

Author's reply to Anonymous Referee #1's (RC1) comments on manuscript egusphere-2024-4044

In this paper, titled “Catalogue of floods recorded at tide-gauge station Bakar in the northeastern Adriatic Sea (Mediterranean)”, the authors explore the dynamics of several flooding events that occurred in the northern Adriatic Sea. I compliment the authors for their in-depth data collection and analysis work. Nevertheless, some aspects mainly related to the manuscript structure and the sea level decomposition methodology need to be improved.

Dear Reviewer,

Thank you for your comments and the time you dedicated to reviewing our manuscript. Our responses to your comments are provided in blue text below. The corresponding changes to the manuscript are shown either as red text insets or by referencing the specific line numbers in the revised version where the changes appear.

Manuscript structure: the paper is too long and needs to be restructured. My suggestions are:

i) move the description of each event into separated annexes or cards that can be easily explored via a dedicated link included in Table 2;

We recognize that the manuscript is longer than a typical research paper; however, we believe that moving all case studies to Appendix would compromise the study's purpose. The analysis is intentionally focused on the distinct characteristics of each episode, as these provide critical insights into the varied roles of sea-level processes in the formation of extreme episodes. To highlight the uniqueness of certain episodes and their clear departure from general patterns, we have strengthened the discussion in line with your suggestions. We have clarified the study's objective in the manuscript and added individual subsections for each episode in Table 2. As suggested by the other reviewer, the episodes and their descriptions now appear in chronological order.

ii) the Summary and Conclusions sections should be improved and split into separated Results and Conclusions sections;

Done! To improve this section and incorporate suggestions from both reviewers, we reorganized the content and added new results. The original *Summary and Conclusions* section has been divided into two parts: 5. *General properties and temporal distribution of SL extremes* and 6. *Conclusions*. The first part now includes some results that were previously in the Appendix (new Figure 73), as recommended, along with new considerations – specifically, the influence of mean sea-level change on the temporal distribution of extremes, and the impact of extreme synoptic and planetary-scale episodes on that distribution (new Figures 74 and 75 and text in lines 2182–2219). The second part now focuses solely on presenting the main conclusions (lines 2224–2243).

iii) move Appendix A on the mean sea level into the Results section;

Here we approached as follows:

- Figure A1 was revised and retained in Appendix A, together with details on sea-level processes on timescales longer than 100 days. The new Figure A1 now shows both *long-term sea-level variability* and intraannual variability, whereas the original Figure A1 showed only *long-term sea-level variability*. Although the information it contains is also included in the new Figure 73, this version provides a clearer view of the seasonal cycle phase during which each extreme event occurred.
- Figure A2 has been revised and relocated to Section 5 (now Figure 73). It now shows *long-term sea-level variability* and its subcomponents, derived as suggested by the reviewer.
- Figure A3 has been removed, as all of its information is now included in the new Figure 73.

iv) there's too much overlap between what is reported in the Introduction and section 3.2 (Decomposition of sea-level and meteorological series). Please provide a general description of the processes in the Introduction and include the detailed methodology only in section 3.2.

The Introduction and Section 3.2 have been rewritten as suggested. The revised portions can be found in the following lines of the manuscript:

Introduction: lines 40–46 and 73–95, general description of the processes is now completely in the Introduction,

Section 3.2: lines 180–221, the methodological details are now completely in Section 3.2.

Sea level decomposition: being aware that the observed sea level is the result of the (linear) sum of different processes, the authors considered the following contributions: local processes, tide, synoptic component, long-period sea-level component and mean sea-level changes. In my opinion, the analysis needs to be adjusted and refined.

In particular:

- local processes: since the decomposition is performed over the time dimension, it is not clear how you linked the temporal scale (9h) to the spatial scale and decided to call this component “local processes”? What's the spatial extent of local? Moreover, some processes, e.g. (meteo)tsunami, induce sea level oscillations within the considered temporal range but are not local dynamics. I strongly suggest using a different term, e.g. high-frequency oscillations. Why did you use the time threshold of 9h instead of 10h as in Ferrarin et al., (2021) and Šepić et al. (2022)?

