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Discussions

Interactive comment on "Ensemble hindcasting of wind and wave conditions with WRF and Wavewatch III® driven by ERA5" *by* Robert Daniel Osinski and Hagen Radtke

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Dear reviewer #1,

Thank you for your review and your comments. Additional supplemental material was prepared and uploaded regarding the calibration/validation procedure of the WWIII model and ensemble hindcasts of the storms Rafael and Toini. Please find in the following answers to your comments.

1 Major comments:

#1) The introduction is well written from the point of view of ensemble modelling, but it totally lacks material on Baltic Sea waves and the relevant research. Please see my list of references in the end as a starting point. Also the discussion of the results needs to be tied better to what we as a community know about Baltic Sea wave conditions.

Thank your for the list of publications concerning wave conditions in the Baltic Sea. We will include additional information and citations to existing studies in the introduction of the article. Following the article of Björkqvist et al. (2017) we added ensemble hindcasts of two additional storm events in the supplemental material and test another discretization of the energy spectrum as proposed by reviewer #2, following Soomere (2005). This will be discussed in the article. We also add a short paragraph on Baltic Sea wave climate to the introduction.

#2) While I can get on board with using only one storm in this study, I think it is very unfortunate that the authors have chosen the 2002 storm when no data from the NBP wave buoy is available. For example the 2004 Rafael storm would have wave buoy data available for validation. It might be unreasonable to redo the model runs (I will leave that to the authors), but at least the authors should discuss how realistic the highest values (Hs>11 m) are by comparing to what we know about the Baltic Sea wave climate (again, see the list of references at the end).

Storm Rafael and Toini were additionally hindcasted with the newest setup (please see the supplemental material). WWIII was calibrated on basis of the UERRA/Harmonie-v1 wind data and gives a satisfactory performance (please compare the supplemental material). It is also shown that the wave heights for the two additional storms (Rafael and Toini) with both WRF-ARW and UERRA/Harmonie-v1 show realistic wave heights.

For this reason, we assume that the significant wave height for the 2002 event with the unperturbed WRF-ARW wind forcing is also realistic. The perturbations of the WRF-ARW model physics were not tuned. To be able to do this, several extreme events would have to be hindcasted. One reason for the extreme wave heights in some ensemble members could therefore be an overdispersion of the wind fields from the WRF-ARW ensemble. In our WRF-ARW setup, the roughness length over the sea is assumed to be constant. Under severe storm conditions the sea surface roughness should increase with an effect on the wind field resulting in a limitation of the wave growth. A coupled WRF-WWIII setup would take this into account. By comparing the EPSgrams from the ECMWF (see for example ECMWF presentation [1] slide 20), one can see that the range of uncertainty can be very large. Based on a limited number of observations of extreme wave heights, it is therefore hard to judge which significant wave height is still realistic. We will discuss this in the article.

2 Specific comments:

#1) The wave model is "WAVEWATCH III", not "Wavewatch III"
This will be changed.

#2) page 1 line 25: Perhaps have a paragraph break at "In principle"?
A paragraph break is added there.

#3) page 3 line 23 "The ERA5 dataset was used in this study to drive the atmospheric model WRF, a coarse Wavewatch III wave model to provide lateral boundary conditions for a Wavewatch III wave model with higher resolution and for comparison with the

[1] https://confluence.ecmwf.int/download/attachments/55116817/OCEAN_WAVE_FORECASTING_AT_ECMWF_version_201602.pdf?api=v2

model results." This is a bit unclear and should perhaps be rewritten.
Changed to: "ERA5 is used for the initial and lateral boundary conditions for the atmospheric hindcasts with the WRF model. Lateral boundary conditions for the Baltic Sea WAVEWATCH III setup originate from a setup for the North Sea. This coarser model is driven by ERA5 winds. ERA5 reanalysis and EDA data are used for comparison of the hindcasts produced with WRF and WAVEWATCH III."

