Author Response to Referee Comments

Referee 2
R2.0 General assessment
The current manuscript described a model framework to estimate the monetary benefits of salt marshes in Chatham County, GA. They couple a hydrodynamic model to a damage assessment to provide a monetary value of around $30 million to $40 million per storm (1% annual exceedance probability). The manuscript is easy to read and has barely any English mistakes. I do have some questions and concerns on the analysis. Therefore I recommend **major revisions.**

Major comments
R2.1
In the introduction there is already a big focus on explaining the methodology. I recommend erasing these explanations (e.g., lines 49 – 56) and making sure this is all covered in the methodology. Aside from that, the contribution to the current literature can be made more clear. There are more models that translate the effectiveness of NBS into a monetary value. What is your specific novelty? The salt marshes that are studied? The NFIP data to construct depth-damage curves?

Response: We thank the reviewer for these helpful comments.

The comment regarding our contribution aligns closely with that raised by Referee 1 (R1.1), who similarly noted that the research gap and contribution could have been stated more clearly. Our response to R1.1 describes the full reorganization of the introduction; here we address the two specific points the reviewer raises.

First, we will remove the methodology portion at lines 49–56 as the reviewer suggested.

Second, we agree that the novelty of our contribution should be stated more directly. We will add the following to the introduction:

> *"Our main contribution is to value salt-marsh flood protection using an empirical, nonlinear depth-damage function estimated from NFIP claims rather than the standard USACE curves. We extend the claims-based approach to residential structures of up to three stories, with and without a basement, and use it to estimate both the aggregate avoided damage and its spatial distribution across Chatham County. Comparing the NFIP-derived and USACE estimates shows how the valuation of marsh benefits depends on how inundation is translated into economic loss."*

Together with the introduction reorganization described in R1.1, this presentation and framing ensure the contribution is stated clearly and consistently throughout the manuscript.

R2.2
In your methodology you compare 2 situations with each other: the setup with and without salt marshes. The situation with the salt marshes is the current situation as I understood from your manuscript. I think the authors should place more emphasis on this. The title could make a reader believe that the authors are quantifying the effects of newly developed salt marshes.

Response: The reviewer is correct that the "with marsh" case is the marsh that exists today, and the "without marsh" case removes that existing vegetation. We estimate the protective value of the marsh already present, not the value of building new or restored marsh.

In the abstract, we will replace “with and without salt marshes” with “with the existing salt marsh and under a counterfactual scenario in which that marsh is removed,” and in Section 2.2, we will add: “This represents the protective value of the marsh vegetation currently present.”

R2.3
For the hazard simulation only 2 storms were modelled of which only 1 storm is used for the main analysis. It is unclear to me why the authors chose to limit themselves to only 1 storm. I can imagine that a storm with a different magnitude (e.g. a 200 year, 500 or 1000 year storm) can drastically influence the results and the monetary benefits of the salt marshes. Moreover, the location where the storm makes landfall can also influence the flooding patterns. I recommend the authors to add an extra analysis testing a few different variations of storms to see how if the monetary benefits are equal in size for other storms.

Response: We agree that inundation can vary substantially depending on storm track and storm-specific characteristics. However, this study focuses on the 1% annual exceedance probability (AEP) event (i.e., the 100-year floodplain), as this is the standard used to evaluate how marshes may influence stillwater elevations during a flood event. These stillwater elevations are the primary metric used to delineate floodplains and inform flood insurance policies. Although the analysis is not intended to capture the full spectrum of possible storm conditions, it represents an important step toward quantifying the role of marshes in modifying flood hazards under a commonly applied flood-risk benchmark.

R2.4
The description of the model validation is lacking. Figure 3 shows the difference between the observed and simulated water levels for a station near the study area. However, there is no figure showing where this station is located. This could be added to Figure 2. Moreover, there is no performance metric reported, for example the RMSE. Right now it is hard to interpret whether the water level differences are very large. Lastly, there is no validation for the storm the authors used in the analysis. I can imagine that there are water levels available for storm 157, and even water extent data to validate the hydrodynamic model.

Response: Yes, this was an oversight by us. The observation station location will be added to Figure 2. Additionally, validation metrics, including RMSE, MAE and R^2, will be added to the plots of Figure 3.

Storm 0157, like the other synthetic storms used in this study, is not based on a historical event. Therefore, observational data is not available for direct validation against measured water levels or inundation extents.

R2.5
Figure 5 shows the USACE damage curves used in the study. However, when looking at the figure I am confused why there is already damage for buildings with no basements when water depths are below 0 meter. This requires further explanation. Moreover, the plot is hard to read with the lack of a grid. I recommend adding a grid to the figure instead of a white background.