Done! The term *local processes* was replaced with *high-frequency oscillations*. In the figures, this component is now labelled as *HF*. A threshold of 9 hours was used, as it corresponds to a minimum in the sea-level spectrum at that period. This point is now emphasized in the manuscript (lines 191–192).

- Long-period sea-level component: the term "long-period sea-level variability" creates confusion with the

longer time-scale contributions (seasonal, inter-annual, ...). I strongly suggest using the term planetary-scale variability.

Done! *Long-period sea-level component* was replaced with *planetary-scale variability*. In the figures, this component is now labelled as *plan/planetary*.

- Mean sea-level change: this term is generally used to describe only the long-term (decadal to secular) sea level variability. Therefore, this contribution must be split into three parts: seasonal, interannual and long-term (mean sea-level change) using the time windows described in lines 194-197. The resulting three components should be presented and discussed separately.

The following actions were undertaken to address this comment:

- The component *mean sea-level change* was renamed to *long-term sea-level variability*. In the figures, this component is now labelled as *long/long-term*.
- This component was further decomposed into:
 - (i) intraannual variability ($100 \text{ days} < T < 15 \text{ months}$),
 - (ii) interannual variability ($15 \text{ months} < T < 5 \text{ years}$), and
 - (iii) mean sea-level change ($T > 5 \text{ years}$).

The reason we chose to calculate intraannual variability, rather than the seasonal cycle as suggested, is that the seasonal signal in the Adriatic exhibits strong interannual variability. As a result, a simple fit using a sum of cosines with annual and semiannual periods would not adequately capture this variability (please see Fig. RC1.1 below). To address this, we filtered out *long-term sea-level component* and defined intraannual variability as processes occurring on timescales between 100 days and 15 months. This range is dominated by the mean seasonal cycle and its anomalies. The upper bound was selected to avoid splitting the annual cycle between intraannual and interannual processes. A brief explanation of this methodology, including the rationale behind it, has been added to the manuscript (Sect. 3.2, lines 210–218).

- When describing individual episodes, the *long-term sea-level variability* is shown as a single contribution in the figures (as done previously), since it acts as constant over the one-month shown windows. Additionally, its subcomponents (intraannual, interannual, and mean SL change) are typically too small to be discernible in the inset histograms relative to other components; therefore, we represent them as a single bar (as done previously). However, in the description of each episode, we now discuss the three individual contributions as defined in the decomposition above, following the reviewer's suggestion. For example, for the episode ID 1 (15 December 1937), lines 300–303:

Long-term sea-level variability contributed 16 cm to this maximum (Figs. A1 and 73). The episode

occurred shortly after a particularly pronounced annual peak (Figs. A1 and 73d), making intraannual variability – including the mean seasonal cycle and its anomalies – the dominant contributor, accounting for 15.6 cm. In contrast, interannual variability slightly reduced this component by 0.2 cm (Fig. 73c), while mean sea-level change contributed just 0.6 cm (Fig. 73b).

- In Section 5, the newly defined subcomponents of *long-term sea-level variability* are shown in Figure 73 and are discussed separately (lines 2123–2126, 2158–2163).