#4) page 5 line 3 "UERRA/Harmonie-v1 was used for calibration and validation of the setup against one month of data from buoys available from the Copernicus Marine environment monitoring service 12 (CMEMS) with the previous Wavewatch III v5.16 version."
Information to these questions is added in detail in form of supplemental material. At this part of the article, we will refer to this supplemental material. We see this article more as a demonstration of a principle idea for an ensemble hindcast procedure. For this reason, we think that it is sufficient if these details are presented as a supplement.

#5) Please add some kind of Table of the different type of ensembles. As written, it is a bit hard to follow.
Will be added.

#6) Fig 2: "results shown at 19.39°E, 56.17°N". Show this point in Fig. 1.
Will be added.

#7) Fig 3.There are a lot of subplot. Would it be sufficient to just use max difference to the mean,or to reduce the number of panels in some other way?
Figure 3 includes only the ensemble mean, minimum and maximum of the different ensemble generation approaches. Only the difference to the mean would neglect the

fact that the spread cannot be assumed to be symmetric around the mean. Figure 4 includes also a lot of subpanels. This presentation called postage stamps, is often used to present ensemble forecasts. For this reason, we prefer to keep in this way.

#8) page 10 line 24: A shortcoming of this procedure ... .A bit unclear what is meant by "this"
Changed to: "A shortcomig of the presented procedure for the wave hindcasts ..."

#9) page 11 lines 1-2: Baltic Sea not really swell dominated, so this shouldn't be an issue in your results, and the discussion seems a bit off key, especially in the middle of the paper concentrating on the Baltic Sea. It is up to the authors if they want to keep it. Just thought I would point out how it looks from a Baltic Sea perspective.
ERA5 is a global reanalysis. This is why the presented procedure for ensemble hindcasting can be applied for any region in the world. For this reason, we mentioned this point.

#10) page 13 line 2.Perhaps start a new paragraph with "Figure 8 shows..."?
We will start there a new paragraph as suggested.

#11) page 13 line 19 "The time step of a high resolution ocean or wave model is normally below one hour."This is slightly misleading, since one hour is a typical time resolution for the output of a wave model. The time step of a wave model can be counted in seconds (typical for explicit numerical schemes) or minutes (typical for implicit numerical schemes). The wave model therefore need updated wind information e.g. every 30 seconds. This is done by interpolation from the wind forcing that is provided e.g. every hour or every third hour.
We will adapt this part to: "The numerical time step of a wave model can be counted

in seconds (typical for explicit numerical schemes) or minutes (typical for implicit numerical schemes). The wave model therefore need updated wind information e.g. every 30 seconds. This is done by interpolation from the wind forcing that is provided e.g. every hour or every third hour."

#12) page 14 line 9-10: "Systematic differences cannot be found based on the small sample, but it indicates that the choice of the 15 minutes resolution is a reasonable compromise between a good representation of the extreme values and file size."I think one could argue that a 60 minute resolution is reasonable, since a difference of 2 cm is under 1%. This is small compared to the sampling variability (roughly 5-10%) that is present in measured significant wave height data that we routinely use to validate the models. Still, 15 minutes is clearly also a reasonable choice, so I'm not arguing with that part of your conclusion.
We agree that 60 minutes is reasonable. We only wanted to demonstrate that there might be an impact if using a higher temporal resolution. Of course, in the demonstrated case it is very small.

#13) page 14 line 15-16: "For this reason, a difference in the spatial pattern can beassumed. "Do you mean that a difference can be expected?
We change this to "expected".

