Responses to the comments of Referee 1

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1 Response

Before anything else, we are deeply appreciative for the time and work Referee 1 has taken to deliver precise and constructive comments, together with some well thought-off suggestions. All of which we are convinced will enhance the manuscript in general, and in particular improving on the overall quality of the sciences, and how it is presented to the reader. Below we present our responses to the comments made by Referee 1.

1.1 General comments

In their article "A probabilistic view of extreme sea level events in the Baltic Sea" the authors describe two hierarchical spatial extreme value models in which the parameters of the Generalized Extreme Value (GEV) distribution are modeled using two variants of latent Gaussian process descriptions within the Bayesian modeling framework. They compare the results against a baseline model with standard maximum likelihood estimation and two simpler Bayesian GEV models over a set of tide gauges on the coastline of the Baltic Sea. Their results show that the spatial models outperform the simpler modeling approaches, model robustness is improved and uncertainty reduced both in the GEV parameter and return level estimates.

This is to my knowledge the first time that such hierarchical spatial GEV models have been applied to observed annual sea level maxima in the Baltic Sea region. The article is within the scope of NHESS, albeit being mathematically rather heavy, and in principle does present some technical developments over previous

studies. The topic of spatial extreme value modeling is, in my opinion, timely, and I appreciate the effort authors have put into this work, as is evident also from the rendered notebooks available as supplementary material.

Unfortunately, the manuscript is a bit unfinished and not mature enough for publication. It was difficult for me in many places to follow the line of thought of the authors, because of the poorly structured text and quality of figures. For example, the description of methodology contains repetition and is unnecessarily long for communicating the main points to the reader. I also have some methodological concerns, which I hope the authors will address in their reply. Lastly, I was not able to access the code or the supplementary material linked to the Code and Data Availability and Supplement sections and therefore was not able to review them. Overall, the manuscript needs a major revision before it can be recommended for publication in NHESS.

In the following, I will first list my major comments regarding the manuscript. I hope they will be helpful for the authors when improving the manuscript. I will also provide a short list of more specific comments.

1.1.1 Major comments

Comment 1. *Please provide sufficient background information on earlier work. There are a plethora of both observation- and physics-based extreme value analysis work done previously in the Baltic Sea region. For example, extreme value analysis of sea level extremes based on hydrodynamical model simulations has not been mentioned at all (e.g. Lorenz and Gräwe, 2023), although it provides a complementary approach to spatially infer statistics of sea level extremes.*

Response 1. We will make sure to add a broader introduction in the revised manuscript, also covering modelling approaches.

Comment 2. *The description of methods is long and contains heavy mathematical jargon. I encourage the authors to concentrate on delivering the core message of theoretical aspects in the main text and provide technical details in the supplementary material or as an appendix, if needed. Examples:*

- *Theoretical background of the block-maxima approach (page 3) is long-winded and should be shortened.*
- *Lines 110–120 (GEV distribution support and tail behavior) could be compressed to a couple of sentences.*

- *Sect. 3.3.3 (Matérn covariance function properties, esp. Eqs. 39–41) could be moved to an appendix.*
- *Sections 3.1.1–3.1.3 could be combined and shortened by removing unnecessary detailed descriptions of GESLA-3 data.*

Response 2. We believe we can considerably shorten the methodological sections in the main text following these suggestions in a revised version.

Comment 3. *Regarding the Results section, Sects. 4.2.1 and 4.2.2 should be expanded. Currently they contain only illustrative examples for some subsets of tide gauges without justification. Suggestions:*

(i) Provide one illustrative example and then quantitatively show reduction in uncertainty (e.g. fractional uncertainty) for all tide gauges, either as a table or map (e.g. 50-year return level).

(ii) Extend leave-one-out validation to cover all tide gauges and compare against the full models using suitable statistics.

Response 3. We will follow the suggestion, adding comprehensive return level table comparison for all of the stations in the training data. Additionally, we will expand the LOO-validation sites to cover all sits with at least 50 annual maxima, together with extending the diagnostics.

Comment 4. *Figures are too small and require reformatting. Increase figure size, remove redundant texts (e.g. orange Baseline labels), duplicate legends, and mask out the Norwegian Sea (not part of the domain). Keep only one spatial model in Sects. 4.2.1 and 4.2.2 and move the other to supplementary material.*

Response 4. We will redraw all figures following the suggestions of the referee.

