Dr. Umesh P. A. University of Bologna ITALY

**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 1**.

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)

# **Responses to Reviewer 1:**

### 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 blue 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)

## **General comments**

The manuscript (MS) examine an in-depth analysis of wind-wave characteristics along Emilia-Romagna (ER) coasts (northern Adriatic Sea, Italy) for 10 years starting from 2010 after fine tuning the numerical model-Wave Watch III at a buoy location. I appreciate the author's efforts to include multidimensional analysis for better understanding of the seasonal and extreme wave impacts along the selected coast. The flow of the MS and specially discussion of research gap gives a clear idea for a reader about this work. There is no doubt about the quality of work. But these are some suggestions for authors which can even elevate the clarity of this research.

**AR:** 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 #1 are incorporated into the revised version of our manuscript.

**a)** There is a great discussion on wind speed in the MS. The wind speed values (section 4.1.1) seems like a low range for me. I strongly recommend the authors to check those values with in-situ measurements if you have any.

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

The study uses ECMWF analysis winds at 0.125° horizontal resolution every 6 hourly as inputs to the wave model. In section 4.1.1. the Figure 4, presents the <u>mean wind speed</u> and direction for the period 2010-2019 in the model domain. As pointed out by the reviewer the wind speed ranges are re-checked and confirmed.

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.

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

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



**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.

Wind speed (m/s)							
Statistics	(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		
RMSC	1.9	1.7	2	1.9	2		
<b>R:</b> Correlation, <b>RMSE</b> : Root Mean Square Error							

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



**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 (see comment c below).

**b)** *Authors could discuss a bit more literatures on research conducted in similar way along global study regions than Adriatic Sea* 

AR: As suggested authors have added a paragraph on similar studies reported across the globe.

The manuscript has been modified to highlight this point as shown below (Page 2, lines: 31-41 in the revised manuscript).

Over the globe, wave climatology studies using reanalysis datasets and model hindcasts are reported by Carter et al. (1991), Sterl et al. (1998), Young (1999), Cox and Swail (2001), Sterl and Caires (2005), Hemer et al. (2010), Semedo et al. (2011), Young et al. (2011), Zheng et al. (2016), and De Leo et al. (2020). Wind speed and wave height climatologies with emphasis on the Southern Ocean is described in the works of Young (1999), Young and Holland (1996), Young and Donelan (2018). Past studies on regional scales (Young et al., 2020) based on observations and numerical modelling were also reported by various researchers on different regions such as: Northern Hemisphere (Woolf et al., 2002; Reistad et al., 2011); Southern Hemisphere (Gorman et al., 2003); Mediterranean Sea (Lionello and Sanna, 2005; Lionello,

2012; Clementi et al., 2017; Ravdas et al., 2018; Morales-Márquez et al., 2020; De Leo et al., 2021; Barbariol et al., 2021; Amarouche et al., 2022), Persian Gulf (Kamranzad et al., 2013), western Australia (Bosserelle et al., 2012), eastern North Atlantic (Dodet et al., 2010), southeast Pacific ocean (Aguirre et al. 2017), Indian Ocean (Stopa and Cheung, 2014), Black Sea (Akpinar and Komurcu, 2013; Arkhipkin et al., 2014; Fedor et al., 2020), and China Seas (Zheng and Li, 2015; Qian et al., 2020).

**c)** Could 10 years include the climatological impacts of wind-wave characteristics? The MS analyse more of seasonal aspects than climatological/long-term variation.

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

The aim of the study is to report the wind-wave characteristics specific for the Emilia-Romagna coastal belt. The authors very well agree to the fact that a 10-year period would generally not be enough to bring out the climatological response to winds. However, ECMWF winds were too low resolution before 2010 and no downscaled limited area meteorological forcing is available. Hence this study for a 10-year period could be useful for researchers and coastal engineers/designers as a reference database for the prevailing wind-wave characteristics in the coastal belt. Future works definitely should deal with longer simulation periods and also higher resolution winds.

We added this comment in the conclusions, line 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.

