

## Response to Reviewer#1 Comments

**Recommendation** – a major revision is required before the paper can be published.

The paper describes a new dataset of storm-surges. The methodology is well described and written. However, a main issue needs to be addressed before the paper can be recommended for publication. The purpose of the dataset development is not well grounded and presented.

**Point 1:** For example, section 3.3 opens with:

"The comparison with TGs indicated that ASM is slightly better than GTSM in the research area. Moreover, the significant advantages of the ASM data-driven model are: (1) compared to single-site data-driven models, it can provide SS information for ungauged points; (2) compared to numerical models, it can reconstruct long-term SSs faster."

These are the advantages of the model while the paper should focus on the benefits of the dataset. One can argue that a single-site data model can provide higher accuracy, and numerical models can also give results in ungauged points and with higher resolution than the newly developed dataset. In which case, who are the target users for the dataset?

The paper should be revised to clarify the advantages and novelty of the dataset.

### **Response:**

Thanks for your constructive suggestions. High spatiotemporal resolution and sufficiently long SS dataset is the basis for analyzing this disaster. However, the existing storm surge datasets cannot fulfill all three demands simultaneously on a global or quasi-global scale. The advantage and novelty of this dataset is that it can fix the gaps among tide gauge observations, global numerical model simulations, and data-driven reconstructions from single-site modeling. We meticulously revised this manuscript based on the reviewer's suggestions, hoping this version can be clearer and more logical:

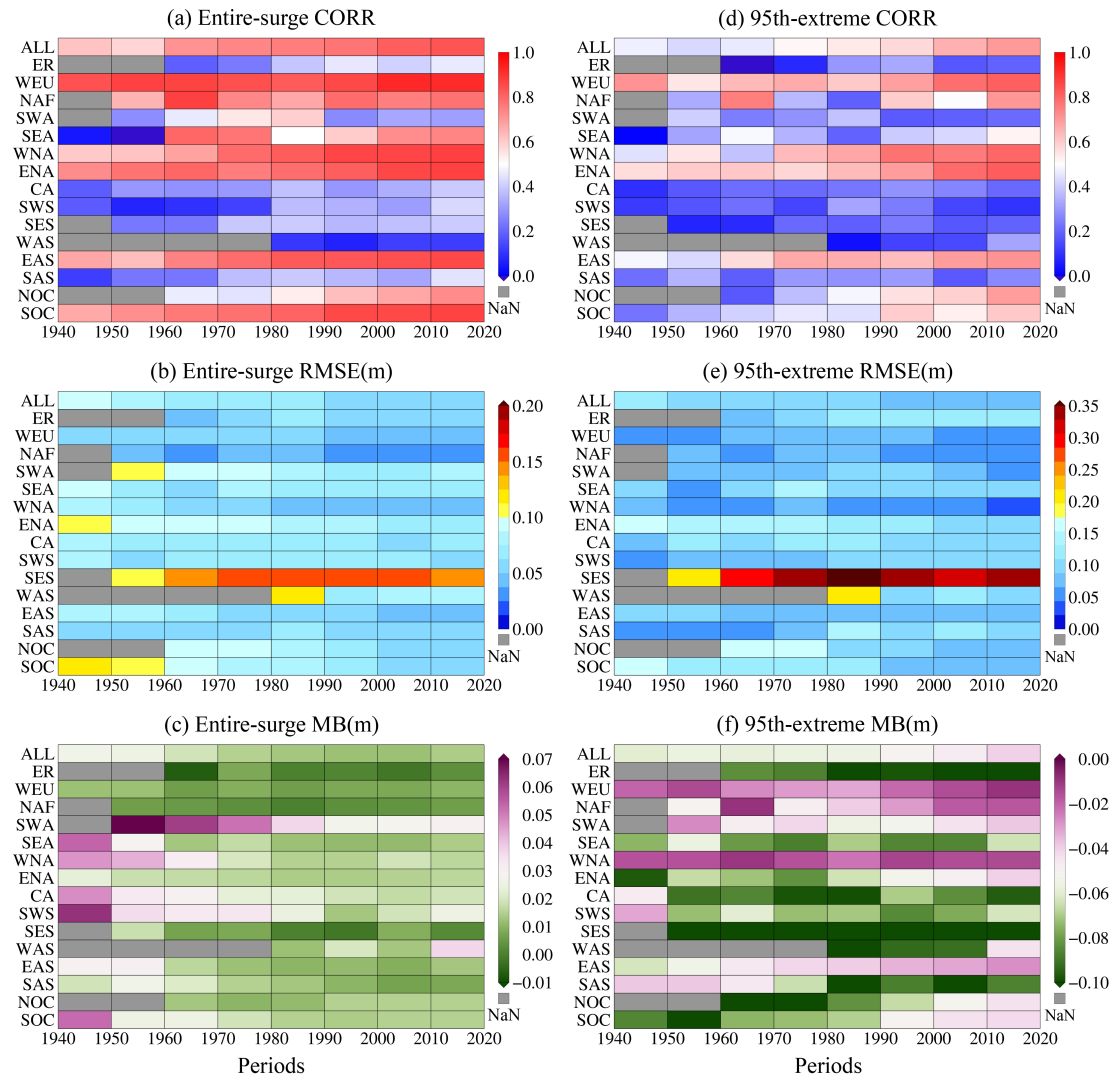
**Point 2:** Here are some points to consider: One of the key features is the spanning. Does the accuracy change over time? It must vary as it is directly affected by the ERA5 inputs.

