# The Voyager storm in the Mediterranean Sea

Luigi Cavaleri and Luciana Bertotti

Institute of Marine Sciences, ISMAR-CNR, Venice, Italy

+39 041 2404746

luigi.cavaleri@ismar.cnr.it

## 1. The storm

Mistral is a strong wind that characterizes the north-western part of the Mediterranean Sea (Figure 1). Blowing across the Carcassone pass that separates southern France from the Gulf of Lion, this northerly wind, enhanced by the funnelling due to and the khatabatic effect soon after the pass, may acquire high speeds (> 30 m/sec). The frequent temperature difference with respect to the warmer waters of the Mediterranean leads also to a substantial gustiness (Abdalla and Cavaleri, 2002).

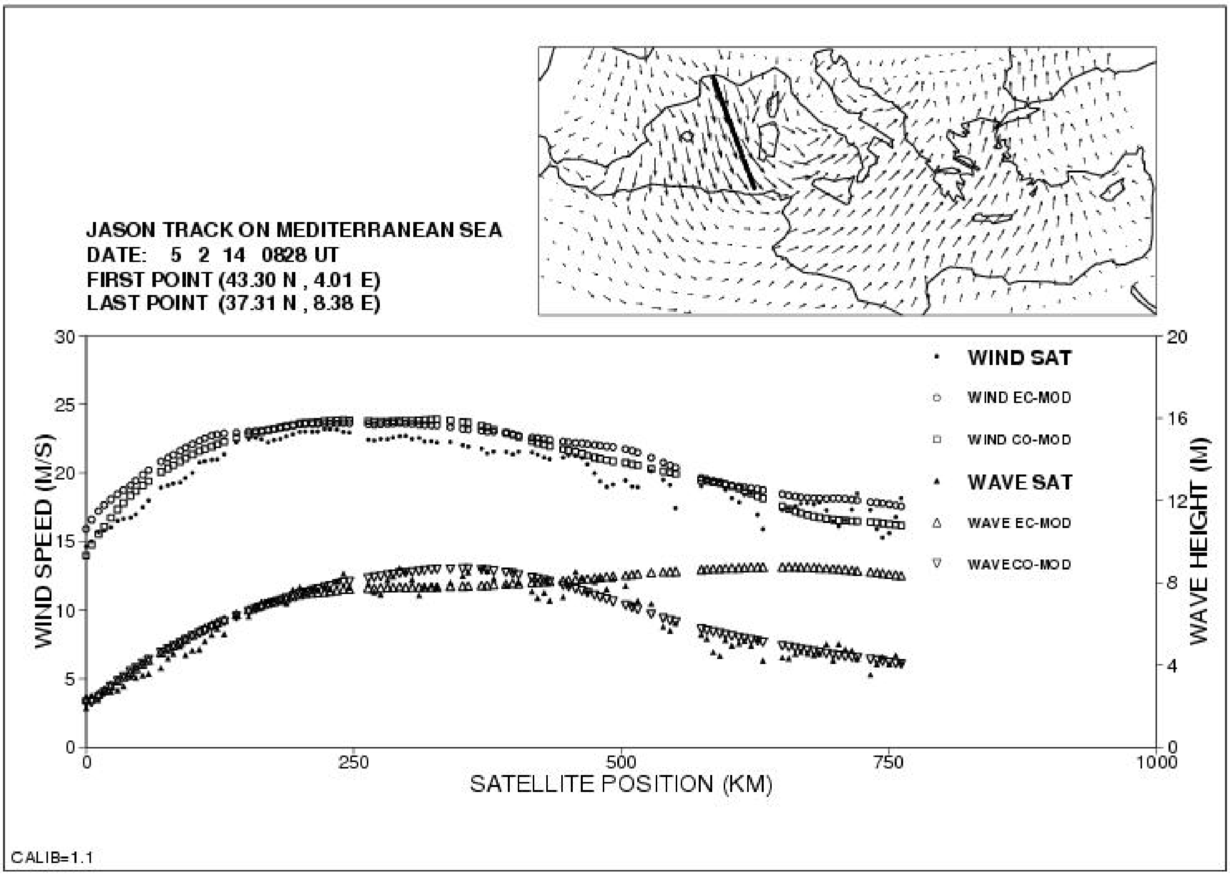


Figure 1 - Comparison between JASON altimeter wind speeds and wave heights and corresponding model results. EC-MOD = ECMWF, CO-MOD = COAMPS. The ground track and the overall wind field are shown in the smaller upper right figure (after Bertotti and Cavaleri, 2007)

On February 14, 2005 a mistral storm caught the liner “Voyager” between Sardinia and Balearic Islands while on route from Tunis to Barcelona with about 780 passengers on board. Reportedly 14 metres high waves hit the ship smashing the windows of the upper deck control room. The ensuing flooding of the ship control system led her to a halt. This unpleasant situation that, although without an immediate danger of sinking, led to a distress call, lasted several hours till when the crew managed to restart one engine (out of four). Then the ship limped slowly towards the closest port, in Sardinia.

Such a report triggers immediately the idea of a freak wave. Being interested both in this subject and more in general in the storms in the Mediterranean Sea, a keen analysis of the event was an obvious follow-up.

In this paper we describe (Section 2) the data available and, in 3, our best hindcast of the storm. The knowledge of the wave spectra in the area and at the time of the accident allowed an estimate of the probability of freak waves (Section 4). Our conclusions, in 5, are that the reported wave heights, even interpreting “wave height” as “crest height”, were within the expectable limits associated to the local wave conditions.

## 2. The available data

Measured wind and wave data along the axis of the storm were available from the JASON satellite altimeter (see Figure 1) that passed close to the time of the accident (8.30 am). This, especially the wave data, was the main source of information that allowed a keen validation of the model results.

