the expectations produced 48 and 72 hours in advance. Also these results are shown in fig. 9, for H_s, T_m, θ_m and also for wind speed and direction. We see clearly that, at least for the forecast of the Parsifal storm (2-3 November), the 1-d and 2-d forecasts are very close to the analysis, *i.e.* the storm was expected since 31 October, two days in advance. The quality of the forecast deteriorates the third day in advance. The results are worse for the second storm (4 November) where the three forecasts (at 1, 2, 3 days) consistently show

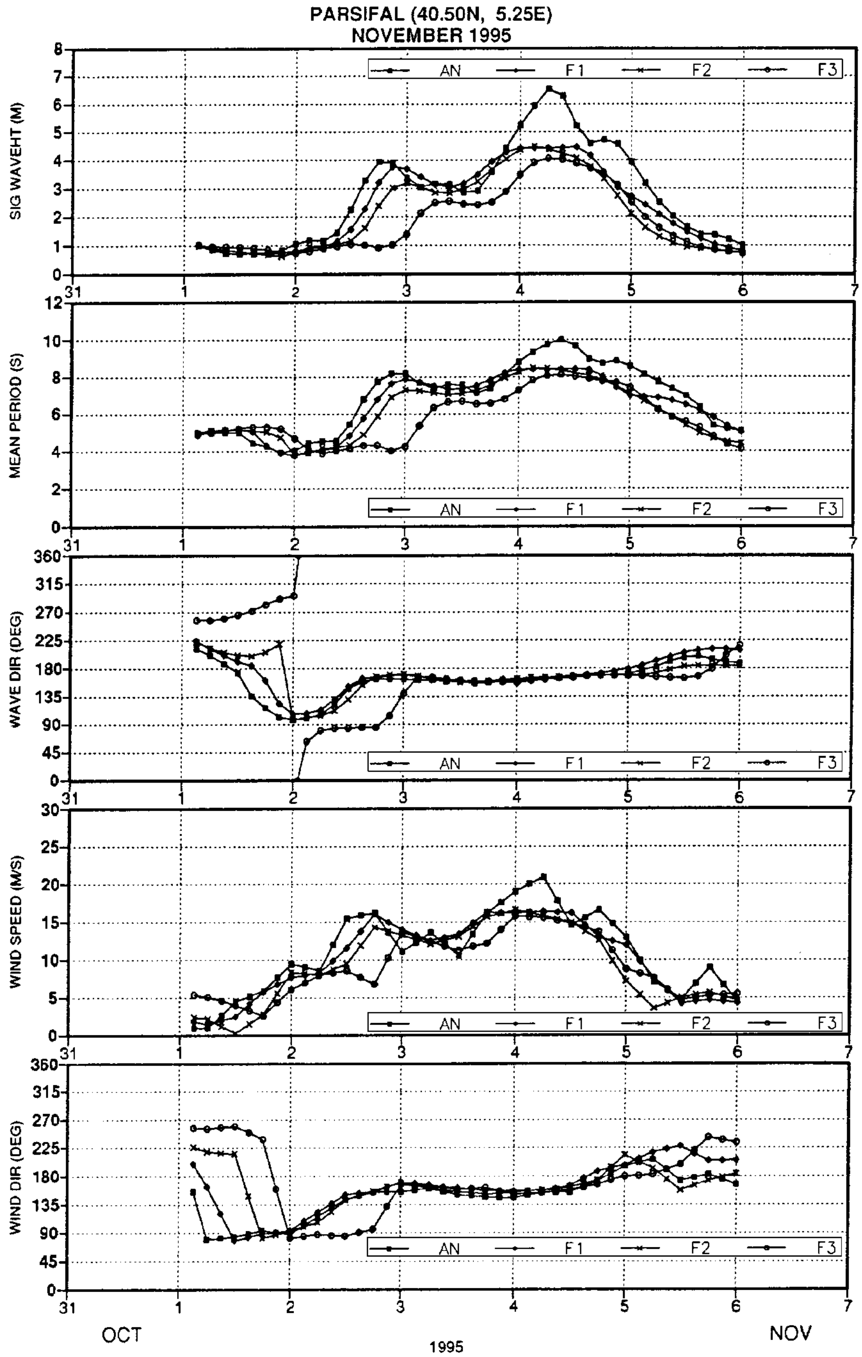

Fig. 9. – Comparison between the wind and wave data at the Parsifal position as derived from the ECMWF analysis and 1-d, 2-d, 3-d forecasts.

a lower H_s with respect to the analysis. Note for the first storm the adherence of the 1-d and 2-d forecast to the analysis, both for the wave characteristics as for the wind (speed and direction).