### **Response:**

Thanks for your professional suggestion. In this version, we added the temporal variation analysis of our model's precision from 1940 to 2020 every 10 years in [Lines](#)

190-206:

It is necessary to evaluate temporal variations in reconstructed SSs further since their length is over 80 years, during which the number of TG stations and the quality of atmospheric data have changed. As shown in Fig. 4, the precision of ASM model at TGs in each sub-region was calculated every 10 years (excluding TGs with less than one year of data in a given decade). Results indicate that the overall precision (i.e., for ALL TGs) of entire surges and 95th extremes gradually increased from 1940 to 2020. Possible reasons are, on the one hand, the increase of TGs in recent decades provided more predictand features; on the other hand, the optimization of ERA5 atmospheric data (predictor) contained more detailed tropical and extratropical cyclone information. At the regional scale, for entire surges, Fig. 4(a) indicates that except for SWA (CORR decreases) and WAS (CORR remains unchanged), CORRs of other sub-regions present an upward trend; Fig. 4(b) shows the RMSE in SES increases, while RMSEs in other regions decrease; Fig. 4(c) gives that MBs of sub-regions have been gradually optimized (excluding WAS). For 95th extremes, in terms of CORR (Fig. 4(d)), WEU, NAF, WNA, ENA, EAS, NOC, and SOC show an upward trend, whereas there is no obvious pattern in other regions; for RMSE (Fig. 4(e)), ER, SEA, and SES present an increasing trend, other regions decrease; for MB (Fig. 4(f)), the underestimation of SSs in ER and SAS rises, and there is no noticeable change in WNA and SES. MBs in WEU, NAF, ENA, WAS, EAS, NOC, and SOC are optimized, while there is no clear pattern in SWA, SEA, CA, and SWS.



**Figure 4: Temporal variations of the ASM model's precision at tide gauges from 1940 to 2020.**  
**(a-c) Entire surge evaluation statistics for different regions every 10 years; (d-f) 95th extreme evaluation statistics for different regions every 10 years**

**Point 3:** The discussion of spatial variability in accuracy needs elaboration. The boxed continental statistics look nice but do not address all the shown differences. For example, performance in U.S. and Canada coasts are much better than in Central America. That could be attributed to the climatology, forcing fields or TG availability.

**Response:**

Thanks for your recommendation. In this version, we divided the research area into more detailed sub-regions (from six in the old version to fifteen in this version), and all relevant figures and descriptions were updated:

As shown in Fig. 3, we divided the research area into fifteen sub-regions (ER: the equatorial region, WEU: Western Europe, NAF: Northern Africa, SWA: Southwestern Africa, SEA: Southeastern Africa, WNA: Western North America, ENA: Eastern North

America, CA: Central America, SWS: Southwestern South America, SES: Southeastern South America, WAS: Western Asia, EAS: Eastern Asia, SAS: Southern Asia, NOC: Northern Oceania, and SOC: Southern Oceania) for more detailed assessment information. Note that the equatorial region ( $\sim 6^\circ\text{S}$  to  $\sim 6^\circ\text{N}$ ) was separated as an independent area since it has almost no tropical or extratropical cyclones.