We had at disposal also the wind fields provided by the QuikSCAT scatterometer. The local passes are always around 4 am and 4 pm, a few hours before and after the waves struck the ship. These data were used to validate the model wind fields used as input to the wave model.

We had available two wind sources, the analysis by the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, U.K.) and the short term forecasts by COAMPS (Fleet Numerical Meteorology and Oceanography Center, Monterey, California, USA). In February 2005 ECMWF was still running the T511 version of their meteorological model (Simmons and Hollingsworth, 2002). This corresponds to a spatial resolution of about 40 km. In enclosed seas, although as large as the Mediterranean Sea, such a resolution leads to a substantial underestimate of the ECMWF surface winds (see Cavaleri and Bertotti, 2004). Therefore we repeated the analysis of the storm running the ECMWF meteorological model with T799 spectral resolution (about 25 km). Out of each experiment we selected the +6/+15 hour section, at 3-hour intervals. This provided a five day long sequence of wind fields then validated with a direct comparison with the corresponding QuikSCAT data. At this aim the model data were interpolated in space and time to the scatterometer ones. The derived scatter diagram, limited to the area of interest, suggested that the T799 ECMWF wind speeds were still too low by 14% (the directions were correct). Consequently we enhanced the ECMWF wind speeds by the same percentage and used them to drive the WAM wave model (Komen et al, 1994) with 0.25 degree resolution. This led to values of the significant wave heights clearly in excess with respect to the corresponding JASON values. The differences suggested 10% as the correct enhancement factor for the T799 ECMWF winds in the area of the storm. The wave hindcast was thus repeated using this factor. The results are shown in the next section.

The WAM model was run using as input also the COAMPS winds. COAMPS, a limited area model with 20 km resolution, is nested in the global NOGAPS model.

## 3. The results

The main results of the hindcast are summarized in Figure 1. The small upper right panel shows the ground track of the JASON pass at 08.22 UTC of February 14, 2005. The larger panel provides the wind speeds and the wave heights along the ground track, respectively from the altimeter and from the ECMWF and COAMPS sources. The horizontal scale is in kilometres, from North to South.