Comment 5. *Put the results into a wider context by comparing with previous studies, e.g. Lorenz and Gräwe (2023).*

Response 5. We thank the referee for this hint, and we suggest adding a paragraph focusing on differences in areas where we don't have gauges like the Southern Baltic coast, and see if we pick up something similar to what the models in the suggested references do.

Comment 6.

(i) Remove orphaned and one-sentence paragraphs (e.g. page 3).

(ii) Move all figure descriptions into captions and keep results discussion in the main text.

(iii) Remove unnecessary repetition (e.g. lines 69–74, 114–120, 164–169, 192–198, 245–250).

(iv) Fix fragmented and erroneous sentences (e.g. lines 28–30), and avoid repetitive use of "respectively".

(v) Correct typographical errors (e.g. missing spaces after Eq., Sect., Fig.).

Response 6. We are grateful for the referees' detailed editorial recommendations concerning both clarity and presentation. We will systematically attend to these points in the revised manuscript, to significantly improve the readability and general presentation of the manuscript.

Comment 7. *The Latent model formulation is unclear. Explain the difference between Hilbert and Latent in Sect. 3.3.4. Elaborate on why Hilbert approximation is included — does it bring computational benefit?*

Response 7. We will elaborate on the computational differences between Hilbert Space approximated GPs and standard GPs in the corresponding subsection. In particular, the use of bases function (eigenvectors), and how the number of bases functions relate to extrapolation.

Comment 8. *The Gaussian process mean function is modeled as a linear function of longitude and latitude. This might be too simplistic given Baltic Sea geometry. Consider including other covariates.*

Response 8. We appreciate the concerns raised by the referee. The covariates of the two spatial models are indeed restrictive with regards to the Baltic Sea geometry, and the consequence of this is effectively acknowledged in lines 545-549. However, we argue that limiting the mean function to two covariates ensures both uniform data, and data accessibility for any location in the region of interests.

Comment 9. *Too general. Suggestion:* ***"A probabilistic view of spatial extreme sea level events in the Baltic Sea"****.*

Response 9. We agree that the title is too general, and propose, according to suggestions, the new title: "A probabilistic view of spatial extreme sea level events in the Baltic Sea".

Comment 10. *Mention earlier studies (e.g. Suursaar et al., 2002; Soomere et al., 2018).*

Response 10. We will mention them in the revised version.

Comment 11. ***Lines 317–320:*** *Sentence unclear, please elaborate.*

Response 11. We recall that Hilbert uses Hilbert space approximated Gaussian processes instead of Gaussian processes (see Section 2.2.2). The approximation is made in the 3-dim Cartesian coordinate system, where $(x_1, x_2, x_3) = \Psi(\text{lat}, \text{lon})$ is obtained from latitude and longitude via the standard geographic-to-Cartesian transformation, which we denote by Ψ. We use this coordinate transformation because the tide gauge data are provided only in latitude/longitude, and without details regarding the local coordinate systems.

Comment 12. ***Lines 338–339:*** *Units of length scales? How were values selected?*

Response 12. We suggest adding the unit of the length scales (km), and a motivation for using deterministic length scales in the revised version.

Comment 13.

- ***Eq. 42:*** *Possible typo.*
- ***Table 2:*** *Reduce number of decimals.*
- ***Line 554:*** *Zenodo link points to Räty et al. (2023).*

Response 13. We will make a thorough revision of the manuscript, to ensure that there are no typos, the number of decimals are sufficient and consistent, and that we use the correct Zenodo links.

1.1.2 References

- Suursaar, Ü., Kullas, T., and Otsmann, M.: A model study of the sea level variations in the Gulf of Riga and the Väinameri Sea, *Cont. Shelf Res.*, 22, 2001–2019, doi:10.1016/S0278-4343(02)00046-8, 2002.
- Soomere, T., Eelsalu, M., and Pindsoo, K.: Variations in parameters of extreme value distributions of water level along the eastern Baltic Sea coast, *Estuar. Coast Shelf Sci.*, 215, 59–68, 2018.

- Lorenz, M. and Gräwe, U.: Uncertainties and discrepancies in the representation of recent storm surges in a non-tidal semi-enclosed basin: a hindcast ensemble for the Baltic Sea, *Ocean Sci.*, 19, 1753–1771, doi:10.5194/os-19-1753-2023, 2023.