#14) last paragraph on page 14: It think it is worth noting that the operational products typically used to force Baltic Sea wave models are already close to the higher resolution (0.063 deg). While this sensitivity test is very welcome, it could easily be read as if the wave modelling communityis currently using insufficient wind forcings is no context is provided. It might also beworth noting, that separate high-resolution wave model implementations might benefit more from higher resolutions in the wind forcing than what is seen in a 1 nmi BalticSea wide wave model. This kind of sensitivity tests for

coastal wave models have been done in the Baltic Sea (see e.g. Tuomi et al., 2014).
This study has been done from the perspective of a research institute rather than an operational forecast centre. We are aware and mentioned it also in the manuscript that an operational product should be of higher quality then what we are able to do with this setup. As a research institution, we often do not have access or cannot rely on operational datasets only, since we are interested in hindcasting events over a long period as determined by the research question. We would be limited by applying operational products regarding to the available periods, but also in terms of homogeneity of the dataset, which is required for investigations of long-term changes. With ERA5 as a global reanalysis and the atmospheric and wave models available from github, we demonstrate an approach, which everybody could repeat for any region in the world. When ECMWF extends ERA5 back to 1950, nearly 70 years of data are available for the production of event based hindcasts in a homogeneous way. One very relevant question is then which resolution is neccessary and how large should be the ensemble for the hindcasts. Should we produce more members or do we get more benefit from a higher resolution ? We tried to discuss these issues in the article. The ensemble runs were also done here in a coarser resolution than 0.063 deg, because it would have delayed the study because of computational limits. We will include this point about the impact of higher wind field resolution on higher resolved wave models and will make it clear that the point of a refined horizontal resolution applies to hindcasts rather than operational applications.

#15) page 16 line 1-2: "As the first twelve hours are not used, because of the model spin-up, this is not really a shortcoming." This will not be true for operational wave forecasts that get their starting conditions fromthe previous run. Will it be a shortcoming then?
We use a reanalysis from a different model and coarser resolution as the WRF model. In an operational setup, one would probably use data assimilation which combines the background from a previous model run based on the same model with the same

parametrisations with actual observations. This should reduce a spin-up significantly. There are other techniques to reduce the spin-up, also mentioned in the article, like Digital Filter Initialization for example. The spread develops also over the forecast horizon, why there might be a lack of spread during the first hours. This can be improved by applying an ensemble data assimilation technique.

#16) page 16 lines 11-13 "To achieve a comparable robust estimate of the uncertainty, the ensemble size for the here presented approach must be larger than the one of operational local area model ensembles. "Just to be clear, is the "here presented approach" choosing the members at random? In other words, is your conclusion that choosing random members requires more members in the ensemble than if they are "screened" in advance using a coarse model, or are you trying to make some additional point?
With the presented approach, the ensemble size must be larger than in case of pre-selecting already a representative subsample of ensemble members, because the ensemble members are generated in a random way in terms of the stochastic perturbations. We will be more specific: "The here presented approach without pre-selection of ensemble member ..."

#17) page 16 line 16-17: "For a strong event, the difference between a 5 and 60 minutes temporally resolved wind forcing is only on the order of 2 cm. "I think it is a bit questionable to give an absolute difference without knowing the significant wave height. This doesn't really provide that much useful information.
The significant wave height of about 6.3m will be mentioned here.

#18) In e.g. Figure 2: are you using the wave product of ERA5, or are you using WAVEWATCH III forced with ERA5 winds?
We tested also the ERA5 wind as forcing data and found a relatively good model

performance with an underestimation of the extreme wave heights in WWIII. For comparison, we showed the significant wave height from the ERA5 ECWAM with about 0.36° resolution (Fig. 6 and 7) and the ERA5 ECWAM uncertainty measure with about 1° resolution (Fig. 6). We will make this clearer.

#19) If you are only simulating the wave field in the Baltic Sea, then there is not really aneed to nest it outside of the Danish straits, since no significant amount of wave energywill penetrate. It's not wrong, just pointing out that it is not really necessary.
Our later application of the ensemble data are transport simulations with an ocean model for which we use the ensemble wave and atmospheric data as input fields. As we want to have also realistic wave parameters north of the Danish Straits, we used the presented nesting procedure.

#20) The figures are sometimes very hard to read. Please prepare them according tothe guidelines of the journal (fonts sizes, labeling of subpanels etc.
We will adapt the figures.

Please also note the supplement to this comment:
https://www.ocean-sci-discuss.net/os-2019-76/os-2019-76-AC1-supplement.pdf

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