

RC1:

Summary: The manuscript presents a statistical analysis of sea-level time series in the Southern Baltic Sea derived from tide-gauge observations and satellite altimetry. The analysis focuses on identifying trends, accentuation, and oscillations in the time series. The authors design a statistical model to extrapolate sea-level time series far into the future. They also analyse trends and acceleration of the cyclic components

Recommendations: Although I think that the study can eventually be published, my opinion is that this version requires a rather deep revision. I have several major concerns regarding the motivation, the writing of some sections and the utility of other sections, which I explain below.

We want to thank the Reviewer for a detailed and constructive review of the manuscript. We agree that the comments are essential for improving the clarity, consistency, and scientific scope of the study. In the revised manuscript, we will address all comments, particularly by improving the text structure, defining the research question and scope more clearly, expanding the literature review, and clarifying the character of the statistical extrapolation.

Main points

1) Regarding the writing of the manuscript, its structure can be clearly improved. The text often includes very long paragraphs, without a clear structure, which will make it difficult for the reader to focus on and follow. This is very clear to me in the introduction, which contains two short paragraphs and one very long paragraph that addresses very different issues and lacks a clear structure.

This problem appears in other sections. I would recommend the authors to revise the text, having a reader in mind. Ideally, one paragraph should develop only one idea.

We thank the Reviewer for this comment. In the revised version of the manuscript, we will reorganize the Introduction section by dividing the extensive paragraphs into shorter sections focusing on individual issues. We will make similar changes in the remaining parts of the manuscript so that individual paragraphs focus on single issues and to improve the logical transitions between the different issues of the paper.

2) The title is not informative. A reader may well interpret the title as a study of a short-term storm-surge predictions. The abstract does not include any information about the timescales that the study targets

We thank the Reviewer for this valuable comment. In the revised version of the manuscript, we will modify the title and abstract so that the character and time span of the study are more clearly defined. We propose changing the title to: “Probabilistic Modeling and Statistical Forecasting of Sea Level Variability in the Southern Baltic Sea Based on Long-Term Tide-Gauge Records and Satellite Altimetry,” which better reflects

the probabilistic and multiscale character of the study. The use of the term “statistical forecasting” is to highlight that the forecast is conditional and based on the statistical properties of the observed time series, rather than a physical projection of future climate change. The study analyses various time scales, including: long-term changes in multi-year tide gauge time series, variability during the period 1993–2024 resulting from the possibility of comparing tide gauge and altimetry data, seasonal and interannual cycles, longer-term multiyear oscillations, short-term variability, and extreme sea levels.

In addition, we will modify statements that may suggest that the methods allow for an obvious determination of the physical cause of the observed changes.

3) The manuscript fails to explain what the research question is. The introduction just includes a sentence, hidden in the last third paragraph, that 'The research hypothesis was that climate

change affects not only the rise in mean sea level, but also the intensity and dynamics of periodic processes and the frequency of extreme events.' Yet, the study just assumes that all trends derived from the observational period are due to climate change. The study does not analyse model output, nor investigate the physical mechanisms as to why greenhouse gas forcing may also affect the amplitude of periodic variations and the frequency of extreme sea levels in the Baltic Sea.

The manuscript gives the impression that the authors have a method, or several methods, that can be applied to any time series, and just happen to apply it here to the series of Baltic Sea level. The reader is left wondering what the research gaps are and why this analysis has to be undertaken in the first place.

We sincerely thank the Reviewer for this insightful comment. We agree that, in the previous version of the manuscript, the research question and research gap were not presented clearly enough, and the formulation concerning the impact of climate change could have suggested a direct attribution of the observed trends and periodic changes to climate change. In the revised version, we will rephrase the hypothesis and the research aim. We do not assume that all observed trends or changes in the amplitude of periodic components are a direct result of climate change. Such an attribution would require the use of climate models and an analysis of physical mechanisms, which are not the subject of this study. The aim of this study is to provide a statistical characteristics of multiscale sea level variability in the southern Baltic Sea and to assess the degree to which trends, periodic components, and stochastic variability can be estimated within the framework of an integrated HA–CWT–AR(1)–Monte Carlo approach.

In particular, the study focuses on the following research questions:

1. Do long-term sea level trends vary among individual tide gauge stations in the southern Baltic Sea, and how do they compare with sea level trends derived from satellite altimetry?

2. Do the observed time series contain repeated periodic components at various time scales, and are their characteristics spatially and temporally stable?
3. To what extent do the results using harmonic analysis (HA) correspond to results from CWT, and how does this consistency change with distance from the Polish coast?
4. Does the combination of the trend, periodic components and the AR(1) stochastic residual model allow for the construction of a probabilistic forecast of future sea level variability, along with a quantitative assessment of uncertainty using Monte Carlo simulations?