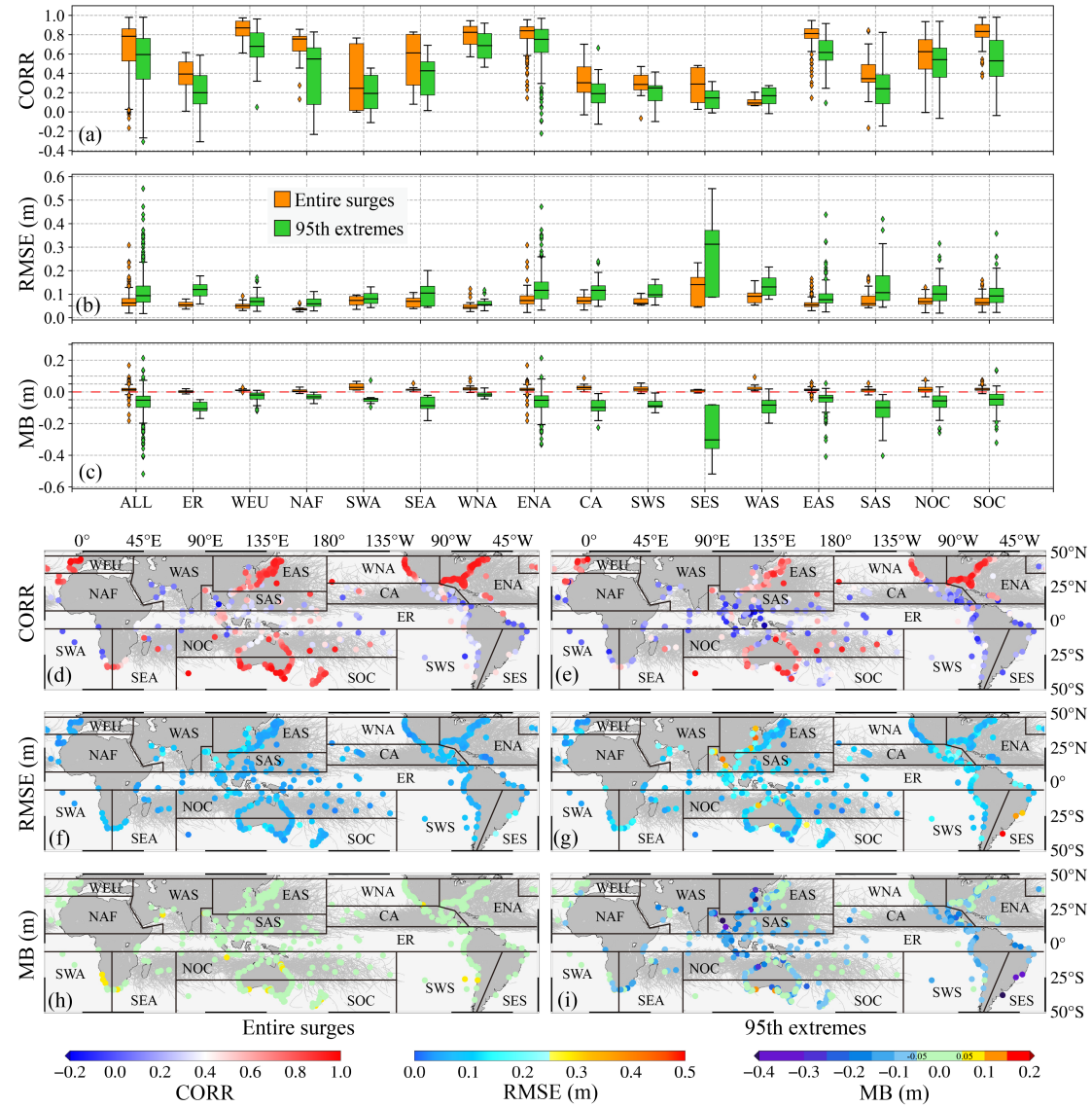


Figure 3: ASM model evaluation at tide gauges from 1940 to 2020. (a-c) Entire surge and 95th extreme evaluation statistics for different regions; (d-i) Distributions of evaluation metrics. Gray lines are tropical cyclone paths.



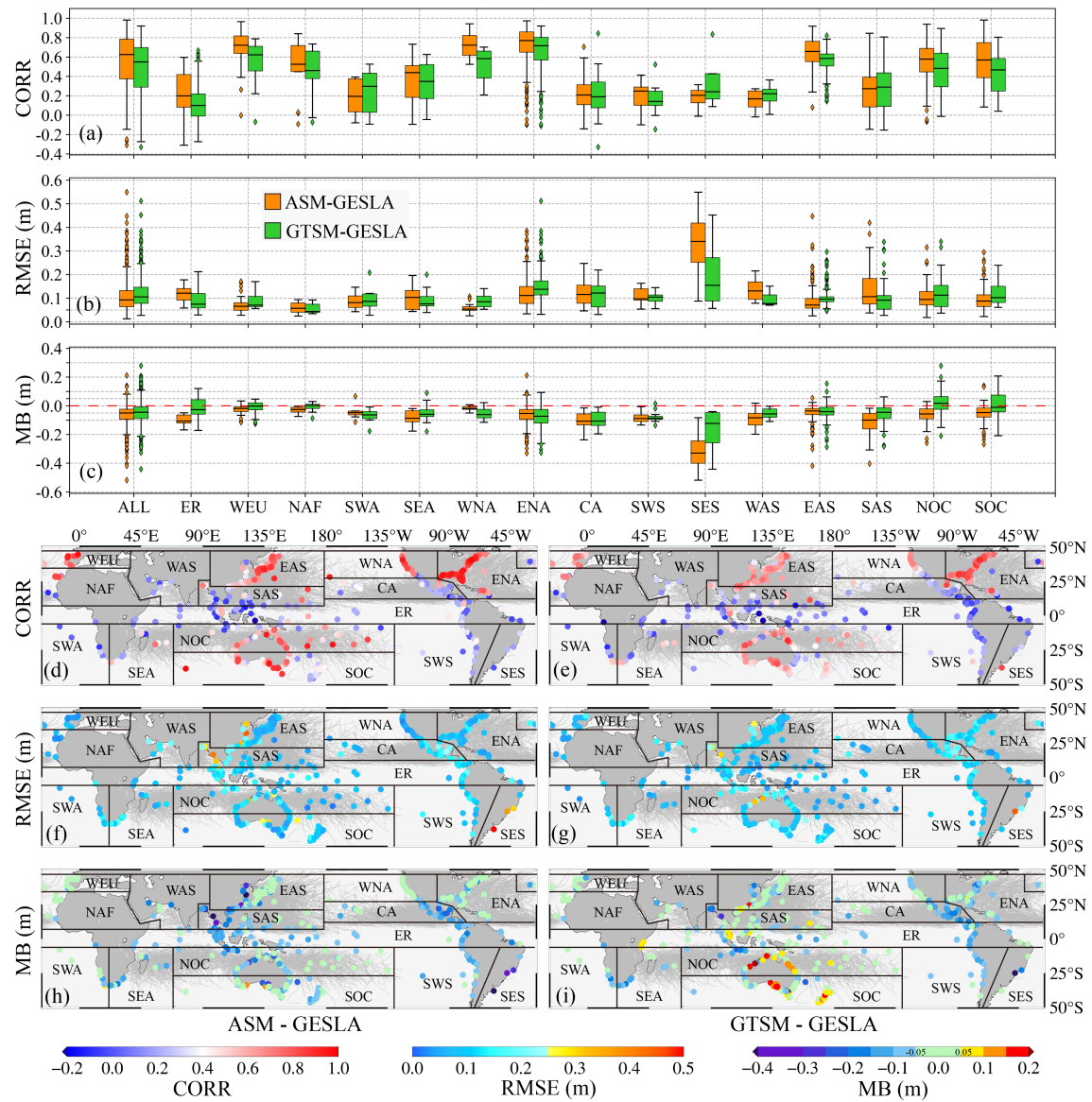


Figure 5: ASM model comparison with the numerical model at tide gauges from 1979 to 2018. (a-c) ASM and GTSM 95th extreme evaluation statistics for different regions; (d-i) Distributions of evaluation metrics. Gray lines are tropical cyclone paths.

