Analysis of the 21/22 October 2014 Storm Experienced by the Sailboat ECO40 in the Gulf of Lion

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Abstract: On October 19, 2014 Matteo Miceli, a known Italian oceanic sailor, left the Port of Riva di Traiano (Rome, IT) with the sailboat ECO40, an Italian vessel, for the Roma Ocean World Project. This ambitious challenge consists in a non-stop sailing alone around the World in energy and food self-sufficiency. ECO40 is a Class 40 oceanic vessel (LOA of 12,0 m) that has been equipped with a data acquisition system for both the met-ocean parameters recorded on-board (i.e. apparent and real wind speed and wind direction, atmospheric pressure, current velocity, air and sea temperature, etc.) and the kinematic characteristics of the boat itself (i.e. speed and course over ground). Furthermore, the boat has been equipped with a three high precision GPS receivers, provided by Leica Geosystem, for measuring the movements of the boat and with an inertial platform. Due to these high-precision instruments it has been possible to fully measure and characterize the six degrees of freedom of the boat, and accordingly to use the boat as a "sailing wave buoy". In this paper we present the first analysis of the met-ocean data measured by the boat during the storm occurred in the Gulf of Lion on October 21-22, 2014 that ECO40 faced just few days after its departure.

1 INTRODUCTION AND AIM OF THE RESEARCH

On October 19 , 2014 Matteo Miceli, a famous Italian oceanic sailor, left the Port of Riva di Traiano located close to Rome (Italy) with the Italian sailboat ECO40 for the Roma Ocean World Project. This ambitious challenge consists in a non-stop sailing alone around the World in energy and food self-sufficiency. The planned route was the classic clipper route which runs from west to east through the Southern Ocean, in order to make use of the strong westerly winds. Namely the route, very similar to that of several prominent yacht races as Around Alone and Vendèe Globe, consists in passing the Gibraltar Strait, then in descending the Atlantic Ocean and sailing around the Antarctic, at a mean latitude of 50º S, from west to east rounding the most famous capes of the world: Cape of Good Hope, Cape Leeuwin and Cape Horn. Finally, ascending the Atlantic Ocean and passing again the Strait of Gibraltar coming back to the homeport. The total distance to be covered by the sailboat was estimated in about 28,000 nautical miles, while the duration was estimated in about five months.

When Matteo was on the way back to Italy, after rounding the three capes and sailing for 25.000 nautical miles, ECO40 capsized at the equator. Matteo was about 600 miles offshore the Brazilian coasts. Matteo was saved by a cargo. When he came back to Italy, he organized a first expedition with four friends to try to recover ECO40, which was not successful. After one month Matteo and his friends tried again and found ECO40 300 miles offshore the Brazilian coasts. Now ECO40 is again in Italy.

ECO40 is a Class 40 oceanic vessel (LOA of 12,0 m) that has been equipped with a data acquisition system for both the met-ocean parameters recorded

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on-board (i.e. apparent and real wind speed and wind direction, atmospheric pressure, current velocity, air and sea temperature, etc.) and the kinematic characteristics of the boat itself (i.e. speed and course over ground). Furthermore, the boat has been equipped with a three high precision GPS receivers, provided by Leica Geosystem, for measuring the movements of the boat and with an inertial platform. Thanks to these instruments it is possible to fully measure and characterize the six degrees of freedom of the boat.

In order to reduce the significant cost of the data transfer just a small part of the measured data were sent to the land team on daily basis; it is worth to note that the transfer of the data is achieved by using a satellite modem. The sampling frequency for the met-ocean data acquisition is 2 Hz, nevertheless only the data averaged over a time window which had a duration of 10 minutes were sent to shore. It is important to stress that these data, measured by the boat and transmitted almost in real time, helped significantly the team in charge of the safety of ECO40; in fact the knowledge of the actual weather conditions that the boat is really facing during its navigation can improve the route strategy and increase the boat safety. Furthermore, the boat performance data (i.e. speed and course over ground) can allow, after a certain amount of time that is required for considering the database statistically meaningful, to estimate the real polar velocity curves of the boat. Indeed these curves were used for the prediction of the optimal route (routage) made by the land team by means of a route optimization software, which was sent daily to ECO40.

It is worth noticing that the actual polar velocity curves of the boat differ from the theoretical ones estimated by the designer of the boat. This is due to several causes, among which plays an important role the ability of the crew to "push" the boat to the maximum of its performance and the presence of waves that normally is not taken into account when calculating the curves themselves.

