Author Response to Referee Comments

Referee 1

R1.0 General assessment

The manuscript under consideration for publication addresses the capacity of salt marsh vegetation to reduce coastal flood damages to buildings at Chatham County, Georgia, USA. The study used an existing hydrodynamic model in combination with depth damage functions to estimate flood damages and corresponding reductions provided by current salt marsh cover. Finally, spatial distribution of these benefits are studied using a GIS overlay with socioeconomic data.

The novelty is in the expansion of the damage function based on National Flood Insurance Program (NFIP) starting from the work by Wing et al. (2020). Specifically, fitting a non-linear function and including residential homes up to three stories with and without basement. I found the research gap poorly described and making a too large claim, as combining hydrodynamic modelling with depth-damage function is to-date a standard procedure and is even applied at the global scale (e.g. Tiggeloven et al., (2022)), and local scale (e.g. Philippines by Menéndez et al. (2018)). In addition, the hydrodynamic model which is presented as state-of-the-art is omitting critical physical processes to accurately predict coastal inundation especially in vicinity of coastal wetlands. Finaly, the level of validation of the integrated framework is lacking and is in my opinion a critical component in the analysis. In this review I highlight a number of attention points that could be implemented as part of a major revision, but would require substantial alternation of the approach and/or structure of the manuscript.

Major comments

R1.1 Research gap

In lines 30-35 the authors start to define the research gap by stating that the physical effects (e.g. water level reductions) provided by coastal ecosystems are evident, but the translation into economic benefits is lacking. Next, the claim that this translation is performed at the global and regional level. In the following paragraph (starting at line 38), they stated that previous work focused mainly on wave attenuation. However, the cited studies in previous paragraph also include other flood components. Eventually, the final research claim is presented in line 40: “The monetary value.. poorly understood”. The built up towards this research gap can be much improved and benefit from a more extensive literature review. In addition, in my opinion, the research gap is too wide and does not match the activities in the study. I would target the research gap towards the novelty of the study; the improvement of depth damage estimates with the NFIP data compared to the USACE standard depth damage curves.

Response: We thank the reviewer for this helpful comment. We agree that the introduction would benefit from reorganization and a more extensive literature review to present the research gap more precisely.

The reviewer is correct that the current introduction contains a logical inconsistency: we cite Costanza et al. (2021), Narayan et al. (2017) and Sun and Carson (2020) as evidence that the economic value of coastal wetland protection has been quantified, then claim in the following paragraph that "the monetary value remains poorly understood." These statements contradict each other.

To resolve this, we will reorganize the introduction around three strands of literature that lead to a narrower, well-supported research gap:

(1) Studies documenting how coastal ecosystems reduce surge and wave energy (Ferrario et al., 2014; Guannel et al., 2015; Möller et al., 2014; Spalding et al., 2014; Van Zelst et al., 2021).

(2) Studies that estimate the economic value of wetland protection by relating wetland coverage directly to observed storm damages (Costanza et al., 2021; Sun and Carson, 2020; Taylor and Druckenmiller, 2022). These studies establish that wetland flood protection benefits are economically significant, but none applies a structure-level depth-damage function.

(3) Studies that pair hydrodynamic models with depth-damage functions to estimate avoided damage (Menéndez et al., 2018; Narayan et al., 2017; Tiggeloven et al., 2022). This integrated approach is well established at the global and local scale. These existing applications, however, rely on engineering-based depth-damage functions developed by the USACE.

The research gap follows directly from strand (3): Wing et al. (2020) demonstrated that an empirical alternative to the USACE curves, estimated from NFIP insurance claims, can yield substantially different damage estimates, but this approach has not been applied to value coastal wetland protection. How estimates of marsh flood-mitigation benefits, and their spatial distribution, change when an empirically derived depth-damage function replaces the USACE curves has not been examined.

We propose replacing the current gap statement with the following:

> *"Economic valuations combining hydrodynamic models with depth-damage functions have demonstrated that coastal wetlands provide substantial flood-protection benefits (Menéndez et al., 2018; Narayan et al., 2017; Tiggeloven et al., 2022). These valuations typically rely on the standard engineering-based depth-damage functions developed by the USACE. However, Wing et al. (2020) showed that an empirical depth-damage function, estimated from NFIP insurance claims, can produce substantially different damage estimates. Whether marsh flood-mitigation benefit estimates change and their spatial distribution change when an empirically derived depth-damage function replaces the USACE depth-damage function has not been examined. Our work addresses this gap by comparing estimates derived from the two approaches."*

This framing acknowledges the prior economic literature, resolves the contradiction the reviewer identified, and effectively presents the research gap and our contribution.