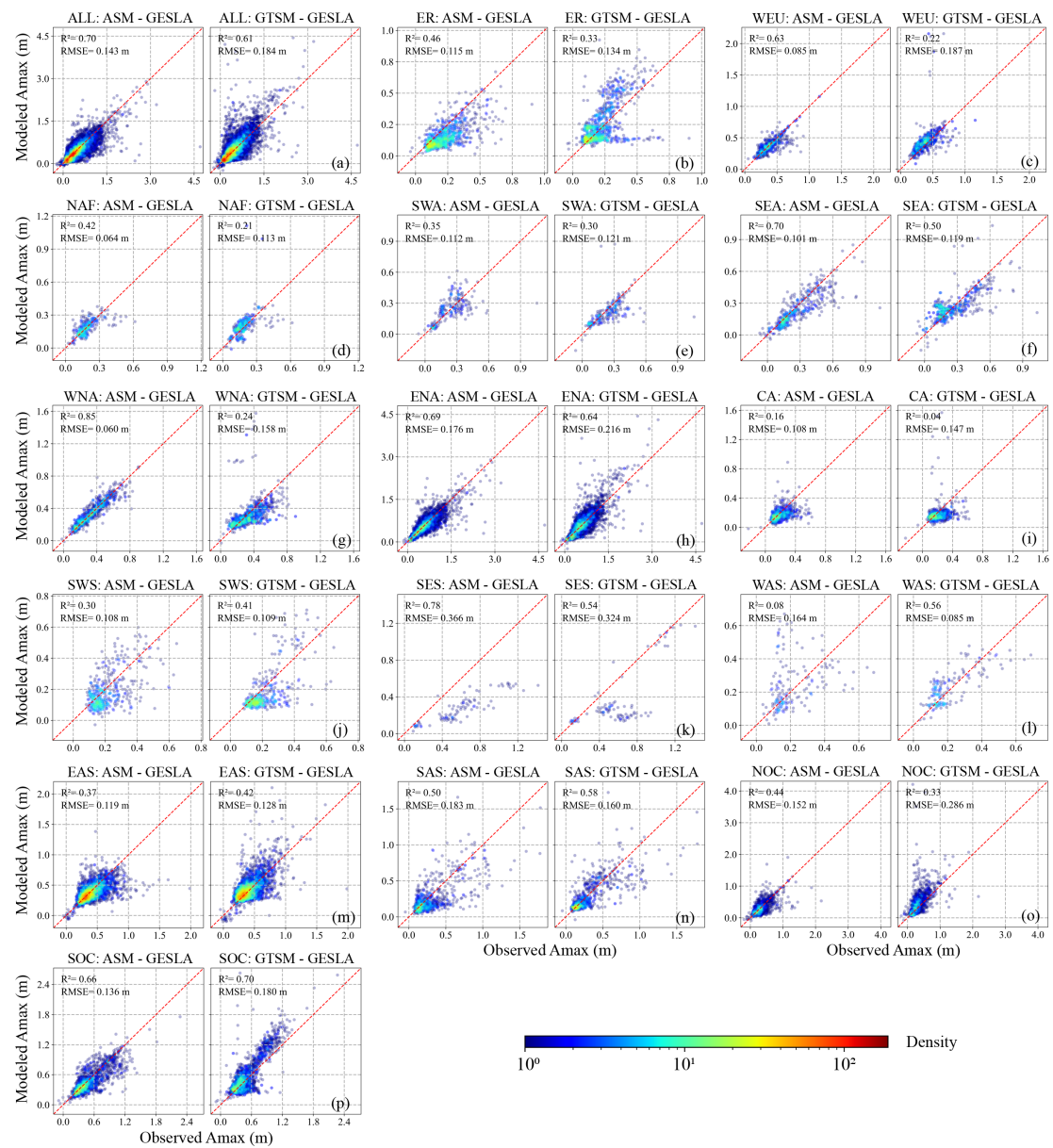


Figure 6: Scatter density plots of ASM and GTSM annual maxima (Amax) compared with tide gauge observations in different regions. The data for tide gauges were combined. The red dotted line indicates the perfect fit line.