The remaining data were supposed to be analyzed once the boat had come back. Fortunately the data were saved together with the boat.

The measurements of the boat movements, obtained from the three GPS receivers, if properly analyzed can provide the characteristics of waves that ECO40 encountered during its navigation. In other words it can be stated that ECO40 can be used as a “moving wave buoy” for measuring the waves characteristics (i.e. significant wave height H_{m0}, peak period T_p and mean direction θ) experienced during navigation.

These data are used mainly for two technical and scientific purposes. The first purpose is the calibration of the numerical models output that are commonly used for the wind and wave forecast and/or analysis into the oceans, and the calibration of the remote sensing data (e.g. satellite wind and wave measurements). The second purpose is directly related to the vessel design. Indeed the knowledge of both the movements and the loads that these kind of vessel can deal with, together with the response of the materials to the fatigue stresses, can improve significantly the designing methods.

The aim of this paper consists in analyzing the first storm experienced by ECO40 during its navigation that occurred in the Gulf of Lion on October 21-22, 2014. In the following sections, first we present the analysis of the Gulf of Lion weather event, and the description of the available wind and waves data. Then we show the results of the comparison between the wind measurements carried out on board and those reconstructed in forecasting and analysis, by using the numerical data of the GFS (Global Forecast System) and ECMWF (European Center for Medium-range Weather Forecast). Finally, we show a comparison of the present data with those related to the storm that occurred in the Gulf of Lion on 2 November 1995, which caused the sinking of the Italian racing boat Parsifal, killing six of its nine crew members. The weather conditions that caused the sinking of the boat have been rebuilt by (Bertotti et al., 1988).

2 THE ECO40’S ROUTE DURING THE GULF OF LION EVENT

On 19 October 2014, when ECO40 left from the Italian Port Riva di Traiano, the weather conditions appeared to be clear: within the next 24/48 hours the first seasonal front of cold air, expected to cause mistral winds having wind speed exceeding 40 knots, would come from the Gulf of Lion. Fortunately, ECO40 was able to reach the Asinara Island and began to follow the route towards the Balearic Islands before the arrival of the main storm: the boat has faced the storm running on the quarter. The route between the Asinara Island and the Balearic Islands that the boat ECO40 has followed is represented in Figure 1. The figure shows also information of the travel times.

Eco 40 has covered more or less 200 nautical miles in 24 hours, with a mean speed of almost 8.3 knots. Figure 2 shows the plots of the speed over ground (SOG) and of the course over ground (COG) during the Gulf of Lion Event. We recall that these values are not the instantaneous ones but are the values averaged over a time interval of 10 minutes.

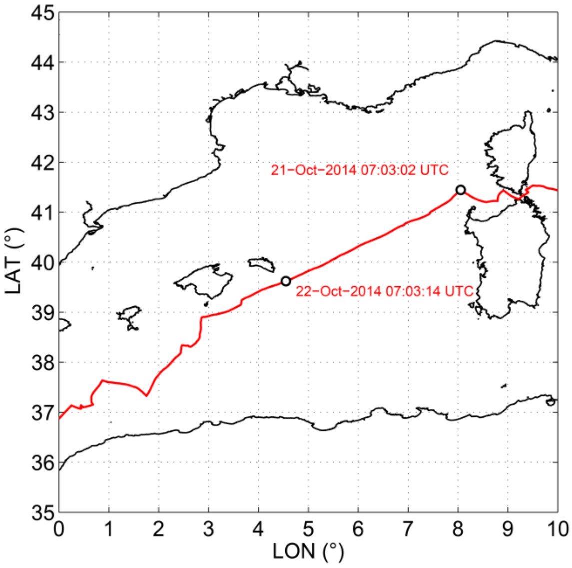

Figure 1: The route between the Asinara Island and the Balearic Islands that the boat ECO40 has followed.

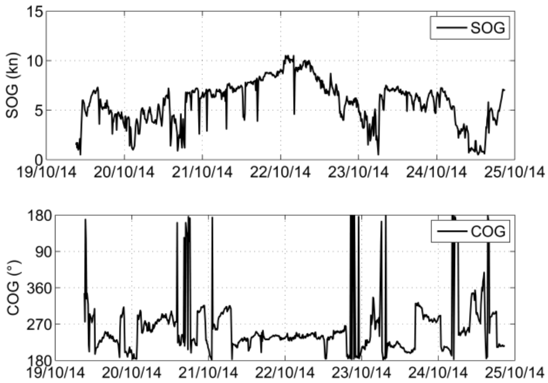

Figure 2: Time series of the speed over ground (upper panel) and of the course over ground (lower panel) during the Gulf of Lion Event.