R1.2 Hydrodynamic model

The authors used the existing ADCIRC – SWAN model. The authors acknowledged that this modelling system is widely used (line 104), thus cannot be presented as novel. The model resolution is up to 50 metres, which is to-date considered low resolution for local inundation models. State-of-the-art processed based inundation models at this scale have typically a resolutions up to 25 – 5 meters. But more importantly, SWAN is an oceanic wave model and unfit to accurately predict processes in the surf zone. For example, as SWAN averages over the wave phase it misses infragravity-wave physics which is critical for inundation levels. The authors should couple the ADCIRC-SWAN model with a dedicated model for the surf zone and increase the resolution to claim the model-setup to be state-of-the-art. Alternatively, and advisable, is to admit the caveats of the hydrodynamic model and focus fully on the depth-damage-estimates.

Response: We thank the reviewer for these comments and accept the technical points raised. We agree that ADCIRC+SWAN as applied here should not be characterized as state-of-the-art for local inundation prediction, and we will remove that language from the manuscript.

As noted in the manuscript, ADCIRC+SWAN is a well-established and widely applied coastal hydrodynamic modeling system. In this study, the model serves as a tool to investigate the influence of marsh vegetation on storm-driven water levels and the resulting impacts on flood exposure and damage.

Regarding mesh resolution, the computational domain spans the southeastern United States and portions of the Mid-Atlantic coast. Within this large-domain framework, a minimum mesh resolution of approximately 50 m in inland and estuarine regions is consistent with the study objectives and with previous regional-scale applications of ADCIRC. While finer resolutions (e.g., 5–25 m) may be advantageous for highly localized inundation studies, they would substantially increase computational costs and impose more restrictive numerical stability requirements without necessarily yielding meaningful improvements in regional-scale overland flood depths, which are the primary focus of this work.

We agree that SWAN, as a phase-averaged spectral wave model, does not explicitly resolve infragravity waves and other detailed surf-zone processes. However, the objective of this study is not to investigate surf-zone hydrodynamics or wave runup. Rather, this work represents a first-order assessment of how storm-driven water levels and associated flood damages may change under scenarios with and without marsh vegetation. Within this context, SWAN is included to account for wind-wave effects and wave radiation stress contributions to water levels, which have been shown to be adequately represented within the ADCIRC+SWAN framework for large-scale storm surge and coastal flooding applications.

Following the reviewer's suggestion, we will revise the manuscript to more clearly acknowledge these limitations and to emphasize that the hydrodynamic simulations are intended to support the flood exposure and depth-damage analyses rather than provide a detailed representation of surf-zone processes. Specifically, we will add in the manuscript's limitations section acknowledging that unresolved infragravity-wave and surf-zone processes could affect local water levels near the shoreline, but are unlikely to materially alter the broader conclusions regarding regional flood exposure and damage estimates.

R1.3 Engineered coastal protection
The authors do not mention if engineered coastal protection is present within the study area and how this infrastructure is represented in the model setup. I cannot imagine there are no coastal protection structures in the area and not accounting for those will greatly influence the results of the integrated results. Ideally, the structures are included in the hydrodynamic model, but at least their protection level should be accounted for in the economic analysis.

Response: We appreciate this helpful comment. Engineered coastal protection structures are largely absent throughout the primary study region, particularly along the Georgia coast, which is characterized by barrier island systems, extensive tidal marshes, and broad back-barrier estuarine environments. Unlike many urbanized coastlines, flood risk reduction in this region is provided predominantly by natural features rather than engineered defenses such as seawalls, levees, or storm surge barriers.

The computational mesh used in this study was developed by the U.S. Army Corps of Engineers' Engineer Research and Development Center (ERDC) and has undergone extensive review and has been applied in numerous coastal storm-surge studies, particularly the South Atlantic Coast Study (SACS). Therefore, the mesh and underlying topographic datasets provide an accurate representation of the regional landscape and any major coastal infrastructure present within the domain. However, engineered flood protection structures are not a dominant feature of the study area and therefore are not expected to influence the regional flooding and damage estimates presented herein.