8. – Limited area models

We have seen a substantial underestimate of the strength of the storm in both the ECMWF and UKMO model results. Following a suggestion by the referee, we have repeated the hindcast of the Parsifal storm using the surface wind out of some limited area models. The aim was to verify if an increased resolution in the input fields would improve the quality of the results; more precisely, if it would lead to higher wind speeds in the Mistral area. The following models have been considered:

Mefisto	(ENEL-CRAM, Milan, Italy)	resolution $\simeq$ 39 km,
Mefisto (modified version)	(ENEL-CRAM, Milan, Italy)	resolution $\simeq$ 39 km,
LAMBO (father)	(SMR-ER, Bologna, Italy)	resolution 0.25 degree,
LAMBO (son-nested)	(SMR-ER, Bologna, Italy)	resolution 0.125 degree,
DALAM	(UCEA, Rome, Italy)	resolution $\simeq$ 30 km.

Note that, similarly to UKMO-LAM (see sect. **2**), these LAMs produce short term forecasts, all starting as initial conditions from the ECMWF analysis at different times.

The overall results for the significant wave height H_s at Alghero, where measurements are available, and at the Parsifal position (see fig. 3 for their location) are shown in figs. 10 and 11, respectively. The results are quite disappointing, because there is no consistent indication that increasing the meteorological resolution leads in any way to a clear improvement. We avoid purposely any discussion on the details of the single hindcasts. The main message is that the model results are grouped together, well below the measured data shown in fig. 10.

Another enlightening comparison is obtained, similarly to what done in fig. 8 for the HYDRUS wave model, *slicing* the wave height distributions of 06 UTC 3 November 1995 along the satellite track marked in fig. 3, and comparing with the estimated altimeter wave height. The one hour difference in time (the satellite passed at 04.55 UTC) is not relevant for the present purposes. The result is given in fig. 12, and it shows again the substantial underestimate of the wave, hence wind, model fields with respect to the actual truth.

9. – Discussion

We summarize here the results and we discuss their different aspects. Since the considered period is too short for any definite conclusion, we purposely avoid discussing the limited differences between the three wave models, and we focus our attention on the storm.

Hindcast

The hindcast has begun using the wind from two different meteorological models as input to three different wave models.

Using the same wind source, the three wave models produce similar results, indicating that the key point in the analysis of the storm is the quality of the wind fields. This is particularly true in this case because of the simple meteorological situation, with a rather uniform unidirectional wind blowing off the coast towards the target point.