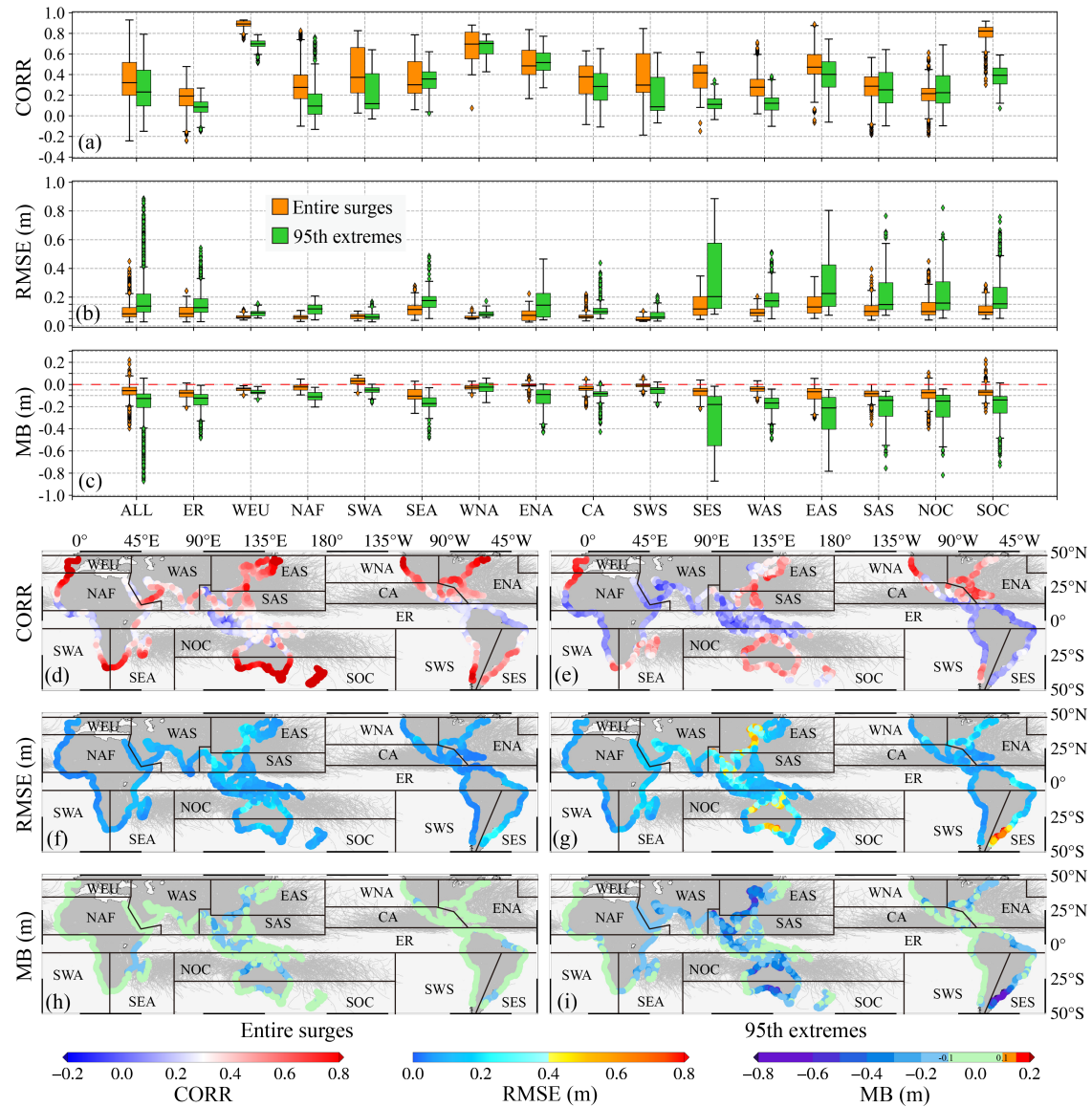


Figure 7: Differences between ASM and GTSM at the coastal scale from 1979 to 2018. (a-c) Comparison statistics between ASM and GTSM modeled entire surges and 95th extremes for different regions; (d-i) Distributions of comparison metrics. Gray lines are tropical cyclone paths.

**Point 4:** Adding for each output point a measure of accuracy/quality based on the author's evaluations will be of much help to the users.

**Response:**

Thanks for your suggestion. The evaluation of accuracy relies on the ground truth from tide gauge stations. However, the spatial resolution of our dataset is 10 km, which means there are no tide gauge stations nearby for most of the output points. The cross-validation in section 3.1 can offer such an assessment. We divided the research area into more detailed parts (see Point 3) and hope it can provide users with more helpful quality

information.

**Point 5:** Excluding most of Europe devalues the significance of the dataset as it is supposed to be "quasi-global".

**Response:**

Thanks for reminding. Since this was the first high spatial coverage dataset generated through the data-driven method over such a large area, we wanted to focus on low-latitude regions where tropical cyclones are frequent. In addition, the Mediterranean Sea was excluded because we found almost no tropical cyclones in this area's history. These two conditions excluded most of Europe from the ASM-SS dataset. In future dataset updates, we will try to expand the data coverage.

**Specific Remarks:**

**Point 6:** Lines 46-47: "Changes in SSs also need to be discussed. Unlike the widely agreed impact of sea level rise on ESLs, the contribution from changes in SSs remains controversial." The sentence is unclear and confusing. Please, rewrite it.

**Response:**

We are sorry for the unclear expression. This version deleted this sentence since we rewrote nearly the whole introduction.

**Point 7:** Line 57: "There are three main ways to obtain high-frequency...". Listing the three ways together is problematic as data-driven models are dependent on TG observations. Additionally, authors' data-driven model depends also on a numerical model. It would be great to introduce the concept of the data-driven model afterwards.

**Response:**

Thanks for your professional suggestion. We rewrote the relevant paragraphs in [Lines 31-74](#), hoping it could be more logical:

High-frequency (at least hourly), sufficient spatial coverage, and long-term records are the basis for SS analysis. To date, tide gauges (TGs) are the most reliable source of coastal sea-level observations (Marcos et al., 2019). However, their distribution is sparse and uneven. For example, as the most complete high-frequency TG collection currently, though the Global Extreme Sea Level Analysis version 3 (GESLA-3) dataset included 5,119 stations around the world, most of them were distributed in North America, Europe, Japan, and Australia (Haigh et al., 2023). Interpolating TG observations among different stations cannot accurately capture the

variabilities of SSs (Muis et al., 2016) since they are affected by many factors, such as storminess, coastline shape, and bathymetry (Resio and Westerink, 2008). This always limits in-depth analysis of the spatial characteristics of SSs from TG records directly, especially on a global or quasi-global scale. In addition, though some of the oldest TG stations can date back to the eighteenth century, only ~10% (554 stations) of TG records in the GESLA-3 dataset were longer than 50 years, which makes it difficult to obtain more detailed long-term variations in SSs.

Numerical models can provide simulated data with better spatial coverage by resolving coastal physical processes inducing SSs (Muis et al., 2016, 2023; Lockwood et al., 2024). A common limitation of numerical models is that they require accurate and high-resolution bathymetric data for sufficiently precise SS estimations since SSs are significantly affected by water depth in shallow water (Resio and Westerink, 2008). However, such bathymetric data is often unavailable in nearshore areas (Cid et al., 2018). In addition, in global or quasi-global SS simulations, the coastal grid resolution of numerical models is usually set to several kilometers to balance the computational complexity (Muis et al., 2020; Mentaschi et al., 2023), which means that nearshore physical features with a spatial scale smaller than this resolution cannot be sufficiently simulated (Parker et al., 2023), and hence affecting the SS precision. Meanwhile, the computational efficiency of global numerical models tends to affect the length of simulated SSs (Muis et al., 2019). For instance, the state-of-the-art Global Tide and Surge Model (GTSM), though its outputs have been widely used in relevant studies (Kirezci et al., 2020; Dullaart et al., 2021; Fang et al., 2021; Yang et al., 2024b), its simulations spaned only the most recent decades from 1979 to 2018 (Muis et al., 2020). This imposed limitations on studies requiring long-term SS records.