To clarify this point, we will add text to section 2.2 describing the study area's coastal setting and noting that flood attenuation is primarily governed by natural landscape features, including barrier islands and coastal marshes.

R1.4 Validation of integrated framework
With the NFIP data the authors possess a very rich data set which provides the opportunity to validate the integrated framework. Firstly, by deriving the claim data corresponding to the selected storm 0157 the authors can visualize the flood depth and flood extent in the study area. This insight could be used to further validate the hydrodynamic model. Secondly, and more importantly, the data could be used to validate the damages that are estimated for the storm0157 and the other selected storm (1313). This would be a crucial step as currently, the accuracy of the presented

data in Table 4 is unknown. Intuitively, the reader assumes that the NFIP derived estimates are more accurate compared to the USACE derived data, but this is not validated nor quantified. In other words, the regression depth-damage formula is based on all claim data and application of this formula to the selected storm and subsequent comparison of claim data of these events would provide valuable insight into the accuracy of the setup. I consider this a critical step which aligns with the novelty of this work.

Response: We appreciate this thoughtful suggestion.

We would like to clarify that Storms 0157 and 1313 are synthetic design storms selected from the USACE South Atlantic Coastal Study (SACS) storm database. Specifically, Storm 0157 was selected to represent the 1% annual exceedance probability stillwater level for the Savannah-Chatham area, and Storm 1313 was used as an additional scenario. They are not historical storms, so there are no NFIP claims directly associated with these storm IDs that could be used to validate the simulated damages in Table 4.

The hydrodynamic model is independently validated against observed water levels at the Fort Pulaski tide gauge, as shown in Figure 3. We will add error statistics (RMSE, MAE, R^2) to that figure in response to this and other reviewer comments in R2.4.

For the damage estimates, the coefficients and marginal effects reported in Table 3 are estimated using the full sample. The R^2 values currently reported in Table 3 are computed on an 80/20 held-out validation, in which the model is estimated using 80% of the claims and evaluated on the remaining 20% excluded from estimation, and therefore they represent out-of-sample predictive accuracy. To strengthen this validation, we will add RMSE and MAE computed on the same held-out sample alongside R^2, and obtain all three measures again from 10-fold cross-validation, reporting one set as additional columns in Table 3 and the other in the table note. Predicting damage for held-out claims is the closest feasible test to the reviewer's suggested approach given that the storms used in the analysis are synthetic.

We will also strengthen the interpretation of the comparison between the NFIP-derived and USACE-based estimates and add the following into the discussion section:

> *"The USACE and NFIP-derived depth-damage functions are two different ways of estimating flood damage, with the NFIP-derived function estimated empirically from historical insurance claims and the USACE curves derived from standardized engineering and expert assessment. We do not interpret the NFIP-derived estimates as inherently more accurate than the USACE estimates. As discussed above, the two functions differ mainly in how they distribute damage across depth: the USACE curves concentrate damage at shallow depths, whereas the NFIP-derived function spreads it across moderate to deeper depths."*

Minor comments:

Title: Suggestion to rephrase in line with the novel aspects of the work. At least remove infrastructure

Response: We will change the title to: "Comparing Engineering- and Claims-Based Valuations of Salt Marsh Flood Protection: Evidence from Chatham County, Georgia"

Figures: Varying font sizes and font types are used across the figures.

Response: We will standardize font size, font type, and formatting across all figures.

Line 21: What part of the 129 million people live in flood prone areas?

Response: The 129 million figure refers to the population living in U.S. coastal counties, not specifically the number of people living in flood-prone areas. We will revise the sentence to make this distinction clear and avoid implying that all 129 million people are directly exposed to flooding.

Line 23: Insert reference

Response: We will add the following FEMA references (FEMA, 2017, 2023) to support the statement that flooding is among the most common and costly natural disasters in the United States:

FEMA: Hazard Overview: Floods, Federal Emergency Management Agency, available at: https://www.fema.gov/sites/default/files/2020-07/fema_p1086_flood_2017.pdf (last access: 24 June 2026), 2017.