3 WEATHER ANALYSIS OF THE GULF OF LION STORM

In the days 20 and 21 October 2014, the atmospheric circulation was characterized by a zonal flux from West to East in the Northern of Europe. A high pressure was centred on the Mediterranean Sea (Figure 3 and Figure 4).

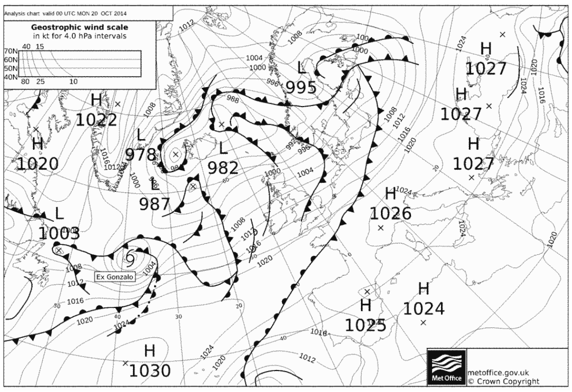

Figure 3: Surface Analysis for 20 October 2014 hour 00.00UTC (source: MetOffice).

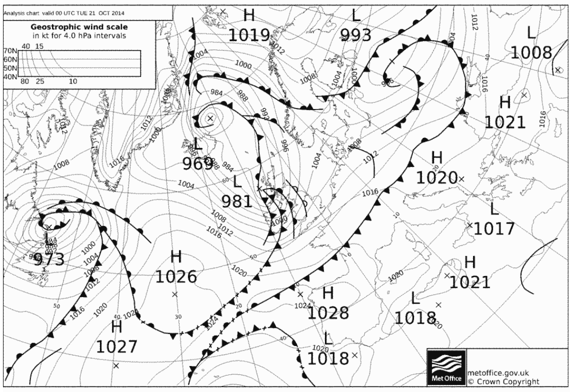

Figure 4: Surface Analysis for 21 October 2014 hour 00.00UTC (source: MetOffice).

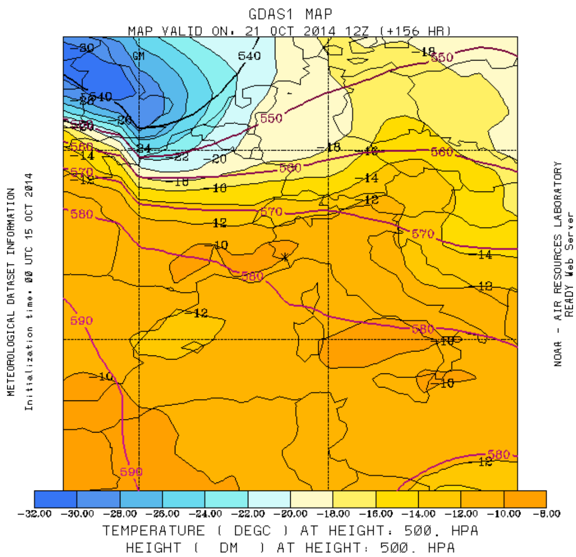

Figure 5: Upper Atmosphere Analysis at 500hPa for 21 October 2014 hour 12.00UTC (source: MetOffice). Color filled area: temperature at 500hPa [°C]. Red solid line: height level at 500hPa [mx10].

At the same time a frontal system, positioned between a low pressure centred on the Atlantic Ocean and a low pressure centred in the Poland's plan, started to move slowly toward South. The movement of this frontal system was generated by the faster change of direction of the zonal flux in the UK island, in turn generated by the movement towards East of the tropical low pressure "Gonzalo". The trough in upper atmosphere (see Figure 5) associated with the cold air movement on the day of October 21 and in the night of the October 22 (see Figure 6), generated the movement to South of the cold front (see Figure 7).