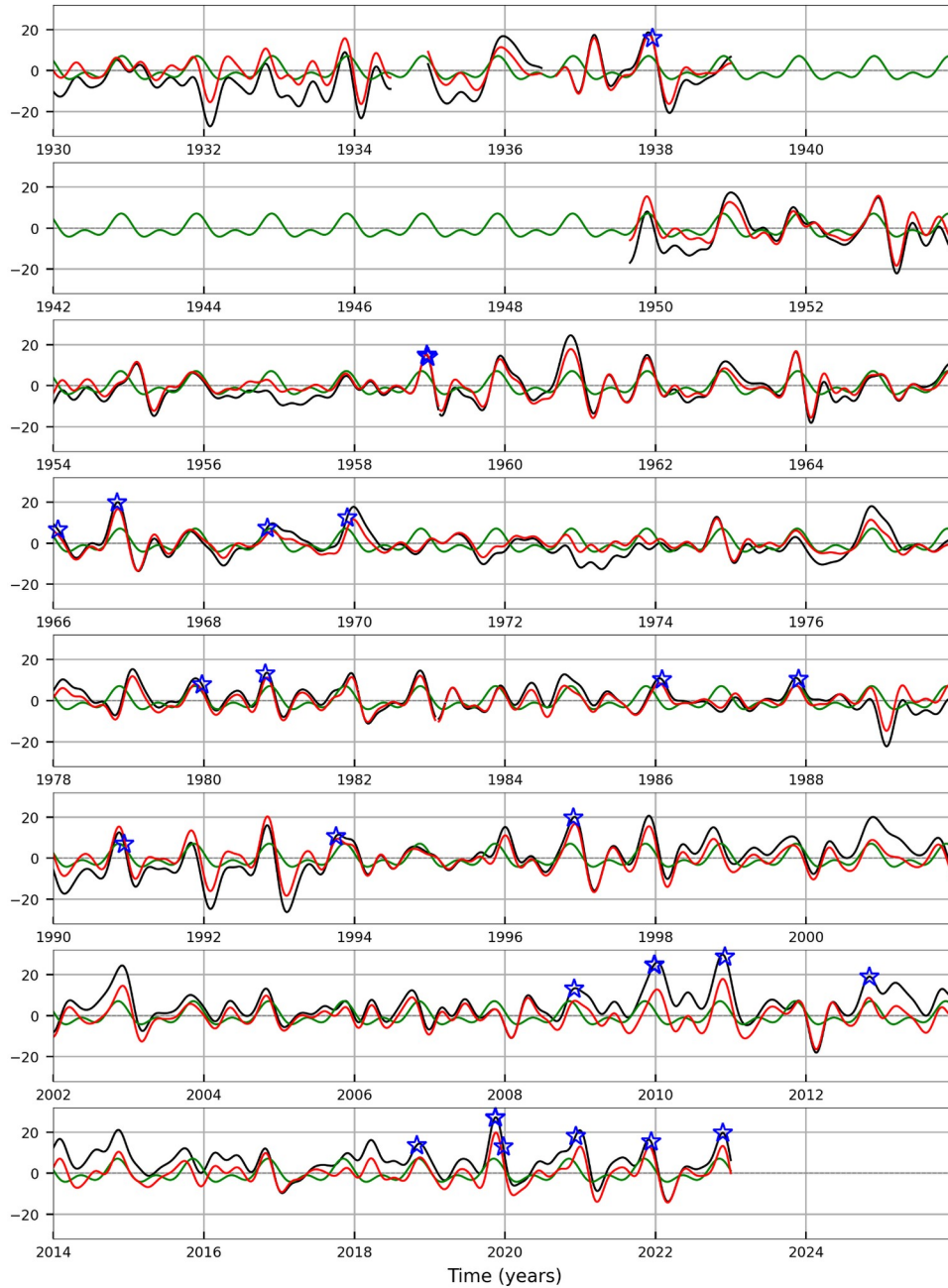


Figure RC1.1: *Long-term sea-level variability* (cm), representing sea-level changes at periods longer than 100 days, is shown in black. Intraannual variability (100 days - 15 months; red) was obtained by high-pass filtering the *long-term sea-level component* to isolate periods shorter than 15 months. The mean seasonal cycle, derived by fitting cosine functions with periods of 365 and 182.5 days to the *long-term sea-level variability*, is also shown (green line), but not used in analysis. Blue stars mark the extracted extreme episodes (Table 2).

My minor suggestions for ameliorating the manuscript are listed here:

- Line 6: add “less than 50 m ...”
Added. Line 27.
- Line 44: “If hourly data ...” I don't think you would obtain different considerations in case of data at a different frequency (e.g., 2h, 3h, 10min, ...)? Please remove the first part of this sentence.
Done! This paragraph has been fully revised. Lines 40–46.
- Line 47: tide is relevant even in the north-western part of the Adriatic Sea.
Included. Lines 47–49.
- Line 113: include the website link.
We have added the link. Line 128.
- Line 117: remove C3S from the citation.
Done! Line 132.
- Lines 2100-2103: specify here the relative role of sea level rise.
Done! It has been incorporated into the text discussing the temporal distribution of both ‘detrended’ and regular extremes (Figure 74). Please see Section 5, lines 2125–2126 and 2193–2202.
- Figure 73: The readability of this figure is complicated by the black bars (indicating the hypothetical SL maxima) in panels c and d. Please remove them. Moreover, I strongly suggest using a realistic temporal scale on the x-axis to show the real distribution of the events in time.
Done! A new figure has been prepared. We removed the hypothetical sea-level maxima from all panels and adjusted the x-axis to reflect the actual timing of events. Unfortunately, due to the close spacing of some events, some overlap was unavoidable. Nevertheless, we believe the new figure serves its purpose. Please see the new figure in Section 5 (Figure 72).
- Figure A2: Use the same y-axis range in all panels.

