Response to Reviewer #3 of our manuscript entitled

Coastal extreme sea levels in the Caribbean Sea induced by tropical cyclones submitted to *Natural Hazards and Earth System Sciences.*

Ariadna Martín, Angel Amores, Alejandro Orfila, Tim Toomey, Marta Marcos

October 7, 2022

This study investigates the storm surge and wind-wave components of extreme sea levels in the Caribbean Sea induced by tropical cyclones. The approach applied in this study is different from previous studies as it is based on a large set of synthetic tracks of tropical cyclones while also taking wind-waves into account. Previous large-scale studies generally excluded wind-waves because of the high model resolution that is required to model the wind-wave component. The study finds that tropical cyclones in the Caribbean come from two well-differentiated families with very distinct intensities and genesis locations. Also, the contribution of each of the forcing mechanisms to the total water level has been investigated. Finally, return levels of wind-waves and sea-surface are provided in a dataset.

Overall I find the study scientifically relevant. However, in my opinion still some substantial improvements are required before this manuscript can be considered for publication in NHESS. My main points of concern are addressed under specific comments. In addition, there are quite some spelling errors. I would advise to let a native English speaker check the manuscript. Some of the writing mistakes that I found are listed under technical corrections, as well as some suggestions to improve on the clarity of the text and figures.

Main comments:

(1) — I am not convinced that the selected subset of 1,000 TC tracks represents the complete 10,000 years of TC activity from STORM. You are arguing that figures 1e, and 1f look very similar. However, I disagree as the patterns don't match. In addition, in the discussion you mention that SSE is very dependent on the morphology of the coastlines. This tells me that even just a very minor shift in storm track could potentially result in a completely different storm surge. The way you checked whether your set of 1,000 TC events represents the STORM dataset (complete 10,000 years) doesn't take this into account.

A — The method to select the subset of TCs follows Toomey et al. [2022]. Our results in Figure 1a and b in the manuscript indicate that the distribution of maximum velocities from TCs is consistent among both datasets, with correlations over 0.9. We recognise that the qualitative comparison of the maps in Figure 1 e and f may be misleading. However, the statistics are also computed and plotted in Figure 1 c and d. Again, we observe that the correlation among the spatial distribution in the maps is about 0.96, thus confirming their consistency.

In terms of the differences in the results of the two subsets along the coastlines, we refer to the comparison between Figures 3c and S1a of the manuscript, where we have mapped the average number of TC per decade hitting every coastal grid point for the subsample and the entire dataset, respectively. The two maps are indistinguishable.

(2) — Linked to this, the historical dataset IBTrACS that contains observed tracks of TCs shows that the north coast of South America experienced basically zero TCs in the past 40 years. In the STORM dataset there are multiple, even within just a decade of data. Most likely due to the way the STORM model was set up, which leaves some freedom to the TCs to travel in a certain

random direction, next to the most common north-west direction for the Atlantic basin. How is the uncertainty related to this represented and illustrated in your results?

A — We are aware of this issue and is an inherent problem with the original data base. Indeed, this is related to the large standard deviation that IBtrACS has in the number of landfalls, that indicates a substantial difference in the year-to-year landfall counts. This is reflected in the STORM dataset. However, on average, the landfall counts for both datasets are within one standard deviation of each other [Bloemendaal et al., 2020]. We have added a comment in the paper to indicate it.

(3) — The different settings that you used for the hydrodynamic model are described in the methods section. However, I am missing an explanation why you chose those settings. For example, why did you use the Pond & Pickard formulation to calculate the wind stress?

A — All our settings are based on both previous studies and tests conducted during the validation process. In particular Pond & Pickard formulation is only used in the section of the contributions to SSE, while for the fully coupled run the wind stress is calculated directly using the forcing fields which proved to be superior to the former when waves are available [Bertin et al., 2015]. This is added in the text.

(4) — Hurricanes Wilma and Thomas are used to validate the numerical simulation set-up. However, no observations are available from nearby tide gauges at the time of these two tropical cyclones. Does this mean that validation of the hydrodynamic model is completely lacking? I don't understand why you pick these events if observations from tide gauges are unavailable? Would it be possible to simulate some other tropical cyclone events for which tide gauge observations are available?

A — In the revised version we have extended the validation to include tide gauges and more buoys. Now, section 3.2 presents a complete validation of the model setup using all in-situ measurements available.

(5) — Suggestion: did you compare SSE return periods, so excluding waves, with the COAST-RP dataset from Dullaart et al. (2021)? It would be interesting to compare because the input dataset, being STORM, is the same. However, this study used 3,000 years of TC activity from the STORM dataset instead of 1,000 events like you did. I realize that COAST-RP includes tidal levels as well, but because the tidal range is very small in this area a comparison could be of added value.

