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The Editor
Dr. Joanna Staneva
Natural Hazards and Earth System Sciences

Dear Dr. Joanna Staneva,

Please find attached the responses to the reviewer comments for the manuscript **NHESS-2022-103** entitled ***"Wind-Wave Characteristics and extremes along the Emilia-Romagna coast"***.

We have carefully examined the constructive suggestions made by the reviewers and we have taken full account of their comments. Hence, the necessary corrections and modifications are incorporated as suggested by the reviewer. The following is a point-by-point response to the comments and inquiries made by **reviewer 2**.

We would like to thank the reviewer for the constructive and competent comments/suggestions which helped to improve the manuscript highly in terms of clarity and readability.

Respectfully yours,

Umesh P. A. (on behalf of all co-authors)

<u>Responses to Reviewer 2:</u>

Dear Reviewer,

We thank you for the thorough evaluation of our manuscript. The constructive comments and suggestions have improved the manuscript highly. Below, we address each of your comments in turn. The comment is repeated in italics and our authors' response (AR) directly follows highlighted in red color. The AR contains our reply and a brief description of what has been modified in the manuscript. In the revised manuscript, the corrections suggested have been addressed.

Best Regards,
Umesh (on behalf of all co-authors)

<u>General comments</u>

The manuscript represent an important work and a substantial contribution to the understanding of natural hazards on ER area by the use of new methods like the hazard index. The used data and tools are up to international state of the art.

The scientific approaches and the applied methods are valid and discussed in an appropriate and balanced way. There are many references considering previous works on the area. The scientific methods and assumptions are clearly presented and can be reproduced thanks to the codes in annexe. The discussion could be broadened by a point on wind quality which is detailed below in this review.

The scientific data and results are precisely and clearly illustrated and presented with appropriate figures and tables. Rare remarks below are aimed to document still wider the results.

<u>AR:</u> Thank you for your in-depth and detailed evaluation of our manuscript. The authors have noted the reviewer's suggestions and comments. The corrections suggested by reviewer #2 are incorporated into the revised version of our manuscript.

<u>Specific comments</u>

(a) *The forcing by a 6-hourly wind at 0,125° on a area with such an important space and time variability than the Adriatic Sea seems to be the first limit of the wave climatology. Several results show it : first of all, the degraded scores on summer. Indeed, you show the worse correlation and bias of SWH in this season. The wave model understimate the wave height of 11 cm. It is known that global atmospheric model at such a scale don't represent explicitly the convection and are not appropriate to simulate surface wind due to heating flux that occurs at this season. It is consistent with the lack of energy in the wave model compared to the observation.*
This limit also appear through the small standard deviation in summer. Is the standard deviation of the observation so weak than in the model during this season ? A part of this decrease is due to the summer low wave height, but it could also come partially from a poor representation of convective wind.
I would recommend to better document this limit by some elements, for instance :

- a comparison with an observed wind climatology, even by a station on land. It could also be the climatology from a mesoscale model with hourly time step. Does it present the same standard deviation of wind speed in summer than the experiment, the same wind rose ? Are the relative quality of wind different between the seasons ?

- more explorative : what is the error in SWH or period depending on the wind direction observation (or from a mesoscale model) ? Indeed the global ECMWF model may have specific limitation for some local wind.

Moreover, a mention of this limit should appear in the discussion. Even in winter a 6-hourly wind has consequences on the model wave quality. Mediterranean sea is known for its very dynamic storms.

AR: The reviewer comment is well appreciated and a clarification is offered.

We present a validation of wind speed and direction from available data sets for the locations of Porto Corsini, Porto Garibaldi and Cesenatico Port, locations are given in Table 1.

Table 1: Details of coastal stations used for validation of wind forcing

Station	Lat (°N)	Lon (°E)
Porto Corsini	44.49	12.28
Porto Garibaldi	44.67	12.24
Cesenatico Port	44.20	12.40