We revised this figure and used the same scale across all panels to make differences between the contributions immediately apparent, while adjusting the y-axis limits to optimize space. Please see the new figure in Section 5 (Figure 73).

Author's reply to Anonymous Referee #2's (RC2) comments on manuscript egusphere-2024-4044

This paper presents a complete list of storm surge events recorded in the Bakar Station, northern Adriatic, in the last 90 years. Each event is analysed using the available data, with good filtering of the sea level signal. The paper is well written and of good scientific quality. I congratulate the authors for their work. I have just some comments (see the PDF for the minor comments):

Dear Reviewer,

Thank you for your comments and the time you dedicated to reviewing our manuscript. Our responses to your comments are provided in blue text below. The corresponding changes to the manuscript are shown either as red text insets or by referencing the specific line numbers in the revised version where the changes appear.

- The authors define these events as "floods", but this word is more related to the inundation aspect, not to the storm surge aspect;

We replaced the word 'floods' with 'extreme sea levels' in the title and throughout the manuscript, where appropriate. However, since observations showed that flooding occurs along almost the entire eastern Adriatic coast when the sea level reaches 90 cm in Bakar, we retained the word 'flood' in the titles of subsections describing individual events.

- The results of each event are well presented and discussed, even if they are a bit too long. On the contrary, the general discussion of all the cases is poor. The authors should analyse a bit more the changes in time of the sea level components, since they are related to climate change issues (e.g., MSL rise, storminess). I suggest adding some more material on this.

To improve readability and navigation, we added individual subsections for each episode listed in Table 2. In response to comments from both reviewers regarding the discussion of all episodes, we have restructured and expanded this section to include more information on climate change. Additionally, we performed further analyses to examine the effects of storminess, msl rise, and other factors on the temporal distribution of the intensity and frequency of extreme episodes, as suggested. These results are presented in Section 5, in Figures 74 and 75 and discussed in lines 2182–2219.

Minor comments from attached pdf document

Lines 71-73: Wave setup was defined a long time ago, find an older citation. It is important only in some areas, specify.

We identified an earlier reference (Bowen et al., 1968) and specified the types of coastal areas where wave setup is

significant. The rewritten paragraph can be found in lines 73–80. Additionally, since this section (1. Introduction) was overlapping with Section 3.2, we have revised both sections.

Line 82: Really? They are slow and well predictable.

Reformulated. We understand now that the term "threatening" could suggest unpredictability, which was not what we intended to say. Therefore, we have replaced 'threatening' with 'critical' (lines 85–88).

Line 88: Why? Important or more studied?

The sentence has been revised to reflect that we consider it more important, given its increased contribution to the most recent extreme sea-level events. The new sentence now reads (lines 93–95):

While its contribution to Adriatic extreme sea levels remains secondary to *synoptic component*, it still represents an important contribution to extremes, reaching up to 28 cm (Međugorac and Pasarić, 2024).

Line 102: Why Bakar? Is the TS very long? Explain.

It is the oldest TG in Croatia and SL measured here represent the longest recorded series of a single oceanographic parameter in Croatia. Clarification added in lines 111–112 and 125–127.

Line 108: Short it. Section title shortened (line 120). Now it reads 2. Data and past studies.

Line 113: Give the web address. We have added the link (line 128).

Line 114: What is it? We replaced 'around' with 'centred' (line 129).

Table 1: The end is now? Yes, we added word 'present' in the Table 1.

Line 144: I do not agree on this. This definition is the extreme sea level. Floodings are related to the inundation of the territory. Changed in the title and throughout the manuscript where appropriate.