First we discuss the wind results. Apparently both the models provide a fair representation of the wind field at the time of the pass (but remember that the ECMWF wind speeds have been calibrated). However, note that the model values are slightly in excess with respect to the altimeter ones. On the other hand in the previous section we have seen that the scatterometer data were higher than the models in Figure 1 by about 4%. So clearly either one of or both the satellite sources are wrong, although only by a few percents. Consistently with previous results, we favour the latter hypothesis. From direct comparison between scatterometer and buoy measured wind speeds in the north-western Mediterranean Sea, Ardhuin et al (2007) have concluded that indeed in the Mediterranean Sea, and more in general in the enclosed seas, the scatterometer data are slightly in excess with respect to the sea surface truth. On the other hand Cavaleri and Sclavo (2006) have carried out a long term (ten years) comparison between altimeter and model wind speeds and wave heights. This combined analysis clearly indicated the underestimate of the altimeter wind speeds in the order of 5-8%. This strongly suggests that the model results in Figure 1 are correct.

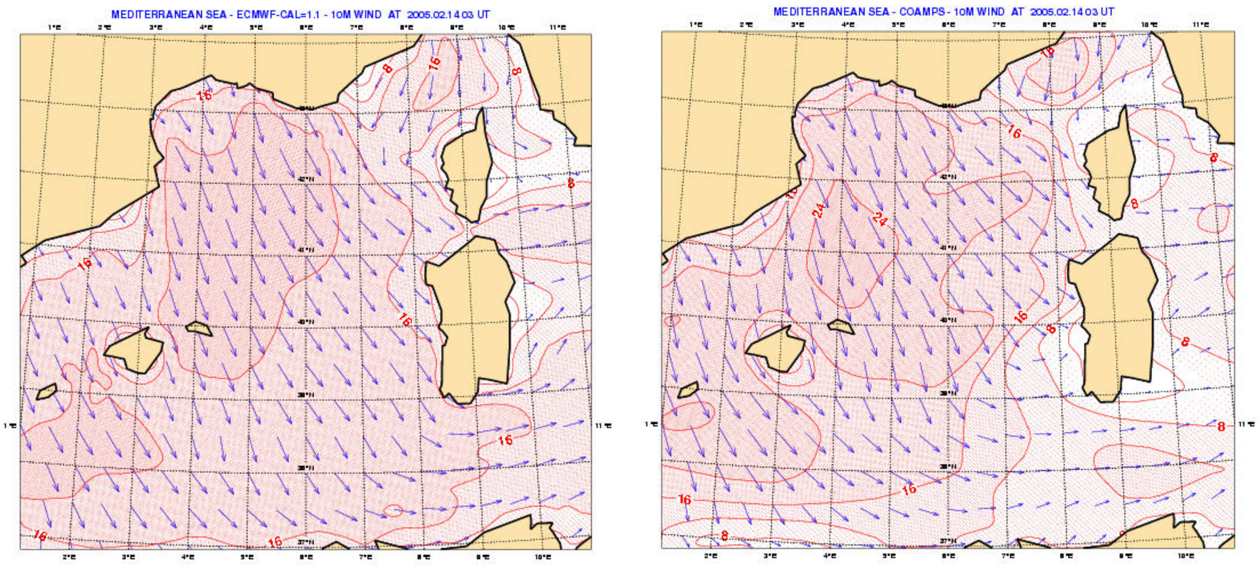


Figure 2 - Wind fields at 03 UTC 14 February 2005. The area is the Western Mediterranean Sea. Isotachs at 4 m/s intervals. Arrows show wind speed and direction. Left, calibrated ECMWF, right COAMPS (after Bertotti and Cavaleri, 2007).