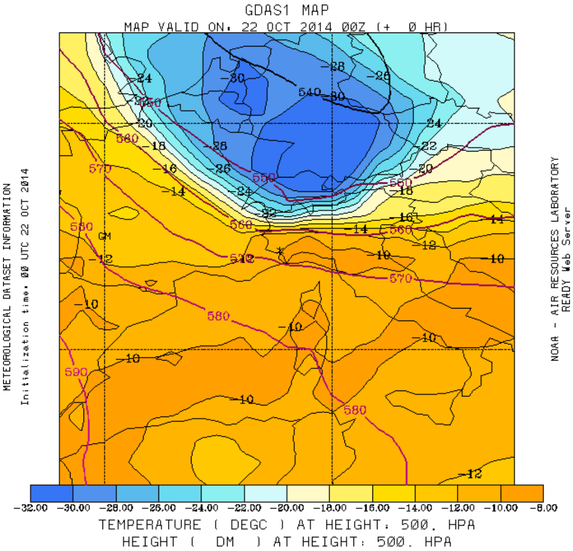

Figure 6: Upper Atmosphere Analysis at 500hPa for 22 October 2014 hour 00.00UTC (source: MetOffice). Color filled area: temperature at 500hPa [°C]. Red solid line: height level at 500hPa [mx10].

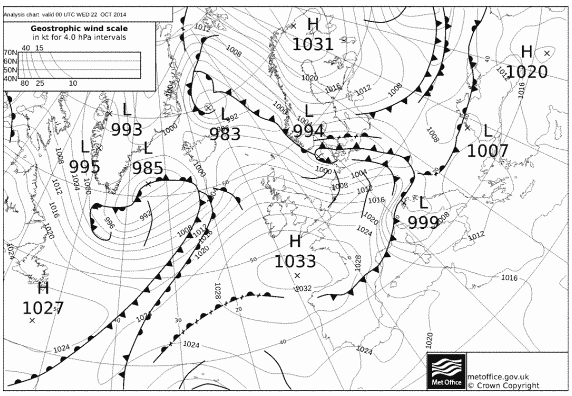

Figure 7: Surface Analysis for 22 October 2014 hour 00.00UTC (source: MetOffice).

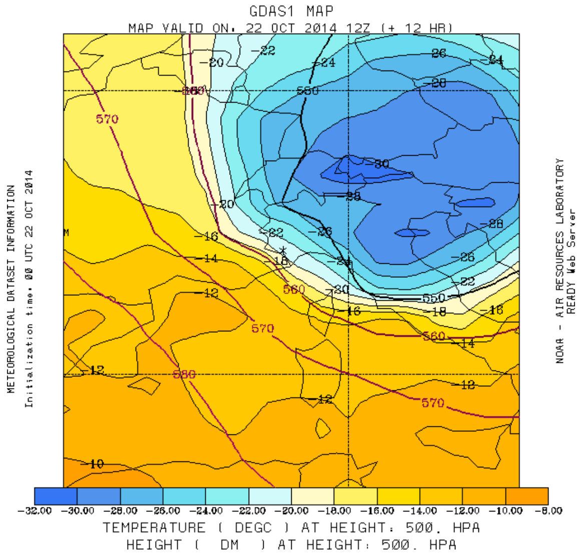

Figure 8: Upper Atmosphere Analysis at 500hPa for 22 October 2014 hour 12.00UTC (source: MetOffice). Color filled area: temperature at 500hPa [°C]. Red solid line: height level at 500hPa [mx10].

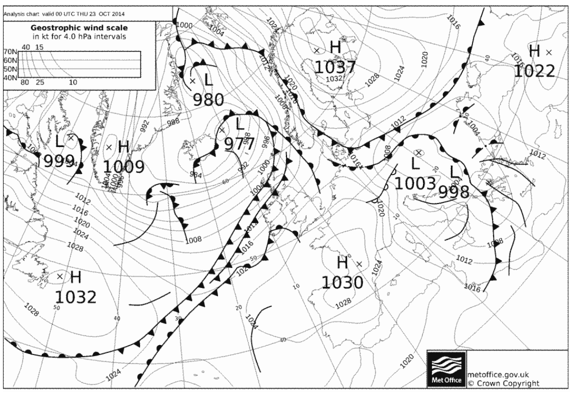

Figure 9: Surface Analysis for 23 October 2014 hour 00.00UTC (source: MetOffice).

When the cold front encountered the Alps, it developed the classical low pressure down-wind to the mountain. Then a low pressure with the center at 998hPa was positioned on the Venice Gulf. The opposition between this low pressure and the high pressure with center at 1033hPa positioned on the Biscay Gulf, jointly with the movement of the cold air in upper atmosphere (see Figure 8), generated an atmospheric situation characterized by an elevated instability. This weather pattern was active on the Mediterranean Sea for the entire day on October 22, 2014 and for a part of the October 23, 2014 (see Figure 9)

This particular baric configuration generated strong wind from N on the Mediterranean Sea in particular on the Gulf of Lion, on the West of Mediterranean Sea, on the Sicily Channel and on the Sardinia Channel. Moreover, the slow movement of the cold front and of the low pressure made an adverse meteorological situation for a time as long as 48h.

