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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Non-stationary analysis of water level extremes in Latvian waters, Baltic Sea, during 1961–2018" *by* Nadezhda Kudryavtseva et al.

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We thank the referee for careful reading the manuscript, critical assessment of the analysis and useful and professional comments which helped to improve the paper. Please find below the detailed replies to all the questions.

1) Please clarify the study area. In L. 83-85 it is said that the study focusses on Gulf of Riga. A bit later (line 97) it said that "The study area – the shores of Latvia with a total length of about 500 km..." I think that neither is fully correct: Besides Gulf of Riga, also Latvian coasts in the Baltic Proper are considered. Secondly, large part of the discussed Gulf of Riga actually belongs to Estonia, including one station where

the data come from (Pärnu). Also the paper title says that the study area is "Latvian waters". I understand that it is difficult to conveniently introduce such details in the title. But the fact about Pärnu and Estonia should be stated possibly earlier in the paper. Currently it is hidden to far quarters of the manuscript.

- Thank you for this observation. The study area involves all Latvian waters, but we also use data from one Estonian tide gauge. We state now this fact earlier in the paper.

2) L.110 "...may increase the average sea level in the entire Baltic Sea by almost 1 m for several months (Soomere and Pindsoo, 2016)". I believe this 1 m is exaggerated for the entire Baltic. Soomere and Pindsoo (2016) said "...raise the average sea level by almost 1 m for a few weeks". Weeks - and it was probably for the eastern part of the sea. But then, sea level must be lower in other parts. Johansson and Kahma (Boreal Env Res, 2016, 21), say on p.34 with monthly-based analysis: "The Baltic Sea average level Hd ranged from –43 to +51 cm in 1933–2012". One month 51 cm, one month 45-50 cm. L.118 Considering the above-said, also this 1+1+1 m quantification does not quite hold.

- Thank you, this was an inexact formulation. We had in mind that large water volumes may increase the water level by 1 m within a few weeks. This increase usually starts from a lower than average water level. Still, Pindsoo and Soomere 2016 have shown that water levels elevated by 60–80 cm over long-term average have persisted for several weeks in the eastern Baltic Sea. We have formulated this aspect carefully now in the manuscript. The increase in water level in the eastern Gulf of Riga by more than 1 m compared to the water level at the Baltic proper shores of Latvia has occurred several times since the 1960s (Männikus et al., 2019). It is natural that the 1+1+1 m process does not work as a simple sum as conditions favourable for one mechanism are not perfect for others.

3) L.130, Table 1. I wonder, in three stations the hourly data completeness is 30% and in other three 99%. Please ensure shortly that it does not influence the statistics

(distribution parameters) – particularly considering the potential completeness changes over years in these 30% stations.

- Although some of the tide gauges had lower completeness, it was uniformly low except for the period after 2005 there was an increase in a number of measurements. None of the stations showed a change in completeness during the years of the abrupt shift. We performed a test to check how low completeness could have affected the results. For that, we took one of the most complete stations, Pärnu, randomly removed 70% of the data and applied precisely the same method of the extreme value analysis. The resulted data had 30% completeness, which is characteristic for the less complete stations, such as Roja and Salacgriva. Running 100 times the same analysis, we found that the same abrupt change in the shape parameter was observed even with only 30% completeness in 85% of the cases. This indicates that in case of the less complete stations, we do see the abrupt shift at an 85% confidence level. However, the tests showed that lower completeness leads to the location parameter being significantly underestimated. An explanation about how the completeness of the data could affect the extreme value distribution fitting is added to the paper.

4) Were the data 1961-2018 detrended before analysis, or perhaps, it is not a problem? I.e., is there a possible influence of local uplift/subsidence or global sea level rise to e.g. variations in location parameter?

- The signal of the mean sea level variations was removed from the extremes. This removes all slowly varying sea level changes, and the analysis focuses only on the storm surges. Therefore, the influence of the local uplift or global sea level rise can not affect the results of the manuscript.

5) L.320- Major regime shift in the Baltic region in 1989/90 is well known indeed. However, how to explain this odd shift in the form of “dent” in the shape parameter inside the Gulf of Riga in 1984-90? Seems like an artefact. In L.430- it is shortly discussed on the basis of changes in average air flow speed (Keevallik and Soomere 2014),

possibly including regime shifts in 1987 (up) and 1993 (down) above the Gulf of Finland. How about changes in wind direction? For instance, Fig.7e,g,h by Suursaar (http://dx.doi.org/10.3176/earth.2013.05) shows variations in annual resulting wind direction at stations near Gulf of Riga. In 1985-94, the direction was quite stable 230-250 deg (good direction for inflow through Irbe Strait), while before and after it fluctuated plus-minus off that direction. Just a guess.

- The problem is that interrelations between wind properties at a single location and extreme water levels are not straightforward. Extreme water levels in this part of the world are created by long sequences of “events” that affect water surface at different locations. The background for the largest extremes (elevated water level of the entire sea) is created by specific atmospheric forcing in the southwestern Baltic Sea. Pumping of water into the Gulf of Riga requires another subsequent forcing pattern and high local surge, possibly the third pattern. The analysis of (Männikus et al., 2019) reveals a recognizable change in the directional structure of strong winds at Vilsandi. We hope to look in more detail into the local wind patterns in the future, but it is currently out of the scope of this manuscript. However, we added a section to the revised version of the manuscript describing the connection between the extreme water levels in the Latvian waters with multiple climatic indices (please check the reply to the referee 2). This shows that the observed phenomenon has a weak relation to the local wind and stronger connection to the global atmospheric circulation.

6) Fig.8. If the numbers in brackets mark the range in centimetres (134,141), why not express it 136-141? What does this range mean anyway - neither explained in the text nor in legend. What does Pärnu 50-yr return value 211,220 mean? Pärnu had measurements 253 cm and 275 cm within 39 years.

- Thank you, the numbers in brackets were changed to the range as advised. The 50-yr return value of Parnu in the range 211-220 cm was obtained by removing the slowly varying components from the data, then the generalized extreme value distribution (stationary in case of Fig. 8) was fitted to all the yearly maxima, and the return value

was calculated. These measurements indeed showed a maximum of 275 cm in Parnu on 9th of January 2005. After removing the mean variation from this extreme, it is only 269 cm. However, this extreme event was only one of a kind. Fitting a distribution considers all the extremes and underestimated this outlier. The outliers are discussed in detail in section 2.3. The corresponding explanation was added to the text.

Minor/technical comments

L.23 too many (9) keywords, some repeating title words

- We reduced the number of keywords.

L.31 This highligh “Best fit in terms of step-like approximation for shape parameter established” makes no sense as a highlight. Also the third highlight misses something.

- We modified the formulation of this highlight

L.39 Mudersbach and Jensen

- We corrected the typo

L.58 easternmost Baltic Sea – feels weird

- We changed to “eastern subbbasins of the Baltic Sea.”

L.78 open coast of Latvia – feels weird

- We changed to “Baltic proper shores of Latvia.”

L.105 (100, etc) Väinameri (Moonsund) sub-basin in the Western Estonian archipelago –> West Estonian Archipelago Sea

- We added this change

Please unify units in the Fig. axes (commas, parentheses): Water level, cm; Return period, year; Time [yr]; Time [yrs] etc.

- The units are unified

L.205 hrs – not much shorter than hours

- The notation for hours is written in a unified way now

L.443 Klevanny -> Klevannyy - Thank you; this name appears differently in different sources.

Please also note the supplement to this comment:
https://nhess.copernicus.org/preprints/nhess-2020-100/nhess-2020-100-AC1-supplement.pdf

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