A — Thank you for the suggestion. We have compared both results and the conclusions are cited the paper in our discussion.

(6) — The relatively coarse coastal resolution of the model grid results in an underestimation of the wave set-up (line 204). This is a major limitation of this study correct? Then why isn't it discussed later on in the discussion section?

A — We explain that our information provides the areas of greatest impact against the SSE, where we provide a threshold value because we may well be underestimating the contribution of the wave setup. In Sec. 4 (Lines: 314-315) we underline these limitations and explicitly discuss this point. To increase the coastal resolution to achieve better results is beyond of the scope of the present manuscript. We are doing this computation in the Mediterranean Sea and requires a lot of computational effort.

(7) — At this point, I am not convinced that performing the study again will result in the same findings. I believe this is crucial for all scientific studies. Improving the clarity of the methods section could be the first step here.

A — We have modified the text according to the suggestions provided by the reviewer above. We hope that these changes will help clarifying the results. In addition, and following the request from reviewer 2, we have now shared all the outputs of the study, for the sake of reproducibility. New repository: 10.5281/zenodo.7069110

Other specific comments:

(1) — You refer to the hydrodynamic model as 'hydrodynamic' or 'numerical' model. Please be consistent.

A — Changed

(2) — Line 12: "Here we focus in" -¿ "here we focus on

A — Changed

(3) — Line 13: "TC" -¿ "TCs". Please check throughout the manuscript.

A — Done

(4) — Line 20: "small islands" -¿ "small island"

A — Changed

(5) — Line 23: "GPD" -¿ "GDP"

A — Done

(6) — Line 58: What do you mean by maximum speed distribution?

A — Maximum wind speed distribution. Is already changed in the text.

(7) — Line 85: I believe this paragraph could be improved. It might help the reader to see a figure of the wind field generated using the holland model. In addition the last sentence requires some explanation. Why do you reduce the velocity by 20% over land areas? Do you maybe have a reference for that?

A — We have used a state of the art approach here. Examples of the Holland wind profiles can be found easily, so we do not feel it is needed to be included in the manuscript. If we have misunderstood the comment, we would be keen to add more information in this respect. We added a reference on the 20% velocity reduction over land [Willoughby and Black, 1996]. We would like to remark that this reduction will not affect the results at all, since we do not account for impacts of wind over land.

(8) — Line 110: How do you know that the selected domain is large enough to allow for a correct generation and propagation of the wind-waves originated by hurricanes affecting the Antilles? Did you perform a test run for this?

A — We conducted a test in which we represent the values of H_s generated by a TC at a range of distances from a point where in-situ buoy measurements are available. The distances vary between 0 and 8000 km. An example is illustrated in Figure 1 (number of figure refers to this document) for one of the buoys. The test has been carried out for every available buoy within or close to our survey domain and for all TC in the IBTrACS dataset. In the figure it is observed that the values of H_s decrease rapidly between 0 and 1000 km. On average, when all buoys are considered, H_s lies below 1 m between 1000 and 2000 km distance. We therefore conclude that 2000 km is a distance long enough for the forcing of the TC to develop the wave field.

(9) — Line 203: This sentence seems incomplete.

A — We have rewritten the sentence

(10) — Line 219: Shouldn't this be part of the methods section?

A — This part with the description of the methodology has been moved to the methods section (new subsection 2.4).

(11) — Line 251: In this paragraph you are describing some storm characteristics. I don't believe this belongs in the summary and discussion section. Instead, maybe put it under the introduction?

A — We understand this point of view. However, we compare our results with past events and we believe that it is important to keep all the information together, so we prefer to leave it in this section.

(12) — Line 288: duplicate of "to"

A — Changed

(13) — Figure 1: This figure is very hard to digest. The letters indicating the subpanels are sometimes hard to see due to the dark background colours. I would suggest you put them just outside of the panel. For consistency it would be nice if you do the same with the other figures. Also, it would be good to reduce the number of subpanel titles and make sure that they are in the same location each time. So for example, in the top left. Last, the figure caption includes f) and g) which should be e) and f). I believe c) is missing.

A — We have added white background to the text of the lower panels to facilitate reading and we also changed the typos in the caption. We have preferred to keep the letters and text inside the plots, as it allows to maintain a larger size in the panels.

(14) — Figure 2: black lines and text on a dark blue background is not a great match.

A — This figure has undergone some modifications, including the removal of the tracks, due to changes in the validation.