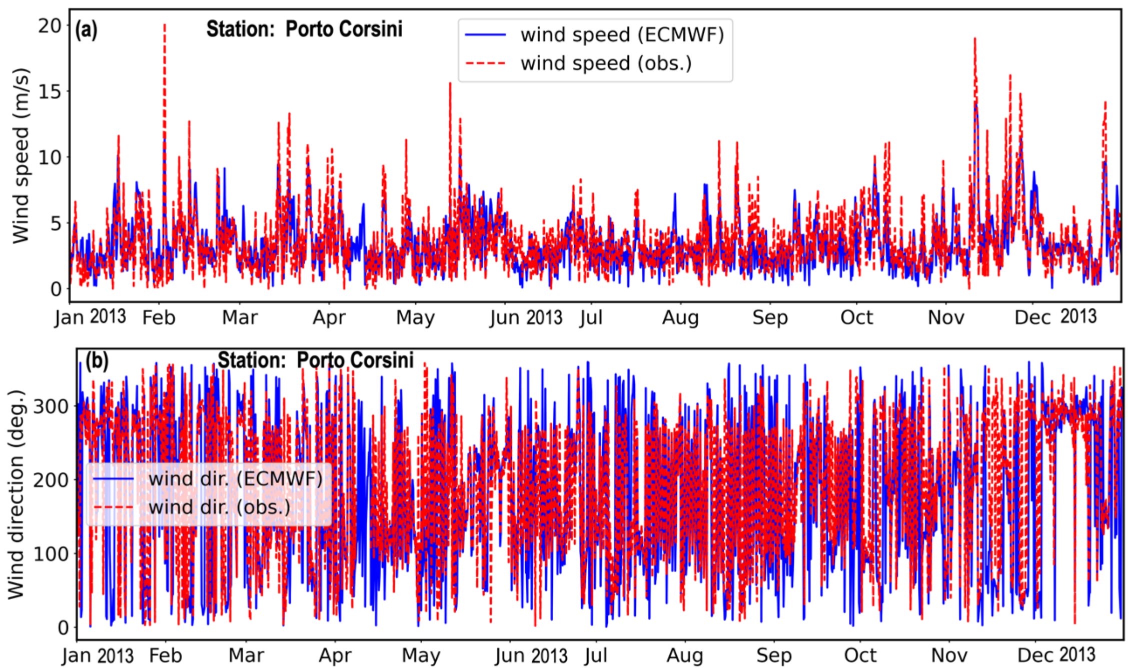

Figure I: Comparison of ECMWF winds with measurements at the Porto Corsini station for the year 2013: (a) wind speed (m/s), and (b) wind direction (deg.).

Figure I (a, b) shows the comparison of wind speed and direction with the observations at Porto Corsini for the year 2013. The ECMWF winds show an overall consistency with observations. The comparison statistics for all three stations is shown in Table 2. We see that overall, the correlation at all stations and seasons is higher than 0.7 with the exception of summer and autumn, as expected because of intense air-sea interaction in the coastal boundary layer which are not captured by the ECMWF model. The Bias is low while the root mean square error between observations and ECMWF is about 2 m/s in all seasons. This is visualized also with the wind speed scatter plots in Figure-II.

Table 2: Quality assessment of ECMWF winds with observed wind speeds for selected stations (refer Table 1).

Statistics	Wind speed (m/s)				
	(a) Porto Corsini [Year: 2013]				
	Full year	**Winter**	**Spring**	**Summer**	**Autumn**
R	0.7	0.7	0.7	0.5	0.7
Bias	-0.2	0.2	-0.1	-0.3	-0.4
RMSE	1.8	1.8	1.9	1.6	2
(b) Porto Garibaldi [Year: 2018]					
R	0.7	0.8	0.7	0.5	0.8
Bias	-0.2	0.2	-0.3	-0.5	0
RMSE	1.8	1.7	1.6	1.9	1.9
(c) Cesenatico Port [Year: 2015]					
R	0.7	0.8	0.8	0.5	0.6
Bias	-0.2	0	-0.3	-0.6	0.2
RMSE	1.9	1.7	2	1.9	2
R: *Correlation,* ***RMSE****: Root Mean Square Error*					