#### **Specific comments**

**1.** It will be greatly appreciated to mark the names mentioned in text to be on the figures. For eg. Line 74 mentions about Po delta, it will be easier for the readers to understand the work more if it's marked in the figure too for visualization.

<u>AR</u>: The reviewer comment is noted and considered. As suggested the Figure 1 (page 4 in the revised manuscript) is corrected by marking the location specific names in the Emilia-Romagna coastal belt for better clarity and visualization.

2. Line 26: Than IPCC, 2007, now IPCC report citations could be included.

**AR:** As suggested the more recent IPCC report is added, in lines 27-30, page 1 in the revised manuscript, as shown below:

IPCC (2021) indicates the necessity of a regional evaluation of climate change, with various target factors that can aid in risk management and policy making. The report points out that over the 21st century nearshore regions will encounter sea level rise, thereby adding to more persistent coastal flooding (across low lying regions) and associated coastal erosion.

**3.** What is restricted/controlled fetch? It will be good to get more clarity on MS too.

**<u>AR</u>**: Restricted fetch means a condition where the wave generating area (i.e. fetch) is relatively small. We added the sentence in lines 97-98, page 4.

- **4.** *Line* 85: *Indicating the dominance of swell or sea in the selected study domain can enhance the knowledge beforehand.* 
  - **<u>AR</u>**: As suggested information on sea/swell dominance in the study area is added as shown below:

Thus the swell seas are controlled by the Sirocco winds and the seas are dominated by the Bora winds (Bonaldo et al., 2017).

These changes appear in lines 99-100, page 5 in the revised manuscript.

5. Figure 1: This can be more legible and well distributed. The mesh and bathymetry info can be in one figure. The figure is not indicating anything like region, the Sea etc. Including that can be a good idea. Figure 1. (a) can be an inset image and other information are important could be enlarged. A legible north arrow with map scales, coordinates lat & long N, E degree etc are also recommended (this comment is applicable for all maps).

**<u>AR</u>**: As indicated in the response to specific comment 1, the Figure 1 (page 4 in the revised manuscript) is modified for better clarity including all suggestions. The authors wish to keep the bathymetry and mesh as separate figures and regions in the map are indicated and also the legends are corrected as suggested. The correction is applied for all maps as suggested.

6. Give the legend names (eg. Figure 7, wave height (m) than mentioning meter in legend ranges), x- and y-axis variables in each plots, etc

**AR:** As suggested all figures are checked and necessary changes are made in the legend and labels wherever appropriate. The revised figures are inserted in the revised manuscript.

7. Line 199: Mention which ECMWF wind: ERA5, ERA interim etc.

**<u>AR</u>**: As mentioned everywhere in the manuscript, we use ECMWF analysis winds (see line 140, page 6 in the revised manuscript) not reanalysis. We added in the caption of Fig. 4 (line 270, page 12 in the revised manuscript) ECMWF analyses specification.

8. Appreciate explaining why the zones or control points are assigned? Or on what basis?

**AR:** The zones are divided based on the various characteristics such as trophic conditions, prevailing local wind-wave characteristics. The control points are the standard locations along the Emilia-Romagna coastal belt where regional agencies such as Arpae carry out measurements. Hence the same has been used in the present study.

We added the following comment at new line 102-105, page 5:

The ER coastal area is subdivided into three major zones (Fig. 1c) which correspond to different coastal trophic conditions (Fiori et al., 2016). The station locations are the land town locations perpendicular to which the environmental agency monitoring transects are done monthly and weekly to monitor the marine ecosystem good environmental status. Thus, knowing the prevailing winds and waves at these locations could be of importance for the management of this important coastal area.

9. Line 156: Why there is no ST6+ JONSWAP (EXP4)?

**AR:** The authors understand this comment and would like to clarify that a combination of ST6+ JONSWAP is not considered because already JONSWAP bottom friction showed less performance in EXP1.

We added the following comment at line 192-193, page 8 in the revised manuscript:

The combination of ST6 with JONSWAP is not considered because this bottom friction is not suitable for sandy beaches as already the EXP1 will show.