Response: We appreciate the reviewer noting this. We will clarify why the USACE depth-damage curves indicate positive damage at water depths below zero and will revise Figure 5 to improve its readability. Specifically, we will add the following explanation to the manuscript:

> *"In the USACE depth-damage curves, flood depth is measured relative to the first-floor elevation rather than the ground. Therefore, negative depths indicate the water surface remains below the first floor. Positive damage may nevertheless occur at these depths because flooding can affect foundations, crawl spaces, exterior components, and building utilities before water reaches the first-floor elevation."*

Following the reviewer's suggestion, we will also add gridlines and revise the figure background to make the curves easier to distinguish and interpret in Figure 5.

R2.6
In paragraph 3.2 the depth-damage curve derived by the authors from the NFIP is presented. Can the authors plot these curves together with the ASACE curves (from Figure 5)? This way a reader can easily compare the difference between both curves.

Response: We thank the reviewer for the helpful suggestion. We will add a combined figure plotting the NFIP-derived empirical depth-damage curves together with the USACE standard curves on common axes, so the differences across water-depth ranges are directly visible. This complements the difference map we plan to add in response to Referee 1's comment on Figure 10.

R2.7
In Table 3 the results from the regression analysis are presented. All 4 regressions have quite low R^2 values (0.0165 – 0.0440). The authors don't reflect on these low values, which indicate quite some uncertainty in the presented depth-damage curves. Endendijk et al. (2023) also used a regression analysis with damage data

collected through a survey after a recent flood and had adjusted R^2 values of 0.193 – 0.196, which are significantly higher.

Response: We thank the reviewer for this careful observation. We agree that the low R^2 values need to be discussed in the manuscript.

The R^2 values currently reported in Table 3 come from an 80/20 held-out validation exercise and reflect the amount of claim-level variation explained by the estimated damage function. The low R^2 values indicate considerable unexplained variation in claim-level relative flood damage. However, a low R^2 does not imply that the estimated depth-damage relationship is not credible or informative. In our model, relative flood damage depends on many factors that are not fully observed in the NFIP claims data, such as flood duration, flow velocity, building materials, maintenance conditions, insurance coverage, and reporting behavior. As a result, water depth and basic building characteristics may explain only a modest share of claim-level variation.

Endendijk et al. (2023) provides a useful reference point, but the R^2 values are not directly comparable to ours. Their study uses survey data collected after the flood event in the Netherlands in 2021 and includes more event-specific information. However, our NFIP claims data are pooled across many storms, years, U.S. locations, and building structures. This broader and more heterogeneous setting may naturally leave more unexplained variation at the individual-claim level.

We will add this discussion of the low R^2 values as a source of uncertainty into the Discussion section of the manuscript. At the same time, the uncertainty does not change our main interpretation: the water-depth coefficients are positive and statistically significant across specifications, and the beta regression produces robust results.

R2.8

In lines 293 – 295 the authors write the following: "The average flood damage per claim was \$19,022 in Chatham County and \$27,177 nationwide, according to the NFIP data over the last 40 years. This indicates that salt marshes' flood damage mitigation benefits, about \$2,000 per storm per house, equal about 10.5% of the average flood damage recorded in the past across homes in Chatham County". I do not understand how the authors conclude that the mitigations benefits are around \$2,000 per storm per house. Please add a further explanation.

Response: Thank you for raising the question. The average flood damage for Chatham County (\$19,022) and nationwide (\$27,177) is calculated from historical NFIP claims over four decades, and we use these values as a benchmark for our results. The approximately \$2,000 benefit per household comes from Table 4, representing an average of our NFIP-without-interaction result (\$1,940 per household) and NFIP-with-interaction result (\$2,120 per household). These avoided flood damages are calculated by dividing the total predicted avoided flood damage by the approximately 15,600 residential structures exposed to inundation in the simulated storm. We will clarify this calculation in section 3.3 by revising the following text after describing Table 4:

> *"The average flood damage per claim was $19,022 in Chatham County and $27,177 nationwide, according to the NFIP historical claim data over the last 40 years; these values provide a benchmark for interpreting the magnitude of our estimates. Table 4 reports both the aggregate avoided damage and the average benefit per household. The average benefit is calculated by dividing the aggregate avoided damage by 15,600 benefiting households. Based on the NFIP-derived estimates from Table 4, salt marshes reduce flood damage by about $2,000 per storm per house. This amount is equivalent to roughly 10% of the average flood-insurance claim in Chatham County ($19,022) and about 7% of the average claim nationwide ($27,177)."*

R2.9
In Figure 9, the authors present two histograms of the monetary benefits per water depth class. Figure A and B are hard to compare because they do not use the same water depth bins. Moreover, they use a different y-axis (0–10,000 and 0–7,000). I recommend to make the bins the same, and ideally to plot the subfigures together with the bars next to each other. This allows for easier comparison.