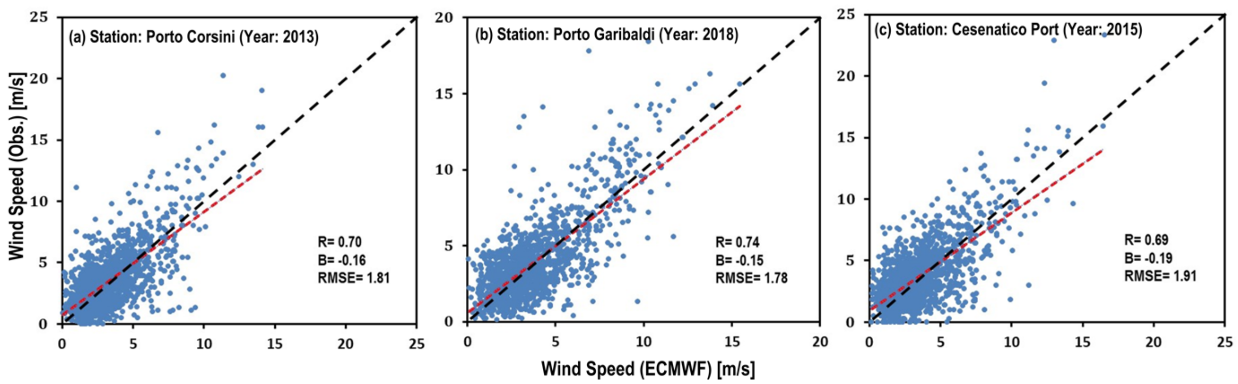

Figure II: Scatter plot of wind speed (m/s) at the three stations **(a)** Porto Corsini, **(b)** Porto Garibaldi, and **(c)** Cesenatico port. The red dotted lines represent the best data fit and the black dotted lines indicates the 1:1 slope. *[R: Correlation, B: Bias, and RMSE: Root Mean Square Error].*

Thus, we argue that in this region ECMWF wind quality is reasonable. Naturally in the future higher resolution limited area modelling winds could be used to reinforce the characterization of the wind climatology in this area but at this time, long time series are not available.

We added the following explanation at line 140-144 (Page 6 in the revised manuscript), along with Table 1 (line 146, page 6 in the revised manuscript) indicating the wind speed validation statistics in the revised manuscript:

The model winds were validated at three stations, namely Porto Corsini (44.49°N, 12.28°E), Porto Garibaldi (44.67°N, 12.24°E) and Cesenatico Port (44.20°N, 12.40°E) along the ER coastal belt. The wind speed comparison statistics as indicated in Table 1 showed correlations of the order 0.7, with bias of -0.2 m/s indicative of underestimation of wind speed, and RMSE of 1.8 m/s. Larger biases of the order of -0.6 m/s and correlations as low as 0.5 exist during summer and some autumn seasons.

Furthermore, in the conclusions section we added a comment about the limitation of the present study due to the low-resolution winds. The comment is added in lines 569-573, page 26 in the revised manuscript:

Another limitation is that a 10-year period would generally not be enough to bring out the complete climatological wave response to winds. ECMWF winds were too low resolution before 2010 and no downscaled limited area meteorological forcing is available. Hence this 10-year period could be the first reference database for the prevailing wind-wave characteristics in the coastal belt for researchers and coastal engineers/designers. Future works definitely should deal with longer simulation periods and also higher resolution winds.

(b) ***l.151*** *Sensitivity experiments for wave model parametrizations: no test of different parameters value of each physics has been conducted, at least there is no mention of it in the paper. The validation of the method by 3 model configurations seems all the same sufficient. But the conclusion could be less affirmative regarding the better capacity of ST6 to represent sea state on ER area. We could think that another parametrisation of ST4 than the one in Ardhuin et al. 2010 could have produced better results than EXP3.*

So I advice to moderate the sentence l.421-422 (Summary and conclusions) in a way like : « The sensitivity tests has shown the good accuracy of ST6+SHOWEX physics for wave hindcasts in the study area. »

AR: As suggested by the reviewer the sentence is corrected as shown below. These changes appear in lines 536-537, page 25 in the revised manuscript.

The sensitivity tests has shown the good accuracy of ST6+SHOWEX physics for wave hindcasts in the study area.

(c) l.160 and 191: *It would be very interesting to add the mean value of the observation for the sensitivity periods and the whole 10 years. Thus the reader would be aware of the relative error at this point.*

AR: Thank you for pointing out this. As suggested the mean values of the observation for the sensitivity periods and the validation period (2010-19) is indicated in the respective sections for better clarity. These changes appear in line 199 (page 8) and lines 228-229 (page 10) in the revised manuscript.

(d) l.267: *Is it possible to add a comparison against the observed wave rose of the station 6?*

AR: The authors very well agree with the reviewer that it would be good to have observed wave rose of the station 6 and hence based on available data for the Cesenatico station the wave roses for selected years are compared with the model estimates as shown in Figure III.