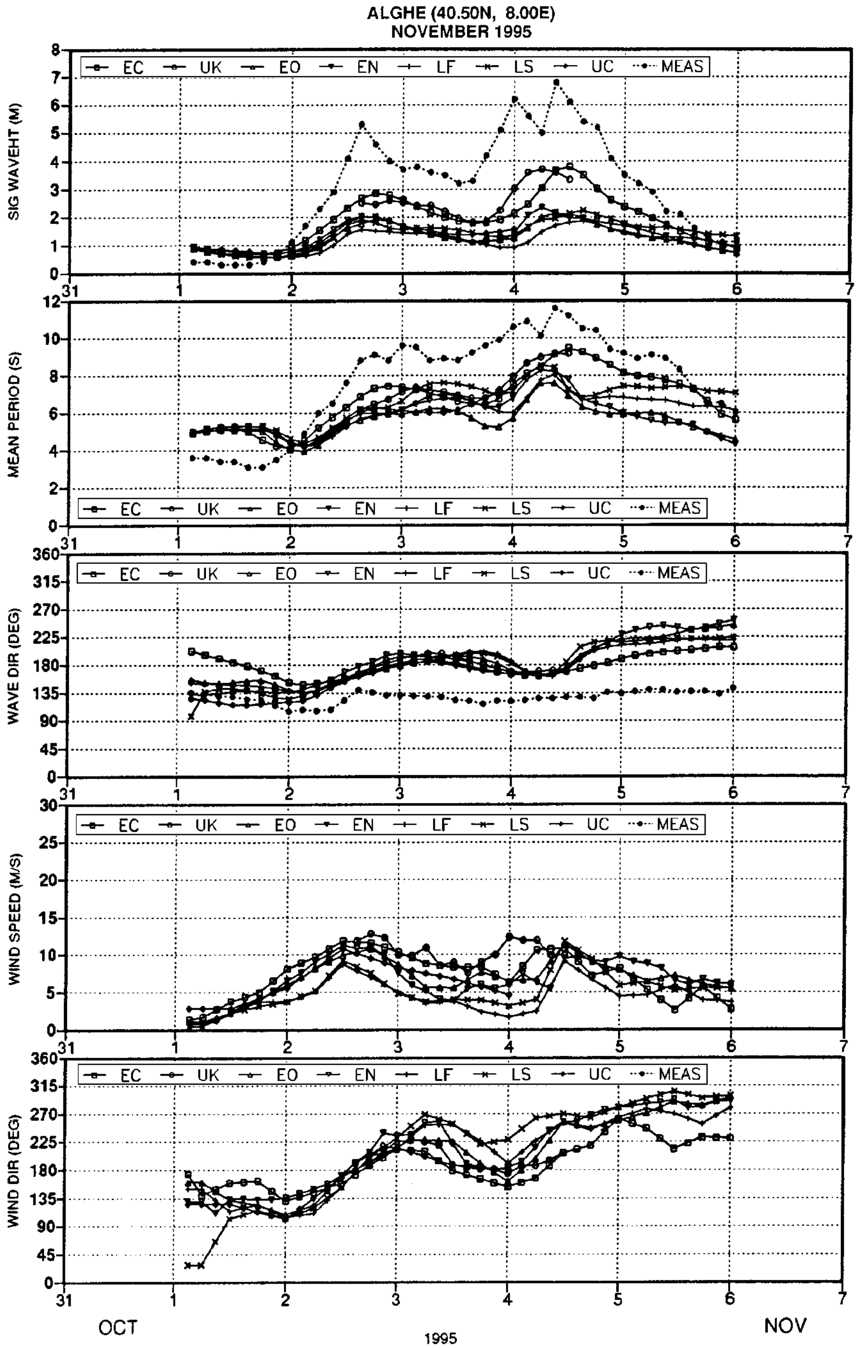

Fig. 10. – Comparison at the Alghero position (see fig. 3 for its location) between the measured wave height and the corresponding results using the wind from different meteorological models. EC = ECMWF, UK = UKMO (see main text), EO = ENEL Mefisto, EN = ENEL modified Mefisto, LF = LAMBO father, LS = LAMBO son, UC = UCEA, MEAS = measured data.