4 WIND DATA ANALYSIS

In this section the wind data measured on board during the the Gulf of Lion event are presented and analyzed.

The true wind speed V_w and the true wind direction θ_w during the Gulf of Lion event, obtained from the apparent wind and from the boat kinematic characteristics, are shown in Figure 10. The upper panel of Figure 10 shows the time series of the mean values (i.e. averaged over 10 minutes) of the true wind speed (black line) and the true wind gust (red line) that represents the highest values of true wind speed measured over 10 minutes. It is worth to note that the maximum value of the averaged wind speed reached 45 knots at the peak of the event, while the values of the gusts were greater than 50 knots, reaching a maximum value of 56 knots. The lower panel of Figure 10 shows the time series of the true wind directions; also in this plot both the quantities that refer to the averaged values and the ones that refer to the gust values are represented.

The upper panel of Figure 11 represents the scatter plot between the averaged true wind speed and the true wind gust. The plot shows that the wind gust values are generally larger of about 15-20%

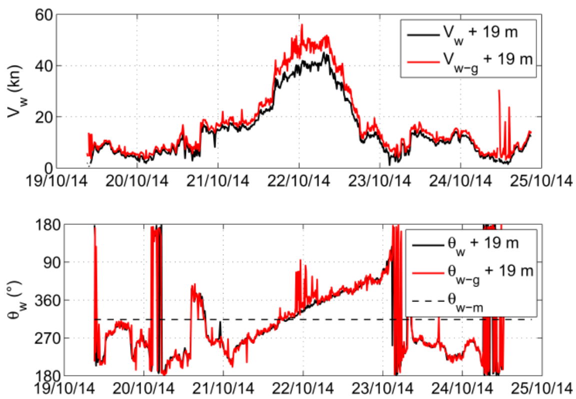

Figure 10: Upper panel: time series of the true wind speed averaged over 10 minutes (black line) and of the true wind gust (red line). Lower panel: time series of the true wind direction averaged over 10 minutes (black line) and of the true wind gust direction (red line); note: the dotted black line refers to the mean direction of the true wind ($\theta_{w\text{-}m}$ during the event is 313.6°).

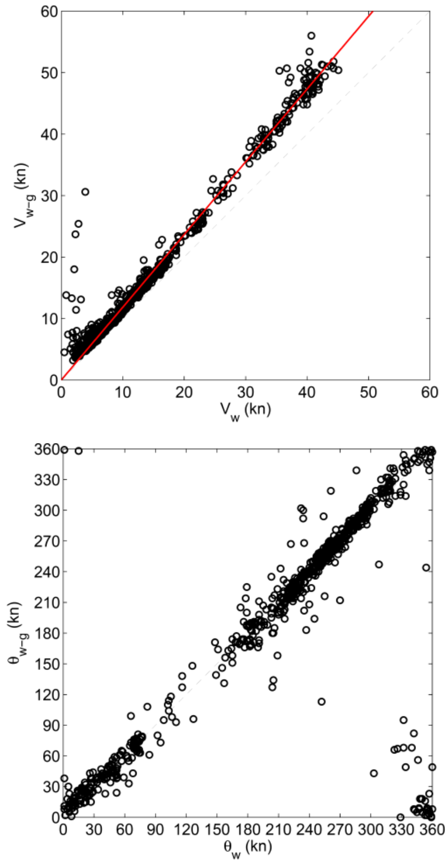

Figure 11: Upper panel: scatter plot between the averaged true wind speed and the true wind gust; the red line represents the functional relationship, as obtained by applying a linear regression to the measured data. Lower panel: scatter plot between the averaged true wind direction and the true wind gust direction.

than the averaged true wind speed; also, the difference between the averaged wind speed and the gusts tends to increase as the wind speed increases.

In order to highlight this feature, the functional relationship, as obtained by applying a linear regression to the measured data, has been represented (red line) in the upper panel of Figure 11.

These wind data, measured by ECO40 during the Gulf of Lion event, have been compared with two different sources of data. The first comparison has been carried out with the ECMWF (European Centre for Medium-Range Weather Forecasts) data. Data are provided with a spatial resolution of 0.125° and with a time resolution of 6 hours.