However, consideration of the model results clearly raises some problem. The two model runs, i.e. the WAM wave model run respectively with the calibrated ECMWF and the COAMPS winds, provide a very good representation of the significant wave height $H_s$ in the first 250 km off the coast. After this distance the ECMWF field leads to a slow, but progressive, increase of Hs towards the South, while COAMPS suggests a peak at about 350 km followed by a marked decrease of the

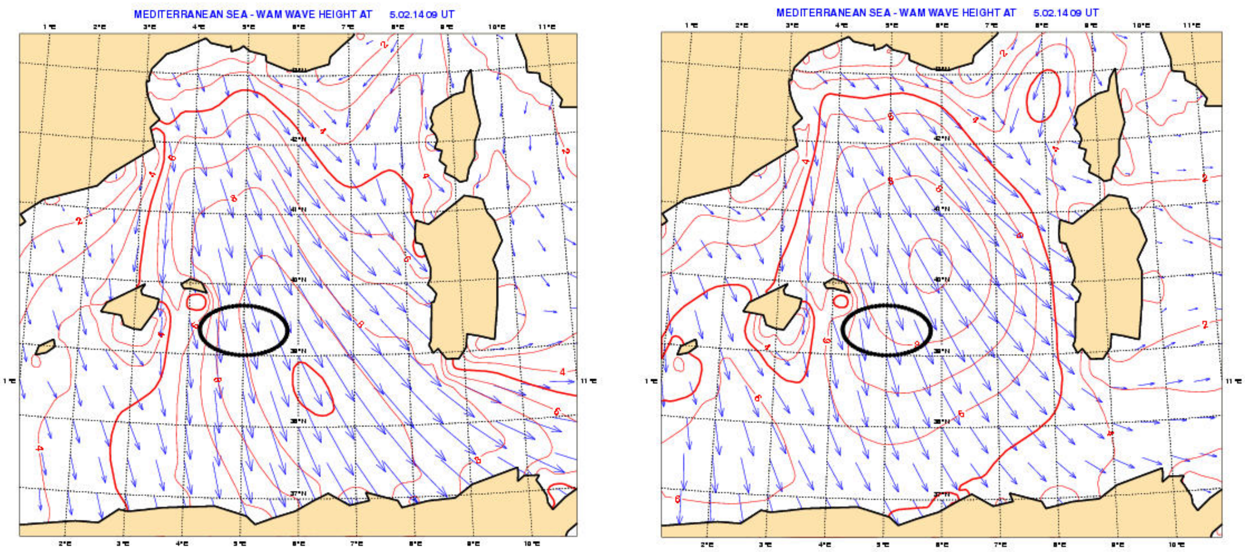


Figure 3 - Wave fields at 09 UTC 14 February 2005. The area is the Western Mediterranean Sea. Isolines at 1 m intervals. Arrows show significant wave height and mean direction. Left, using calibrated ECMWF winds, right using COAMPS winds. The ellipse shows the approximate position of the cruiser Voyager at the time of the accident (after Bertotti and Cavaleri, 2007).

Hs values towards the African coasts. The explanation is found in Figure 2 and Figure 3, comparing respectively the two wind fields and the two derived wave fields. From Figure 2 it is evident that, although the two structures off the French coast are similar, ECMWF is putting the meteorological front, indicated by the abrupt change in wind directions, well in advance with respect to COAMPS. This implies that also the ECMWF wave field is moved ahead, the more extended storm leading to a higher peak (see Figure 3, left panel) towards the African coast. The ellipse indicates the area of the accident. We see that indeed from the French coast till this area the two wave fields are very similar. On the contrary, moving further south, the ECMWF field keeps increasing, while COAMPS places its peak very close to the area of the accident.

Given the comparison with the altimeter data (Figure 1), it is clear that COAMPS provides the most accurate representation of the storm. However, it is remarkable that for our present purpose of analysing the accident, the two models provide similar results, suggesting significant wave heights where the ship was located between 8 and 10 metres (we did not manage to know the position of the ship with sufficient accuracy). On the base of this result we analyse in the next section the probability of large or freak waves.

