JOURNAL OF COASTAL AND HYDRAULIC STRUCTURES

Review and rebuttal of the paper

Estimating the Influence of Sea Level Rise and Climate Change on Storm Surges in Western Taiwan

Yuchia Chang, Martin Mäll, Ryota Nakamura, Tomoyuki Takabatake, Jeremy Bricker, Miguel Esteban, Tomoya Shibayama

Editor handling the paper: Nguyen Danh Thao

The reviewers remain anonymous.

Reviewer 1:

The present manuscript deals with numerical simulations of storm surges along the western coast of Taiwan, considering future sea level rise and climate change. The numerical model used (WRF and FVCOM) was verified by the observed data during one of the past events, and the results and discussions were clearly shown. But there are some points which should be included or modified, as explained in the following comments.

The authors would like to thank the reviewer for the time taking to read the paper and the constructive comments provided. All of these have been addressed, as per the point-by-point reply to each of them below.

(1) The title of the manuscript includes “coastal defences”, but the present study didn’t focus on impacts on coastal structures. I can understand that the results of the present study can contribute to design and maintenance of coastal structures, but if the authors want to include “coastal defences” in the title, more data and discussions on this topic should be included.

The authors agree that the inclusion of the word “coastal defences” in the title was maybe not idea. The authors have thus changed the title to “Estimating the Influence of Sea Level rise and Climate Change on Storm Surges in Western Taiwan”.

(2) In Introduction, the authors mentioned that storm surge simulations in Taiwan received little attention and showed 3 references (Yang et al., 2018, Chang, et al., 2004, Chang, et al., 2008), which were master thesis, conference paper, etc. It looks reviewing the previous studies on storm surge in Taiwan is not enough, because there are many journal papers published on this topic that were not cited in this manuscript. For example,

- Assessment of storm surge inundation and potential hazard maps for the southern coast of Taiwan, Natural Hazards, 2016, https://doi.org/10.1007/s11069-016-2199-y

- Assessing the Potential Highest Storm Tide Hazard in Taiwan Based on 40-Year Historical Typhoon Surge Hindcasting, Atmosphere, 2019, https://doi.org/10.3390/atmos10060346

- Investigating typhoon-induced storm surge and waves in the coast of Taiwan using an integrally-coupled tide-surge-wave model, Ocean Engineering, 2020, https://doi.org/10.1016/j.oceaneng.2020.107571

In-depth review on previous related studies should be included.

The authors would like to thank the reviewer for highlighting these references. These were added to the introduction, with the new sentences reading:

"Nevertheless, some research has been conducted in recent years to study the effect of storm surges in Taiwan utilizing a variety of methods, with one common approach being the combined use of the Simulating Waves Nearshore (SWAN) model and the ADvanced CIRCulation (ADCIRC) model. Yu et al. (2019) assessed the potential highest storm surge tide using this coupled model by evaluating the highest storm surges and highest astronomical tides. A hazard map was then plotted by categorizing the hazard level based on its results. Liu & Huang (2020) also used this model to attempt to understand the physical factors that dominate storm surge heights during the passage of typhoon in Taiwan. However, the use of a wider variety of models is warranted, in order to obtain a better picture of how storm surges are generated in the country, especially around the western coast. Particularly, given the challenge that climate change represents for coastal areas, is important to further the understanding of potential storm surge impacts under climate change induced environmental changes (including both changes in atmospheric and water temperatures, and sea level rise)."

(3) The details of ODB bathymetry data that was used in this study should be mentioned, such as resolution of the data, when it was created, accuracy of the data, etc. Otherwise, it is difficult to see how the simulation can be improved in terms of bathymetry data. And if possible, it is better to show the differences between ODB and other data, such as GEBCO.

The following sentence was added to the methodology section: "The data was provided in a 200m grid size and mostly collected by research vessels using single-beam echo sounder system since 1989, including few areas in which such data replaced by that collected with a multi-beam echo sounder in survey EW9509 in 1995."

(4) What type of equation was used in FVCOM? The present manuscript just said "the governing momentum equations". The equations solved in FVCOM should be explained in more detail.

Details about the equations used in FVCOM have now been added to section 3.1., as indicated below:

This study used FVCOM version 4.1 (Chen et al., 2013) for the simulation of storm surges, which is a prognostic, unstructured grid, finite-volume, 3D primitive equation coastal ocean circulation model. The model is well known for its flexible unstructured grids that help better resolve coastal areas and estuaries with complex geometry. The model, in the absence of ice and snow, consists of momentum, continuity, temperature, salinity, and density equations. It uses the finite-element method (FEM) to solve the following governing momentum equations by computing fluxes between non-overlapping horizontal triangular control volumes:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho_0}\frac{\partial(p_H+p_a)}{\partial x}-\frac{1}{\rho_0}\frac{\partial q}{\partial x}+\frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right)+F_u \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho_0}\frac{\partial(p_H+p_a)}{\partial y}-\frac{1}{\rho_0}\frac{\partial q}{\partial y}+\frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right)+F_v \quad (2)$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho_0}\frac{\partial q}{\partial z}+\frac{\partial}{\partial z}\left(K_m\frac{\partial w}{\partial z}\right)+F_w \quad (3)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (4)$$

where x, y, and z are the east, north, and vertical axes in the Cartesian coordinate system; u, v, and w are the x, y, z velocity components; ρ is the density; p_a is the air pressure at sea surface; p_H is the hydrostatic pressure; q is the non-hydrostatic pressure; f is the Coriolis parameter; K_m is the vertical eddy viscosity coefficient.