FEMA: Everyone Needs Flood Insurance, Fact Sheet, Federal Emergency Management Agency, available at: https://agents.floodsmart.gov/sites/default/files/media/document/2025-07/fema-nfip-everyone-needs-flood-insurance-fact-sheet-05-2023.pdf (last access: 24 June 2026), 2023.

Line 24: Is this global, or only US?

Response: The $32.1 billion estimate refers to annual flood damages in the United States. We will revise the sentence to make the geographic scope explicit.

Line 29: change to: 'traditional gray infrastructure. Natural coastal ecosystems can reduce flood risk by attenuating storm surges and waves'

Response: We will revise the sentence as suggested to improve clarity.

Line 30: A barrier island is a morphological feature, I would not classify it as a separate coastal ecosystem. For example, mangroves or marshes can occupy barrier islands.

Response: We agree. We will remove "barrier islands" from the list of coastal ecosystems to avoid this confusion.

Line 40: "combination of coastal wetlands and levees" instead of marshes and levees.

Response: We will revise the sentence as suggested.

Line 43: Remove ‘high resolution’
Response: We will remove “high resolution” from this sentence.

Line 71-75: I would use past tense to refer to the Wing et al. study.
Response: We will revise the discussion of Wing et al. (2020) into past tense.

Line 80: I would not start a paragraph with a reference to a figure. Not reader friendly. For example start with: “An existing hydrodynamic model is used to provide tropical cyclone induced inundation depth and extent for scenario..”
Response: We thank the reviewer for this helpful suggestion. We will revise the opening sentence so that the paragraph begins with the methodological context, then refers to the flowchart.

Line 102: 50 meters is rather coarse for a local model. Could you include a figures showing what part of the computational grid has the 50 meters resolution and what part has a lower resolution.
Response: We addressed the comment regarding model resolution in response to comment R1.2. We are happy to generate an additional figure. However, since this is not central to the manuscript’s focus, we could add it to a supplemental document as necessary.

Line 102: Is the wave model using the exact same grid and the flow model?
Response: Yes, both ADCIRC and SWAN are using the same unstructured mesh. The manuscript text will be altered to make this clear.

Line 109: The ADCIRC model is also solving the Shallow Water Equations, in addition to the wave continuity equation?
Response: ADCIRC solves the GWCE and 2D momentum equations. We will correct the text to reflect this, as it currently only states “GWCE”.

Line 113: Manning bottom friction coefficient?
Response: Yes, Manning’s bottom friction. We will clarify this in the text.

Line 125: What is the total storm duration? A 20 min interval seems okay, but it depends on the total storm duration.
Response: The storm duration is dozens of hours – a 20-minute SWAN time step is very typical in these studies to balance convergence/iterations and computational speed.

Figure 3: Please add some statistics, e.g. RMSE, MAE + R2 scatter plot
Response: Error statistics will be added to the validation plots.

Line 138: The marsh areas are not treated as open-water as the elevations remained the same. Thus rather implementing them as bare grounds, but with a roughness coefficient like open-water. Using this set-up bottom friction is limited, but depth-induced wave breaking still occurs.

Response: Yes, we concur. We will clarify in the manuscript that marsh platform elevations are retained in the no-marsh-vegetation scenario, while Manning's n is reduced within mapped marsh areas.

Line 140: Please clarify what you mean with 'storm surge-driven waves'
Response: This is a typo, and should refer to tropical cyclone-driven waves. The word surge will be removed.

Line 140: The effect of vegetation on wave propagation is not accounted for? In other words, the formulations by Suzuki et al. are not activated in SWAN?
Response: We will review the vegetation formulations presented by Suzuki et al. and assess the sensitivity of the model results to their implementation. At present, however, we are unaware of these formulations being available within the coupled ADCIRC+SWAN modeling framework. Furthermore, because the primary focus of this study is on total water levels rather than wave attenuation by marsh vegetation, we do not expect that inclusion of this formulation would materially alter the results or affect the main conclusions of the manuscript.

Line 152: "A subset" reads like you rerun a substantial amount of simulations, but you selected two storms.
Response: The text states that the full SACS study had 1,700 storms, which covers the full southeast US. Since our focus is only on a portion of the Georgia coast, a few select storms were pulled from the overall 1,700 storms.