**10.** *Line 157: Apt to mention why the representative months are February and September?* 

<u>AR:</u> The months of February and September are considered mainly representing the seasons namely winter and autumn.

These changes appear in line 192, page 8 in the revised manuscript.

**11.** Section 3.3: Why the validation was done for each year separately? What is the significance of that?

**AR:** A clarification is offered. The comparison of significant wave height is shown for each year in Fig. 2 (Page 9) so as to have an immediate check on the reproduction of wave heights by the model at the buoy location over the years 2010-19. This is sometimes called *"consistency check"* in meteorological literature which we now mention.

We added the following sentence at line 209-210, page 8 in the revised manuscript:

This is a consistency check of model against observations as required for "goodness" indicators in numerical weather predictions (Murphy, 1993).

**12.** Figure 3 (*f*-*j*): It might be suitable to use 45-degree line than best fit line to best understand the underestimation and bias in validation. Check for wave characteristic notations in graph axis too.

**<u>AR</u>**: As suggested the line of no deviation (1:1 slope) is added in the Figure 3 (page 11, in the revised manuscript). The notation in the graph axis is checked and corrected. The figure legend is corrected (lines 248-249, page 11 in revised manuscript).

**13.** Sub-section 4.1.1 is the only subsection under 4.1, which can be merged with section 4.1 itself.

**AR:** The authors wish to retain the section heading as such.

14. Section 4.1.1: The wind speed values seems to be lower than a desired value. And SD is more than the annual mean wind speed which is not right. Check those values for wind speed everywhere. The mean value can come around 5 m/s to 20 m/s to produce the wave characteristics indicated in the MS. Make changes in text and figures accordingly. I recommend comparing these values with in-situ measurement if you have any for authors clarity.

<u>AR:</u> The authors have responded to this comment in the general comments (a). Please see above.

15. Figure 4 &6, mark degree N, E on Latitude and Longitude coordinate axis

<u>AR:</u> As suggested the Figure 4 & 6 (Pages 12 & 14 in the revised manuscript) axis labels are corrected.

**16.** *Revise Figure 5 according to new wind speed data and try to correlate Figure 5 and Figure 7 for any influence of predominant wind direction on wave characteristics.* 

<u>AR:</u> The authors would like to clarify again that there is no error in the wind data as responded in the **general comments (a)**.

**17.** *Line 285: Sticking to one notation of position can help the reader understand better. Either 'control points' or 'stations. Indicating 'point' can sometimes make confusions.* 

**<u>AR</u>**: The control points (1-5,7,8) refer to the locations considered along the Emilia-Romagna coastal belt where the wind-wave characteristics was analyzed. But the location 6 alone is referred as station because it the coastal buoy location where the validation was executed. It is to be made clear that other 7 control points are not stations but are points chosen by authors for the wind-wave analysis in the present study.

**18.** What is the significance of analysis of 25<sup>th</sup> day of month and monthly mean seasonal spectra for each year? What are the concluding remarks of these analysis could be mentioned?

# AR: The 25<sup>th</sup> day of the month is chosen to show an example and it just our choice.

The instantaneous spectra are presented to show the co-existence of sea-swell characteristics in the study domain. Unlike the averaged spectra the instantaneous spectra provide a clear picture of the sea-swell dominance characteristics during the period 2010-19.

The monthly mean seasonal spectra are considered for each year to have an idea about the evolution of wave spectra for the years respective of each season. This gives us an idea about the spectral shapes as well as the spectral features (single/double-peaked) prevalent in the coastal belt. Note that there is no other study that has reported on the wave spectra characteristics in the Emilia Romagna coastal belt. The limitation being the non-availability of wave spectra measurements for comparison.

For better clarity the authors analyzed the percentage of occurrence of single and doublepeaked spectra for the various seasons for the 10 years. The conclusion from this analysis is 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 in different seasons (2010-19) is also added (Page 19, line 400 of the revised manuscript).