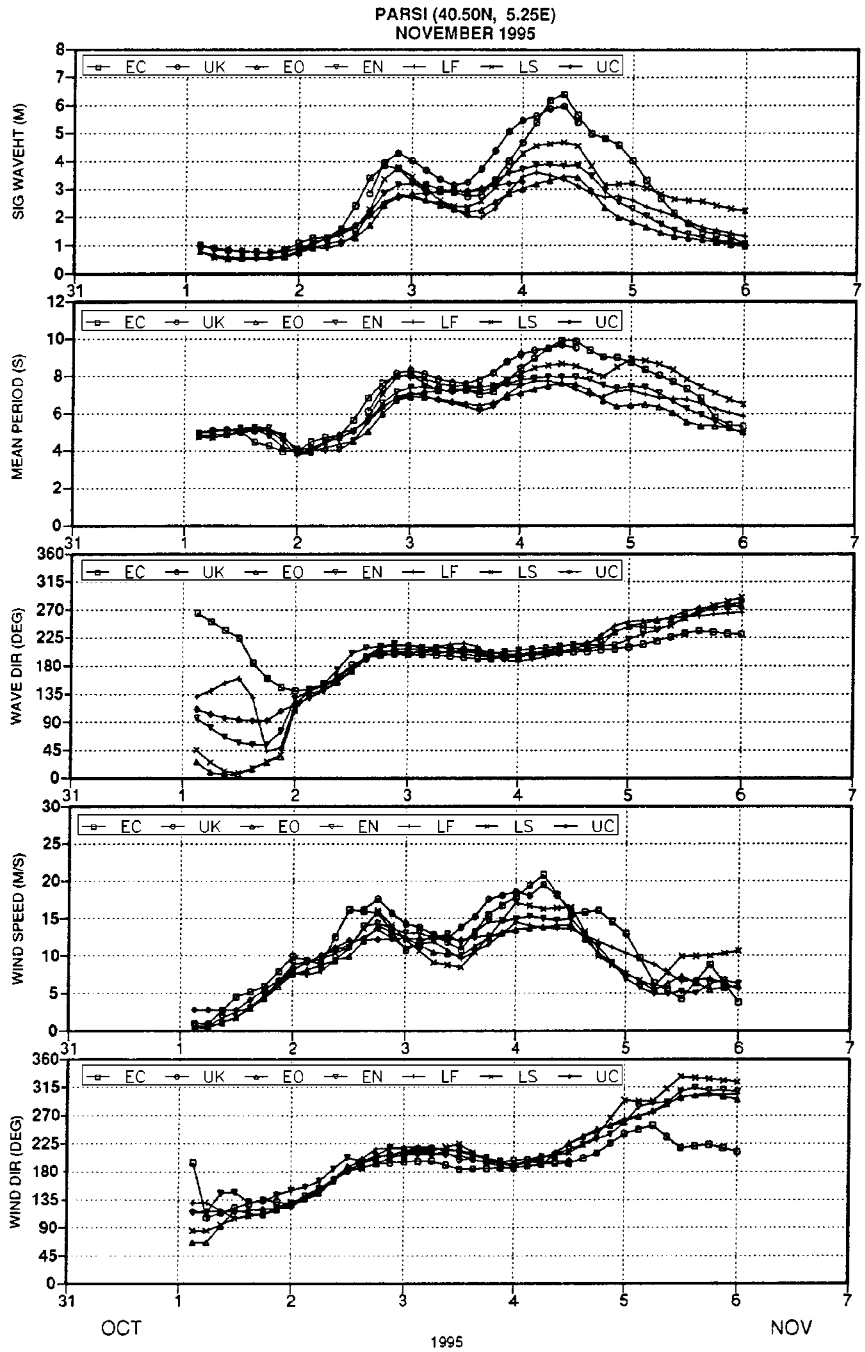

Fig. 11. – As fig. 10, but for the Parsifal position, where no measurements are available.

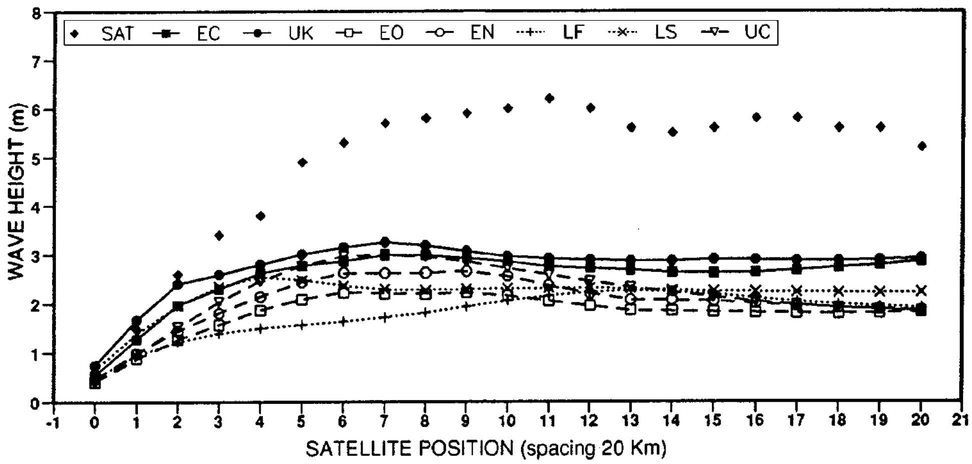

Fig. 12. – Comparison between the significant wave height, obtained using the WAM wave model with winds from different meteorological models, and the measurements with the Topex altimeter, along the line shown in fig. 3. See caption to fig. 10 for model acronyms.

The various hindcasts show a significant wave height lower by about 30% with respect to the data derived from buoy and the Topex altimeter. Then the wave generation laws suggest an underestimate of 15-20% for the mean wind speed produced by the meteorological model. However, a second factor should be considered. Cavaleri and Burgers (1992) have analysed the effect of air turbulence on the process of wave generation. The result is an enhanced wave growth, with both a more rapid growth in the initial stage and higher final wave heights. A 20-30% variance of the wind speed leads to an increase of H_s of about 15-30%, respectively. In the considered period, with cold air blowing above the still warm water of the Mediterranean Sea, the air-sea conditions were highly unstable with an intense turbulence. The problem is that the meteorological model output fields used here do not include an estimate of the level of turbulence. Consequently, this aspect is not considered in the present wave models. The high turbulent level in the Mistral flow and the lack of its consideration in the numerical modelling partly justify the underestimate seen in figs. 7 and 8. This could reduce the apparent underestimate of wind speed to 10-15%, a value more consistent with the comparison of wind data at Mahon shown in table III.