Line 182: What did you do with the ambiguous data without unit (either feet or inch?) You filtered them out I suppose? What percentage of the total data concerns this?
Response: We thank the reviewer for this important observation. The NFIP claims record a depth value without a per-record unit. Although FEMA's dictionary lists inches, the distribution shows depths are recorded predominantly in feet (consistent with Wing et al. (2020)'s research), with anomalous records at multiples of 12 (12, 24, 36 ft) that appear to be inches mis-entered as feet. These account for about 5% of positive-depth records. We follow Wing et al. (2020) and restrict the sample to claims with reported flood depths of 8 feet or less to reduce the influence of depth-unit inconsistencies, which removes about 11% of single-family claims. In the revised manuscript, we will add an appendix documenting the depth-unit check, including the distribution of recorded depths and the share of anomalous records.

Line 233: Did you regrid the model results to a equidistant raster? If yes, what resolution and how?

Response: We will clarify the structure-level matching with the following text:

> *"The simulated inundation-depth raster is matched to NSI building locations, and the corresponding water depth is extracted for each structure; the above-ground foundation height is then subtracted to obtain the structure-level flood depth used in the depth-damage functions."*

Line 240: Maybe start with some context on the storm impact first, prior to stating effects of marshes

Line 243: 'up to' is vague. Use statistics to underpin the statements. What is the average reduction plus percentile spread in absolute values and percentual reduction.

Response: We address these two comments together as they concern the same opening paragraph of section 3.1. We will revise the opening to first describe the storm's overall impact (answering line 240) and replace "up to" with summary statistics for the marsh-induced water-level changes (answering line 243). The revised opening paragraph for section 3.1 is as follows:

> *"Storm 0157 caused widespread flooding across low-lying areas of Chatham County, with flood depths in inundated areas averaging 2.69 meters (median 3.01 meters) and reaching up to 4.86 meters. Across inundation areas, salt marsh reduced flood depths by an average of 0.12 meters (6.9% reduction) and a median of 0.07 meters (3.6% reduction), with a maximum reduction of 0.47 meters (77% reduction). The greatest reductions occur along the Ogeechee River near Georgetown. Other regions, including areas near Savannah, also experience reductions, though typically around 0.1 meters. While there are a few locations where the salt marsh vegetation raises water levels, these increases are negligible (less than 0.05 m). Figure 7 illustrates the impact of salt marshes on flood depth and extent of storm 0157. Warmer colors indicate areas where marsh vegetation substantially reduces peak water levels, while cooler colors indicate regions where marshes slightly increase flood depths."*

Line 261: The whole point was that the regression formula account for non-linearity?

Response: The fractional logit specification is nonlinear through the logit link function. The reported 6 percentage-point effect is an average marginal effect, summarizing the average change in predicted relative damage associated with a one-meter increase in water depth rather than a constant linear slope. We will state this explicitly to avoid the impression of a linear specification.

Figure 10: Consider including a difference map USCACE versus NFIP approach

Response: We will add a difference map comparing the two damage-estimation approaches, calculated as the USACE-based predicted benefit minus the NFIP-derived predicted benefit. This will make the spatial differences between the two approaches easier to interpret.

Line 366: Weighted average seems to suggest something else.

Response: We will revise the wording "weighted average" to a more precise term, such as "property-value-weighted mean benefit per household," and define it clearly in the table note.

Line 395: Be specific that this concerns storm 0157 (a single storm)

Response: We will revise the sentence to specify that the $30 to $40 million figure refers to Storm 0157.

Line 408: Remove state-of-the-art
<u>Response</u>: We will remove "state-of-the-art" from the discussion.

Line 434: Not surge?
<u>Response</u>: We will revise the sentence to avoid focusing only on wave height and energy. The revised wording will state that coastal habitats can reduce flood risk by attenuating waves, influencing storm surge and inundation depths, and reducing flood-related damages.

Line 445: I would not state that this framework is applicable globally, as it requires detailed claim data such as provided by the NFIP, which is not widely available in other countries that do not have an insurance-culture.
<u>Response</u>: We agree that the original statement was too broad. We will revise this statement in the Conclusion section to clarify that the approach is most applicable to settings where property-level exposure data and observed damage or claims data are available. For places without similar data, the general hydro-economic framework can still be useful, but the NFIP-derived damage function would need to be replaced by locally appropriate damage estimates.

References

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