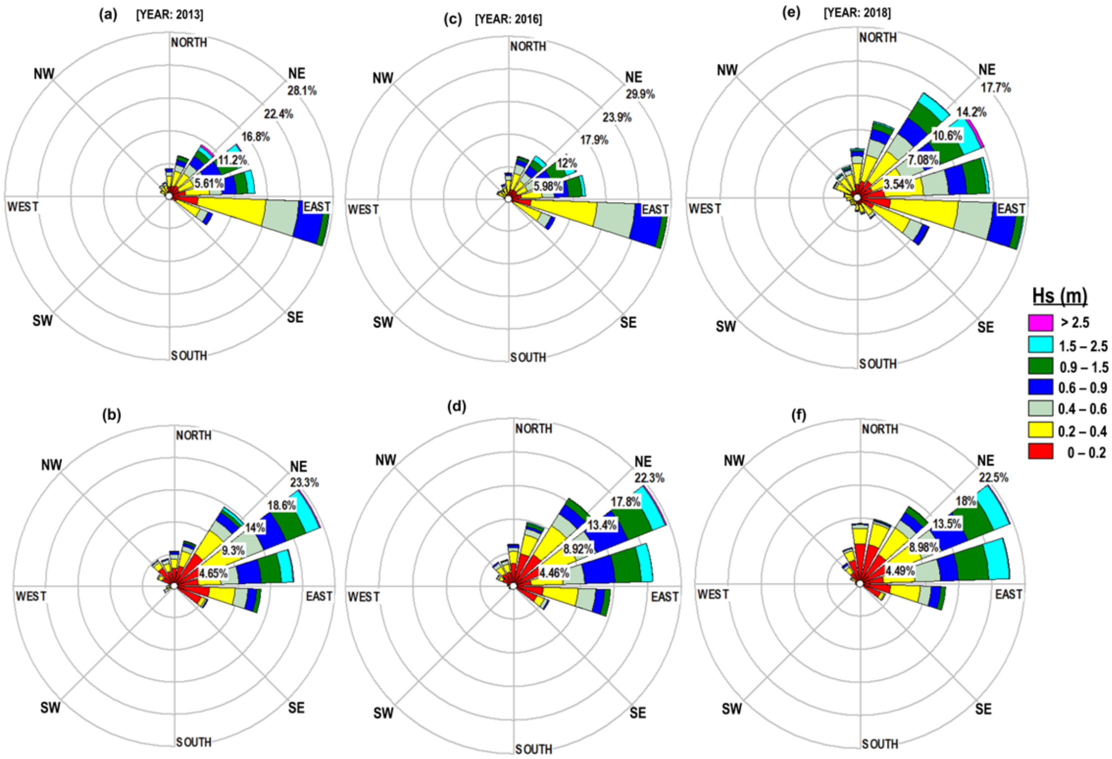

Figure III: Comparison of directional histograms of wave heights: buoy (a, c, e), and simulated data (b, d, f) at the station 6 (Cesenatico).

These changes including Figure 8 (page 16 in the revised manuscript) showing the comparison against the observed wave rose of the station 6 are presented in lines 354-361, page 16 in the revised manuscript and as shown below.

Based on available buoy data for the Cesenatico station the observed wave roses are compared with the model estimates for selected years as shown in Fig. 8. Overall, the modelled wave roses (Figs. 8b, d, f) shows a reasonable correspondence with the observed data (Figs. 8a, c, e), even with some difference in magnitudes. An underestimation of model wave heights in the lower ranges is noted. Comparing the directional distributional of waves, the directions are comparable being in the same sectors but there exist higher differences in their magnitudes. Similar wave climate by the Nausicaa buoy located offshore of Cesenatico is reported in studies by Armaroli et al. (2012), and Romagnoli et al. (2021), which shows that this is the representative wave climate of the Emilia-Romagna coast. This qualitative comparison shows that at the Cesenatico station overall characteristics of waves are fairly reproduced by the model.

(e) l.304: *The bimodality in winter and summer doesn't seem so obvious on the graphics. In winter, I consider visually 3 cases of double peaked spectra. In summer, it is more complicated to distinguish and I don't see a lot more than 1 case. Thus majority of cases appear to be single peaked.*

I would recommand either to write clearly the number or proportion of cases that are bimodal by season in order to attest it solidly, or to pursue the exploration of data by adding more cases. Indeed all the days of February (August) of the 10 years could be examined. The proportion of bimodal cases could then be adressed on a significant number of occurrences.