A second comparison has been carried out by using the forecast data provided by the numerical model GFS (Global Forecast System). It has to be stressed that the output of this model, that has a spatial resolution of 1.0° and a time resolution of 3 hours, are the ones which have been used for the routing of ECO40.

The results of these comparisons are shown in Figure 12. The upper panel of Figure 12 represents the time series of (i) the averaged wind speed (black line) measured by ECO40 by the anemometer placed on the top of the mast (as shown in Figure 10), and (ii) the time series of the wind speed obtained in analysis and by the GFS, linearly interpolated (in time and space) along the route of the boat between Sardinia Island and the Balearic Islands. The results of the GFS model (i.e. forecast data) are identified by a red dashed line, while the results of the ECMWF model (i.e. analysis data) are identified by a continuous blue line. Now, the forecast data have been sent to the boat on October 10, 2014; therefore we can evince that they have a higher accuracy in the first 24-48 hours; obviously, as shown in Figure 12 as the time increases (over 24-48) the agreement between the forecasted data and the measured ones deteriorate.

The upper panel of Figure 12 shows that the wind speed values measured on board are larger than those estimated by the numerical models. Indeed, this comparison is not completely correct given that the results of the numerical models are provided at the conventional height of +10 m above the mean sea level, while the wind data measured on board have been registered at the actual position of the anemometer that is placed on the top of the mast: when the boat is at its rest position (i.e. the boat is not heeled), then the height of the anemometer is about +19 m above the mean sea level (i.e. the height of the top of the mast). Thus, in order to properly compare the measured data with the numerical results, it is therefore necessary to reduce the measured wind data to the height of +10 m above the mean sea level. This has been carried out by using the vertical profile of the wind speed proposed by (Pierson, 1955). This relationship describes a logarithmic vertical profile of the wind velocity, that has the following functional form:

$$\frac{U_z}{U_{10}} = 1 + \frac{\sqrt{C_{10}} \cdot \mathrm{Ln}\dfrac{z}{10}}{C_K} \tag{1}$$

where U_z is the wind speed at the height z, U_{10} represents the wind speed at +10 m above the mean sea level, C_{10} is a coefficient that is function of the flow regime of the wind speed and of the surface roughness that theoretically depends on the waves conditions. In order to estimate C_{10} the functional form proposed by (Wu, 1969) has been used.

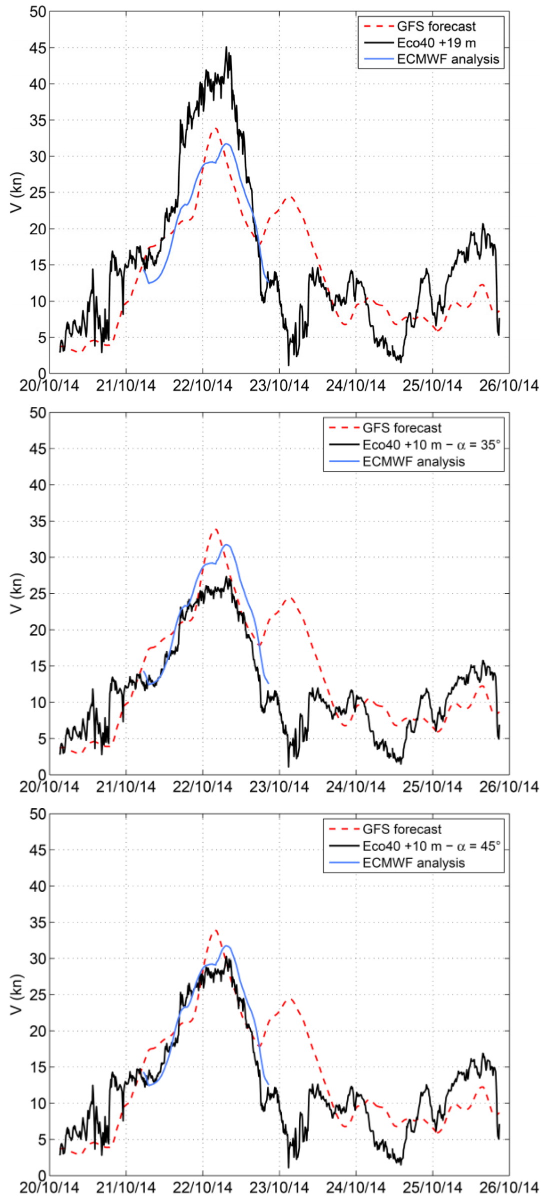

Figure 12: Upper panel: comparison between the true wind speed (averaged over 10 minutes) measured at the top of the mast (black line) and the numerical model output of the GFS (dashed red line) and of the ECMWF data in analysis (continuous blue line). Middle and lower panel: comparison between the true wind speed (averaged over 10 minutes), evaluated at the height z = +10 m above the mean sea level (black line) l.m.m as a function of two heeling angles (α = 35°, middle panel; α = 45°, lower panel),) and the numerical model output of the GFS (dashed red line) and of the ECMWF (continuous blue line).