Response: We agree. We will redraw Figure 9 using the same water-depth bins and a shared y-axis scale, and we will plot the two series as grouped bars so the panels can be compared directly.

R2.10
In Figure 10 the colour scale is an odd choice. Negative benefits are plotted in blue and positive benefits in red. Usually red is associated with something negative. I recommend the authors to change this colour scale to (for example) red (negative) to green (positive).

Response: In the revised Figure 10, we will retain a colorblind-friendly red–blue palette but reverse the color assignment: negative benefits will be shown in red, while positive benefits will be shown in blue. We will also revise the legend and figure caption to clearly indicate the meaning of each color.

R2.11
In paragraph 3.5 the authors present a spatial distribution of mitigation benefits for several socioeconomic factors like racial composition and poverty rate. This adds an interesting angle to the results. However, the source of the data is not described in the methodology, as well as the details of the method. I also find it odd that the main focus is placed on the racial composition, while the poverty rate is only mentioned in 9 lines. I think this paragraph should be rewritten to be more balanced. Moreover, it is impractical that some of the figures which the authors refer to are put in Appendix B. I recommend at least adding some of the results for the poverty analysis to the main manuscript.

Response: Following the reviewer's recommendation, we will expand the Methods section to provide a detailed description of the socioeconomic distribution analysis. This description will identify the data source and spatial unit of analysis, explain how the racial-composition and poverty-rate quartiles were constructed, describe how parcel-level mitigation benefits were aggregated to the relevant geographic units, and clarify how the reported correlations were calculated.

We will also revise Section 3.5 to provide a more balanced discussion of racial composition and poverty. In particular, we will expand the poverty analysis and move the most relevant poverty results currently reported in Appendix B into the main manuscript.

R2.12

The discussion chapter lacks a thorough discussion of the uncertainties in the results, especially in the hydrodynamic modelling (e.g., model choice, storm choice, method of modelling salt marshes) and the creation of their own depth-damage curve. Some uncertainties now are only mentioned, but it is not very well explained how they effect the main findings of the study.

Response: We agree. In the revised Discussion section, we will add discussion of uncertainty for both the hydrodynamic and economic parts of the analysis.

For the hydrodynamic analysis, we will add a discussion on modeling errors and uncertainties to improve transparency and provide additional context. Here, the uncertainty comes from our model inputs and assumptions: available topography and bathymetry, namely, marsh platform elevations are overestimated in lidar-DEMs due to the vegetation density and height; our model contains static topography, and it does not evolve in time. Therefore, we do not capture any barrier island breaching or other storm-driven morphology that could impact our analysis. These considerations do not change the interpretation of the main findings, but they will be discussed as important sources of uncertainty.

For the economic analysis, we will expand the discussion of uncertainty in both the USACE and NFIP-derived depth-damage functions, including measurement error and sample selection in the NFIP claims data, uncertainty in property values, and omitted determinants of damage such as flood duration, flow velocity, salinity, and building materials. We will further explain how these uncertainties may affect the results. For example, measurement error in recorded flood depth could attenuate the estimated relationship and potentially understate marsh benefits, and the restriction to insured properties limits the representativeness of the estimated curve.

These revisions will clarify how the main sources of uncertainty affect the interpretation of our findings.

R2.13
The authors in the discussion emphasize that the monetary benefits of the salt marshes are around $30 million to $40 million per storm. How do these benefits compare to similar NBS? Is it a lot, or quite little?

<u>Response</u>: We thank the reviewer for this helpful comment. We will add a comparison with estimates from prior studies of nature-based solutions. Specifically, we will add the following discussion:

> *"Our estimate of $30–$40 million in avoided property damage from a single 1% AEP storm in Chatham County, equivalent to approximately $1,940–$2,650 per affected household, can be compared with estimates from two related studies. Narayan et al. (2017) estimate that wetlands prevented approximately $625 million in property damage across 12 states during Hurricane Sandy, reducing losses by about 11% in areas where wetlands remained and by 20%–30% in states with the greatest wetland coverage. Sun and Carson (2020), using observed damages from 88 U.S. tropical cyclones, estimate an average annual value of approximately $1.8 million per square kilometer of wetland. Although these estimates are not directly comparable because they differ in geographic coverage, time horizon, and valuation method, they indicate that our county-level estimate represents a substantial flood-mitigation benefit and is broadly consistent with the magnitude of benefits reported in the prior literature."*

References

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