Considering the wave model results at different points and the available measured data, we have estimated a significant wave height around 6.5 m at the time and position where the Parsifal sank. Note that the 6 metres measured by the Topex altimeter correspond to the decay phase of the storm, already in the early morning of 3 November and in a slightly offset position.

On the whole, the Parsifal storm was not exceptional. Storms of similar intensity (see, *e.g.*, Pontes *et al.*, 1996) appear several times per year. Only two days later a stronger one hit the area. The one year return H_s in this offshore area is estimated at nearly 9 m from altimeter statistics (SOS, 1996), while it is 7.5 m at the Alghero buoy (Franco and Contini, 1997).

Forecast

After hindcasting the storm with analysis winds, we have repeated the computation using the forecast winds of ECMWF. The results clearly indicate that the storm was expected since two days before, with the characteristics of the sea fully defined. A deterioration of the forecast appears only three days in advance. All this is reflected, although in the usual approximate general terms, in the forecasts of the conventional weather bulletins, available when Parsifal left a Ligurian port on 1 November.

Modelling

While the research on wave modelling is still active, presently the quality of the results from an advanced wave model depends basically on that of the driving wind fields. In turn, the latter is connected to the spatial resolution of the meteorological model. For this reason it would have been interesting to check the quality of the UKMO-LAM forecast. This was not possible because this forecast is not archived.

In any case, wind and wave forecasts are now available daily both from ECMWF and UKMO. While their quality is generally high in the open oceans (see K for a thorough discussion on the subject), a diffused underestimate is still present in the enclosed basins and, in particular, in the Mediterranean Sea. This is mostly due to the complex orography that characterizes the basin and to the consequent limitations of the operational meteorological models, that lack the necessary resolution to represent properly the interactions with the orographic features and therefore the details of the surface wind fields. The Mistral is a very good example in this sense. There is emerging evidence, for example, that even an isolated obstacle, or what can be schematically represented with a semi-infinite barrier, can induce very strong low level jets that are associated with the generation, through non-trivial dynamics, of vorticity (and perhaps potential vorticity) *banners* (for example, see Buzzi *et al.*, 1997). The Mistral has many aspects in common with such jets. In these cases, the relevant horizontal scale is the scale of the orographic slope in the direction perpendicular to the flow. In the case of the western arc of the Alps, with northerly flow, this is of the order of a few tens of kms, requiring a grid distance of 10-20 km for a suitable modelization.

Pursuing this line of action, we have repeated the hindcast using as input the wind produced by several limited area models. However, the results are far from satisfactory, as they do not show any substantial and coherent improvement with respect to ECMWF, being in some cases even lower. While from the practical point of view we acknowledge the fact, these findings arise questions on the reasons of this failure. This is out of the scope of the present paper, and will be the subject of a devoted research.

A further factor of uncertainty is the gustiness of the northerly storms, particularly in fall. This is not sufficiently considered in the present meteorological and wave models. The effect is expectably higher in the Mediterranean Sea than in the open oceans, because of the larger air-sea temperature differences.

Availability of forecast

Still within the mentioned limitations, a detailed wave forecast is daily available for the Mediterranean Sea up to five days in advance. Produced at ECMWF, the forecast is daily transmitted to the Meteorological Service of the Italian Air Force (Aeronautica Militare). From here, contrarily to the meteorological information, it is distributed only upon a specific agreement. Agreements exist only with specific institutions and authorities, but no broad public distribution is done. While other activities are on the way in Italy to provide alternative high resolution forecasts, the ECMWF one is at present the only one potentially available via the national Meteorological Service. Given the deep implications, both from the economical and from the safety point of view, the authors stress the importance of a similar agreement by a state authority for a capillary and timely distribution of this essential information.

It is also important to check further the reliability of wave measurements from satellites in limited closed basins, and to receive and distribute both satellite and buoy measurements in real time to improve the forecast.

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