Unlike numerical models, data-driven models do not need to resolve coastal physical processes. They obtain the statistical relationship between SSs (predictand) and relevant atmospheric factors (predictor) through multiple linear regression (Cid et al., 2018) or artificial intelligence (Bruneau et al., 2020). Therefore, the precision of data-driven models is unaffected by bathymetric data and grid resolution. In addition, long-term SSs can be reconstructed efficiently after the statistical relationship is established (Tadesse et al., 2020). However, the commonly used single-site modeling framework for data-driven models heavily relies on TGs; it must establish independent relationships for every TG site by site (Cid et al., 2017; Bruneau et al., 2020; Tiggeloven et al., 2021) and cannot provide any SS information at ungauged coastal locations. For example, the Global Storm Surge Reconstruction (GSSR) database, the only publicly



released global SS dataset from the data-driven model, provided SS reconstructions at 882 points globally going as far back as 1836, which benefited the research on long-term trend analysis of SSs (Tadesse and Wahl, 2021). However, it cannot address issues caused by the sparseness and uneven distribution of TG stations. Some studies replaced TG observations with numerical SS simulations to train the data-driven model (so-called 'surrogate model') (Lee et al., 2021; Ayyad et al., 2022; Lockwood et al., 2022). This combination improved the spatial resolution, but numerical models' precision limitations were also transferred to the surrogate model. Moreover, in theory, surrogate models cannot be better than numerical models compared to TG observations. Yang et al. (2023) proposed a novel all-site modeling (ASM) framework, which allowed the data-driven model to reconstruct high spatial-coverage SSs in research areas by learning from TG observations (without SS simulations from numerical models). Although single-site modeling and ASM belong to the data-driven model, their basic ideas differ. The former presumes SS observations at different TGs are independent. Therefore, the relationship between predictors and SSs needs to be learned for every TG site by site; this relationship is unsuitable for other locations. In contrast, the latter believes there is a universal connection between SSs at different TGs, so all available TGs within the research area can be pooled into one model to learn the only regional relationship between predictors and SSs. This essential difference enables the ASM framework to reconstruct SSs at any coastal point in the research area. In addition, the study has shown that ASM's precision is better than single-site modeling's (Yang et al., 2023).

**Point 8:** Line 66: "However, numerical models are relatively time-consuming, especially for the global simulation." Time-consuming is not the most concerning matter for the dataset users. What are the disadvantages of numerical models related to their performance?

**Response:**

Thanks for your professional recommendation. Precise numerical simulations require accurate and high-resolution bathymetric data, which is often unavailable in nearshore areas. In addition, the coastal grid resolution for global or quasi-global numerical models is usually set to several kilometers, which means small-scale physical features cannot be sufficiently simulated, and hence affecting the precision. We rewrote this paragraph in [Lines 41-52](#):

Numerical models can provide simulated data with better spatial coverage by resolving coastal physical processes inducing SSs (Muis et al., 2016, 2023; Lockwood

et al., 2024). A common limitation of numerical models is that they require accurate and high-resolution bathymetric data for sufficiently precise SS estimations since SSs are significantly affected by water depth in shallow water (Resio and Westerink, 2008). However, such bathymetric data is often unavailable in nearshore areas (Cid et al., 2018). In addition, in global or quasi-global SS simulations, the coastal grid resolution of numerical models is usually set to several kilometers to balance the computational complexity (Muis et al., 2020; Mentaschi et al., 2023), which means that nearshore physical features with a spatial scale smaller than this resolution cannot be sufficiently simulated (Parker et al., 2023), and hence affecting the SS precision. Meanwhile, the computational efficiency of global numerical models tends to affect the length of simulated SSs (Muis et al., 2019). For instance, the state-of-the-art Global Tide and Surge Model (GTSM), though its outputs have been widely used in relevant studies (Kirezci et al., 2020; Dullaart et al., 2021; Fang et al., 2021; Yang et al., 2024b), its simulations spaned only the most recent decades from 1979 to 2018 (Muis et al., 2020). This imposed limitations on studies requiring long-term SS records.

**Point 9:** Line 85: "Therefore, the ASM provides an opportunity to obtain global long-term and high spatial coverage SSs simply and efficiently." This para emphasizes the effectiveness of the model rather than ensuring that data-driven models provide reliable results. Please, rewrite it.

**Response:**

Thanks for your suggestion. We rewrote this paragraph in [Lines 53-74](#):

Unlike numerical models, data-driven models do not need to resolve coastal physical processes. They obtain the statistical relationship between SSs (predictand) and relevant atmospheric factors (predictor) through multiple linear regression (Cid et al., 2018) or artificial intelligence (Bruneau et al., 2020). Therefore, the precision of data-driven models is unaffected by bathymetric data and grid resolution. In addition, long-term SSs can be reconstructed efficiently after the statistical relationship is established (Tadesse et al., 2020). However, the commonly used single-site modeling framework for data-driven models heavily relies on TGs; it must establish independent relationships for every TG site by site (Cid et al., 2017; Bruneau et al., 2020; Tiggeloven et al., 2021) and cannot provide any SS information at ungauged coastal locations. For example, the Global Storm Surge Reconstruction (GSSR) database, the only publicly released global SS dataset from the data-driven model, provided SS reconstructions at 882 points globally going as far back as 1836, which benefited the research on long-