## 4. The probability of large or freak waves

Starting from the 8-10 metres significant wave height range derived from the models, we estimate the probability of a 14 metres high wave. We begin with the standard Rayleigh distribution. The results are reported in the upper half of Table 1. It is immediately evident that the probability is very high. Arguing with $H_s$=8 m, a 14 metres high wave is 1.75 times larger. This corresponds to one encounter every 500 waves. With a peak period of 11 seconds (derived from the model), this corresponds to one encounter every 1.5 hour. With $H_s$=10 m clearly all these figures decrease, with a resulting encounter every 0.18 hour (about 11 minutes, $T_p$=13 sec).

| | | | |
|---|---|---|---|
| Hs | 8 | 10 | m |
| H = 14 m | 1.75 | 1.4 | times larger |
| Rayleigh every | 500 | 50 | waves |
| i.e. every | 1.5 | 0.18 | hours |
| Hypothesis: | Hc = 14 m → | H = 18 m | |
| H = 18 m | 2.1 | 1.8 | times larger |
| Rayleigh every | 13000 | 550 | waves |
| i.e. every | 40 | 2 | hours |

Table 1 - Encounter probability of a 14 (upper part) or 18 (lower part) metres wave height according to Rayleigh distribution. The 18 metres are supposed associated to a 14 metres high crest.

The availability of the model spectra in the area of the accident allowed an estimate of the probability of freak waves, in practice to take into account the nonlinearity of the field. This is related to the so-called Benjamin-Feir index BFI, a parameter depending on the shape of the spectrum. Onorato et al (2006) have carried out a series of wave tank experiments, and they showed that a progressive increase of BFI moves the probability distribution further and further away from the Rayleigh one. Their result is shown in Figure 4, and we see that for, e.g., BFI = 0.9 there is an increase between four and five times of the probability of very large waves (compared to the local $H_s$).

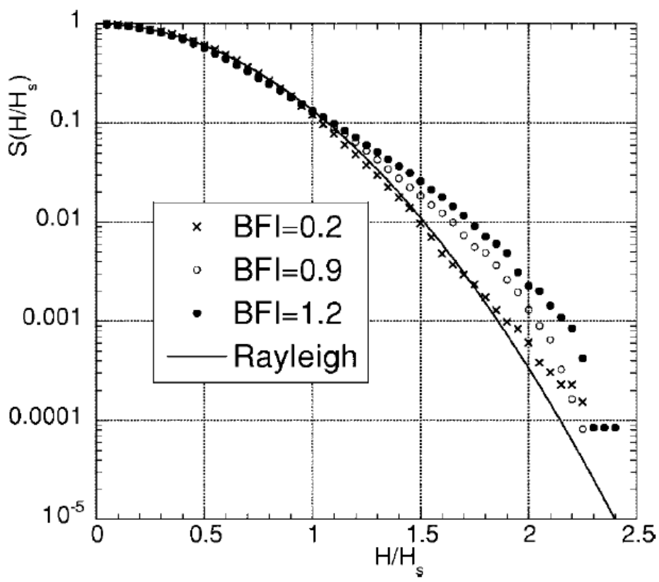


Figure 4 – Modification of the wave height distribution as fuction of the Benjamin-Feir Index BFI (after Onorato et al., 2006).

Janssen (2003) managed to relate BFI to the kurtosis of the wave spectrum, in so doing allowing a quick method to estimate BFI. The consequent results for our case of interest are summarised in Figure 5, where we have plotted the BFI values vs the corresponding significant wave heights.

The Janssen method is slightly different from the one followed by Onorato et al. (2006), providing slightly lower BFI values. In any case it is clear that, although limited, there is an increase of the probability of large waves with respect to the Rayleigh distribution. The key point is that large waves were indeed more likely to appear than indicated in Table 1.

