

## Reply on Reviewer #2

We appreciate the constructive comments of the reviewer. They helped us to clarify and improve our manuscript. In the following, the reviewer's remarks are listed and followed by our point-by-point response in [blue](#).

### General comments

This study systematically examines the extent to which non-linear processes are relevant to the estimation of extreme water levels in the German Bight at present-day mean sea level and in the case of a sea level rise of 1 m. The scenario of rising sea level, in particular, is a highly relevant issue. This article provides a comprehensive insight into how non-linear processes increase or decrease extreme water levels. The study design, which involves carrying out various well-designed simulations and systematically defining and analysing the various factors that contribute to extreme water levels, is well thought out.

Overall, the article is well written. However, I have some general comments for improvement. The manuscript could benefit from being structured more systematically. Furthermore, the method used and the definitions employed should be described in more detail in some places. A paragraph should be added to the manuscript discussing the limitations of the methods and any potential drawbacks.

The study is of scientific significance. I recommend publication after revision. A detailed list of comments follows below.

### Specific comments

Structure of the manuscript:

I believe that here and there, the distinction between the 'Methods', 'Results', and 'Discussion' sections could be made clearer. Some methodological explanations in the 'Results' section could be moved to Section 2. I feel that the comparison of the results presented here with the literature, on the other hand, belongs in the 'Discussion' section. The 'Discussion' section, like the 'Results' section, contains results. Please consider moving the results presented (i.e. Fig. 14 and Fig. 15) to the 'Results' section.

[Response: We thank the reviewer for this helpful comment. We will revise the manuscript to distinguish more clearly among Methods, Results, and Discussion. Definitions and analytical procedures previously introduced in the Results section will be moved to Section 2. Results associated with Figures 14 and 15 will be moved to the Results section, whereas their](#)

interpretation, comparison with previous studies, and discussion of limitations will be presented in Section 4.

Discuss limitations of the study:

In the 'Discussion' section, a paragraph on potential limitations of the results presented is missing. Please discuss the drawbacks of the model used. Its spatial resolution of 1.6 km is not fine enough to resolve local tidal inlets, channels, and intertidal flats. How would you rate the robustness of your results if you were to use a higher model resolution? Do you believe that your results can be generalised to locations other than the three analysed? Fig. 14b shows, the changes in values of WL changes due to SLR near the coast appear to be larger. Are these values reliable? Please discuss the possibility that the results might differ in estuaries, particularly in regions where water levels are influenced by river discharge.

Response: We thank the reviewer for identifying these important limitations. We will add a dedicated limitations paragraph to the discussion that will address:

- the inability of the 1.6 km grid to resolve individual tidal inlets, narrow channels, and detailed intertidal morphology;
- the sensitivity of the simulated tidal response to model and bathymetric resolution;
- the increased uncertainty of local patterns near the coast and close to the wetting-and-drying boundary;
- the limited spatial generalizability of the detailed site-based results; and
- the fact that estuarine responses may differ where river discharge and river-tide-surge interactions are important but are not represented explicitly in our analysis.

Because no higher-resolution sensitivity simulation was conducted, we do not quantify how the reported values would change at finer resolution. At the same time, spatial patterns obtained in this study (e.g. changes in water level and M2 under SLR) are comparable to similar results from previous studies, some of them obtained with finer model resolution, e.g. Rasquin (2020) or Arns (2015). We will therefore modify the relevant conclusions and will emphasize that the process-based findings apply primarily to the German Bight and the present model configuration.

Specific comments by text location:

L 31: It would be helpful for the reader, when the term 'storm surge' first appears, to briefly explain how this term is defined in the context of this article.

Response: A brief definition of storm surge will be added.

L 116: consider including reference to Figure 1a: “The model domain covers the North Sea and adjacent parts of the northeast Atlantic with 12.8 km spatial resolution (Figure 1a), with ...”

Response: Will be added accordingly.

L151: The discrepancies between the model and the observations could, in part, also be due to the use of hourly water levels.

Response: We agree that the use of hourly model output and observations may contribute to the discrepancies, particularly because sub-hourly maxima are not resolved. We will add this point to the discussion of model validation.

L230-331: This sentence might easily slip the reader’s mind. Please note, in all figures where appropriate, that the data relate to Helgoland.

Response: We will add *Helgoland* to all relevant figure captions.

Figure 3a and L270-273: In Figure 3a, the NTR values are color-coded according to the tidal phase. However, the method used for this grouping is not explained until the introduction of Figure 4. Please ensure that all methods used are explained before referring to their results.

Response: Thank you. We will move the definition of the four tidal phases to Methods Section 2.2.

Line 290: Delete “for example”, as the results displayed relate to Helgoland and no other results are shown.

Response: Will be deleted.

Line 291: How long is the averaging period for “rising tide” and “falling tide”? I assume it refers to the period between high tide  $\pm 1$  hour and low tide  $\pm 1$  hour. Please clarify.

Response: Yes, rising tide is defined as the period between low tide  $\pm 1$  hour and the subsequent high tide  $\pm 1$  hour, while falling tide is defined as the period between high tide  $\pm 1$  hour and the subsequent low tide  $\pm 1$  hour. We will clarify this in Methods Section 2.2. Because of tidal asymmetry in the German Bight, the rising tide period is generally shorter than the falling tide period. In our case, the average period of rising tide is 2.6 hours, while the average period of falling tide is 4.1 hours. We will also add a short explanation in the revised manuscript.

Line 365: Why “could”? Suggestion: “SLR effects on TSI can be quantified with our simulations.”