**19.** *Line 315: 'As seen from the Fig.???' to be filled* 

**AR:** The Figure number is added as suggested.

**20.** *Line 425: 'the comparison of Tm and Tp..... 10 years' needs clarity. Please reframe by adding adequate information.* 

**AR:** The sentence is corrected for better clarity (line 540, page 25 in the revised manuscript).

**21.** *A discussion on limitations/uncertainties of this study could be added. Such as limitations of Weibull distribution.* 

**AR:** The author comment is well appreciated, and limitations are added in the conclusions. This has been stated in the revised manuscript (Pages 25 & 26, lines 563-568 in the revised manuscript) and as shown below.

The limitation in the present study is the non-availability of wave spectra measurements at the coastal locations for validation. Future study will aim to consider data assimilation (de Rosnay et al., 2022) and to have higher resolutions winds as forcings for the wave model. In the context of heavy tailed data sets the Weibull distribution may not represent a best description of the peak and tail. These limits can be overcome by adding more parameters such as the 4-parameters exponentiated Weibull distribution (Mahmoudi et al., 2018) such that the extra shape parameter can provide more versatility to the distribution in the shape of the tails.

#### **Technical /minor corrections**

*i.* Line 13: 'direction' to 'wave direction'

**AR:** The correction is made as indicated.

*ii.* Significant wave height could be H subscript s. This applies with every wave characteristic. Using the global notations can be beneficial for a wider audience in understanding this research more.

**AR:** The authors have used uniform abbreviations to represent the significant wave parameters mentioned in the text such as significant wave height (Hs), Mean wave period (Tm), peak wave period (Tp), and mean wave direction ( $\theta$ m) which are mostly commonly used ones. Hence the authors wish to retain it in the present form.

*iii.* Expand acronym at first appearance will be appreciated. Few eg: are line 26 IPCC, WW3 is not expanded anywhere in MS, Line 101: 'JONSWAP parameterization (Joint North Sea Wave Project)', this can be 'Joint North Sea Wave Project (JONSWAP) parameterization', Explain ST4, ST6, CFL etc. Could use the acronyms after defining. PDF is expanded twice and is using the same.

**<u>AR</u>**: The acronym expansions at its first appearance is checked and corrected as pointed out (IPCC, WW3, CFL, PDF). In the case of JONSWAP and SHOWEX the authors prefer to indicate the expansion in brackets as they are well known formulations. ST4 and ST6 are wind-input dissipation parametrizations, and they are mentioned the same way as indicated in the WW3 manual. Repetitive mention of PDF is corrected as suggested.

*iv. Line 121: check '~4.5 km hourly'* 

**<u>AR</u>**: The typo is corrected.

v. After defining Significant wave height (HS) use the same in everywhere.

**AR:** The same has been responded in technical/minor corrections, comment (ii).

vi. I recommend the authors to make the decimal places consistent in entire MS. Eg. Line 126 location coordinates has 4 decimal places. Most research work would go for 2 decimal numbers.

<u>AR</u>: The location coordinates are corrected to two decimal places as suggested. While in the tables indicating the statistics the authors wish to retain up to third decimal places and hence the same is retained.

vii. Line 180: 'measurement's' to 'measurements'

**AR:** The correction is made as indicated.

viii. Line 188: 'Fig. 3' to 'Figure 3'

**AR:** The correction is made as indicated.

*ix. Line 190: 'relatively a good' to 'relatively good'* 

**AR:** The correction is made as suggested.

*x. Line 250: 'and northern' to 'and the northern'* 

**<u>AR:</u>** The correction is made as suggested.

- *xi.* Line 327: 'upon blowing of the wind' to 'wind characteristics'AR: The sentence is corrected as indicated.
- *xii.* Line 348: 'costal' to 'coastal'

**<u>AR:</u>** The typo error is corrected.

xiii. Line 423: 'A Hs' to 'An'

**<u>AR:</u>** The typo error is corrected.

*xiv. Line 435: 'waves' to 'wave'* 

**<u>AR:</u>** The correction is made as suggested.

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