We find this result unsatisfactory. Although severe, this mistral storm was not exceptional. It was also well forecast, and it is hard to believe that a cruise ship could be put in danger by waves expected to appear in the order of every hour or less. Rather, we hypothesize that the reports were incorrect and that, instead of “14 metres wave heights”, people on board referred to “14 metres crest heights”. This may sound like a long shot, but it is the only way we see to reconcile our reliable results with what happened to the “Voyager”. Therefore we consider a highly nonlinear, highly crested wave, with 14 metres crest and 18 metres overall height, and we work out the probability of such an encounter. The results, still for the Rayleigh distribution, are reported in the lower half of Table 1. With the above hypothesis such a wave could appear once every 40 and 2 hours, for $H_s$ = 8 and 10 metres respectively. Consideration of BFI and nonlinearities lead to a substantial reduction of these figures.

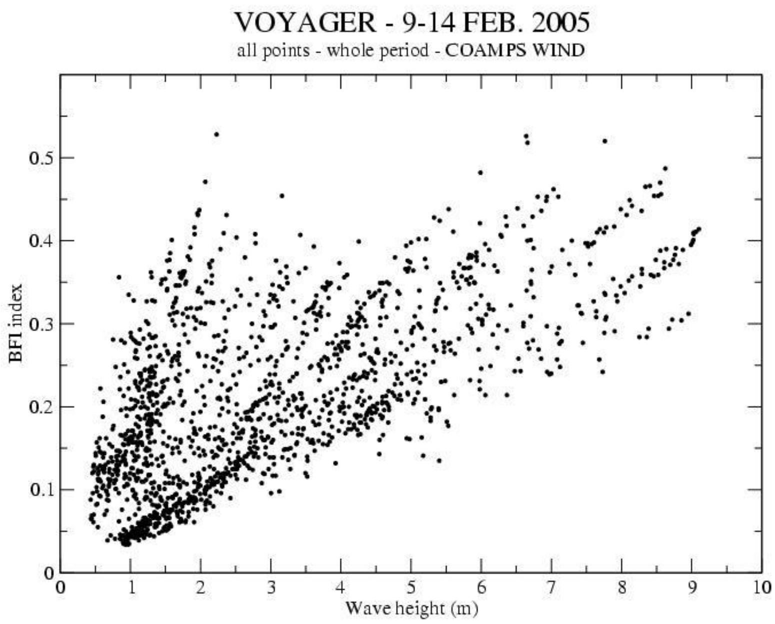


Figure 5 - Scatter diagram of the Benjamin-Feir instability indices vs the corresponding significant wave heights in the area of the Voyager storm (after Bertotti and Cavaleri, 2007).

## 5. Discussion

Our wave results are quite robust and supported by the altimeter measurements. Therefore they are a good background to estimate the probability of large waves in the area where the "Voyager" ran into trouble.

The reports, expectably derived fom the same source, talk of 14 metres high waves. In our opinion this is unrealistic and, if true, it would be very negatively surprising. In the conditions of the storm, that, although severe, was not exceptional, such wave heights were to appear every hour or less. Our uncertainty in this respect derives from the uncertainty on the actual position of the ship, hence on the local significant wave height. Consideration of nonlinear effects, leading to the so-called freak waves, would further increase the encounter probability.

Consequently we have hypothesized that, rather than about "wave heights", the original source talked about "crest heights", an expression probably less familiar to the media. A repeated analysis based on this hypothesis provided more realistic, i.e. lower, encounter probabilities, varying between one every 2 and 40 hours, depending on which significant wave height, respectively 10 and 6 metres, is assumed it was present at the uncertain ship position. Although significantly lower, these values are well within the realm of the practical possibilities.

**Acknowledgements**

Our experiments have been carried out at the European Centre for Medium-Range Weather Forecasts. We are grateful to Jean Bidlot for smoothing our way in the local computer system.

Peter Janssen has kindly provided the program for the estimate of the Benjamin-Feir instability.

The altimeter and scatterometer data have been provided by the European Centre for Medium-Range Weather Forecasts.

The COAMPS winds have been provided by Paul Wittmann of the Fleet Numerical Meteorology and Oceanography Center in Monterey, California, USA.

Susanne Lenher pointed the storm to our attention.

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