term trend analysis of SSs (Tadesse and Wahl, 2021). However, it cannot address issues caused by the sparseness and uneven distribution of TG stations. Some studies replaced TG observations with numerical SS simulations to train the data-driven model (so-called 'surrogate model') (Lee et al., 2021; Ayyad et al., 2022; Lockwood et al., 2022). This combination improved the spatial resolution, but numerical models' precision limitations were also transferred to the surrogate model. Moreover, in theory, surrogate models cannot be better than numerical models compared to TG observations. Yang et al. (2023) proposed a novel all-site modeling (ASM) framework, which allowed the data-driven model to reconstruct high spatial-coverage SSs in research areas by learning from TG observations (without SS simulations from numerical models). Although single-site modeling and ASM belong to the data-driven model, their basic ideas differ. The former presumes SS observations at different TGs are independent. Therefore, the relationship between predictors and SSs needs to be learned for every TG site by site; this relationship is unsuitable for other locations. In contrast, the latter believes there is a universal connection between SSs at different TGs, so all available TGs within the research area can be pooled into one model to learn the only regional relationship between predictors and SSs. This essential difference enables the ASM framework to reconstruct SSs at any coastal point in the research area. In addition, the study has shown that ASM's precision is better than single-site modeling's (Yang et al., 2023).

**Point 10:** Line 95: The section opens with describing the inputs to the model. It would be better to start by explaining the methodology in general.

**Response:**

Thanks for your suggestion. We chose this logic since we can give the specific composition of each column of matrices when explaining the methodology, which may make it easier for readers to understand the modeling process. Therefore, we retained this logic in this version.

**Point 11:** Line 98: <https://doi.org/10.1002/qj.4803> should be also referenced since you use the extended version of ERA5.

**Response:**

Thanks for your attention. We are sorry for forgetting to add it when submitting the manuscript since the newest paper of ERA5 was not published when we started to write our manuscript. It was updated in this version in [Line 87](#):

...from the European Centre for Medium-Range Weather Forecasts (ECMWF)

Reanalysis v5 (ERA5) database ([Soci et al., 2024](#))...

**Point 12:** Line 131: "every 20 km per coastal station." The choice of the 10km resolution in the developed dataset is unclear and not explained. The Numerical model resolution is 2.5 and the data-driven model resolution is 20km yet the dataset is provided at 10km. Please justify this choice.

**Response:**

We are sorry for the confusion. Though the numerical model was solved with the unstructured grid resolution of 2.5 km, the spatial resolution along the coast was resampled to ~20 km when the numerical product was released (considering the data volume). Hence, when we compared the data-driven model with the numerical model at the coastal scale, we needed to reconstruct storm surges to the same coastal points of the numerical product, whose spatial resolution is 20 km. Then, in order to distinguish our data-driven dataset from the global numerical product, we generated our storm surge product with a resolution of 10 km. A higher spatial resolution may provide more information for data users.

To make it clearer, we rewrote this sentence in [Lines 121-122](#):

...It provided outputs both in the ocean and along the coastline; the latter's resolution was resampled to approximately every 20 km per coastal station to limit the data volume ([Muis et al., 2020](#)).

**Point 13:** Line 137: "coastal stations with a 10 km resolution" the using term station here is confusing. Please, find a different way to call the model results (maybe nodes).

**Response:**

We are sorry for the confusion. We changed it in this version in [Line 129-133](#):

...After smoothing the shoreline with a window of 50 points, coastal nodes with a 10 km resolution were sampled evenly from the smoothed coastline. Figure 2 shows their distribution. The total number of nodes is...

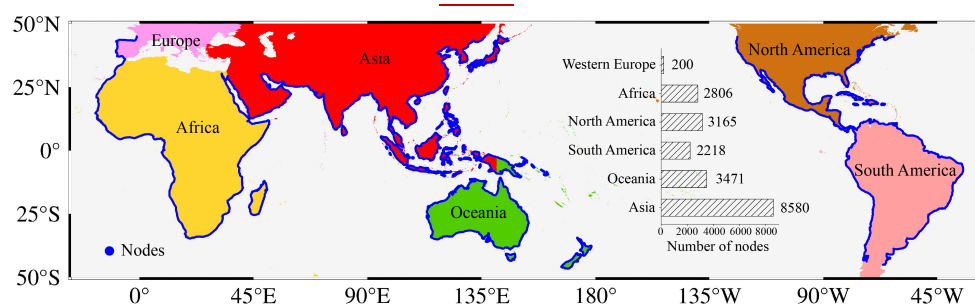


Figure 2: The distribution of coastal nodes for reconstructed storm surges.

**Point 14:** Line 175: "In addition, as mentioned in the introduction, our analysis here did not focus on the equatorial region ( $\sim 6^{\circ}\text{S}$  to  $\sim 6^{\circ}\text{N}$ ), the South Atlantic, and the southeastern Pacific." If these areas are a part the published dataset they must be evaluated as well. It is suggested to have the evaluations of the entire domain as the primary and the limited evaluations in the appendix.

**Response:**

Thanks for your constructive suggestions. In this version, we moved the evaluations of the entire domain from the appendix to the main text and divided the research area into more specific parts. We rewrote this paragraph in [Lines 173-181](#):

As shown in Fig. 3, we divided the research area into fifteen sub-regions (ER: the equatorial region, WEU: Western Europe, NAF: Northern Africa, SWA: Southwestern Africa, SEA: Southeastern Africa, WNA: Western North America, ENA: Eastern North America, CA: Central America, SWS: Southwestern South America, SES: Southeastern South America, WAS: Western Asia, EAS: Eastern Asia, SAS: Southern Asia, NOC: Northern Oceania, and SOC: Southern Oceania) for more detailed assessment information. Note that the equatorial region ( $\sim 6^{\circ}\text{S}$  to  $\sim 6^{\circ}\text{N}$ ) was separated as an independent area since it has almost no tropical or extratropical cyclones.