As shown in the following relationship the coefficient C_{10} depends just on the wind velocity, while it does not take into account the wave field

$$C_{10}=0.65\cdot(U_{10})^{1/2}\cdot10^{-3} \text{ per } \quad (U_{10}\leq15\ m/s)$$
$$C_{10}=2.4\cdot10^{-3} \text{ per } \quad (U_{10}>15\ m/s) \qquad (2)$$

C_K represents the Von Karman coefficient, equal to 0.4. Thus, eq. (1) has been used to evaluate the measured wind speed at the conventional height of +10 m above the mean sea level, once the actual wind speed U_z and the actual measurement height z are known.

As already pointed out, the anemometer is placed on the top of the mast, thus its height (and of course the measurement height z) can change over time. This is related to the changes in the boat heeling, which for certain sailing trim, can be characterized by very pronounced heel angles. Consequently, in order to carry out a proper comparison between the measured wind data and computed ones, a parametric analysis, by varying the measurement height z, has been performed.

As qualitatively shown in Figure 13, the heeling angle α modifies the measurement height to be used in the equation (1). The middle and the lower panel of the Figure 12 show the results of the comparison between the measured wind data and the numerical ones. In these case equation (1) has been used by varying the heeling angle α (equal to 35° and 45°), and the measurement height z (equal to 15.56 m and 13.43 m respectively). It appears that as the heeling angle increases (e.g. α > 35°) then the measured wind data and the numerical ones (both those obtained by using the GFS and the ECMWF) are in agreement.

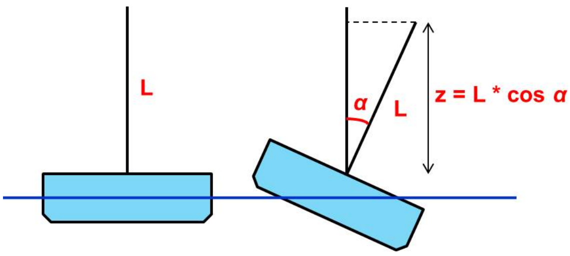

Figure 13: Sketch of the measurement height z as a function of the heeling angle α.

Ongoing research is focused on improving the comparison between the measured wind data and the calculated ones by using the trim boat measurements, as obtained from GPS measurements, and by using a more accurate relationship for the vertical profile of the wind speed, that takes into account the sea surface roughness in a real sea state (i.e. presence of waves).

5 WAVE DATA ANALYSIS

This section describes briefly the analysis carried out on the wave data collected during the Gulf of Lions event. The available wave data sources are: the buoy of Alghero (Italy), that is part of the RON (Italian National Network for the wave measurements; see Piscopia et al., 2002) and the data provided by the numerical model of the ECMWF. Figure 14 shows the time series of the significant wave height H_s (left panels) in few points of interest placed along the route of the boat (right panels). The upper panel shows the comparison between the significant wave height H_s measured by the Alghero buoy and the H_s obtained by linearly interpolating the data provided in analysis by ECMWF (dashed line). It is worth to note that the two set of data are in good agreement: indeed both the shape and the maximum values appear quite similar. The remaining panels (second,