At the same time, we will refine the research gap. Previous studies have analyzed long-term trends and the rate of sea level rise in the Baltic Sea and the effects of isostatic processes, among other things. In this study, we propose a more integrated approach in which the long-term trend, periodic components, time-frequency variability are analyzed using both long-term tide gauge observations and satellite altimetry.

Another aspect of the study is the comparison of data collected at different distances from the Polish coast. This allows to investigate whether the characteristics of sea level variability and the agreement between methods change as the distance from the Polish coastal zone increases. In this way, the analysis focuses on the specific problem of spatial and temporal sea level variability in the southern Baltic Sea and on the integration of tide gauge and satellite observations.

In the revised manuscript, we will modify the Introduction section accordingly so that the research gap, research questions, and aims of the study are presented before the description of the methodology.

This point is related to my following point

4) The manuscript has not considered previous publication o acceleration of the Baltic Sea level. I include three here, but there may be more. Actually, I may have missed it, but the manuscript does not include any reference to previous studies on Baltic Sea level acceleration.

Also, other relevant papers on the Baltic Sea level are not cited. An example is Stramska (2013) Temporal variability of the Baltic Sea level based on satellite observations, *Estuarine, Coastal and Shelf Science* 133 (2013) 244- 250, which also includes a spectral analysis of Baltic satellite time series.

Spada, G., Olivieri, M., & Galassi, G. (2014). Anomalous secular sea-level acceleration in the Baltic Sea caused by isostatic adjustment. *Annals of Geophysics*, 57(4), S0432-S0432.

Hünicke, B., & Zorita, E. (2016). Statistical analysis of the acceleration of Baltic mean sea-level rise, 1900–2012. *Frontiers in Marine Science*, 3, 125.

Jevrejeva, S., Moore, J. C., Grinsted, A., Matthews, A. P., & Spada, G. (2014). Trends and acceleration in global and regional sea levels since 1807. *Global and Planetary Change*, 113, 11-22

We would like to thank the Reviewer for pointing out these important publications. In the revised version, we have expanded the literature review to include the papers indicated by the Reviewer.

5) I am very critical of section 5.4 on the statistical sea level rise forecast. This section just extrapolates the identified trends and quasi-oscillations to produce a 'forecast' of sea-level rise. However, future sea-level rise will be affected by many physical factors that may or may not behave as in the past. For instance, the melting of glaciers and polar ice sheets. There is a huge uncertainty in this factor, and it is really quite a stretch to assume that the melting rate will remain unchanged as it has over the past decades. The same can be said about quasi-oscillations. The only oscillatory phenomena that can be used for sea-level prediction are astronomical factors, which can be reliably calculated. All other climate-related oscillations may or may not change in the future. The issue also remains of how large the variance described by these oscillations is at the relevant time scales, which, unless I missed it, is not addressed in the study. If the variance explained by one oscillation is small, its relevance for any prediction is also small.

My recommendation is to delete this section entirely, as it can be misleading. At the very least, it should be accompanied by a clear disclaimer stating that this prediction is merely an extrapolation of current trends into the future, assuming those trends remain unchanged, which is quite unlikely. I honestly do not see a lot of value in this section.

We greatly appreciate the Reviewer's important comment. We agree that future sea level changes depend on many physical processes that cannot be fully determined based only on historical observations.

However, we would like to clarify that the procedure in this paper is not a deterministic trend extrapolation. The modified Monte Carlo method uses the estimated trend, identified periodic components, and the autocorrelation structure of the residuals described by an AR(1) model. Next, multiple realizations of the future series are generated, which allows us to account for the uncertainty associated with the model parameters and the stochastic component.

As a result, we obtain a distribution of possible future sea level values and prediction intervals. Therefore, we think that the approach can be described as a probabilistic statistical forecast.

At the same time, we agree with the Reviewer that such a forecast should not be interpreted as a physical climate projection. In the revised version of the manuscript, we will clearly state that the forecast is conditional and is based on the assumption that the

statistical properties identified during the observation period remain stable over the forecast period.

This means that the model may account for statistical uncertainty resulting from the observed time series and the applied model structure. However, it does not include all possible future changes in physical processes, such as changes in the mass balance of ice sheets and glaciers or future atmospheric and oceanic circulation.

Therefore, we have decided to retain Section 5.4, but we will significantly modify its description and interpretation. We will clearly define the scope and limitations of the probabilistic forecast and remove statements that could suggest that the model represents a physical climate projection.

In response to the Reviewer's comment regarding the importance of the individual oscillations, we will also extend the analysis by assessing their contribution to the total variability of the time series. This will allow us to determine which components make a significant contribution to the variance and how they contribute to the resulting forecast.

We propose to retain Section 5.4 as a probabilistic statistical forecast based on the observed properties of sea level. This approach allows us to assess the potential future evolution of the time series while providing a quantitative estimate of the associated uncertainty.