(5) In Figure 6, observed sea level and storm surge component were shown. It is better to also show the predicted tide level in the same figure. Then, it is much easier to see how to calculate storm surge component from the observed data.

This is indeed a good recommendation. The figure was modified to add the predicted tide level.

(6) The forward speed of typhoon was not discussed in detail in this manuscript. But the forward speed is one of the important factors. It is better to discuss also how CMR and the future climate change can affect the forward speed.

The authors agree that this is indeed a very important issue, and the following sentences were added to the end of the discussion:

“Finally, it is worth noting that it is expected that climate change could change other characteristics of tropical cyclones around the planet, including their translate speed, with some evidence existing that this could already be happening (Inagaki et al., 2021). This could have a large effect on their wind field and, consequently, on the waves generated by such a typhoon, in turn impacting the size of the storm surge. The waves generated by large typhoons could increase in size if they accelerate just before landfall (Inagaki et al., 2021), and this could affect the stability of coastal structures, which would have to withstand higher waves and storm surges”

Reviewer 2:

The paper presents a nice piece of work on assessing effects of climate change and sea level rise on maximum storm surges at a study location on the western coast of Taiwan. Predictions were made in connection with a historical typhoon event in 2015, as the result of meteorological modelling systems in combination with FVCOM model.

The results are very encouraging and generally eligible for publication in the journal. However, the authors are advised to revise the manuscript with consideration of comments given below:

The authors would like to thank the reviewer for the time taking to read the paper and provide constructive comments on how to improve the research. All of these have been addressed, as per the point-by-point reply to each of them below.

*** Major:**

It is obvious that typhoon stacks greatly affect storm surge heights (as consequential effects by terrain and seabed bathymetric conditions). For areas on the western coast of Taiwan, storm tracks crossing through the eastern side like that of typhoon Soudelor in 2015 is perhaps not critical (apart from shielding effects by the central mountain ranges), though it was very catastrophic one. It is therefore necessary to have a review on historical typhoon events influencing the study area, whereby a selection of a representative one can be made. Discussions/assumptions should be made accordingly. It deems that typhoons which cross well outside the study area, i.e. the northern/southern sides of Taiwan, may bring about higher surge heights.

Thank you for the comment and the authors agree that further description regarding the typhoon choice and tracks are needed. Regarding the typhoon tracks and spatial surge impact along the Taiwan coast have been well studied in the work of Yu et al. (2019). Also, as mentioned by the reviewer the track location (and typhoon intensity) highly influences the spatial and surge max distributions. Following sentences were added for clarification in Section 2:

“Typhoon Soudelor (2015) was mainly chosen as a representative case study due to its relative recency and high impact along the Yunlin coastline. It is therefore desirable to further understand the potential impacts of such typhoon under future (warmer) climate conditions when also considering

the effects of land subsidence in the area. For other localized impact studies different typhoon cases are more suitable and representative typhoon cases should be selected accordingly (e.g. after Yu et al., 2019).”

*** Minor:**

- Readability of the paper must be improved. Unclear and wordy sentences need to be rewritten; the manuscript should thoroughly checked for syntax and grammar. Some examples are:

The authors have re-read and checked the entire manuscript, improving a number of instances of poor grammar and syntax.

+ paragraph on pp. 3, lines 3 - 9: unclear, too complex sentences;

Indeed, these sentences were too complex, and were simplified to:

“The aim of this paper is thus to understand the effect that potential changes in typhoon intensity due to climate change and sea level rise could have on storm surges on the west coast of Taiwan (particularly in areas that are below mean water level due to rapid levels of land subsidence). To do so, the authors first validated WRF and the Unstructured Finite Volume Community Ocean Model (FVCOM) by hindcasting Typhoon Soudelor in 2015. The future conditions in the area were then simulated to understand the likely intensification of future typhoons in the Western Pacific Ocean due to higher sea surface temperatures. To do so, the CMIP5 GCMs were utilized, considering also a variety of different likely SLR scenarios.”

+ pp.9, lines 14-17: "the estimated storm surges…", unclear

The authors here were trying to explain how the tidal curve was calculated, given that the data obtained only provided 4 data points for it per day (i.e. the two highest and lowest points). But, this additional information is probably not necessary, so the sentences were change to “The estimated storm surge was calculated from data from CWB”.

+ pp.10, lines 8-9: written information and Fig.7 are mismatched ("2.16 m, or 0.3 m higher; +20.8%");

Apologies for this mistake. They text has been changed to “(0.3 m higher; +26.3%).“

- Use of too many acronyms and abbreviations; uncommon ones such CMR, TC, etc. should be removed and replaced with full text;

Indeed, there are too many acronyms and abbreviations, many of which are unnecessary. The authors went through the manuscript and replaced many of these with full text.

- The paper title does not closely reflect its content. perhaps consider replacing "coastal defences" by "storm surges" or "design water levels".

The authors agree that the inclusion of the word “coastal defences” in the title was maybe not idea. The authors have thus incorporated the suggestion of the reviewer, and changed the title to “Estimating the Influence of Sea Level rise and Climate Change on Storm Surges in Western Taiwan”.