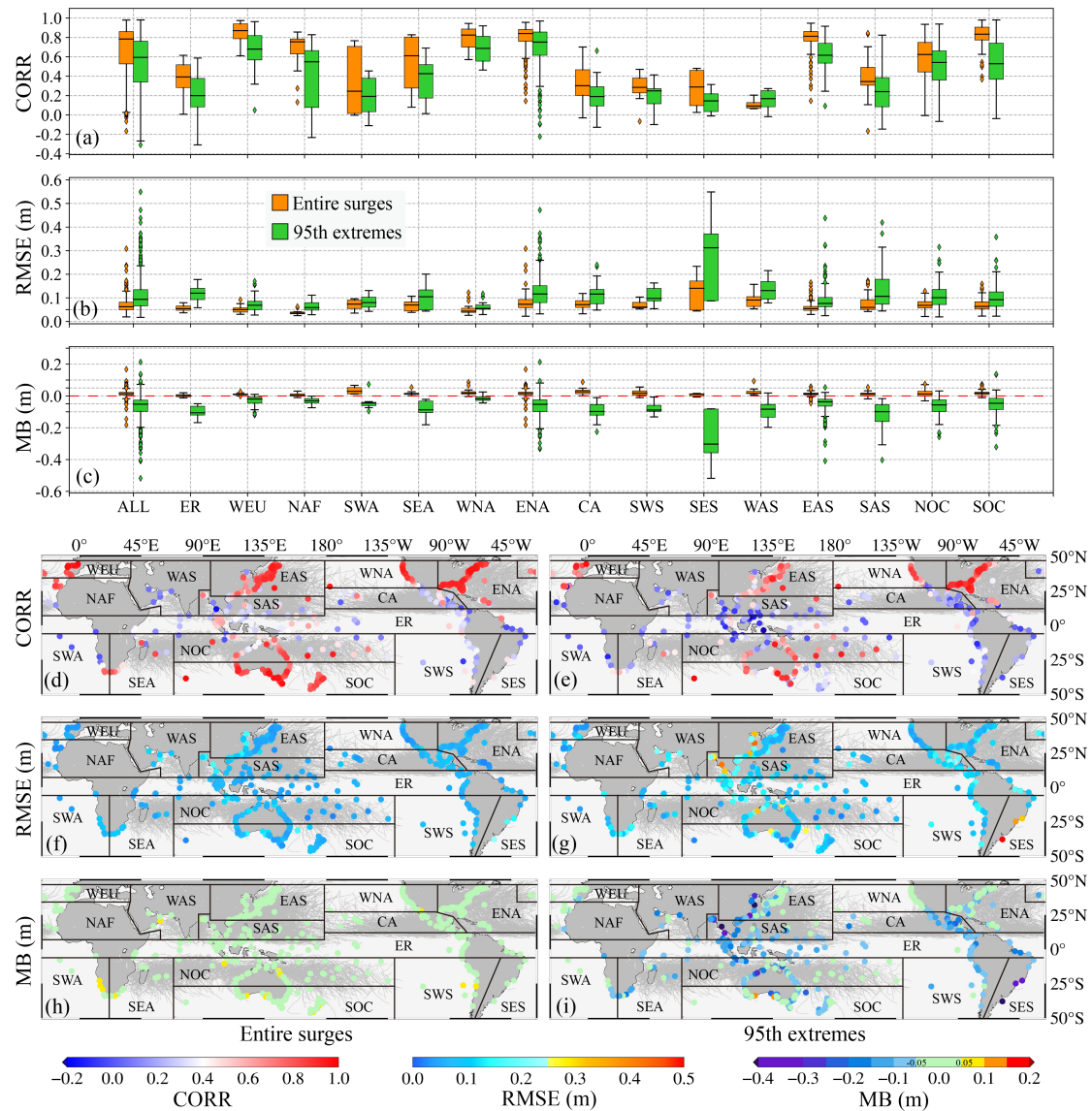


Figure 3: ASM model evaluation at tide gauges from 1940 to 2020. (a-c) Entire surge and 95th extreme evaluation statistics for different regions; (d-i) Distributions of evaluation metrics. Gray lines are tropical cyclone paths.

**Point 15:** Line 180: Fig 3 caption says "Model evaluation at tide gauges..". Since there are several models involved in the work there should be a naming consistency to avoid confusion.

**Response:**

We are sorry for the inaccurate wording. We rewrote it in Line 180 and Line 213:

Figure 3: ASM model evaluation at tide gauges from 1940 to 2020....

Figure 4: ASM model comparison with the numerical model at tide gauges...

**Point 16:** Line 214: "the significant advantages of the ASM data-driven model are: (1)

compared to single-site data-driven models, it can provide SS information for ungauged points; (2) compared to numerical models, it can reconstruct long-term SSs faster. In this section" As it was mentioned above, these advantages are first and foremost related to the model itself rather than the developed dataset and its preference compare to the similar datasets.

**Response:**

Thanks for your constructive suggestions. In this version, we focused on clarifying the dataset's advantages. This description was changed in [Lines 239-243](#) into:

As mentioned in the introduction, though ASM and single-site modeling belong to the data-driven model, the former can provide SS information for ungauged points since their basic ideas differ. This advantage of ASM allows us to compare the data-driven model and numerical model on a quasi-global scale with high spatial resolution. In this section, the ASM model was trained based on all 1,315 TGs within the research area with records longer than one year from 1940 to 2020 (Fig. 1). Then SSs from 1979 to 2018 were reconstructed to all coastal points of GTSM to assess their differences (Fig. 7).

**Point 17:** Appendix A: Either add text to the appendix or move the figures to the sections which mention them.

**Response:**

Thanks for your suggestion. In this version, we deleted Appendix A and analyzed the whole area in relevant sections.

Overall, the authors showed the new dataset has potential. But the paper requires significant improvement to be published.