(15) — Figure 3: panel b shows a percentage correct? So a positive 100 % means that for every tropical cyclone with Caribbean origin, there are 0.5 cyclones with an Atlantic origin? If so, the percentage will exceed 100% in some locations correct? Right now the maximum value is 100% according to the colour bar. In addition, you mention "radius of maximum speed". Do you mean radius of maximum winds? Rmax is more commonly used as an abbreviation for this.

A — Former panel b (now panel d) shows the percentage of the dominant family (of Atlantic or Caribbean origin) at each grid point. We have modified the figure caption to make it clearer. What we show here is that 100% (red) means that all TC affecting that point are of Caribbean origin, while -100% (blue) indicates that all are of Atlantic origin (the eastern Antilles being a good example).

We have changed radius of maximum speed by Rmax, as suggested.

(16) — Figure 5: caption -¿ What do you mean by 'poor shore resolution'?

A — We meant here that we have a relatively coarse resolution ($\sim$ 2 km) to represent nearshore coastal processes and therefore we represent the points that are clsoe to the shoreline but at 20 m depth. The text has been slightly modified.

References

Tim Toomey, Angel Amores, Marta Marcos, Alejandro Orfila, and Romualdo Romero. Coastal hazards of tropical-like cyclones over the mediterranean sea. *Journal of Geophysical Research: Oceans*, 127(2): e2021JC017964, 2022. doi: https://doi.org/10.1029/2021JC017964.

Nadia Bloemendaal, Ivan D Haigh, Hans de Moel, Sanne Muis, Reindert J Haarsma, and Jeroen CJH Aerts. Generation of a global synthetic tropical cyclone hazard dataset using storm. *Scientific data*, 7(1):1–12, 2020. doi: 10.1038/s41597-020-0381-2.

Xavier Bertin, Kai Li, Aron Roland, and Jean-Raymond Bidlot. The contribution of short-waves in storm surges: Two case studies in the bay of biscay. *Continental Shelf Research*, 96:1–15, 2015.

HE Willoughby and PG Black. Hurricane andrew in florida: Dynamics of a disaster. *Bulletin of the American Meteorological Society*, 77(3):543–550, 1996. doi: https://doi.org/10.1175/1520-0477(1996)077⟨0543:HAIFDO⟩2.0.CO;2.

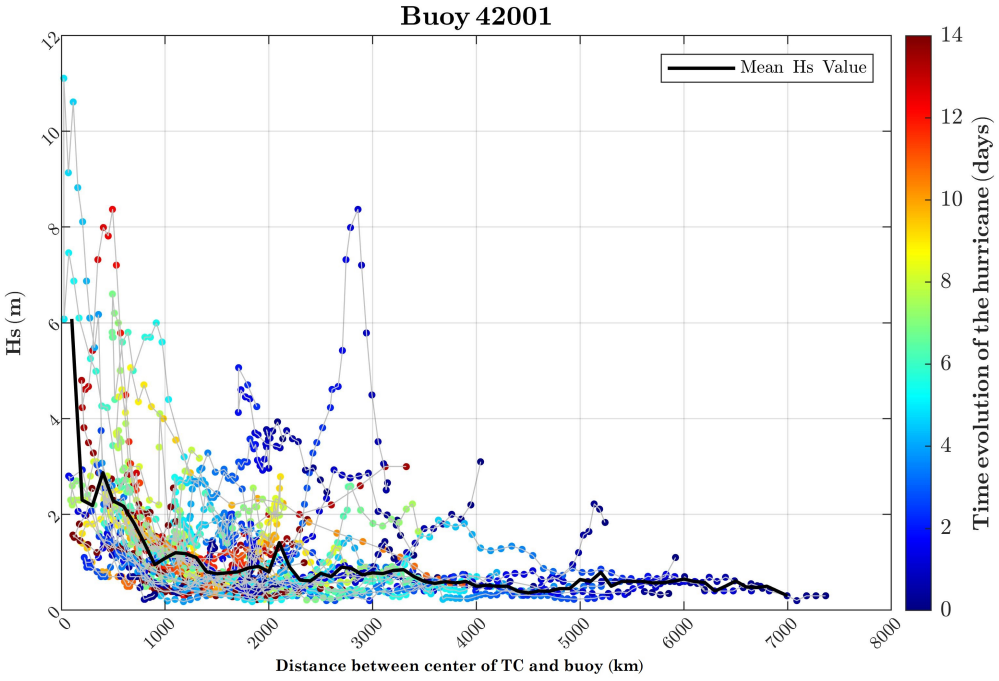

Figure 1: Example for buoy 42001 of the calculation of the H_s as a function of distance from the buoy, using all the TCs in the IBTrACS database that affected that buoy.This particular buoy is located in the Golf of Mexico, near the Yucatan channel.. Each TC is coloured according to its lifetime at each point, and the black line represents the median H_s value of all TCs as a function of distance.