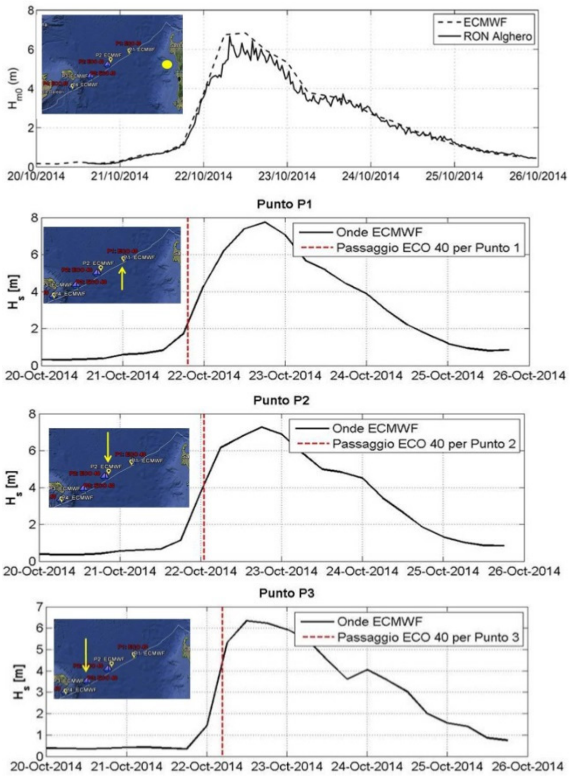

Figure 14: First panel (i.e. upper panel): comparison between the significant wave height *Hs* measured by the Alghero buoy and the same quantity obtained from the analysis data of the ECMWF. Remaining panels (i.e. second, third and fourth): evolution over time of the significant wave height *Hs*, as obtained from the numerical model of the ECMWF, evaluated in three points of interest placed along the route of the boat. Note: the vertical dashed red lines identify the time at which the boat has passed in that point.

third and fourth) show the evolution over time of the significant wave height H_s, as obtained from the numerical model of the ECMWF, evaluated in three points of interest placed along the route of the boat. The vertical dashed red lines identify the time at which the boat has passed in that point and therefore show the values of the significant wave height experienced by the boat. Note that, in the future, such numerical wave data will be compared with the ones obtained by the signals measured by the three high-precision GPS.

Finally, Figure 14 shows the significant wave height time series during the Gulf of Lions storm of November 1995 that has been reconstructed by (Bertotti et al., 1998). We recall that this storm caused the sinking of the Italian sailboat Parsifal and the death of 6 crew members. Although a quantitative comparison is not actually possible here, we can qualitatively assess that the magnitude of the sea state that ECO40 has faced is quite comparable with that suffered by the Parsifal.

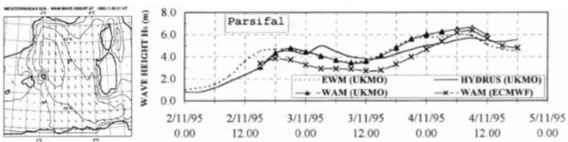

Figure 15: Significant wave height time series during the Gulf of Lions storm of 2 November 1995 that has caused the sinking of the Parsifal (Figures 5 and 6 of the paper of Bertotti et al., 1998).

6 CONCLUDING REMARKS AND ONGOING RESEARCH

This paper analyses the storm of October 21/22, 2014 faced by the boat ECO40 during the sailing in the Gulf of Lion. The storm has been analysed on the basis of the wind data, averaged over ten minutes, measured and transmitted almost in real time from the boat. These wind data have compared with the ones obtained by using two numerical models: the forecast data as from the GFS and the analysis data as from the ECMWF. This comparison has shown that the wind measurement height can play an important role and therefore has to be considered by knowing the arrangement of the boat (i.e. heeling angle, etc.).

The measured values of the wind, averaged over ten minutes, are comparable with the results obtained from the numerical models: a good agreement is noticeable within the first 24-48 hours. As the time increases, then the numerical results tend to deteriorate.

Furthermore, the forecast data seem to well predict not only the magnitude of the event, in terms of wind speed, but also the exact time of occurrence of the storm peak, a parameter often prone to error.

A direct comparison between the forecast and the measured wind showed relevant discrepancies, that can be up to 50%. This difference is due to: (i) the differences in altitude (i.e. the height at which the wind measurements are carried out) that is estimated to yield almost a 35% error and (ii) the gust (approximately a 15% error).

Finally, we presented qualitative comparison between the present wave data (obtained from the RON buoy of Alghero and from the ECMWF analysis data) and those reconstructed by (Bertotti et al., 1998) that refer to the storm of November 1995 that caused the sinking of Parsifal. We have found a substantial similarity in terms of sea-state magnitude between the two events.

Currently, the ongoing research activities are focused on improving the comparison between the measured wind data and the calculated ones by using the trim boat measurements, as obtained from GPS measurements, and by using a more accurate relationship for the vertical profile of the wind speed, that takes into account the sea surface roughness in a real sea state (i.e. presence of waves).

Furthermore, it is worth noticing that in the future a comparison between the measured wave data, as obtained by the signals measured by the three high-precision GPS placed on the sailboat, and the ones obtained from the available source of wave data (e.g. numerical models, remote sensing techniques, wave buoys, etc.) will be performed.

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