Line 146: You can simply define greater eq than 90cm. While that would be simpler, it would not be accurate in our context, as the 99.99th percentile is 89 cm for the specified period.

Line 163: Introduce that you remove tide to analyse the residual, etc...

Done! The whole subsection was rewritten to address overlap with the Introduction. In lines 180, 187–188, we explain that the tide was first calculated and then removed in order to analyse the residual.

Line 168: Detided. Use a different acronym or specify it. We specified it (we are now using 'de-tided SL').

Lines 172-173: Insert some citations.

Done! We added (lines 196–197): Goldberg and Kempni, 1938; Ruić et al., 2023.

Lines 179-184: Not clear, rephrase it. We have rewritten the paragraph describing how the presence of basin-wide seiches was identified. The revised text is in lines 202–207.

Figure 2: Not clear, rephrase it. We have rewritten the description of Figure 2. The revised text is in lines 176–179.

Line 190: Citation. This text was moved to Introduction with citation added (lines 81–85).

Line 193: this paper. The phrase ‘the main body of the article’ has been replaced with ‘this paper’ (line 210).

Line 226: Why don't you start from 1 to 27 with the numeration? It's more logical.

Done! The extreme sea-level episodes are now listed in chronological order (1 to 27), both in Table 2 and in the order of their descriptions.

Lin 127: () only in the year. Reference was corrected (line 2033).

Line 128: Define the acronym. Done! Line 2034.

Line 2081: This section must be reformulated. Please provide some more figures showing general statistics involving all the cases. How (if) did the components change in time?

We have reorganized and expanded this section to address comments from both reviewers. We analysed temporal changes in the episodes of *synoptic component* and *planetary-scale variability*, focusing on their frequency and intensity. The results are presented in the new Figure 75 and discussed in lines 2203–2219.

Line 2083: The ‘89 cm’ was removed from this section.

Line 2090: This is obviously due to the msl rise. Have you also subsidence in the station? A detrended figure would be more interesting.

The Bakar station is located on a stable ground (Medugorac et al., 2022); therefore, subsidence does not contribute to observed sea-level rise at this site. This is now stated in the paper (lines 2195–2197). Also, we have added ‘detrended’ extremes (derived from total sea levels with mean sea-level change ($T > 5$ years) removed) alongside ‘regular’ extremes (derived from raw total sea levels), and we discuss the resulting temporal distribution in relation to mean sea-level rise, storminess, and other contributing factors. Results are shown in Figures 74 and 75 and discussed in lines 2182–2219.

Line 2094: What do you mean as intensity? Maximum wind speed? Maximum sea level or wave height?

We meant maximum sea level. This is now clarified in the text (lines 2185–2186).

Lines 2100-2103: This sentence is a bit misleading. Is the relative weight of the components that changed? Or, does the storminess increase? Or does the msl rise accelerate? Show in a graph.

The sentence was rewritten (lines 2121–2123) and additional figures and discussion have been included to help explain the increased number of extremes toward the end of the studied period. The new results are presented in Figures 74 and 75 and discussed in lines 2182–2219.

Line 1102 - 1103: This is not correlated with the previous sentence. This sentence was removed.

Line 2108: Cite the figures. Done! Line 2131.

Figure 73: The caption is hard to understand. Moreover, you should discuss the changes on time. Where is the msl rise? I don't understand the component f. Is the synoptic/storminess component changing (It seems not)? And the other components?

The terminology we originally used for sea-level components was evidently unclear, as reviewers either suggested changes or expressed confusion about what certain components represented. Therefore, we revised the names of the sea-level components:

- (a) The *long-period sea-level component* was renamed to *planetary-scale variability* (representing processes with periods between 10 and 100 days). In the figures, this component is now labeled as *plan/planetary*.
- (b) The *mean sea-level change* component was renamed to *long-term sea-level variability*, (representing processes with periods longer than 100 days). In the figures, this component is now labeled as *long/long-term*.

To address the issue of temporal variability in these components, as raised by the reviewer, we carried out additional analyses, as described in our previous responses (Figures 74 and 75, lines 2182–2219).

Line 2148-2156: This is more an introduction than a discussion of the result. This paragraph was removed.