If the results show effectively a proportion of around 30% of bimodal spectra on these 2 seasons, I would nuance the conclusion. For instance, it would be appropriate to write « during winter and summer the spectra have often/sometimes bimodal characteristics », than « during winter and summer the spectra have bimodal characteristics » (l304-305).

AR: The reviewer comment is well appreciated and for better clarity the authors analyzed the model instantaneous wave spectra data for the complete period of 2010-19. The seasonal percentage of occurrence of single, double-peaked and multi-peaked spectra is presented in Table 3 as shown below.

Table 3. Number of occurrences of single-peaked, double-peaked, and multi-peaked wave spectra at Cesenatico location for different seasons (2010-19).

Seasons (2010-19)	Single-peak (%)	Double-peak (%)	Multi-peak (%)
Winter	31	45	24
Spring	32	45	23
Summer	27	53	20
Autumn	33	49	18

The conclusion from this analysis (as shown below) are included in the lines 390-396 (Page 18 in the revised manuscript) and in the summary & conclusions section (lines 551-553, page 25). Table 5, indicating the number of occurrences of single-peaked, double-peaked, and multi-peaked spectra at Cesenatico location for different seasons (2010-19) is also added (Page 19, line 400 of the revised manuscript).

The spectra vary considerably over the years and in general, the wave spectra at the Cesenatico coastal location showed signatures of single and double-peaked spectra for the period 2010-19 (Table 5). The wave spectra were prominently double-peaked during all seasons (45-53 %), along with single-peaked spectra but with a lesser percentage of occurrences (27-33 %). Double peakedness was highly prominent in summer season (53%), while winter, spring and autumn showed dominance of single-peaked spectra (31-33 %). As evident from Table 5, the percentages of the number of peaks (single/ double) in the Cesenatico location clearly depicts the co-existence of sea-swell characteristics in the study domain.

Technical corrections

(i) ***l.24:*** *« is crucial » instead of « is a crucial »*

AR: The correction is made as indicated.

(ii) ***l.30:*** *« Other state-of-the-art models include » instead of « Other state-of-the-art models includes »*

AR: We have applied the reviewer suggestion.

***(iii) l.89:** the formulation isn't very clear. Proposition : « Armaroli et al. (2012) reported that waves originating from east correspond to a proportion of 91%HS < 1,25 m, owing to the controlled fetch. »*

AR: We revised the sentence as suggested by the reviewer (line 110, page 5 of revised manuscript).

***(iv) l.93:** « action-density » without space.*

AR: The typo error is corrected as pointed out.

***(v) l.109:** « The model spectrum is sampled in 24 directions and 30 frequencies (0,0500-0,7932 Hz), with an increment factor of 1.1.*

AR: The sentence is reframed as suggested by the reviewer (line 131, page 6 of revised manuscript).

***(vi) l.113:** ST4 isn't mentioned there, wich is a bit confusing. Indeed ST4 and ST6 are both introduced earlier, and are actually used in the validation. It would be clearer to add a mention here of JONSWAP and ST4, precising that they were used only for the validation.*

AR: Thank you for the comment. We realized that repetition was not needed so we deleted the phrase with ST6 in this position.

***(vii) l.176:** Please indicate in the legend of the table 3 the number of used buoys to be sure that it takes into account only the station 6 or the whole control points.*

AR: The legend of Table 3 (i.e Table 4 in the revised manuscript) is corrected as shown below for better clarity (line 226, page 10 in the revised manuscript).

"Statistics of the comparison of buoy measurements (Cesenatico, Station 6) with model results for 2010-2019".

***(viii) l.388:** The chosen value of Xc could appear in the legend of Table 4. Its value appears only in page 20.*

AR: The Xc value is added in the legend of Table 4 (i.e. Table 6 in the revised manuscript) as indicated below (line 502-503, Page 23 in the revised manuscript):

"Table 6. The best-fit Weibull scale and shape parameters for Hs (columns 3-4) at the eight control points. Column 5 shows the estimated χ^2 values. Mean, variance, skewness, and kurtosis of the Hs (columns 6-9) computed from the model data (left sub-columns) and from the Weibull fit parameters (right sub-columns), and the wave height hazard index (with threshold value Xc, Hs=1.08m) calculated with (eq. 6) for the eight control points (indicated in column 10) along the Emilia-Romagna coastal strip".

***(ix) l.418:** I would suppress the upper-case C of Conclusions, except if asked by the editor.*

AR: The typo is corrected as suggested.

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