Response: Thank you. Will be revised as suggested.

Line 396: Please check whether the reference to Fig. 3a is correct. Shouldn't it actually be Fig. 3b?

Response: Thank you. Will be corrected to *Fig. 3b*.

Figure 10: Please, give a short explanation for the two larger red spots in Figure 10.

Response: We thank the reviewer for drawing our attention to these features. The two areas show changes of opposite sign relative to most of the domain, but their magnitudes remain within approximately 2–3 cm. Both occur in shallow, semi-closed coastal regions close to the effective resolution limit of the model. We therefore cannot determine conclusively whether these localized patterns represent robust physical responses or are influenced by the coarse representation of bathymetry, coastline geometry, and wetting and drying. We will add this explanation and explicitly state that these local features should be interpreted with caution.

Section 3.4: This section needs to be revised or removed. As this section does not contribute to the main findings of the study in terms of the argument put forward it is a nice addition, but it is not strictly necessary.

Response: We thank the reviewer for these comments and agree that changes in high-water level should not be used as a direct proxy for changes in M2 amplitude. We have therefore revised Section 3.4 in two ways. First, M2 amplitude changes are now calculated directly from the tide-only simulations, enabling a comparison with previous studies. Second, the high-water analysis is retained as a separate metric because of its direct relevance to EWLs. The revised text will clearly distinguish these two diagnostics and no longer interpret them as equivalent.

Line 448-449: Why were only the highest 200 storm surge events analysed? As tide-only simulations are analysed here, storm surge events are not relevant to the analyses.

Response: We thank the reviewer for this comment and agree with this point. The selection of the 200 events was inherited from the surge analysis but indeed not necessary for the tide-only analysis. We will revise the analysis using all high tides from one year, which is more consistent and objective.

Line 452-454: Comparing changes in high tides with the M2 amplitude is flawed. This would only be feasible on the assumption that the low tides remain unchanged in the simulation with SLR. As an alternative to directly comparing the M2 amplitude, it would also be possible to compare the tidal range with the M2 amplitude.

L483-488: The final sentence of this section notes that the metric of high tide and M2 amplitude are not equivalent. Yes, which is why it makes little sense to compare them. I recommend revising this section in the light of my comments to L452-454.

Response: Thank you for these two comments, and we fully agree. We will add the analysis of M2 amplitude for better comparability with previous studies and keep the high tide analysis because of its direct relevance to EWLs.

L515-L516: As far as I understand, the increase in water level beyond SLR due to the weakening of the negative TSI could be higher, were not for the countervailing effect of the reduction in SURGE caused by SLR (as described in L434-435). This should be mentioned here in order to provide a complete picture.

Response: Will be added as suggested.

L521-531: This paragraph is important. However, it appears rather suddenly. Please reconsider its placement in the article. It definitely belongs in the 'Discussion' section. Maybe it seems a little out of place because the 'Discussion' section is very similar in style to the preceding 'Results' section (see also general comment on structure).

Response: We will move the figure and its description to the Result section and expand this paragraph in the revised Discussion Section 4.3 Limitations.

L533-534: Please provide a clear definition of 'WL changes due to SLR'. Is it the difference:  $WL_{SLR} - WL - SLR$ ?

Response: We will add a definition in Methods section 2.4 with Eq. 5.

Line 541-543: In view of the results presented above, it seems surprising at first glance that the difference between  $WL_{SLR}$  and  $WL+SLR$  is only 1%. However, this is the case because the value refers to the total water level and not to the SLR used. Please consider whether, in general, a table showing the key values might be helpful. It would, for example, clarify this point and bring all the values together in one place – effectively as a summary of the results.

Response: We thank the reviewer for this suggestion. To avoid ambiguity between percentages relative to total water level and changes relative to the imposed SLR, we now report the key differences in centimeters as well as percentages. Because only a small number of summary values are required, we have incorporated them directly into the revised text rather than adding a separate table.

L548: The term “non-surge conditions” suggests, that surge conditions are excluded from the analysis. However, this does not appear to be the case, as the caption for Figure 15 states that ‘all flood levels’ were analysed. Please clarify.

Response: Thank you for pointing this out. We will change the wording to “At all high tides”.

## Technical corrections

Figure 1b: The Figure is too small. The text in particular is difficult to read. Labelling of the Y-axis: Which height reference system is used? Metres above mean sea level?

Response: Will be revised. Yes, it shows water level above mean sea level.

Table 2: The terms given in brackets at the end of each line refer to terms used in the equations defined in Section 2.4. It would be great, if the connection between the model simulations and these notations would be highlighted more. Maybe change order: “WL: Baseline total water level” instead “Baseline total water level (WL)”

Response: Thank you. Will be revised as suggested.

Line 437: Check formulation “is a dominant control” Do you mean: “Overall, these results demonstrate that TSI dominates the timing and magnitude of surge-related water levels.”?

Response: Will be revised to “dominates the modulation of”.

Line 541: Typing error: (Linear\_0)

Response: Thank you. Will be corrected.

## References:

Arns, A., Wahl, T., Dangendorf, S., and Jensen, J.: The impact of sea level rise on storm surge water levels in the northern part of the German Bight, Coastal Engineering, 96, 118–131, <https://doi.org/10.1016/j.coastaleng.2014.12.002>, 2015.

Rasquin, C., Seiffert, R., Wachler, B., and Winkel, N.: The significance of coastal bathymetry representation for modelling the tidal response to mean sea level rise in the German Bight, Ocean Sci., 16, 31–44, <https://doi.org/10.5194/os-16-31-2020>, 2020.